Bitterroot Front Project Comments

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Submitted via Bitterroot National Forest Website:
https://cara.fs2c.usda.gov/Public//CommentInput?Project=57341

Please accept the following comments respectfully submitted by Friends of the Bitterroot (FOB), WildEarth Guardians (WEG), Friends of the Clearwater (FOC), Flathead Lolo Bitterroot Citizen Task Force, Montana Chapter Sierra Club, Center for Biological Diversity, Alliance for the Wild Rockies (AER), Western Watersheds Project, Native Ecosystems Council (NEC), plus Stephen S. and Gail H. Goheen. These comments are in response to the August 2023 Draft EA, for the Bitterroot Front Project.

Therefore, these objections incorporate the scoping comments submitted by each organization and all previous submissions (and attachments) to the Forest Service on the proposed Project from these organizations.

In addition, all scoping comments, analysis comments, attachments and cited literature, and/or objections provided by FOB, WEG, AWR, FOC, NEC, and the Goheens for the Darby Lumber Lands II Project (2019), the Eastside Forest and Habitat Improvement Project (2023), the Gold Butterfly Project, the Bitterroot Front Project (2022), the Mud Creek Project (2023), and Forest Plan Programmatic Amendments Package (2023) are fully incorporated.

The following points below represent our statements of the issues and parts of the Project to which these comments apply and to those we raised in scoping comments that the Forest Service fails to properly address in the Draft EA.

The proposed project location is described as (Draft EA, pp. 1-2):

> The project area is along the eastern face of the Bitterroot Range from the Bitterroot National Forest boundary at the northern end of the Stevensville Ranger District near McClain Creek to the southern end of the Darby-Sula Ranger District near Trapper Creek (figure 1-1). The Bitterroot Front project area runs north to south, bounded on the east by private lands and communities situated along U.S. Highway 93 and the Selway-Bitterroot Wilderness to the west. The elevation within the project area ranges from about 3,400 to over 9,100 feet. Notable landforms include Lolo Peak on the project area's northern end and Trapper Peak on the south. Blodgett Canyon, Mill Creek, Lake Como, and Bass Creek Recreation Areas, as well as various motorized and nonmotorized recreational trails, fall within the project boundary.

The project area is 143,340 acres; most of the project area (97 percent) falls within Ravalli County, Montana, with the remaining 3 percent in Missoula County, Montana. No management activities under private or other ownerships are considered with this proposal; this is because the Forest Service does not have jurisdiction to make decisions on lands of other ownership.

The fuels management project area is spread across the Stevensville and Darby-Sula Ranger Districts in the Bitterroot National Forest and is divided into priority areas (appendix C, figure 1-2). Proposed project activities are near the following communities: Florence, Stevensville, Victor, Corvalis, Pinesdale, Hamilton, Grantsdale, Ward, Charlos Heights, Como, Darby, University Heights, and Conner.

The Introduction to the Draft EA states (Draft EA, at 1):

The United States Forest Service Bitterroot National Forest Stevensville and Darby-Sula Ranger Districts propose conducting **forest management activities** in the Bitterroot Front project area to **address the wildfire risk** to the nearby communities and **promote forest restoration**. The forest management activities include a variety of actions that mostly fall within the categories of vegetation management, fuels reduction, and transportation system management. The project's primary purpose is to reduce the risk of a stand-replacing wildfire and return the forest to a healthy and resilient ecosystem, which includes high-frequency and low-intensity fire. Additional benefits of the project would include improving vegetation, watershed, wildlife and fish habitat, and transportation resources.

The section under Existing Forest Vegetation and Conditions lists:

<u>Influences of Management Activities and Wildfire</u> (Draft EA, pp. 2-3)

Since the early 20th century, fire suppression efforts have resulted in a departure from historical fire regimes within the project area. While the proposed fuel reduction treatments (in cooperation of both the Forest Service and the Natural Resource Conservation Service) would not cover the entire project area, they would address fuel loading and fire risk, and take another critical step to returning fire to its historical role on the landscape. The project would also increase the success of future wildfire suppression operations to protect critical infrastructure that occurs in or adjacent to the treated landscapes.

A large portion of the project area falls within the community protection zone (CPZ). The CPZ identifies where hazardous fuel conditions currently put communities, community assets, and private land at very high risk of damage from wildfires. Wildfires that start in this zone contribute more to the potential loss of community assets than any other strategic fire management zone. Fuel reduction treatments and fire protection are generally needed in this zone to prevent direct threats to life or property. Wildfire in this zone is suppressed under most conditions due to the significant risk, potential economic loss, and public safety concerns. Additional details are available in the Fire and Fuels Specialist Report (PF-FIRE AND FUELS-001).

In 2019, a comprehensive wildfire risk assessment was completed for the Bitterroot National Forest, using modeling and fire simulations (Scott 2019). One of the outputs from that simulation modeling was the creation of an ignition density layer that allows for areas to be classified based on the probability that fire ignitions originating in those areas will reach identified values (such as communities, infrastructure, and habitat). The CPZ ignition density layer spatially displays percentile classes across the Bitterroot National Forest that, if a fire were to start in those areas, have a certain probability of reaching structures on private land within Ravalli County's valley communities or forest inholdings. The data are broken into 10 classes based on probability percentiles. For example, 61 to 70 percent of the fire starts within the 61– 70 percentile class area would reach a private structure if suppression actions are not successful. In short, if a wildfire occurs within a CPZ , the designated percentile represents the probability that a wildfire will impact private property including structures and critical infrastructure. The main area of concern for this project included the 50-100 percentiles.

<u>Insect and Disease Hazard (Draft EA, at 3)</u>

Forest insects and diseases can dramatically alter forest structure, composition, and age class distribution. The Region I Forest Insect Hazard Rating System developed hazard ratings to aid in identifying stands that are at risk for significant insect activity. Western pine beetle (*Dendroctonus brevicomis*), mountain pine beetle (*Dendroctonus ponderosae*), Douglas-fir beetle (*Dendroctonus pseudotsugae*), and western spruce budworm (*Choristoneura freemani*) are all actively present in the project area. These insects can negatively affect stands dominated by ponderosa pine (*Pinus ponderosa*); Douglas-fir (*Pseudotsuga menziesii*); mixed, shade-tolerant conifers; spruce (*Picea* spp.); and subalpine fir (*Abies lasiocarpa*). The listed insect species above occur across much of the project area. Tree stands dominated by mixed, shade-tolerant conifers; Douglas-fir; and ponderosa pine have moderate to high insect hazard ratings.

Dwarf mistletoe (*Arceuthobium* spp.) also impacts Douglas-fir in the project area. Dwarf mistletoe is a parasitic plant that depends on a living host for water and nutrients. Infected trees form witches' brooms in the tree canopies that divert nutrients to the mistletoe plant and reduce the amount of available nutrients to the rest of the tree. Eventually, this lack of nutrients leads to a slow death starting from the top down. Severe infestations cause tree growth loss and make the tree more vulnerable to attack by other insects or diseases. Additionally, witches' brooms are highly flammable and increase the fire risk and intensity within a stand.

White pine blister rust is a nonnative fungal disease that infects five-needle pines (whitebark pine [*Pinus albicaulis*] in the Bitterroot Front project area). White pine blister rust requires living host tissue, and it requires two hosts, five-needled pines, and shrub or herbaceous alternate hosts, to complete its complex life cycle. Infections occur through needles by spores that come from alternate hosts in late fall during periods of high humidity. The rust fungus grows through branches toward the bole about 2 inches per year, killing tissue as it advances. Once the fungus reaches the bole, it creates stem cankers that eventually girdle the stem and kill or top kill the tree. All sizes of trees are attacked, and small regeneration can be killed rapidly.

Annosus root disease (P type and S type) is common in the Bitterroot National Forest. P type annosus primarily affects ponderosa pine, whereas S type annosus can affect Douglas-fir, grand fir (*Albies grandis*), and subalpine fir. Root disease causes decay in the roots of the infected trees, preventing the uptake of water and nutrients, which increases the susceptibility to bark beetle attack and eventually leads to mortality. The spores infect freshly cut stump surfaces and basal wounds. Once infected, the fungus grows through the root system and can infect neighboring pine through root-to-root contact.

<u>Existing Transportation System (Draft EA, at 3)</u>

The Bitterroot Front interdisciplinary team (IDT) has conducted a travel analysis and has identified opportunities to modify existing roads based on the following condition:

- Implement road improvements and best management practices to reduce sedimentation effects on watersheds.

The proposed project's **Purpose and Need** is (Draft EA, pp. 3-4):

Over the past decade, the project area has experienced extreme fire behavior with numerous large fires; the most recent fires were the Roaring Lion (2016) and Lolo Peak (2017). The Forest Service conducted a geospatial analysis to predict stand-replacing fire behavior across the project area. Modeling results of the current conditions within the project area show that the forest is at extreme risk of a catastrophic fire. The modeled outputs from the present fuel arrangement conditions do not mimic the natural fire spread type for sustainable ecosystem management in the Bitterroot National Forest. Graphics of the modeling results are in appendix C, figures 1-4 to 1-7. They include:

- Fire regime groups (figure 1-4)
- Vegetation condition class (figure 1-5)
- Existing flame length conditions (figure 1-6)
- Crown fire activity (figure 1-7)

Additional details on these models are available in the Fire and Fuels Specialist Report (PF-FIRE AND FUELS-001).

Climate change affects human health and well-being through more extreme weather events, increased wildfire activity, decreased air quality, and increased disease transmission. Prolonged periods of high temperatures associated with droughts contribute to conditions that lead to larger wildfires and longer fire seasons (United States Global Change Research Program 2023). Increased wildfire activity can lead to the loss of recreational opportunities, homes, and livestock, and cause community-wide evacuations.

The Forest Service recognizes unfavorable fire behavior conditions exist across the project area, as well as the potential impacts on the neighboring communities and first responders.

The Forest Service recognizes these conditions exist by, but are not limited to, the following reasons:

- The shift in historical plant community composition and condition class toward fire-intolerant plant species
- Overstocked and overcrowded forest stand conditions
- An increase in insect and pathogen outbreaks
- Climatic warming trends and unseasonably longer summers and dryer winters

The purpose of the Bitterroot Front project is to address the wildfire risk to the nearby communities and promote forest restoration using a wide range of tools, including tree thinning, harvesting, and prescribed burning. Specifically, the Bitterroot Front project aims to:

1. Reduce fire behavior and intensity by reducing the fuel quantity, modifying the arrangement of the fuels, and reducing the current and future wildfire risk to people, private lands, and resource values.
2. Improve forest landscape health and resilience by reducing the risk or extent of, or increasing resilience to, insect and disease infestation.
3. Reduce the risk to first responders and raise the probability of success during direct and indirect engagement on wildfires by treating fuels to modify fire behavior and increasing operational opportunities to protect values.

What **Will Be Decided** states (Draft EA, at 7):

This EA discloses the environmental consequences of implementing the no-action alternative and the proposed action. The Forest Supervisor for the Bitterroot National Forest is the deciding official who will review the anticipated consequences to determine whether a significant effect on the quality of the human environment is likely to occur, in accordance with Forest Service Handbook 1909.15, chapter 40, section 43.1. If the Forest Supervisor determines that the selected alternative would have a significant effect on the human environment, an EIS would need to be prepared. If no significant effect is determined, then the proposed action will be implemented based on the following criteria:

- The extent that the proposed action addresses the project's purpose and need.
- Consistency with the goals and standards of the forest plan and other relevant legal mandates.
- How well the proposed action addresses environmental issues identified through internal and external scoping and whether the project design, design features, and implementation process would minimize those environmental issues.
- Whether the forest plan should be amended for elk habitat objectives, snags, old growth, and coarse woody debris standards to accomplish the project objectives.

The **Proposed Action Overview** declares (Draft EA, pp. 8-9):

The proposed action consists of fuel arrangement activities to address undesirable flame lengths and prescribed fire behavior. The fuel arrangement and conditioning objectives of the proposed action include:

- Reducing fuel loading and arrangement of fuels to protect private property immediately adjacent to the forest boundary and forest ecosystems that are at risk to stand-replacing fire behavior.
- Restoring and maintaining ecosystem health by continuing to move the fire regime condition class toward the desired future condition through continued treatments that create disturbance.
- Restoring stands devastated by insects, disease, and overstocked conditions to young, vigorous stands of fire-adapted species historically found within the project area.
- Improving stand health and individual tree vigor for increased resistance to insects and disease using a variety of treatments, such as thinning, mechanical fuel reduction, and prescribed fire.
- Restoring and maintaining fire-adapted species across the landscape.
- Utilizing prescribed fire for maintaining these stands into the future, which would result in the reduction of future hazards to the public, critical values, and first responders.

In accordance with the condition-based approach, the proposed action describes the existing vegetative conditions in the project area and the range of treatments that would be used to accomplish the project needs based on the fuel conditions at the time of implementation. The exact location of a treatment is not defined.

I. Flawed Rationales Used to Support the Claimed Purpose and Need Related to Vegetative Management

The Forest Service provides cursory rationales to support its vegetation treatments, namely by citing departures from historic conditions, threats from natural disturbances (wildfire, insects, and diseases), and increased wildfire risks due to past suppression actions. The Agency's underlying assumptions are both highly controversial and uncertain, thereby necessitating detailed environmental analysis under an EIS. To ensure that the Agency has taken the required "hard look," courts hold that the Agency must use "public comment and the best available scientific information." *Biodiversity Cons. Alliance v. Jiron*, 762 F.3d 1036, 1086 (10th Cir. 2014) (internal citation omitted). As such, the Forest Service must demonstrate that the widespread use of specific proposed treatments under the proposed actions will actually improve ecosystem resilience and, that attempting to attain such a goal, will in fact restore ecological integrity. Therefore, we caution the Forest Service not to rely on uncertain and controversial assumptions that the proposed treatments will effectively achieve the intended purposes and meet the stated needs.

A. Global Warming & Historical References

As noted, the Agency relies heavily on assumed departures from historic conditions to support this Project's purpose and need. Relying on presumed historic conditions to inform vegetative treatments necessitates accounting for the fact that global warming is fundamentally altering the Agency's assumptions about the efficacy of the proposed actions. Recent scientific research calls into question declarations that some forested landscapes historically experienced low-intensity wildfire and that current trends toward higher intensity are substantially departed from historic ranges of variability.

> The structure and fire regime of pre-industrial (historical) dry forests over ~26 million ha of the western USA is of growing importance because wildfires are increasing and spilling over into communities. Management is guided by current conditions relative to the historical range of variability (HRV). Two models of HRV, with different implications, have been debated since the 1990s in a complex series of papers, replies, and rebuttals. The "low-severity" model is that dry forests were relatively uniform, low in tree density, and dominated by low- to moderate-severity fires; the "mixed-severity" model is that dry forests were heterogeneous, with both low and high tree densities and a mixture of fire severities. Here, we simply rebut evidence in the low-severity model's latest review, including its 37 critiques of the mixed-severity model. A central finding of high-severity fire recently exceeding its historical rates was not supported by evidence in the review itself. A large body of published evidence supporting the mixed-severity model was omitted. These included numerous direct observations by early scientists, early forest atlases, early newspaper accounts, early oblique and aerial photographs, seven paleo-charcoal reconstructions, >18 tree-ring reconstructions, 15 land survey reconstructions, and analysis of forest inventory data. Our rebuttal shows that evidence omitted in the review left a falsification of the scientific record, with significant land management implications. The low-severity model is rejected and mixed-severity model is supported by the corrected body of scientific evidence. (Baker et al 2023)[1]

The Forest Service cannot rely on a single interpretation of historic reference conditions to formulate its vegetation treatments. The Agency must look beyond HRV and inform restoration objectives based on reference sites that represent current ecological conditions of the project area. Such sites would have experienced broadscale disturbances in areas that have a passive management emphasis. Additionally, based on the best available climate models, the Forest Service should analyze how those reference conditions may change over the next 50 -100 years. It is likely that such analysis will indicate the best management approach is, as a recent study suggests, to allow for natural adaptation.

> Forests are critical to the planetary operational system and evolved without human management for millions of years in North America. Actively managing forests to help them adapt to a changing climate and disturbance regime has become a major focus in the United States. Aside from a subset of forests wherein wood production, human safety, and experimental research are primary goals, we argue that expensive management interventions are often unnecessary, have uncertain benefits, or are detrimental to many forest attributes such as resilience, carbon accumulation, structural complexity, and genetic and biological diversity. Natural forests (i.e., those protected

[1] Baker, William L., Chad T. Hanson, Mark A. Williams, and Dominick A. DellaSala (2023) "Countering Omitted Evidence of Variable Historical Forests and Fire Regime in Western USA Dry Forests: The Low-Severity-Fire Model Rejected" Fire 6, no. 4: 146. https://doi.org/10.3390/fire6040146

> and largely free from human management) tend to develop greater complexity, carbon storage, and tree diversity over time than forests that are actively managed; and natural forests often become less susceptible to future insect attacks and fire following these disturbances. Natural forest stewardship is therefore a critical and cost-effective strategy in forest climate adaptation. (Faison et al 2023)[2]

Forest Service actions that seek to resist natural adaptation need careful evaluation to determine if such resistance will in fact meet restoration goals, especially given that "in a time of pervasive and intensifying change, the implicit assumption that the future will reflect the past is a questionable basis for land management (Falk 2017)." (Coop et al 2020). While it may be useful to understand how vegetative conditions have departed from those of the past, the Agency cannot rely on those departures to define management actions, or reasonably expect the action alternatives will result in restoring ecological processes.

Given changing climate conditions, the Forest Service should emphasize reference conditions based on current and future ranges of variability, and less on historic departures. The Agency needs to shift its management approach to incorporate the likelihood that no matter what vegetation treatments it implements, there are going to be future forest wildfire-triggered conversions to other vegetation types. As Coop et al (2020) explains, the Forest Service cannot rely on the success of resistance strategies.

> Contemporary forest management policies, mandates, and science generally fall within the paradigm of resisting conversion, through on-the-ground tactics such as fuel reduction or tree planting. Given anticipated disturbance trajectories and climate change, science syntheses and critical evaluations of such resistance approaches are needed because of their increasing relevance in mitigating future wildfire severity (Stephens et al. 2013, Prichard et al. 2017) and managing for carbon storage (Hurteau et al. 2019b). Managers seeking to wisely invest resources and strategically resist change need to understand the efficacy and durability of these resistance strategies in a changing climate. Managers also require new scientific knowledge to inform alternative approaches including accepting or directing conversion, developing a portfolio of new approaches and conducting experimental adaptation, and to even allow and learn from adaptation failures (Coop et al 2020).

Equally important to acknowledging the limitations of resistance strategies is the fact that other pertinent scientific findings show warming and drying trends are having a major impact on forests, resulting in tree die-off even without wildfire or insect infestation. See, e.g., Parmesan, C. 2006; Breshears et al 2005; Allen et al 2010, 2015; Anderegg et al 2012; Williams et al 2013; Overpeck 2013; Funk et al 2015; Millar and Stephenson 2015; Gauthier et al 2015; Ault et al 2016 ("business-as-usual emissions of greenhouse gases will drive regional warming and drying, regardless of large precipitation uncertainties"); Vose et al 2016 ("In essence, a survivable drought of the past can become an intolerable drought under a warming climate").

[2] Faison, E. K., Masino, S. A., & Moomaw, W. R. (2023) The importance of natural forest stewardship in adaptation planning in the United States. Conservation Science and Practice, e12935. https://doi.org/10.1111/csp2.12935

Given the fallacies of using historic conditions as a reference for desired conditions and the uncertainty that treatments will maintain or restore ecological integrity in the context of global warming and likely forest conversion scenarios, the Forest Service must reevaluate its assumptions about its proposed vegetative treatments. Many of the Agency's assumptions run contrary to the most recent science regarding the impact of logging on wildfire behavior, resilience of the forest to large-scale disturbances, and ability to provide quality wildlife habitat. Many of the scientific studies cited within our comments call into question the Forest Service's assumption that its proposed actions will achieve the stated purpose and need. Thus, the Agency cannot truthfully assert that there is broad consensus in the scientific literature that commercial timber harvest or thinning in combination with prescribed fire reduces the potential for high-intensity wildfire to the extent characterized in the Project's scoping letter and Draft EA documentation. Such an approach has been broadly questioned within scientific literature.

> Fire suppression policies and "active management" in response to wildfires are being carried out by land managers globally, including millions of hectares of mixed conifer and dry ponderosa pine (Pinus ponderosa) forests of the western USA that periodically burn in mixed severity fires. Federal managers pour billions of dollars into command-and-control fire suppression and the MegaFire (landscape scale) Active Management Approach (MFAMA) in an attempt to contain wildfires increasingly influenced by top-down climate forcings. Wildfire suppression activities aimed at stopping or slowing fires include expansive dozerlines, chemical retardants and igniters, backburns, and cutting trees (live and dead), including within roadless and wilderness areas. MFAMA involves logging of large, fire-resistant live trees and snags; mastication of beneficial shrubs; degradation of wildlife habitat, including endangered species habitat; aquatic impacts from an expansive road system; and logging-related carbon emissions. Such impacts are routinely dismissed with minimal environmental review and defiance of the precautionary principle in environmental planning. Placing restrictive bounds on these activities, deemed increasingly ineffective in a chang[ing] climate, is urgently needed to overcome their contributions to the global biodiversity and climate crises. We urge land managers and decision makers to address the root cause of recent fire increases by reducing greenhouse gas emissions across all sectors, reforming industrial forestry and fire suppression practices, protecting carbon stores in large trees and recently burned forests, working with wildfire for ecosystem benefits using minimum suppression tactics when fire is not threatening towns, and surgical application of thinning and prescribed fire nearest homes. (DellaSala et al 2022).[3]

This article comes in response to an article, Prichard et al 2021, that we see the Forest Service typically cite to support its proposed actions and assert broad scientific consensus as to their efficacy. Here the researchers raise several factors that the Forest Service must address in a detailed analysis. They explain:

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[3] Dellasala, Dominick & Baker, Bryant & Hanson, Chad & Ruediger, Luke & Baker, William. (2022). Have western USA fire suppression and megafire active management approaches become a contemporary Sisyphus? Biological Conservation. 268. 109499. 10.1016/j.biocon.2022.109499

> Fuel reduction treatments are not appropriate for all conditions or forest types (DellaSala et al 2004, Reinhardt et al 2008, Naficy et al 2016). In some mesic forests, for instance, mechanical treatments may increase the risk of fire by increasing sunlight exposure to the forest floor, drying surface fuels, promoting understory growth, and increasing wind speeds that leave residual trees vulnerable to wind throw (Zald and Dunn 2018, Hanan et al 2020).

Those conclusions indicate that treatments within areas of mesic site conditions may not be appropriate. In addition, Prichard et al 2021 explains:

> In other forest types such as subalpine, subboreal, and boreal forests, low crown base heights, thin bark, and heavy duff and litter loads make trees vulnerable to fire at any intensity (Agee 1996, Stevens et al 2020). Fire regimes in these forests, along with lodgepole pine, are dominated by moderate- and high-severity fires, and applications of forest thinning and prescribed under burning are generally inappropriate.

Nowhere does the Forest Service state it has any plans to allow unmanaged wildfire to play a natural ecological role. Here, what the Agency proposes is a long-term active-management regime that will require repeated tree cutting and burning. That equates to perpetual management with logging and prescribed burning—hardly ecological restoration. The Agency's misguided efforts to mimic natural disturbance patterns create novel ecosystems with unknown long-term results, fail to allow natural processes to function.

And in addition, although the Forest Service is a federal agency, when performing management activities (i.e., projects) in Montana, it must abide by restrictions contained in Montana's constitution. More plainly, Montana's constitution promises a clean and healthful environment.

> Article IX -- ENVIRONMENT AND NATURAL RESOURCES. Section 1. Protection and improvement. (1) The state and each person shall maintain and improve a clean and healthful environment in Montana for present and future generations.

Thus, the Forest Service must ensure that its management activities do not contribute to the degradation of the future environment. Management actions which release greenhouse gases (GHG) into the atmosphere or lessen the environment's ability to sequester CO_2 do just that and run afoul of Montana's constitution. (See *Held v. State of Montana, CDV-2020-307* – August 14, 2023)

B. Assumptions And Uncertainty About Vegetation Treatments And Wildfire

Ultimately, we question the Agency's assumption that reducing tree densities and fuel loadings will result in less intense fire behavior. Powell, H. 2019 ("what fire scientists call a forest's 'fuel load' is not the main cause of large, unstoppable fires; it's climate factors such as temperature, humidity, and especially wind. But the weather is ephemeral and invisible, while thick underbrush is easy to see and photograph."; Exhibit 1); see also, ProPublica, 2020 "Despite What the Logging Industry Says, Cutting Down Trees Isn't Stopping Catastrophic Wildfires" (Exhibit 2) and Mountain Town News, 2020 "Colorado's Troublesome megafire" (Exhibit 2).

Science shows that fuel treatments have a modest effect on fire behavior and that fuel reduction does not necessarily suppress fire. Lydersen, et al 2014 (explaining that reducing fuels does not consistently prevent large forest fires, and seldom significantly reduces the outcome of large fires). Studies from the Forest Service's own Rocky Mountain Research Station refute the Agency's assumptions that vegetation treatments will result in less intense fire behavior. Calkin, D.E. et al 2014 (explaining, "[p]aradoxically, using wildfire suppression to eliminate large and damaging wildfires ensures the inevitable occurrence of these fires").

Large fires are driven by several conditions that completely overwhelm fuels (Meyer, G. and Pierce, J. 2007). Because weather is often the greatest driving factor of a forest fire, and because the strength and direction of the wildfire is often determined by topography, fuels reduction projects cannot guarantee fires of less severity (Rhodes, J. 2007, Carey, H. and Schumann, M. 2003).

Vegetation treatments based on historical reference conditions to reduce high-intensity wildfire risk on a landscape scale are undermined by the fact that land managers have shown little ability to target treatments where fires later occur. Barnett, K. et al 2016, Rhodes, J. and Baker, W. 2008 (finding that fuel treatments have a mean probability of 2-8% of encountering moderate- or high- severity fire during the assumed 20-year period of reduced fuels). Analysis of the likelihood of fire is central to estimating likely risks, costs, and benefits incurred with the treatment or nontreatment of fuels. If fire does not affect treated areas while fuels are reduced, treatment impacts are not counterbalanced by benefits from reduction in fire impacts. Results from Rhodes and Baker 2008 indicate that "even if fuel treatments were very effective when encountering fire of any severity, treatments will rarely encounter fire, and thus are unlikely to substantially reduce effects of high-severity fire."

Fuel treatments could even make fires worse, exacerbating the very problems the Forest Service is claiming to address. In some cases, fuel reduction may intensify fire severity as such projects produce and leave combustible slash through at least one dry season, open the forest canopy to create more ground-level biomass, and increase solar radiation which dries out the understory. Graham, R.T. et al 2012, Martinson, E. J. and Omi, P.N. 2013 (finding that in about a third of cases reviewed mechanical fuel reductions increased fire spread). In addition, fuel reduction can and often does worsen fire spread by opening a forest to wind penetration.

We question the wisdom of attempting to control wildfire instead of learning to adapt to fire. See Powell 2019 (Exhibit 1 - noting that severe fires are likely inevitable and unstoppable). See also Schoennagel, T. et al 2017 (explaining, "[o]ur key message is that wildfire policy and management require a new paradigm that hinges on the critical need to adapt to inevitably more fire in the West in the coming decades"). The Forest Service must recognize that past logging and thinning practices may have increased the risk of intense fire behavior on this landscape. Regrettably, instead of learning from these past mistakes, the Agency is committing to the same mistakes by proposing widespread tree cutting and repeated burning across the landscape.

It is well-established that communities (homes) are best protected from fire by home hardening, and judicious removal of fuels within the surrounding 100 - 200 ft radius. (Syphard et al 2014, Cohen, 2000).[4] The Forest Service needs to address the fact that addressing the home ignition zone will do more to protect property than the proposed action.

We also question the need to reduce wildfire, a natural forest process. While some may view wildfires as tragic and the aftermath as a destruction zone, natural ecology shows otherwise. See Powell 2019, (Exhibit 1 - explaining how a young, burned forest is an essential natural process and "nature's best-kept secret," providing new habitat for a plethora of birds, abundant wildflowers, insects, mushrooms, etc.). Further, conservation scientists Dominick DellaSala and Chad Hanson published a 2019 study disputing the assumption that high-intensity has increased in recent decades. In this megafire trend study, the researchers analyzed data on large high-intensity burn patches across 11 western dry pine and mixed-conifer forests over three decades. They found no significant increase in the size of large high-intensity burn patches since the early 1990s (DellaSala, Hanson, 2019). Most research studies define high intensity as 90% tree mortality. (Moritz et al 2014). Thus, the Forest Service may be overestimating any increase of the amount of high intensity wildfire that has been occurring in recent decades. This leads to a bias towards carrying out widespread and intensive fuel treatments to respond to the alleged increase in high-intensity fire.

Impacts from global warming, including changing weather patterns and drought, are the driving factors for wildfires. *Id*. Instead of focusing on thinning and prescribed burning to manage the forest, the Forest Service should focus on how it needs to change its practices to adapt to the changing climate. At an absolute minimum, these studies demonstrate that the proposed treatments are controversial, ill-supported, and have the potential for significant impacts requiring preparation of an EIS.

C. Assumptions and Uncertainty About Vegetation Treatments and Forest Resilience

The Forest Service explains that "Overall, the proposed action would trend the landscape toward desired conditions and improve the landscape's resilience to natural disturbances such as insects, disease, fire, and drought." (Draft EA, at 96). Yet the best available science brings into question many of the Agency's underlying assumptions about the efficacy of vegetation treatments in reducing the effects from what can be characterized as a natural response to changing climate conditions. See Hart, S.J. et al 2015 (finding that although mountain pine beetle infestation and fire activity both independently increased with warming, the annual area burned in the western United States has not increased in direct response to bark beetle activity); see also Hart, S.J. and Preston, D.L. 2020 (finding "[t]he overriding influence of weather and pre-outbreak fuel conditions on daily fire activity . . . suggest that efforts to reduce the risk of extreme fire activity should focus on societal adaptation to future warming and extreme weather"); see also Black, S.H. et al 2010 (finding, inter alia, that

[4] See also, Exhibit 3 containing a series of articles featuring Dr. Cohen.

thinning is not likely to alleviate future large-scale epidemics of bark beetle); see also Six, D.L. et al 2018 (study that found during mountain pine beetle outbreaks, beetle choice may result in strong selection for trees with greater resistance to attack, and therefore retaining survivors after outbreaks—as opposed to logging them—to act as primary seed sources that could act to promote adaptation); see also Six, D.L. et al 2014 (noting "[s]tudies conducted during outbreaks indicate that thinning can fail to protect stands").

Ultimately, science provides weak support for vegetative treatments as a way to improve forest resilience to large-scale disturbances such as high intensity crown fire, insects, or disease. Numerous studies question this approach or have found it to be ineffective. Moreover, all mechanized treatments guarantee damage to ecosystem components, including soils, mycorrhizal networks, aquatics, and vegetation; they also have the potential to spread exotic plants and pathogens.

The Agency claims fuel treatments will help prevent outbreaks of bark beetle, but they typically always leave slash through the next warm season, when a bark beetle outbreak could occur. Slash should not be left on the ground through the warm season following thinning treatments. This could precipitate a bark beetle outbreak throughout large sections of the Bitterroot National Forest. This risk must be addressed.

As such, the Forest Service must prepare the appropriate NEPA document which carefully considers these impacts and determines the efficacy of specific treatments.

II. The Bitterroot Front Project Will Negatively Impact the Human Environment and Requires an Environmental Impact Statement (EIS)

The Draft EA explicitly states that the Forest Service (FS) proposes to execute a "condition-based" implementation of this Project. (Draft EA, at 9)

NEPA requires federal agencies to prepare a full EIS for "major Federal actions significantly affecting the quality of the human environment." 42 U.S.C. § 4332(2)(C). If "substantial questions are raised" as to whether a proposed federal Agency action may have a significant effect on some human environmental factor, then the Agency must prepare an EIS. *Klamath Siskiyou Wildlands Ctr. v. Boody*, 468 F.3d 549, 562 (9th Cir. 2006). "This is a low standard." *Id.*

The Forest Service cannot, with any credibility, claim there will not be any significant impacts from the implementation of this proposed Project. The low standard for triggering the duty to prepare an EIS is easily met here, given the massive scale of the Project; the intensity and extent of logging and road construction; the many at-risk species at issue; the significant scientific controversy and uncertainty surrounding logging to reduce fire risk and otherwise address forest health; the cumulative effects of this Project considered together with logging projects and other actions in the area; and the many uncertainties surrounding the Project due to the proposed use of condition-based management. *See*, *e.g.*, *Bark v. U.S. Forest Service*, 958

F.3d 865 (9th Cir. 2020) (requiring EIS for much smaller logging project due to significant scientific controversy surrounding logging and fire and due to significant cumulative effects).

The Draft EA identifies specific management actions and suggests they will be "near" certain Bitterroot communities. However, there is no indication of exactly where management actions would be implemented. Implied, is that such decisions would be made at some undetermined point in the future, well after the NEPA process is completed. Because a list of site-specific management actions is not made public during the NEPA process, a condition-based procedure effectively eliminates meaningful public input.

The Project area is just under 144,000 acres (Draft EA, at 1). That is almost 3 times as large as the Gold Butterfly Project which covers approximately 55,000 acres. The suggestion that this proposed Project can satisfy NEPA regulations using an Environment Analysis (EA) is questionable when a project a fraction of its size, Gold Butterfly, required an EIS and a Supplemental Environmental Impact Statement (SEIS).

The attempt by the Agency to conduct this gigantic, multi-year Project using an EA indicates three things.

First, advertising that this proposed Project will be conducted using an EA reveals the FS has already completed the decision process. Exposed is what has long been suspected; asking for public input is nothing more than window dressing used to satisfy NEPA requirements. [5]

Second, the Agency has no interest in achieving broad public support for its actions. The use of an EA forces those segments of the public whose interests are being threatened with harm to petition the courts simply to be heard.

Three, the negative impact this multi-year Project may have on the human environment has been ignored in both the scoping and Draft EA documentation. For example, logging/thinning trees, removing vegetation, and disturbing soil all have a negative effect on ecosystems and the ability of the forest to sequester carbon. Weakened forest ecosystems are less able to reliably provide much-needed services such as clean water. Diminishing carbon sequestration means increased Greenhouse Gasses (GHG) in the atmosphere and increased temperatures. In other words, the implementation of this proposed Project will be a degraded human environment.

III. A Condition-based Implementation Approach Violates the National Environmental Policy Act (NEPA) and the National Forest Management Act (NFMA)

This proposal is not for a "project." It is a Condition-Based management approach that violates NEPA's hard-look requirements and is fundamentally flawed. True project planning includes the disclosing of specific activities proposed for specific locations, identifying the current conditions in those specific locations and project area. An evaluation of site-specific condition,

[5] Fleischman, F. et al. (2020) US Forest Service implementation of NEPA - fast, variable, rarely litigated and declining - https://academic.oup.com/jof/article/118/4/403/5825558?login=true

based on current data gathering, should inform a detailed analysis that includes the direct, indirect, and cumulative impacts of the proposed activities. Project planning also requires disclosing details on how the suggested management activities are consistent with all relevant management direction in the current (1987) Forest Plan.

The Forest Service cannot approve the proposed actions without providing the public with a detailed analysis that discloses and discusses relevant information and applicable studies the Agency used to support the Project's purpose and need. We caution the FS against asserting the underlying science the Agency relies upon, and cites, is settled. Significant controversy and uncertainty exist regarding the efficacy of vegetation management as a tool to reduce high-intensity wildfires, to improve wildlife habitat, or to increase forest resilience. As such, the Agency must conduct a detailed analysis that addresses the significant effects that will result under the proposed actions. NEPA regulations state that:

> NEPA procedures ensure that environmental information must be available to public officials and citizens before decisions are made and before actions are taken. The information must be of high quality. Accurate scientific analysis, expert Agency comments, and public scrutiny are essential to implementing NEPA. [40 C.F.R. § 1500.1(b) (1978)]

To ensure an Agency has taken the required "hard look," courts hold that the Agency must use "public comment and the best available scientific information." [6]

This proposed Project involves delaying site-specific data gathering and analysis until after a decision has already been reached—all under a predetermined assumption that there would be no significant impacts. The legality of Condition-Based projects has been litigated and found to be outside current laws and regulations.[7]

Recently, 94 organizations sent a letter to CEQ requesting guidance or rule changes to address the unlawful use of conditions-based management, which identifies many ways condition-based management may be used to circumvent NEPA and other requirements.[8] We incorporate that letter in our comments.

The National Environmental Policy Act (NEPA) and the National Forest Management Act (NFMA) were instituted because federal agencies, the Forest Service and the Bureau of Land Management in particular, were misusing their legislated flexibility to devastate the public lands they were expected to protect. With this Project the Forest Service is asking the public to forget their unchecked abuse before NEPA and NFMA and to trust them with the unimpeded flexibility of a condition-based process.

Without legislated constraints, the Agency has shown how it treats our public lands. We have not forgotten that and so, are unwilling to "trust" the Forest Service to conduct this Project using a condition-based process.

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[6] Biodiversity Conservation Alliance v. Jiron et al., 762 F.3d 1036, 1086, 10th Cir. 2014

[7] Southeast Alaska Conservation Council, et al. v. U.S. Forest Service, 443 F.Supp.3d 995 (D. Alaska 2020).

[8] Exhibit 4 available at https://westernlaw.org/wp-content/uploads/2022/02/2022.02.03-Request-to-CEQ-re-CBM.pdf (enclosed)

IV. The Purpose and Need is Narrowly Crafted to Reject Reasonable Alternatives, Shun Public Concerns, and Ignore the Best Available Science

The Draft EA states (pp. 3-4):

> The purpose of the Bitterroot Front Project is to address the wildfire risk to the nearby communities and promote forest restoration using a wide range of tools, including tree thinning, harvesting, and prescribed burning. Specifically, the Bitterroot Front Project aims to:
>
> 1. Reduce fire behavior and intensity by reducing the fuel quantity, modifying the arrangement of the fuels, and reducing the current and future wildfire risk to people, private lands, and resource values.
> 2. Improve forest landscape health and resilience by reducing the risk or extent of, or increasing resilience to, insect and disease infestation.
> 3. Reduce the risk to first responders and raise the probability of success during direct and indirect engagement on wildfires by treating fuels to modify fire behavior and increasing operational opportunities to protect values.

CEQ's, A Citizens Guide to NEPA, at 13, states, "The purpose and need statement explains to the reader why an Agency action is necessary and serves as the basis for identifying the reasonable alternatives that meet the purpose and need." [9] By including in the Purpose and Need the remedy of "modifying forest structure," you violate legal precedent and rule out all other remedies and alternatives for achieving the purpose. For example, the intention to *"promote forest restoration using a wide range of tools, including tree thinning, harvesting, and prescribed burning"* narrows the alternatives to include only one small set of remedies. This prevents any other alternatives from being considered, even if other alternatives might be more effective at improving resilience or reducing the intensity of wildfire. In relation to insects and disease, a substantial body of research (Bailey et al 2005; Christiansen et al 1987; McNulty et al 2014; Six et al 2014, 2018, 2021; Sthulz et al 2009) suggests the best way to improve resilience to insects and disease is through passive management to let the forest adapt.

Please offer additional alternatives for achieving the Purpose and Need.

The Draft EA documents do not define either "resilience" or "healthy Forest" in any objective, measurable terms nor do they cite data which supports the FS implication of "inadequate forest resilience in the proposed Project area."

Please supply the most recent scientific research that supports the Project Draft EA documentation's repeated implication that there is inadequate forest resilience in the proposed Project area.

A. The Forest Service must consider a wide range of alternatives

[9] CEQ's A Citizens Guide to NEPA 2021 - https://ceq.doe.gov/docs/get-involved/citizens-guide-to-nepa-2021.pdf

Whether an Agency prepares an EIS or an EA, NEPA requires an Agency to "study, develop, and describe appropriate alternatives." *N. Idaho Cmty. Action Network v. U.S. Dep't of Transp.*, 545 F.3d 1147, 1153 (9th Cir. 2008). NEPA and Forest Service regulations require considering alternatives when there are unresolved conflicts concerning the resources at issue. 42 U.S.C. § 4332; 36 C.F.R. § 220.7(b)(2)(i). There are multiple unresolved conflicts surrounding the Project (as discussed throughout these comments) and many valid alternatives the Forest Service should consider, including:

- An alternative with no new road construction and no commercial logging.
- An alternative with no regeneration logging.
- An alternative with no project activities in IRAs, old growth, Recommended Wilderness, or Research Natural Areas.
- An alternative that does not use any project-specific amendments.
- A non-conditions-based-management alternative, which identifies specific timing, locations, and types of Project activities.

B. Expand the Project's purpose to include the Forest Service's duty to identify the minimum road system

The Forest Service explains that "[i]n 2015, the Bitterroot National Forest conducted a forest-wide travel analysis in compliance with the January 12, 2001, Road Management Rule (66 FR 3206)" (Bitterroot Front Project Travel Analysis Report at 2). Notwithstanding that the travel analysis came 14 years later, the Forest Service cannot assert that the 2015 Forestwide travel analysis report or the Bitterroot Front travel analysis report equates to compliance with the subpart A of the Travel Management Rule at 36 CFR 212.5(b). In fact, the Forest Service fails to acknowledge there is still a need. To fulfill its regulatory duties under this rule even though applicable statutory and regulatory requirements should shape a project's statement of purpose and need. When the Agency takes an action "pursuant to a specific statute, the statutory objectives of the project serve as a guide by which to determine the reasonableness of objectives outlined in an EIS." *Westlands Water Dist. v. U.S. Dept. of Interior*, 376 F.3d 853, 866 (9th Cir. 2004).

Under subpart A, the Forest Service has a substantive duty to address its over-sized road system. Identifying a resilient future road system is one of the most important endeavors the Forest Service can undertake to restore aquatic systems and wildlife habitat, facilitate adaptation to climate change, ensure reliable recreational access, and operate within budgetary constraints. This underlying substantive duty must inform the scope of, and be included in, the Agency's NEPA analysis. More than 20 years after finalizing the subpart A rules, the Forest Service can no longer delay in addressing this duty. We detail the agency's failure to comply with it obligations under subpart A in the enclosed report.[10] However, the Forest Service fails to incorporate this duty within this Project's purpose and need, let alone implementing a minimum road system, thereby failing to ensure the road system provides

[10] See Exhibit 5. A Dilapidated Web of Roads - The USFS's Departure from a Sustainable Forest Road System. Jan 2021_WildEarth Guardians.

for the protection of Forest Service System lands, reflects long-term funding expectations, and minimizes adverse impacts. See 36 C.F.R. 212.5(b).

As such we urge the Agency to include subpart A compliance as part of the Project's purpose, especially given the proposed actions include road construction and adding undetermined roads to the system. Complying with subpart A is a win-win-win approach: (1) it's a win for the Forest Service's budget, closing the gap between large maintenance needs and inadequate (and declining) funding through congressional appropriations; (2) it's a win for wildlife and natural resources because it reduces negative impacts from the forest road system; and (3) it's a win for the public because removing unneeded roads from the landscape allows the Agency to focus its limited resources on the roads we all use, improving public access across the forest and helping ensure roads withstand strong storms.

1. Disclose Site-specific Information

We asked the Forest Service to provide detailed, site-specific information regarding existing road conditions and how the proposed action regarding roads will affect forest resources including wildlife, wildlife habitat, along with streams and riparian areas. We were particularly interested in the disclosure of site-specific impacts to any at-risk wildlife. At a minimum, the Agency must disclose the location of proposed road activities in relation to wildlife that may be present in the Project area and important wildlife habitat, as well as perennial or ephemeral streams and riparian areas. We provide further comments on the lack of roads analysis and site-specific information in Section XIV below.

2. Consider Impacts from Roads and Motorized Use

Site-specific analysis is crucial to NEPA's goal of ensuring informed and science-based decision-making. To fully comply with NEPA, the Forest Service must also adequately assess and disclose numerous impacts related to forest roads and the transportation system generally including impacts from road presence, temporary and/or permanent road construction, and motorized use. The Agency must consider these impacts in the context of global warming, increased instances of human wildfire ignitions, and impacts to wildlife. The Forest Service must also assess and disclose the cumulative impacts of forest roads, access and fire, and forest roads and global warming. The current analysis fails to discuss or disclose these issues.

The best available science shows that roads cause significant adverse impacts to National Forest resources. See, e.g., 66 Fed. Reg. at 3208 ("Scientific evidence compiled to date [2001] suggests that roads are a significant source of erosion and sedimentation and are, in part, responsible for a decline in the quality of fish and wildlife habitat"). (WildEarth Guardians, 2020; Exhibit 6, entitled, "The environmental Consequences of Forest Roads and Achieving a Sustainable Road System") provides a literature review that discloses the extensive and best available scientific literature—including the Forest Service's General Technical Report synthesizing the scientific information on forest roads (Gucinski 2001)—on a wide range of road-related impacts to ecosystem processes and integrity on National Forest lands. Erosion, compaction, and other alterations in forest geomorphology and hydrology associated with roads, seriously impair water quality, and aquatic species viability. Roads disturb and fragment wildlife habitat, alter species distribution, interfere with critical life functions (e.g., feeding, breeding, and nesting,) and result in loss of biodiversity. Roads facilitate increased human intrusion into sensitive areas, resulting in poaching of rare plants and animals, human-ignited wildfires, introduction of exotic species, and damage to archeological resources. Given these widely accepted ecological impacts from roads and motorized use, we urge the Forest Service to conduct a robust analysis of its road-related proposed actions.

3. Use an Appropriate Baseline

The logical place to begin this requisite analysis is to use an accurate baseline to compare Project alternatives. To fully disclose the environmental consequences between alternatives as NEPA requires, the Forest Service must differentiate between the existing condition in its No Action Alternative and the legal baseline of system roads and trails. The Forest Service fails to do so, even after disclosing the project area has 60.84 miles of unauthorized roads that the agency labels "undetermined." Draft EA, PF-Transportation-01 at 3, Table 2. The Forest Service includes these roads in its existing condition, but fails to differentiate between them in its analysis, rather it simply lists some of them in a table with a final recommendation from the resource specialists in the project's travel analysis report. Draft EA, PF-Transportation-02. However, this does not disclose the actual resource impacts occurring from the unauthorized roads, and it is unclear how many (if any) of these road segments were part of the risk-benefit assessment. In any case, it is apparent that the agency did not include all 60.84 miles because the final recommendations lists obliterating all the unauthorized roads even though the proposed action would add 8.54 miles to the system. Draft EA at 18, Table 7, PF-Transportation-02. Further, the agency fails to disclose the environmental consequences from the unauthorized roads in its risk-benefit assessment or overall analysis. *Id.*

The CEQ recognizes the baseline and no-action alternative can, and sometimes do differ.[11] As such, the analysis of the road system and related impacts in this Project area should recognize and build on this distinction. Specifically, the Agency must differentiate between the miles of national forest system roads and the network of non-system within the Agency's jurisdiction. The baseline should only include the former and be separate from the no action that retains the existing condition. Such an approach is necessary to fully disclose the environmental consequences of the no action alternative. By failing to include a baseline of only system roads and trails in its analysis, the Forest Service risks not properly disclosing the effects of the no-action alternative, which would then skew the analysis for any action alternative. Adding existing road prisms to the National Forest System is not a simple administrative action, and the Agency cannot just assign road numbers in INFRA by claiming there are no immediate

[11] See, e.g. , FSH 1909.15, 14.2; Council on Environmental Quality's (CEQ) Forty Most Asked Questions (1981), #3 (explaining "[t]here are two distinct interpretations of 'no action'"; one is "'no change' from current management direction or level of management intensity," and the other is if "the proposed activity would not take place").

on-the-ground actions or direct effects from expanding the road system. While there may be no immediate effects because the unauthorized roads are part of the existing condition, the fact remains that the Forest Service must account for their potential environmental consequences. Without differentiating between system and unauthorized roads in the analysis, the Forest Service would fail to adequately disclose the direct, indirect, and cumulative effects to lands, water, and wildlife from adding non-system roads to the system. Without fully accounting for non-system and unauthorized roads not being added to the system in the analysis, any finding of no significant impact will be arbitrary and capricious, and a violation of NEPA.

4. Forest Roads, Human Access, and Fire

Numerous factors drive instances of wildland fires. Typically, the Forest Service acknowledges topography, weather, and fuel as the primary drivers but often asserts fuels are the only component that can be altered. The agency goes to great lengths attempting to demonstrate how vegetative treatments will change wildland fire behavior. But another major factor is human impact. Human-ignited wildfires account for more than 90% of fires on national lands and are five times more likely in areas with roads. Plus, roads can affect where and how forests burn and the vegetative condition of the forest. Yet, despite the stated need to establish a resilient future forest, the Forest Service proposal increases the need to demonstrate how the agency will enforce road closures. Given the scope and scale of the agency's proposal and the stated need to reduce instances of wildland fires, the agency must consider human caused wildfire ignitions in a detailed statement. The Draft EA and supporting project files fail to do so. Specifically, the project travel analysis report only lists roads as a benefit for fuel management and fire suppression access, and fails to recognize the risk of human wildfire ignitions from road and motorized trail access. PF-Transportation-002. The agency must correct this deficiency to comply with NEPA.

5. Avoid over-reliance on BMPs, Resource Protection Measures, or Design Criteria

The Forest Service cannot rely on best management practices (BMPs), design features/criteria or resource protection measures as a rationale for omitting proper analysis. Specifically, when considering how effective BMPs are at controlling nonpoint pollution on roads, both the rate of implementation, and their effectiveness should both be considered. The Agency tracks the rate of implementation and the relative effectiveness of BMPs from in-house audits. This information is summarized in the National BMP Monitoring Summary Report with the most recent data being the fiscal years 2013-2014 (Carlson et al 2015). The rating categories for implementation are "fully implemented," "mostly implemented," "marginally implemented," "not implemented," and "no BMPs." "No BMPs" represents a failure to consider BMPs in the planning process. More than a hundred evaluations on roads were conducted in FY2014. Of these evaluations, only about one third of the road BMPs were found to be "fully implemented." *Id.* at 12.

The monitoring audit also rated the relative effectiveness of BMPs. The rating categories for effectiveness are "effective," "mostly effective," "marginally effective," and “not effective.” “Effective” indicates no adverse impacts to water from project or activities were evident. When treated roads were evaluated for effectiveness, almost half of the road BMPs were scored as either “marginally effective” or “not effective.” *Id.* at 13.

A technical report by the Forest Service entitled, “Effectiveness of Best Management Practices that Have Application to Forest Roads: A Literature Synthesis,” summarized research and monitoring on the effectiveness of different BMP treatments for road construction, presence, and use (Edwards et al 2016). The report found that while several studies have concluded some road BMPs are effective at reducing delivery of sediment to streams, the degree of each treatment has not been rigorously evaluated. Few road BMPs have been evaluated under a variety of conditions, and much more research is needed to determine the site-specific suitability of different BMPs (Edwards et al 2016, also see Anderson et al 2011). Edwards et al (2016) cites several reasons for why BMPs may not be as effective as commonly thought. Most watershed-scale studies are short-term and do not account for variation over time, sediment measurements taken at the mouth of a watershed do not account for in-channel sediment storage and lag times, and it is impossible to measure the impact of individual BMPs when taken at the watershed scale. When individual BMPs are examined, there is rarely broad-scale testing in different geologic, topographic, physiological, and climatic conditions. Further, Edwards et al (2016) observes, “[t]he similarity of forest road BMPs used in many different states’ forestry BMP manuals and handbooks suggests a degree of confidence validation that may not be justified,” because they rely on just a single study. *Id.* at 133. Therefore, ensuring BMP effectiveness would require matching the site conditions found in that single study, an aspect rarely considered by land managers.

Global warming will further put into question the effectiveness of many road BMPs (Edwards et al 2016). While the impacts of climate will vary from region to region (Furniss et al 2010), more extreme weather is expected across the country which will increase the frequency of flooding, soil erosion, stream channel erosion, and variability of streamflow (Furniss et al 2010). BMPs designed to limit erosion and stream sediment for current weather conditions may not be effective in the future. Edwards et al (2016) states, “[m]ore-intense events, more frequent events, and longer duration events that accompany climate change may demonstrate that BMPs perform even more poorly in these situations. Research is urgently needed to identify BMP weaknesses under extreme events so that refinements, modifications, and development of BMPs do not lag behind the need.” *Id*. at 136.

Because of global warming, significant uncertainties persist about the effectiveness of BMPs or resource-protection measures. Inconsistencies revealed by BMP evaluations suggest the Forest Service cannot simply rely on them to mitigate Project-level activities. This is especially relevant where the Agency relies on the use of BMPs instead of fully analyzing potentially harmful environmental consequences from road design, construction, maintenance, or use, in studies and/or programmatic and site-specific NEPA analyses.

It would be arbitrary and capricious for the Forest Service to assume 100 or even 80 - 90 percent proper BMP implementation and effectiveness as a rationale for not determining potential sedimentation without BMP application. The Agency must demonstrate how BMP effectiveness will be maintained in the long-term. Given the lack of adequate road maintenance capacity, it is a serious omission for the Agency not to acknowledge it has inadequate funding and must prioritize roads open to passenger vehicles for annual maintenance.

6. Consider impacts to watersheds, water quality, and water quantity.

Consider and disclose the direct, indirect, and cumulative impacts of the proposed action to water quality, water quantity and overall watershed conditions. To take a hard look at the potential environmental consequences to watershed conditions from the proposed actions, the Forest Service must provide a detailed analysis. Absent a more tailored and specific watershed assessment we recommend using the Watershed Condition Framework (WCF) in a manner that addresses each applicable indicator and attribute. *See* Figure 1 below.

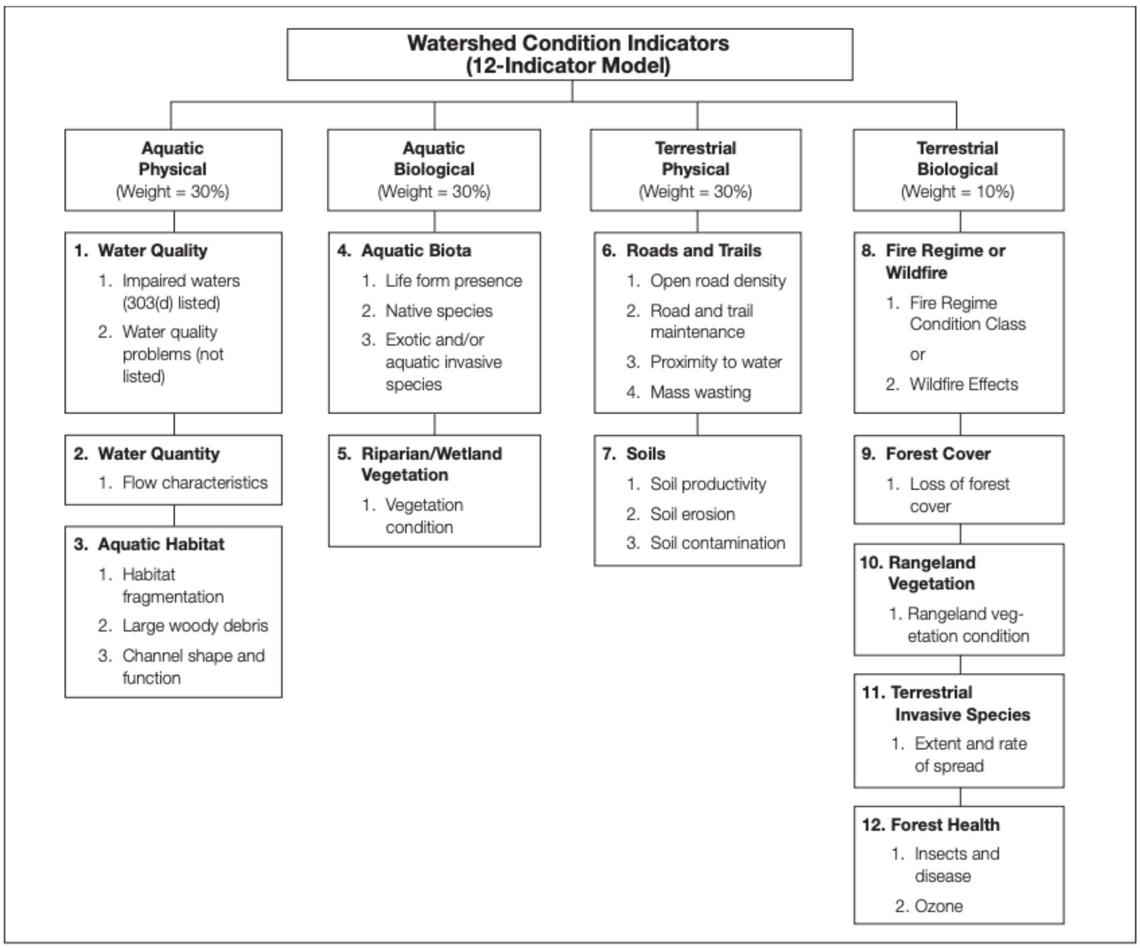

Figure 1. WCF Indicator and Attributes[12]

[12] *Id.* at 6, Figure 2.

We are particularly interested in the Road and Trail indicator and attributes. It is important to note that for classification purposes and thus analysis purposes under NEPA, the Watershed Condition Classification Guide (WCCG)[13] clarifies the meaning of its road attribute as follows.

For the purposes of this reconnaissance-level assessment, the term "road" is broadly defined to include roads and all lineal features on the landscape that typically influence watershed processes and conditions in a manner similar to roads. Roads, therefore, include Forest Service system roads (paved or nonpaved) and any temporary roads (skid trails, legacy roads) not closed or decommissioned, including private roads in these categories. Other linear features that might be included based on their prevalence or impact in a local area are motorized (off-road vehicle, all-terrain vehicle) and nonmotorized (recreational) trails and linear features, such as railroads. Properly closed roads should be hydrologically disconnected from the stream network. If roads have a closure order but are still contributing to hydrological damage, they should be considered open for the purposes of road density calculations (WCCG at 26).

Road densities, the proximity to water, maintenance and mass wasting are essential attributes to consider when determining potential watershed impacts. The Forest Service must consider these attributes, especially the effects of any necessary road-related actions such as construction, reconstruction, and road use. Further, when analyzing the impacts to water quality and water quantity, the Agency must provide site-specific analysis of the location of riparian areas, water springs, fens, wetlands, etc., in the Project area, and then disclose the foreseeable adverse impacts from the proposed action.

As it stands, the Forest Service failed to utilize the WCF or disclose how the proposed action would affect the condition class scores overall, the Road & Trail Indicator ranking or their specific attributes.

7. Demonstrate Compliance with the Clean Water Act

Under the Clean Water Act (CWA), states are responsible for developing water quality standards to protect the desired conditions of each waterway within the state's regulatory jurisdiction. 33 U.S.C. § 1313(c). Water bodies that fail to meet water quality standards are deemed "water quality-limited" and placed on the CWA's § 303(d) list. The CWA requires all federal agencies to comply with water quality standards, including a state's anti-degradation policy. 33 U.S.C. § 1323(a). The Forest Service must ensure all activities in this proposal comply with the CWA. The agency must ensure its proposal for logging, and the associated road reconstruction, maintenance, and ongoing log hauling other uses of these roads, will not cause or contribute to a violation of water quality standards. We strongly caution the Forest Service against relying on best management practices as the sole mechanism for CWA for the reasons explained above. At a minimum, the agency must ensure its analysis does not assume 100 percent BMP

[13] See Exhibit 7. Potyondy, J.P and Geier, T. W. 2011. Watershed Condition Classification Technical Guide. USDA Forest Service FS-978.

effectiveness and include water quality analysis that compares alternatives with and without the use of BMPs to disclose the potential sedimentation resulting from the Project activities. At bottom, the Forest Service must demonstrate that it is not contributing sediment to water-quality-limited stream segments or exceeding any road-related total daily maximum loads for sediment and ensure compliance with Montana's antidegradation rules. We caution the agency against over-reliance on best management practices in complying with the CWA requirements as we explained above.

V. Project is So Inadequately Defined the Public Cannot Fully Understand the Intent or Consequences

The Draft EA documents do not define "resilience" in any objective, measurable terms nor do they cite data that supports the FS implication of "inadequate resilience in the proposed Project area."

Without an objective way to measure "resilience," it is impossible to know if the management activities proposed for this Project (or past projects on the BNF) do in fact improve resilience.

No objectively measurable definition of resilience or proof of having improved resilience during past BNF management activities is offered, a fact which suggests the need for this proposed Project is questionable and is, at the very least, debatable.

Please provide an objective way to measure resilience and a thorough, scientifically based explanation of the necessity for this proposed Project.

Although a 20-year span is suggested, the Agency does not specify the exact length (in years) of this proposed Project.

> Temporary roads for one harvest area could be in use for up to 5 years (Draft EA, at 20).
>
> The activity types are the tools that could be used to manage the project area over the next 20 years based on what is known from existing data or conditions (Draft EA, at 21).
>
> The proposed action describes a suite of activities available to manage the project area over a period of approximately 20 years (Draft EA, at 22).
>
> The implementation period would be 5 to 20 years (Draft EA, at 24).
>
> The time frame considered is approximately 20 years in the future, at which time the proposed treatment activities would be completed, and vegetation and fuels response to those treatments would be stabilized (Draft EA, pp. 58-59).

If, as is likely to be the case for such a large scheme, implementation will take place over decades even while on-the-ground conditions undergo significant change. In effect, the Agency is expecting the public to accept the notion that the FS's implied assertion (based on current conditions) that "no significant impact" will occur even if on-the-ground conditions have drastically changed by the time later segments of the Project are implemented.

Please provide scientific evidence supporting the validity for the implied conclusion—based on current conditions—that “no significant change or impact” (will occur) during a possibly decades-long Project.

The documentation for this proposed Project suggests project-specific collaboration between the FS and the Confederated Salish & Kootenai Tribes (CSKT), the result of which was a memorandum of understanding (MOU). (Draft EA, at 124)

Please make public the MOU, other records of that collaboration, and copies of any agreements which were reached.

The Draft EA documentation offers no science, let alone recent research, which supports the statements, “The desired condition is a forest with an open-grown stand that is resilient to insects, fire, and disease in the face of climate change. Forest resilience can be improved by increasing the presence and dominance of ponderosa pine, western larch, and whitebark pine; increasing tree species diversity across the landscape; promoting the presence of large tree sizes with a focus on ponderosa pine; and reducing expected fire behavior in warm/dry biophysical settings.” (PF-VEGETATION-001, at 10)

Please supply recent scientific research which supports these multiple assertions.

Please reveal how the “desired outcome” was determined. What exactly does a “desired condition” look like and how is it measured?

The Draft EA did not address any of our concerns or recommendations. No consideration of the whitebark pine science we presented as included in the Draft EA, nor did you include in the Project documents the Biological Assessment for WBP which you claim to have submitted to USFWS for approval.

This proposed Project is directly adjacent to Wilderness and covers not only Inventoried Roadless Areas (IRA) but Recommended Wilderness Areas (RWA) and Research Natural Areas (RNA). Therefore, management activities included in the proposal will have a direct impact on the Wilderness and its inhabitants. A systematic and thorough analysis must show that the Project will not diminish the Wilderness quality of these areas.

VI. The Agency Systematically Exempts Projects from Forest Plan Standards

Project analysis should demonstrate to the public that the Project and Project activities comply with Forest Plan standards and objectives in accordance with NFMA. We addressed some forest plan compliance issues in FOB scoping comments pages 59-60. These have not been resolved by information in the EA or in the specialists’ reports available in the Project files. Our concerns carry into these comments. We have further concerns after reading the Draft EA and Project files.

- Project documentation does not ensure compliance with visual quality standards.

- Project activities are not in compliance with standards and objectives for Management area 3, Management area 5, Management area 6, Management area 9, and other Management areas included in the Project area.
- Project activities on steep slopes are not in compliance with Forest Plan standards and objectives.

We asked for on the ground surveys of old growth in the Project area using both the 1987 Forest Plan criteria for identifying old growth and the proposed amendment criteria for analyzing old growth. This information is vital to understanding how the site-specific amendment affects the "support of viable populations of native and desirable non-native wildlife and fish (1987 FP II-3)."

The 1987 Forest Plan criteria for identifying old growth protected mature forests. It relied on dbh and old-growth characteristics rather than age, so mature forests and future old growth were protected. The new criteria for identifying old growth does not protect future old growth and mature forests. In the Buckhorn project EA, it was explained that an old-growth stand which had been identified as old growth was disqualified because:

> "Unit 14 contains portions of two stands (4502062 and 4502063) that are identified as OG in the OG database. OG plots installed in the portions of these stands within the Unit 14 boundary on 11/14/2019 determined that 4502062 did not qualify as OG because the trees >20" DBH averaged about 114 years old, with a range from 76 years to 134 years. OG in this habitat type group is defined as more than 8 trees/acre that are over 21" DBH and are greater than 170 years old. **Harvesting in this stand will not reduce the existing OG percentage in this drainage/MA polygon because the trees are too young** to qualify as OG." (Buckhorn PF WILD-001, emphasis added)

The Draft EA does not analyze or disclose the natural historic range vs. current conditions regarding patch size, edge effect, and amount of interior forest old growth in the Bitterroot National Forest and how this will affect management indicator species and sensitive species that rely on old growth and mature forests.

Project activities do not comply with old growth retention standards in the 1987 Forest Plan. How will the site-specific standard retain old growth percentages when it suspends the standard that states, "Old growth stands may be logged and regenerated when other stands have achieved old-growth status. (Draft EA, Appendix F, at 3)."

The Draft EA does not fully disclose impacts to Management Indicator Species especially those reliant on thermal cover, old growth, mature forests, Coarse Woody Debris (CWD), and snags.

The Draft EA does not fully disclose the direct, indirect, and cumulative effects of the site-specific amendment for elk security and thermal cover on elk, sensitive species, and other desirable native wildlife and fish.

According to the Draft EA, the introduction of beaver is outside the scope of the Project (Draft EA, Appendix F, at 3). But is it clearly promised in the 1987 Forest Plan. Beaver reduce the risk of wildfire and improve watershed and forest habitat. The Draft EA and purpose and need of this Project do not support the idea that introducing beaver is out of the scope of this Project.

The BNF should analyze the introduction of beaver to reduce risk of wildfire and to improve habitat in the Project area. According to a NASA article, "In 2018, the Sharps Fire burned about 65,000 acres including large portions of the Baugh Creek watershed. After the fire, areas where beavers had created wetland complexes remained vibrant emerald-green amid a sea of brown, burned land (Figure 2) (NASA Earth Observatory Journal, at 2)." (See below **XVI. The Current (1987) Forest Plan States That Beavers Will Be Introduced in the BNF**, pp. 78-79)

Figure 2 - an aerial view of the wetlands around Baugh Creek after the fire

The Draft EA does not disclose how Project activities on slopes 40% and over will comply with Forest Plan standard, "Plan and conduct land management activities so soil loss, accelerated surface erosion, and mass wasting, caused by these activities, would not result in an unacceptable reduction in soil productivity and water quality (Draft EA, Appendix F, at 9)." Or Forest Plan standard to "Design or modify management practices to protect land productivity and to maintain land stability, as necessary (*ibid*, at 9)."

The Draft EA does not analyze the direct, indirect, and cumulative effects of Project activities on Wild and Scenic rivers to maintain the standard, "Eligible river wild, scenic, or recreational values would be protected until suitability studies provide the basis for future disposition (Draft EA, Appendix F, at 13)." The only explanation in the Draft EA is, "There are 2,130 acres of priority fire treatment areas (labeled priority level 1 or 2) within 1 mile of eligible WSRs in the Project area (USFS GIS 2023)" (Draft EA,at. 52). Priority fire treatment areas do not override the Forest Plan.

VII. After-Project Monitoring of Forest Service Projects is Missing or Inadequate

The purpose of the Bitterroot Front Project is to address the wildfire risk to the nearby communities and promote forest restoration using a wide range of tools, including tree thinning, harvesting, and prescribed burning. Specifically, the Bitterroot Front Project aims to (Draft EA, at 4):

1. Reduce fire behavior and intensity by reducing the fuel quantity, modifying the arrangement of the fuels, and reducing the current and future wildfire risk to people, private lands, and resource values.
2. Improve forest landscape health and resilience by reducing the risk or extent of, or increasing resilience to, insect and disease infestation.
3. Reduce the risk to first responders and raise the probability of success during direct and indirect engagement on wildfires by treating fuels to modify fire behavior and increasing operational opportunities to protect values.

According to the Agency, each of those goals can and will be met by using commercial logging, thinning, and/or prescribed fire. The Draft EA document claims, without providing evidence, there is a "need" for these management activities.

Although the same management activities have been implemented for decades on the Bitterroot National Forest (BNF), the Agency offers no proof that the suggested activities accomplish the alleged results. There have been ample opportunities for the FS to monitor the results of past projects. Unfortunately, the Agency has a history of not completing the monitoring it promised as part of those projects. That lack of adequate project monitoring makes the FS's projected results from management actions highly suspect. Please provide monitoring results of past projects that "prove" the proposed management actions are effective.

No monitoring records of past projects are offered to confirm that the proposed management actions included in the Bitterroot Front Project "would improve big game and other wildlife habitat quality." [14] No data is offered to indicate that habitat quality even needs improvement. Please provide scientific studies and on-the-ground research that indicates habitat quality and quantity is lacking in the area being proposed for this project. Please provide after-project records, generated by the monitoring of previous BNF projects, which confirm that habitat quality is improved by management actions.

No monitoring of previous management actions is offered to confirm the efficacy of the proposed mastication. (Draft EA, Appendix A, at 85)

> "Mastication would be used to reduce the potential for crown fire behavior by modifying the arrangement of surface and canopy fuels. Mastication would be designed to raise canopy base heights and to reduce the potential for canopy ignition by removing ladder

[14] The Biennial Monitoring Evaluation Report for the BNF (2022) consists only of forest-wide monitoring. No results of after-project monitoring are included - https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd1000570.pdf

fuels. Mastication also is intended to reduce potential flame lengths by rearranging and compacting existing surface fuels."

Please supply records from after-project monitoring of past BNF projects and the results of same that confirms your assertions. Please supply scientific evidence that "… increasing crown spacing, raising canopy base heights …" improves, not just "timber stands" but "overall forest ecosystem health, carbon sequestration, and biodiversity."

Documentation declares this Project is intended to "… improve landscape resilience to disturbances, such as insects, diseases, and fire, by modifying forest structure, composition, and fuels" (Draft EA, at 82). However, without monitoring records from past projects, this claim is without merit, especially given recent research which contradicts that assumption.[15] [16] [17]

Please provide the most recent scientific research and after-project monitoring (project-specific) records which support the Agency's assertion that establishing historic stand structure characteristics improves resilience or the assertion that projects which modify forest structure and composition "improve landscape resilience."

VIII. Proposed Project Does Not Include Adequate Protection for Mature Trees and Old-Growth Stands

The Draft EA documentation provides no information about how Project-area old growth will be impacted by the proposed management actions nor does it indicate how old growth or the diverse ecosystems and species that depend on that increasingly rare habitat will be protected.[18]

On Earth Day 2022, President Biden issued an executive order requiring the Forest Service and Bureau of Land Management (BLM) to "define, identify, and complete an inventory of old-growth and mature forests" on their respective lands and to "make such inventory publicly available."[19] The order set forth several actions each agency must complete. First, the Agencies must "define" mature and old-growth forests, "accounting for regional and ecological variations." *Id.* Second, after the Agencies have defined mature and old-growth forests, they must then "identify" where those forests are and "complete an inventory" of those forests and make that inventory available to the public. *Id.* Third, after the inventory process is complete, the Agencies must then (i) "coordinate conservation and wildfire risk reduction activities,

[15] Bradley, C.M. et al. (2016) Does increased forest protection correspond to higher fire severity in frequent-fire forests of the western United States - https://esajournals.onlinelibrary.wiley.com/doi/pdf/10.1002/ecs2.1492
[16] Scullion, J.J. et al (2019) Conserving the last great forests - a meta-analysis review of intact forest loss - https://www.frontiersin.org/articles/10.3389/ffgc.2019.00062/full
[17] Moomaw, W.R. et al. (2019) Intact Forests in the United States - Proforestation mitigates climate change and serves the greatest good - https://www.frontiersin.org/articles/10.3389/ffgc.2019.00027/full
[18] See Exhibit 8. Juel, J. (2021) Management of Old Growth in The U.S. Northern Rocky Mountains Debasing the concept and subverting science to plunder national forests.
[19] *See* Strengthening the Nation's Forests, Communities, and Local Economies, 81 Fed. Reg. 24851, 24852 (Apr. 22, 2022) ("EO 14072").

including consideration of climate-smart stewardship of mature and old-growth forests," with other agencies, States, Tribal Nations, and private landowners, (ii) "analyze threats to mature and old-growth forests," and (iii) "develop policies" that address threats to mature and old-growth forests." *Id.*

On April 20, 2023, the Forest Service and BLM took the first step in complying with EO 14072 by publishing *Mature and Old-Growth Forests: Definition, Identification, and Initial Inventory on Lands Managed by the Forest Service and Bureau of Land Management* (MOG Report; Exhibit 9). The MOG Report "contains the first national inventory of old-growth and mature forests focused specifically on Forest Service and BLM lands." (MOG Report, at 1) Importantly, the report's findings are only "*initial* estimates of old-growth and mature forests" on Forest Service and BLM lands. *Id*. (emphasis added). Indeed, throughout the MOG Report, the Agencies repeatedly affirm the sequential nature of EO 14072 and that the current definitions and inventory are preliminary in nature.

- "The ***initial*** inventory and definitions for old-growth and mature forests are part of an overarching climate-informed strategy to enhance carbon sequestration and address climate-related impacts, including insects, disease, wildfire risk, and drought. ***Initial*** inventory results will be used to assess threats to these forests, ***which will allow consideration of appropriate climate-informed forest management, as required by subsequent sections of Executive Order 14072***." (MOG Report, at 1)
- "The ***initial*** inventory will ***then*** be used to assess threats to these forests, ***which will allow consideration of appropriate climate-informed forest management***, as required by subsequent sections of the Executive order." (MOG Report, at 4)
- "***Once the definitions and inventory are established***, section 2c then calls on the Forest Service and BLM to:
  - Coordinate conservation and wildfire risk reduction…
  - Analyze the threats to mature and old-growth forests on Federal lands…and…
  - Develop policies…to institutionalize climate-informed management and conservation strategies that address threats to mature and old-growth forests on Federal lands." (MOG Report, pp. 10-11)
- "This ***initial*** inventory represents the current condition of forests managed by the Forest Service and BLM at the time of the most recent FIA measurement; it does not provide any information on resilience or climate response of these forests … The team plans to apply working definitions for old-growth and mature forest to prior FIA data, which will inform how these forests have changed over the past 10-20 years. In addition, ***the team will explore how old-growth and mature forests are distributed in additional land use allocations that are currently grouped into the 'other' category.***" (MOG Report, at 26)
- "Executive Order 14072 section 2c and USDA Secretarial Memo 1077-004 provide some clarity on ***next steps*** following the initial classification presented here." (MOG Report, at 26)

Contemporaneous to the publication of the MOG Report, the Forest Service also published an advance notice of proposed rulemaking (ANOPR) that, in part, "[b]uilds on ongoing work to implement" EO 14072.[20] The ANOPR explains that EO 14072 "calls particular attention to the importance of Mature and Old-Growth (MOG) forests on Federal lands for their role in contributing to nature-based climate solutions by storing large amounts of carbon and increasing biodiversity." *Id*. at 24498. Elsewhere, the ANOPR stresses "the importance of mature and old-growth forests'' for "large tree retention and conservation" and that "[o]lder forests often exhibit structures and functions that contribute ecosystem resilience to climate change." *Id*. at 24502-24503. Finally, the ANOPR states the MOG inventory that is currently "being developed" will "help inform policy and decision-making on how best to conserve, foster, and expand the values of mature and old-growth forests on our Federal lands." *Id*. at 24501.

The ANOPR also announced the "beta version of a new Forest Service Climate Risk Viewer"[21] that "was developed with 38 high-quality datasets and begins to illustrate the overlap of multiple resource values with climate exposure and vulnerability." *Id*. at 24501. "Core information from the [initial] MOG inventory has been integrated into the viewer" to "help inform policy and decision-making on how best to conserve, foster, and expand the values of mature and old-growth forests on our Federal lands." *Id*. The initial MOG inventory displayed in the Climate Risk Viewer was derived from the Forest Inventory and Analysis (FIA) field plot networks, the "primary source for information about the extent, condition, status, and trends of forest resources across the U.S." (*See* Climate Risk Viewer). The map displays MOG estimates on Forest Service land within 250,000-acre fireshed polygons, which are considered "the appropriate scale for statistical inference using FIA plots." *Id*. The matrix colors indicate the degree of mature or old-growth forest within each polygon (light-to-dark pink = low-to-high mature forest; light-to-dark blue = low-to-high old-growth forest). *Id*. Polygons classified as "low" indicate 0-25,000 acres of mature or old-growth forest, "intermediate" (25,000-75,000 acres), and "high" (75,000-250,000 acres). *Id*.

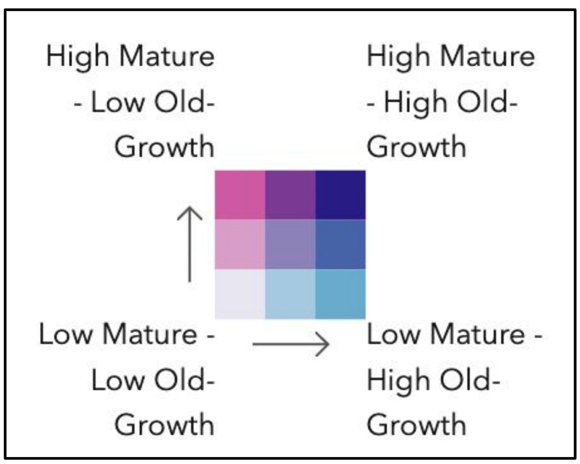

Figure 3 - Mature and Old-Growth Estimates in Forest Service Climate Risk Viewer

[20] *See* Organization, Functions, and Procedures; Functions and Procedures; Forest Service Functions, 77 Fed. Reg. 24497 (Apr. 21, 2023).
[21] The Forest Service Climate Risk Viewer is available at: https://storymaps.arcgis.com/collections/87744e6b06c74e82916b9b11da218d28?item=8.

The Project area is within polygons that fall between "high mature-low old growth" and "high mature- high old growth," indicating the project area has significant existing and potential carbon storage benefits. ***The Forest Service must further refine this inventory in a detailed statement and disclose the exact amount of mature and old growth trees in the Project area at the stand level, and how the proposed action may affect these inventories*.** In doing so, we urge the agency to consider other approaches from independent researchers. Specifically, in September 2022, researchers published the "first comprehensive and spatially explicit assessment of MOG in the conterminous United States,"[22] and made the result publicly available.[23] Here, researchers "mapped the relative level of forest structural maturity using three published spatial data sets that include forest canopy cover, canopy height, and above-ground living biomass derived from modeled satellite data (Table 1)." *Id.* The results were calibrated with FIA plot data, and found that on the Bitterroot National Forest approximately 676,520 acres have reached maturity, of which 32.4 percent are within Inventoried Roadless Areas. *Id.* at Table. S1._Another approach utilizes carbon as the basis for defining maturity. Here scientists explained the following.

> Our approach requires addressing two components: (1) individual trees referred to as the "larger" trees in a forest; and (2) mature forest stand development represented by stand age. This method for identifying larger trees in mature stands—and the related assessment of above-ground live carbon stocks and annual carbon accumulation—is intended to be broadly applicable and readily implementable independent of how mature stands are defined. We settled on defining stand maturity with respect to the age of maximum Net Primary Productivity (NPP), which is estimated as the annual net quantity of carbon removed from the atmosphere and stored in biomass (see section 2.2 for definitions of key terms). (Birdsey et al 2023).[24]

Researchers then provided the following definition: "Mature forests are defined as stands with ages exceeding that at which accumulation of carbon in biomass peaks as indicated by NPP," and used Culmination of Net Primary Productivity (CNPP) "to describe the age at which NPP reaches a maximum carbon accumulation rate." With this approach, scientists used FIA plot data for 11 national forests in the lower 48 states including those dominated by frequent-fire return intervals associated with dry pine and dry mixed conifer forest sites. Researchers found that trees within these stands on the Flathead National Forest reach CNPP at 9 inches dbh. We expect the same results apply to the Bitterroot NF since they represent similar ecological conditions for dry pine and dry mixed conifer stands within the region.

Both Birdsey et al. (2023) and DellaSala et al. (2022) demonstrate the ability to define mature forests, quantify their capacity to store carbon, and provide a specific inventory. The Forest Service now has its own FIA-based inventory as well, and together all three approaches demonstrate the agency has the tools to perform site-specific, field-verified inventories within

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[22] DellaSala, D.A. et al (2022) Mature and old-growth forests contribute to large-scale conservation targets in the conterminous United States. *Front. For. Glob. Change*, 5:979528, 3

[23] *See* https://www.matureforests.org/data (last accessed September 2, 2023)

[24] Birdsey R.A., DellaSala D.A., Walker W.S., Gorelik S.R., Rose G. and Ramírez C.E. (2023) Assessing carbon stocks and accumulation potential of mature forests and larger trees in U.S. federal lands. Front. For. Glob. Change 5:1074508. http://doi.org/10.3389/ffgc.2022.1074508

mature and old-growth stands. As such, we urge the Forest Service to complete such an inventory across the Project area as part of a detailed analysis necessary to comply with NEPA. Such a stand-level inventory is essential to conduct adequate carbon accounting that we discuss below. The importance of identifying and preserving these forests cannot be overstated as they are part of "nature-based climate solutions" for mitigating the effects of anthropogenic global warming. (MOG Report, at 3) DellaSala et al 2022 explains how mature forests "provide superior values compared to logged forests as natural climate solutions" to meet the objectives of EO 14072. *Id*. at 16 (citations omitted). But "the current status quo management of MOG and low protection levels on all lands presents unacceptable risks at a time when the global community is seeking ways to reduce the rapidly accelerating biodiversity and climate crises." *Id.* at 16-17 (citation omitted).

Further, we urge the Forest Service to recognize that as they mature, forests sequester and accumulate massive amounts of atmospheric carbon stored mainly in large trees and soils making an invaluable contribution to climate smart management and international climate commitments. (Stephenson et al 2014,[25] Mildrexler et al 2020.[26]) Other studies demonstrate that unmanaged forests can be highly effective at capturing and storing carbon (Luyssaert et al 2008[27]). Further, mature, and old-growth forests have received increased global attention in climate fora (IUCN 2021)[28] and in the scientific community as natural climate solutions (Moomaw et al 2019[29]). Notably, Article 5.1 of the Paris Climate Agreement calls on governments to protect and enhance "carbon sinks and reservoirs." Article 38 of the UNFCCC COP26 Glasgow Climate Pact emphasizes "the importance of protecting, conserving and restoring nature and ecosystems, including forests … to achieve the long-term global goal of the Convention by acting as sinks and reservoirs of greenhouse gasses and protecting biodiversity…" (UNFCCC 2021[30]). The USA was also one of 140 nations at the COP26 that pledged to end forest degradation and deforestation by 2030. Logging both mature and old-growth forests is a form of forest degradation as it removes important forest structural features.

In addition, several studies demonstrate that maintaining forests rather than cutting them down can help reduce the impacts of climate change. "Stakeholders and policy makers need to

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[25] Stephenson, N & Das, Adrian & Condit, Richard & Russo, S & Baker, Patrick & Beckman, Noelle & Coomes, David & Lines, Emily & Morris, William & Rüger, Nadja & Alvarez Davila, Esteban & Blundo, Cecilia & Bunyavejchewin, Sarayudh & Chuyong, George & Davies, S & Duque, Alvaro & Ewango, Corneille & Flores, O & Franklin, Jerry & Zavala, Miguel (2014) Rate of tree carbon accumulation increases continuously with tree size. Nature. 507. 10.1038/nature12914

[26] Mildrexler, David & Berner, Logan & Law, Beverly & Birdsey, Richard & Moomaw, William (2020) Large Trees Dominate Carbon Storage in Forests East of the Cascade Crest in the United States Pacific Northwest. Frontiers in Forests and Global Change. 3. 10.3389/ffgc.2020.594274

[27] Luyssaert, Sebastiaan & Ernst Detlef, Schulze & Borner, A. & Knohl, Alexander & Hessenmöller, Dominik & Law, Beverly & Ciais, Philippe & Grace, John. (2008). Old-growth forests as global carbon sinks. Nature. Nature, v.455, 213-215 (2008). 455(11). *See also* Law et al (2018), Hudiburg et al (2009)

[28] IUCN (2022) IUCN 2021 annual report. Gland, Switzerland: IUCN

[29] Moomaw, William & Masino, Susan & Faison, Edward (2019) Intact Forests in the United States: Proforestation Mitigates Climate Change and Serves the Greatest Good. 27. 10.3389/ffgc.2019.00027

[30] Exhibit 10: Article 38 of the UNFCCC COP26 Glasgow Climate Pact

recognize that the way to maximize carbon storage and sequestration is to grow intact forest ecosystems where possible" (Moomaw, et al 2019). Another report concludes:

> *Allowing forests to reach their biological potential for growth and sequestration, maintaining large trees (Lutz et al 2018), reforesting recently cut lands, and afforestation of suitable areas will remove additional CO2 from the atmosphere. Global vegetation stores of carbon are 50% of their potential including western forests because of harvest activities (Erb et al 2017).* Clearly, western forests could do more to address climate change through carbon sequestration *if allowed to grow longer* (T. Hudiburg et al 2019).[31]

Also, a June 2020 paper from leading experts on forest carbon storage reported:

> *There is absolutely no evidence that thinning forests increases biomass stored (Zhou et al. 2013).* It takes decades to centuries for carbon to accumulate in forest vegetation and soils (Sun et al. 2004, Hudiburg et al. 2009, Schlesinger 2018), and it takes decades to centuries for dead wood to decompose. We must preserve medium to high biomass (carbon-dense) forest not only because of their carbon potential but also because they have the greatest biodiversity of forest species (Krankina et al 2014, Buotte et al 2019, 2020). (B. Law, et al 2020).[32]

Further, to address the climate crisis, agencies cannot rely on the re-growth of cleared forests to make up for the carbon removed when mature forests are logged. One prominent researcher explains: "It takes at least 100 to 350+ years to restore carbon in forests degraded by logging (Law et al 2018, Hudiburg et al 2009[33]). If we are to prevent the most serious consequences of climate change, we need to keep carbon in the forests because we don't have time to regain it once the forest is logged (IPCC, 2018)." *Id.*

Clearly the role of mature and old-growth forests to store carbon and serve as a natural climate-crisis solution must be part of any detailed project-level analysis. The Forest Service owes a duty to the public to ensure that these forests remain standing so that they can continue to perform their vital function of "storing large amounts of carbon." MOG Report 3; *see also Light v. U.S.*, 220 U.S. 523 (1911) ("the public lands . . . are held in trust for the people of the whole country."); *Juliana v. U.S.*, 217 F.Supp.3d 1224, 1259 (D. Or. 2016) ("[t]he federal government, like the states, holds public assets . . . in trust for the people.") (*rev'd on other grounds*, *Juliana v. U.S.*, 947 F.3d 1159 (9th Cir. 2020)); *Selkirk-Priest Basin Ass'n Inc. v. State ex rel Andrus*, 899 P.2d 949, 952-54 (Idaho 1995) (public trust doctrine permits challenge to timber sales since increased sedimentation could impact trust resources).

[31] Hudiburg, Tara & Law, Beverly & Moomaw, William & Harmon, Mark & Stenzel, Jeffrey (2019) Meeting GHG reduction targets requires accounting for all forest sector emissions. Environmental Research Letters. 14. 095005. 10.1088/1748-9326/ab28bb.
[32] B. Law et al (2020) The Status of Science on Forest Carbon Management to Mitigate Climate Change. Exhibit 11.
[33] Hudiburg, Tara & Law, Beverly & Turner, David & Campbell, John & Donato, Daniel & Duane, Maureen (2009) Carbon dynamics of Oregon and Northern California forests and potential land-based carbon storage. Ecological applications : a publication of the Ecological Society of America. 19. 163-80. 10.1890/07-2006.1.

As such, the Forest Service should not be logging any mature and/or old-growth forests, at least until it has completed the rulemaking that is currently being considered. Therefore, we are calling for a moratorium on mature and old-growth logging considering EO 14072 "calls particular attention to the importance of (MOG) forests on Federal lands for their role in contributing to nature-based climate solutions by storing large amounts of carbon and increasing biodiversity" (77 Fed. Reg. 24497, 24498; *see also* MOG Report, at 3). Continuing to cut down and remove mature and old-growth trees and forests before the "definitions and inventory are established" and the current rulemaking is completed undermines the administration's focus on "nature-based climate solutions" for "storing large amounts of carbon."

IX. Proposed Project Does Not Include Adequate Protection for Soil or Water

Most management activities, especially road construction and use, cause the degradation and compaction of forest soils and worsen the quality of surface water.

During the second phase of the Darby Lumber Lands project the Agency was found to be in violation of Montana's regulations for roads near streams. Please explain exactly how that breach of regulations will not be repeated during the Bitterroot Front Project. Please explain how soils will be protected during the duration of this proposed long-term Project. Please explain what mitigation measures will be implemented and monitored to ensure that streams will not be impaired (for example, sedimentation, water temperatures, impediments to natural stream flow, etc.) in any way during Project implementation.

X. The Forest Service is Knowingly Intensifying Global Warming and Reducing Carbon Sequestration

Most management activities associated with Agency projects contribute to the increasing accumulation of Greenhouse Gases (GHG) in the atmosphere. For example, logging, thinning, prescribed fire, pile burning, travel to and from project sites, etc. all release GHG into the atmosphere.

Issued on August 1, 2016, this directive from Executive Office of the President, Council on Environmental Quality has been reimplemented as national direction. (*See* 86 Fed Reg. 10252 (Feb. 19, 2021))

The 2016 CEQ guidance acknowledges, "changes in our climate caused by elevated concentrations of greenhouse gases in the atmosphere are reasonably anticipated to endanger the public health and public welfare of current and future generations." It directs federal agencies to consider the extent to which a proposed action such as this Bitterroot Front Project would contribute to climate change. It rejects as inappropriate any notion that this Project is of too small a scale for such consideration:

> "Climate change results from the incremental addition of GHG emissions from millions of individual sources, which collectively have a large impact on a global scale. CEQ recognizes that the totality of climate change impacts is not attributable to any single action, but is exacerbated by a series of actions including actions taken pursuant to decisions of the Federal Government. Therefore, a statement that emissions from a proposed Federal action represent only a small fraction of global emissions is essentially a statement about the nature of the climate change challenge, and is not an appropriate basis for deciding whether or to what extent to consider climate change impacts under NEPA. Moreover, these comparisons are also not an appropriate method for characterizing the potential impacts associated with a proposed action and its alternatives and mitigations because this approach does not reveal anything beyond the nature of the climate change challenge itself: the fact that diverse individual sources of emissions each make a relatively small addition to global atmospheric GHG concentrations that collectively have a large impact."[34]

The FS must quantify GHG emissions. The Agency can only use a qualitative method if tools, methodologies, or data inputs are not reasonably available, and if that is the case, there needs to be rationale as to why a quantitative analysis is not warranted. Quantitative tools are available, so the FS must comply.[35]

Judging by its actions, the Agency is a huge global-warming denier.

The Draft EA documentation includes little analysis of climate change because of global warming. That omission is unacceptable. What the Draft EA does instead is make unsubstantiated declarations of how global warming will affect the forest if the No Action alternative is followed.

Given the urgency of preventing additional greenhouse gas emissions to the atmosphere and continuing carbon sequestration to protect the climate system, it would be best to protect trees for their carbon stores and for their co-benefits of habitat for biodiversity, resilience to drought and fire, and microclimate buffering under future climate extremes.

According to a 2021 article, "Keeping trees in the ground where they are already growing is an effective low-tech way to slow climate change."[36]

> "Compared with other terrestrial ecosystems, forests store some of the largest quantities of carbon per surface area of land." Much of the carbon stored is within the soils, with a smaller part in the vegetation. Forest management can modify soil organic carbon stocks. For example, conventional harvests like clearcutting or shelterwood cutting cause soils to lose organic carbon which is not the case for soils in unharvested forests. Not only does it

[34] Fed Reg. 10252 (Feb. 19, 2021) - https://www.govinfo.gov/content/pkg/FR-2021-02-19/pdf/2021-03355.pdf

[35] Greenhouse Gas (GHG) Accounting Tools - https://ceq.doe.gov/guidance/ghg-accounting-tools.html

[36] Law, B.E. and Moomaw, W.R (2021) Keeping trees in the ground where they are already growing is an effective low-tech way to slow climate change - https://theconversation.com/keeping-trees-in-the-ground-where-they-are-already-growing-is-an-effective-low-tech-way-to-slow-climate-change-154618

lose the carbon stored in the soils, but cutting trees eliminates the trees' potential to continue to sequester carbon.[37]

"Our study showed that, compared with conventional stem-only harvest, removing the stem plus the harvesting residues generally increases nutrient outputs thereby leading to reduced amounts of total and available nutrients in soils and soil acidification, particularly when foliage is harvested along with the branches. Losses of available nutrients in soils could also be explained by reduced microbial activity and mineralization fluxes, which in turn, may be affected by changes in organic matter quality and environmental conditions (soil compaction, temperature, and moisture). Soil fertility losses were shown to have consequences for the subsequent forest ecosystem: tree growth was reduced by 3–7% in the short or medium term (up to 33 years after harvest) in the most intensive harvests (e.g., when branches are exported with foliage). Combining all the results showed that, overall, whole-tree harvesting has negative impacts on soil properties and trees that may have an impact on the functioning of forest ecosystems."[38]

Other than to declare that, with the advent of global warming, the Project is required, the Draft EA provides no analysis of the interaction between management actions and global warming.

Vegetation management efforts attempt to replicate how the FS theorizes forests looked pre-European influence, ignore the larger pattern of climate, global warming, and disregards natural succession. The Draft EA for this Project clearly shows that the Agency continues its attempts to replicate the past and reveals its refusal to accept that rapidly increasing global warming has made such an endeavor impossible.

Please provide the most recent scientific research that supports the Agency's belief that the FS should continue its (so far unsuccessful) attempts to replicate pre-European forest conditions and how the resulting conditions are more resilient and healthier than current forest conditions. Please explain how removing trees from the forest contributes to carbon sequestration. Please explain exactly how GHG emissions will be minimized and monitored during the duration of this proposed Project.

A. The Forest Service must account for greenhouse gas emissions and provide a total carbon budget

The Forest Service must provide detailed analysis for a project of this scope and scale which uses readily available methods and models that represent high quality information and accurate greenhouse gas accounting[39] when undertaking environmental reviews of logging

[37] Achat, D.L. et al (2015) Quantifying consequences of removing harvesting residues on forest soils and tree growth - A meta-analysis - https://www.sciencedirect.com/science/article/abs/pii/S0378112715001814?via%3Dihub

[38] Achat, D.L. et al (2015) ibid.

[39] Hudiburg, T.W. et al (2011) Regional carbon dioxide implications of forest bioenergy production. Nature Climate Change 1:419-423 https://www.nature.com/articles/nclimate1264 Hudiburg, T.W. et al (2019) Meeting GHG reduction targets requires accounting for all forest sector emissions. Environmental Research Letters 14 (2019) 095005 https://doi.org/10.1088/1748-9326/ab28bb

projects on federal lands. Research, including studies done by the U.S. government,[40] indicates that logging on federal forests is a substantial source of carbon dioxide emissions to the atmosphere.[41] Notably, logging emissions—unlike emissions from natural disturbances—are directly controllable. Models and methods exist that allow agencies to accurately report and quantify logging emissions for avoidance purposes at national, regional, and project-specific scales. As such, the Forest Service has the ability and responsibility to disclose estimates of such greenhouse gas emissions using published accounting methods with the express purpose of avoiding or reducing the greenhouse gas associated with logging, and acknowledge the substantial carbon debt created by logging mature and old-growth trees and forests on federal lands.[42]

In particular, we recommend that:

1. The agency should identify and assess the carbon stock of mature and old-growth forests and trees[43] given the substantial carbon value of such trees and forests;[44]
2. The agency should identify and assess ***gross*** emissions from logging, particularly logging mature and old-growth trees and forests on federal lands, and including the emissions from logging on site and downstream emissions through the entire chain of custody of milling, manufacturing, and transportation; and
3. The agency should provide a high standard of scientific support for any asserted offsets of gross emissions, including discussion of timing factors that address the carbon debit created from logging vs avoiding logging and allowing stocks to further accrue.[45] We also note that storing some carbon in short-lived wood product pools is not

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[40] Merrill, M.D. et al (2018) Federal lands greenhouse emissions and sequestration in the United States—Estimates for 2005–14, Scientific Investigations Report. https://doi.org/10.5066/F7KH0MK4

[41] Harris, N.L. et al (2016) Attribution of net carbon change by disturbance type across forest lands of the conterminous United States. Carbon Balance Manage:11-24 https://doi.org/10.1186/s13021-016-0066-5

[42] Hudiburg, Tara W., Beverly E. Law, William R. Moomaw, Mark E. Harmon and Jeffrey E. Stenzel. "Meeting GHG reduction targets requires accounting for all forest sector emissions." *Environmental Research Letters* (2019): n.pag. https://doi.org/10.1088/1748-9326/ab28bb
Harmon et al. "Forest Carbon Emission Sources Are Not Equal: Putting Fire, Harvest, and Fossil Fuel Emissions in Context." Frontiers For. Glob. Change (2022) https://www.frontiersin.org/articles/10.3389/ffgc.2022.867112/full

[43] Krankina, O. et al (2014) High biomass forests of the Pacific Northwest: who manages them and how much is protected? Environmental Management. 54:112-121. Law, B.E., et a. 2021. Strategic forest reserves can protect biodiversity in the western United States and mitigate climate change. Communications Earth & Environment | https://doi.org/10.1038/s43247-021-00326-0

[44] Mackey, B., et al (2013) Untangling the confusion around land carbon science and climate change mitigation policy. Nature Climate Change, Vol. 3 (June 2013)| VOL 3 | JUNE 2013 | www.nature.com/natureclimatechange
Keith, H. et al (2019) Contribution of native forests to climate change mitigation. Environmental Science and Policy 93:189-199 https://www.sciencedirect.com/science/article/abs/pii/S146290111830114X. Law, B.E. et al (2022) Creating strategic reserves to protect forest carbon and reduce biodiversity losses in the United States. Land https://doi.org/10.3390/land11050721. DellaSala, D.A. et al (2022) Mature and old-growth forests contribute to large-scale conservation targets in the conterminous United States. Front. For. Glob. Change 5:979528. doi: 10.3389/ffgc.2022.979528. Birdsey, R. et al (2023) Assessing carbon stocks and growth potential of mature forests and larger trees in U.S. federal lands. Frontiers For. Glob. Change. https://www.frontiersin.org/articles/10.3389/ffgc.2022.1074508/full

[45] Moomaw, W.R. et al (2019) Intact forests in the United States: proforestation mitigates climate change and serves the greatest good. Frontiers in Forests and Global Change. https://doi.org/10.3389/ffgc.2019.00027

compensatory as an offset or avoidance for using other carbon-intensive materials in construction.[46]

The Forest Service must disclose direct and indirect climate pollution from removing, transporting, and milling wood. This includes emissions from loss of stored carbon during the removal at the forest (in-boundary) and manufacturing and transport process (out-of-boundary). That is, Guidance should more closely specify the need to disclose the GHG emissions from logging on site through the entire chain of custody of milling, manufacturing, and transportation, including:

- construction, reconstruction, and maintenance of logging access routes;
- all forms of logging operations (clearcut, selective, postfire, commercial thinning, etc.), including any herbicides, insecticides, and related treatments;
- transport of logs to mills;
- milling of the wood; and
- transport of products to other sectors.

These emissions and others are all foreseeable impacts of logging projects. In some cases, these impacts may be considerable. For example, the South Plateau Project in Montana, will result in at least 40,000 trips by fully loaded logging trucks to remove the 83 million board feet of timber and will involve the construction (and subsequent obliteration) of up to 57 miles of temporary road. We note that in addressing the impacts of coal mine expansions, federal agencies have disclosed the GHG emissions of equipment used to mine coal and to transport it to market. Land management agencies can and should make similar projections for GHG pollution associated with vegetation removal projects.

The Forest Service routinely asserts that the impacts of logging on carbon stores will be minimal because carbon from logged trees will be stored long-term in forest products. Such assertions are contrary to research indicating that much of the carbon stored in removed trees is lost in the near term, and little carbon is stored long-term in wood products.

For example, a 2019 study evaluated the quantification of biogenic emissions in the state of Washington, which included GHG emissions from logging, but not decomposition of wood products. The study concluded that the failure to address decomposition losses amounted to as much as a 25% underestimation of carbon emissions.[47]

Losses from decomposition vary over time and depend on the lifetime of the wood product being produced from the timber. Paper and wood chips, for example, have very short lifetimes and will release substantial carbon into the atmosphere within a few months to a few years of production. Bioenergy production and burning has been found to release more emissions than burning even coal, including methane. Product disposal in landfills results in anaerobic

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[46] Harmon, M.E. (2019) Have product substitution carbon benefits been overestimated? A sensitivity analysis of key assumptions. Environmental Research Letters (2019) https://iopscience.iop.org/article/10.1088/1748-9326/ab1e95

[47] Hudiburg, Tara W., Beverly E. Law, William R. Moomaw, Mark E. Harmon and Jeffrey E. Stenzel (2019) "Meeting GHG reduction targets requires accounting for all forest sector emissions." *Environmental Research Letters* (2019): n.pag. https://doi.org/10.1748-9326/ab28bb

decomposition that also releases methane. Methane has a global warming potential about 30 times that of carbon dioxide over 100 years, and over 80 times that of carbon dioxide over 20 years,[48] magnifying the impact of disposal of short-term wood products.

Longer term wood products can store carbon for many decades, but this depends on the life of the product. To give a sense of the larger picture, a study modeling carbon stores in Oregon and Washington from 1900-1992 showed that only 23% of carbon from logged trees during this time period was still stored as of 1996.[49] Similarly, > 80% of carbon removed from the forest in logging operations in West Coast forests was transferred to landfills and the atmosphere within decades.[11] Hudiburg (2019) concludes that state and federal carbon reporting had erroneously excluded some product-related emissions, resulting in a 25-55% underestimation of state total CO_2 emissions from logging.[11] Many of the aforementioned decomposition emissions could be avoided if trees were left standing, especially by protecting carbon stocks from logging of mature and old-growth trees and forests on federal lands.

The detailed NEPA analyses we are calling for would disclose the trade-off and the importance of maintaining the stock value of mature and old-growth trees. The analysis should quantify both the short-term *and* long-term gross and net impacts of logging projects. This will allow agencies to disclose and assess the trade-offs between increasing GHG emissions via logging now—when decreases are most sorely needed—versus alleged increases in storage later. Detailed NEPA analysis would also avoid ignoring short-term carbon losses due to logging based on the erroneous assumption that the residual forest will have significantly reduced potential to have its carbon stores diminished by high-severity fires. Decades of research, however, call these sorts of blanket assertions into question.[14] Moreover, this is not a basis for failing to disclose emissions from the logging itself, especially in comparison to fire. Research shows that emissions from logging greatly exceed those from all natural disturbances combined (fire, insects, windstorms).[50]

Further, the CEQ recently issued Guidance clarifying that agencies must address the emissions and storage impacts of project-specific vegetation removal projects, "such as prescribed burning, timber stand improvements, fuel load reductions, and scheduled harvesting."[51] We support this direction. In addition, the Forest Service should also assess emissions from pile burning related to forestry operations, as such actions can intensify carbon release.

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[48] Intergovernmental Panel on Climate Change, AR6 WG1 (2021): Forster, Piers; Storelvmo, Trude (2021) "Chapter 7: The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity." (See Exhibit 18)

[49] Harmon, M.E., Harmon, J.M., Ferrell, W.K. et al (1996) Modeling carbon stores in Oregon and Washington forest products: 1900–1992. *Climatic Change* 33, 521–550 (1996). https://doi.org/10.1007/BF00141703

[50] Harris, N.L. et al (2016) Attribution of net carbon change by disturbance type across forest lands of the conterminous United States. Carbon Balance Manage:11-24 DOI 10.1186/s13021-016-0066-5 and Merrill, M.D. et al (2018) Federal lands greenhouse emissions and sequestration in the United States—Estimates for 2005–14, Scientific Investigations Report. https://doi.org/10.5066/F7KH0MK4, Zald, H.J., and Dunn, C.J. (2018) Severe fire weather and intensive forest management increase fire severity in a multi-ownership landscape. Ecological Applications 28(4):1068-1080 https://doi.org/10.1002/eap.1710

[51] CEQ, National Environmental Policy Act Guidance on Consideration of Greenhouse Gas Emissions and Climate Change, 88 Fed Reg. at 1206.

The nature of the global warming emergency is based on multiple points of emission sources, with each contributing to the problem cumulatively. Therefore, project level analysis is a critical undertaking and one for which land management agencies now have the tools to quantify the contribution of each federal action, including in cumulative effects analyses.

Given the significant climate impact of logging on federal lands, it is critical that agencies estimate and quantify greenhouse gas emissions associated with each individual logging project and provide annual estimates associated with total logging on federal lands.

All agencies should expand their abilities and expectations around accounting for logging emissions as a significant contributor to climate change in tandem with continued progress in fire emissions accounting that more accurately captures actual carbon emissions from forest fires.[52]

Finally, the need to provide detailed carbon accounting was a central feature in a recent U.S. District Court (Montana) decision (*Center for Biological Diversity et al v. U.S. Forest Service*; CV 22-114-M-DWM, where Judge Molloy states:

> Ultimately, "[greenhouse gas] reduction must happen quickly" and removing carbon from forests in the form of logging, even if the trends are going to grow back, will take decades to centuries to re-sequester. FS-038329. Put more simply, logging causes immediate carbon losses, while re-sequestration happens slowly over time, **time that the planet may not have**. FS-020739 (I[t] is recognized that global climate research indicates the world's climate is warming and that most of the observed 20th century increase in global average temperatures is very likely due to increased human-caused greenhouse gas emissions.").
>
> …NEPA requires more than a statement of platitudes, it requires appraisal to the public of the actual impacts of an individual project. …(T)he USFS has the responsibility to give the public an accurate picture of what impacts a project may have, no matter how "infinitesimal" they believe they may be.

We agree and the Forest Service must provide the requisite analysis that acknowledges and addresses the court's opinion. We recognize the Forest Service provided two project files to support its carbon analysis in the Draft EA. Overall, these reports still fail to provide the requisite hard look NEPA requires. For example, the Forest Service failed to conduct the stand-level inventory of mature and old growth trees within the project area necessary to determine above-ground carbon storage capacity currently existing and how that would change under the proposed action. Instead, the agency provides unquantified statements such as this: "Reducing stand densities would reduce forest carbon storage in the short term, until the desired tree species begin to regenerate." Draft EA at 93. The Forest Service fails to specify the time period regeneration would take to match the amount of above-ground carbon lost under the proposed action, or quantify the amount of carbon lost. Further, the supporting project files are regional and forest-wide assessments (PF-Climate-01 & 02 respectively), and fail to provide detailed

[52] Harmon, M.E., Hanson, C.T., and DellaSala, D.A. (2022) Combustion of aboveground wood from live trees in megafires, CA, USA. Forests. Forests 13 (3)391; https://doi.org/10.3390/fl3030391

carbon accounting of the current conditions. In fact, the information used in these reports does not include recent information or the best available scientific information. For example, the report titled "Forest Carbon Assessment for the Bitterroot National Forest in the Forest Service's Northern Region" used three models to assess carbon across the forest, none of which include current conditions. The Carbon Calculation Tool (CCT) spans from 1990 – 2013, the Forest Carbon Management Framework (ForCaMF) "ForCaMF estimates how much more carbon (non-soil) would be on each national forest if disturbances from 1990 to 2011 had not occurred," and the Integrated Terrestrial Ecosystem Carbon (InTEC) model considers carbon accumulation from 1950 to 2011. PF-Climate-002. Further, the Forest Service failed to field verify these models to ensure the results reflect current on-the-ground conditions in the project area. Given that the agency did not include a project-specific carbon assessment and that models only consider carbon up to 2013, the analysis fails to meet the hard-look threshold expected by the court.

XI. Agency Makes Unsubstantiated Claims of Wildfire History

Your statement "In some of the drier ponderosa pine forest types, low-intensity fires burned through the stand every 6 to 7 years (Arno 1976)." (Draft EA, at 87) is a misrepresentation of Arno's work. His re-examination of this research (Arno and Peterson, 1983) revealed some important nuances.

First, he determined that the larger the fire scar sample area, the shorter the fire-free interval. They postulated that this is because all fire scars in the study area are added together, but not all fires recorded spread through the entire study area, resulting in an apparent shorter fire-free interval than reality. Second, they divided the data into forest zones-habitat types. Valley edges showed the shortest fire-free intervals, presumably because they were subject to frequent Indian burning. For the montane slopes, lower to mid-elevation forests (4,200 to 6,200 ft) with seral ponderosa and potential climax Doug fir, that comprise the majority of the low-mid elevations of the Bitterroot Front Project, they found fire free intervals to be 20-31 years for study areas of the grove (intermediate) size. Subsequently, Arno et al. (1995) found mean fire-free interval to be 50 years at all study plot sizes at another BNF site (Fales Flat, Ponderosa pine-dominated with some Doug fir; 5,400-5,900' elevation). Arno and Peterson (1983) and Fryer (2016) also pointed out problems with basing fire history solely on fire scar studies, particularly the difficulty of determining the extent of pre-historic high severity fires. Many fire history researchers have attempted to address these problems and concluded that mixed severity fires were historically common in Ponderosa-pine-dominated forests (Baker et al 2006; Odion et al 2014; Lindbladh et al 2013; Pierce and Meyer 2008; Baker 2017) .[53] [54] [55] [56].

[53] Baker, W.L. et al (2006) Fire Fuels and Restoration of Ponderosa Pine Douglas-fir Forests in the Rocky Mountains USA - https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2699.2006.01592.x

[54] Odion, D.C. et al (2014) Examining Historical and Current Mixed-Severity Fire Regimes in Ponderosa Pine and Mixed-Conifer Forests of Western North America - https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0087852

[55] Lindbladh, M. et al (2013) Past forest composition, structures and processes - How paleoecology can contribute to forest conservation - https://www.sciencedirect.com/science/article/abs/pii/S0006320713003388?via%3Dihub

For example, Pierce and Meyer (2008) state: "*our results support a natural regime of mixed-severity fire in ponderosa-dominated forests in Idaho, a fire model that only includes frequent, low-severity fire is not applicable to this region".*

In addition, much of the Bitterroot Front Project is above the ponderosa pine-dominated area of frequent fire, in forest types that historically had infrequent, high-intensity fires.

Please provide more recent scientific research than Arno 1976 which supports the Agency's assertion that, "These forest types were historically characterized by frequent low-intensity fire, fire resistant and shade intolerant species and lower stem densities." Further, the Forest Service must demonstrate that historical fire regimes are applicable under current and future modeled climate conditions.

This Project proposal is based on the assumption that active forest management is required because "Fire regime condition class is a qualitative measure describing the degree of departure from historical fire regimes, possibly resulting in alterations of key ecosystem components such as species composition, structural stage, stand age, canopy closure, and fuel loadings" (Draft EA, at 26)

Please justify why management activities are required when naturally occurring disturbances—insects, disease, and wildfire—achieve the same result (as they have always done) without human intervention.[57]

The Draft EA document states (Draft EA, at 1):

> The Bitterroot National Forest (BRF) contains five of the 250 highest-risk fire sheds in the nation; four of these are in the Bitterroot Front Project area. The Montana State Forest Action Plan has identified the area as having high wildfire risk to communities and infrastructure and significant forest health concerns. Also identified in the MFAP, Ravalli County currently has the greatest risk from wildfires in Montana, with six communities in the top 10 of all Montana communities with structures at risk from wildfire (Montana Forest Action Advisory Council 2020).

The CPZ map (Draft EA, PF-FIRE AND FUELS-001, p,14) shows a similar high fire risk hazard, with most WUI-adjacent areas showing highest (>90%) risk. Both the MFAP and CPZ maps appear highly inaccurate and incomplete, although the WUI area shading on the CPZ map obscures the fire risk rating there.

For example, on the MFAP map between Lost Horse and Roaring Lion Creeks, areas that have been recently logged in the Westside (2018) and Hayes Creek (2010) project, as well as areas burned in the 2016 Observation and Roaring Lion fires still show high to very high fire hazard.

Amazingly, the 2016, 1,500-acre Observation Fire is not even shown on the MFAP Recent Fire History map. And none of the areas commercially logged in the Westside project (2018) were rated as high hazard by BNF even before they were logged!

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[56] Baker, W.L. (2017) Restoring and managing low-severity fire in dry-forest landscapes of the western USA - https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0172288

[57] Pearce, F. (2020) Natural Debate - Do Forests Grow Better With Our Help or Without - https://e360.yale.edu/features/natural-debate-do-forests-grow-better-with-our-help-or-without – Exhibit 14

The Bitterroot Front CPZ map shows a similar high fire-hazard rating for this area. Below is the map (Figure 2) released in the Westside project EA showing fire potential for this area following completion of the Westside project. Note that there is virtually no potential for active crown fire (there was little even before the project according to the Westside EA), with most areas having only potential for ground fire.

Additionally, the Roaring Lion fire burned through the north half of this area, further lowering fire risk. So, why do the MFAP and CPZ maps show such high fire risk for this area? Similarly, why didn't the 2016 Roaring Lion and Observation Fires lower this risk?

Are the data for all the Bitterroot Front areas as inaccurate and incomplete as they are for this one? We must assume so. If the data are flawed, then the results are, too.

Please provide maps similar to those released on the Westside EA (Figure 4) showing fire potential maps for ground, passive crown (torching), and active crown fire for the entire Bitterroot Front Project so that we are able to accurately evaluate the fire risk for ourselves. Please justify the risk shown on your CPZ map with the data used to generate it. Please remove the WUI overlay so the fire risk is not obscured.

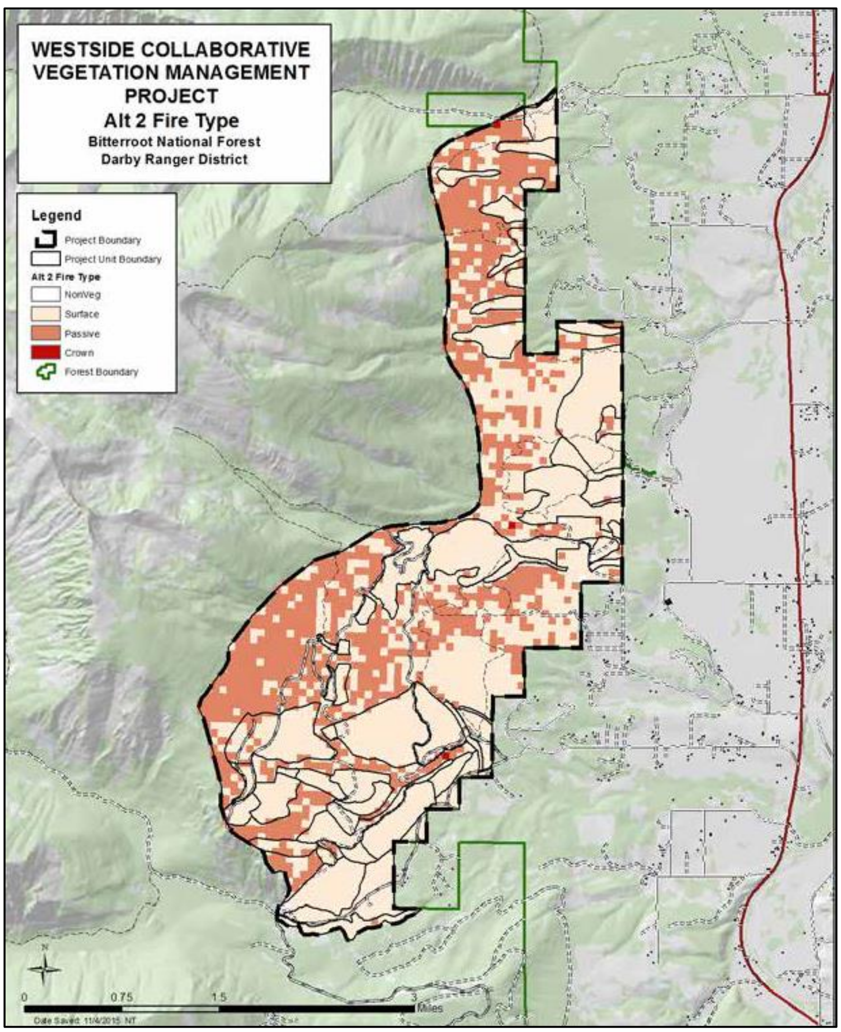

Figure 4

The Draft EA documentation does not include adequate visuals for the public to fully understand the scope and possible consequences of this proposed Project.

Please provide a wildfire history map for the area of this proposed Project. Please include all wildfires that occurred after 1950.

Please provide a map of the proposed project area which shows (in combination) each "opportunity area," the WUI, and all private-property structures.

Please provide a map for this proposed Project area which shows the community protection zone (CPZ).

Please provide a map showing areas that have already been logged/thinned (including treatment dates) for the area of this proposed Project.

XII. Project Lacks Adequate Protection for Wildlife and Wildlife Habitat

The FS hired a group of experts, headed by Martin Nie, to research who had the ultimate responsibility for managing and protecting wildlife—the states or the federal government—on federally managed lands. Through research of U.S legal documents and case law, the group unequivocally established that, federal agencies have the ultimate responsibility for managing and protecting wildlife.[58]

Please provide a list of species-specific measures which will be implemented to ensure that all wildlife and their respective habitats in the area proposed for this Project will be protected during and after management activities.

A. Bull Trout

The Draft EA does not address concerns addressed or consider references cited in the May 20, 2022, FOB et al scoping comments (pp. 22-29). We include by reference those issues and references.

Of the two fisheries biologists listed in the Project files, one retired 3 months ago and the other works in Region 6. Even if new fisheries biologists are hired, they will have no experience with the area or the Project. Who will monitor the effects of this Project and analyze impacts from Project activities during implementation?

The Project area includes 29 miles of bull trout critical habitat and many more miles of bull trout occupied streams. The Draft EA finds that Project activities are likely to adversely affect bull trout (Draft EA, at 116). The Draft EA claims that design features will minimize impacts but shares no evidence of their efficacy in Project documentation.

Direct, indirect, and cumulative effects of Project activities on bull trout recovery have not been fully analyzed in Project documentation.

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[58] Nie, M. et al (2017) Fish and Wildlife Management on Federal Lands Debunking State Supremacy - https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2980807

According to the Draft EA, "Each resource specialist described the existing conditions for their resource and identified specific present and future foreseeable actions relevant to their resource" (Draft EA, at 24). This is not the case. Project analysis does not fully disclose current conditions for bull trout and bull trout habitat in the Project area. The USFS Region 1 Conservation Strategy for Bull Trout (2013) that gives an overview of current conditions for bull trout occupied streams is not discussed or included in the references section.

The USFWS Columbia Basin Recovery Unit Implementation Plan for Bull Trout (RUIP 2015) makes it clear that fish surveys are lacking in the Project area, "Bitterroot River tributaries are high priorities for additional presence/absence survey mapping, potentially using new e-DNA survey techniques (D-70)". While the implementation plan promises fish surveys before Project activities occur, this does not allow for trend analysis and does not suffice for the hard look required by NEPA. The Draft EA refers to a Biological Assessment for bull trout, but it is not disclosed in the Project files.

RUIP 2015 finds, "Riparian habitat trend has been generally improving in SR habitat over the past 25 years or longer on Federally managed timber lands (see, *e.g.*, PACFISH/INFISH Biological Opinion effectiveness monitoring [Archer and Groce 2015]), due in part to recent improvements in management practices, but also as an artifact of declining timber harvest and the virtual cessation of road building on Federal lands (USFS 2013).

The Draft EA claims there is no net increase in FS roads because new roads will be closed and most of the road prisms exist on the landscape. The effects of re-blading and widening old, grown-in road prisms in Management Area 5 and Inventoried Roadless Areas (IRA) that were considered roadless in the 1987 Forest Plan have not been analyzed. Many older road prisms are not wide enough for log hauling. The width of these prisms can be discerned from LIDAR and should be disclosed. The NEPA behind these roads should also be disclosed. If they were previously decommissioned, it does not count to decommission them again.

Currently, the U.S. Department of Agriculture, Forest Service is establishing a strategy for working with partners to dramatically increase fuels and forest health treatments by up to four times current treatment levels in the West. This strategy can be viewed at "Confronting the Wildfire Crisis: A New Strategy for Protecting Communities and Improving Resilience to America's Forest." This policy and myriad projects like the Bitterroot Front, Mud Creek, Gold Butterfly, Stevi West Central, Trapper Bunkhouse, fuel break projects, private and State land logging, and more will greatly increase timber harvest and exponentially change the trend of "declining timber harvest" that has allowed for generally improving riparian habitat on federally managed public lands.

The Draft EA does not fully disclose or analyze the direct, indirect, and cumulative effects of Project activities on bull trout and watersheds. RUIP 2015 describes two threats to bull trout habitat that Project activities will definitely exacerbate in the Project area:

> **Management** (1.1) Sediment from forest roads, logging practices, livestock grazing, and agricultural practices (irrigation impacts and dewatering) are causing riparian and instream degradation, loss of LWD, and pool reduction in FMO habitat and some SR

tributaries; **Instream Impacts** (1.2) Transportation corridors along riparian areas contribute to instream habitat degradation through the loss of LWD, pool reduction, increased sedimentation, and loss of structure due to streambank stabilization in some SR tributaries (*e.g.*, Lolo Creek) (RUIP D-13-D-14).

The only sediment delivery analysis in the Draft EA is for road segments <100 feet from streams. Sediment created from heavy logging trucks, removing vegetation on road prisms, and roads in general is not addressed. The WEPP system is designed for prioritizing best management practices, not for analyzing sediment delivery from landscape scale logging projects. Illegal use of roads and the ease of illegal access both summer and winter created by intermediate cuts and re-blading impassable roads is not analyzed.

The Project area includes steep slopes, the Draft EA does not analyze the effects to bull trout and bull trout recovery of road actions and Project activities on steep slopes. Instead, the Draft EA states, “The potential for erosion is lowest for soils on slopes less than 40 percent. Most roads in the forest (311 miles) are on slopes less than 40 percent, and there are no roads on sensitive soils with slopes greater than 60 percent” (Draft EA, at 102). This means 167 miles of roads and road activities will occur in areas over 40% and roads and skid trails will be created on slopes (without sensitive soils) greater than 60%. How will debris flow and road failure caused by these activities affect bull trout and water quality?

Bull trout need cold water to survive and propagate. According to the USFWS “Rivers in the CHRU [Columbia Headwaters Recovery Unit] are often fed by colder tributaries, especially in the headwaters, and these mixing areas provide thermal refugia during the warmer seasons (RUIP D-33).” Land management activities affect water quantity which affects temperatures during warmer seasons. The Draft EA does not disclose effects of activities that could impact water yield because, “specific timing and location of treatments have not been identified” (Draft EA, at 100). 101.92 miles of proposed actions would occur within HUC12 watersheds. But the effects of these actions are not analyzed, according to the Draft EA, “Under the proposed action, additional time would be needed for field verification to determine the risk to water yield and channel stability prior to implementation (Draft EA, at 101)**.** All this would be completed by a new fisheries biologist if one is hired.

The Clark Fork Coalition identified many of the tributaries in the Project area as depressed spawning and rearing habitats and vital migratory corridors for bull trout (Figure 5). The effects to these critical areas must be disclosed in Project documentation.

[continued on next page]

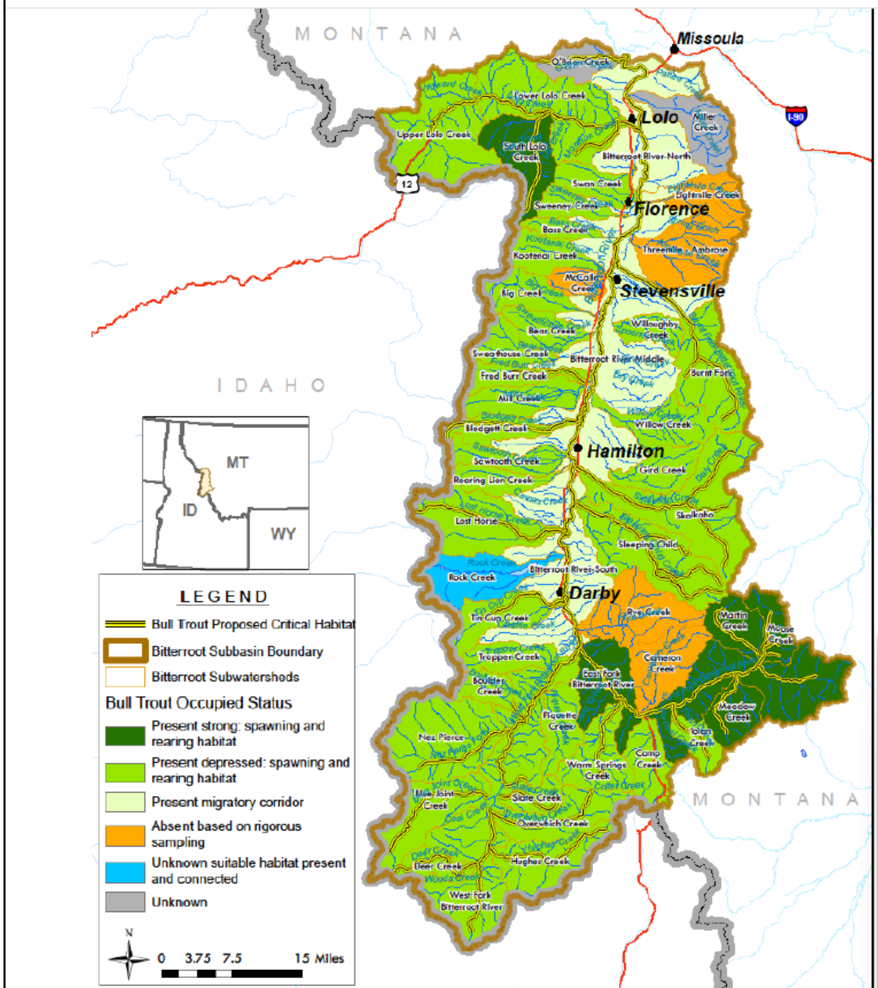

Figure 5: Bull trout habitat status by sub watershed.

Figure 5 - 2017 Bitterroot Strategy, Clark Fork Coalition, (page 9)

FOB scoping comments recommended the dismantling of the Fish Creek dam to improve habitat which, according to the Project documentation, was not analyzed.

The Project proposes removing and replacing culverts to improve fish habitat (Draft EA Appendix F, at 16). The Draft EA does not disclose whether these are funded. The Draft EA fails to include a list of culverts in the Project area that were promised to be replaced by previous projects but were not due to lack of funding. The Draft EA should also include a list of all malfunctioning culverts in the Project area and projected costs for replacement.

The permanent road leading to the SNOTEL site in the Lost Horse watershed should be removed from the Project. The SNOTEL site has functioned without road access for decades. This road construction does not meet the purpose and need of the Project and Lost Horse is a 303(d) impaired stream as well as critical bull trout habitat.

The Biological Opinion on bull trout for this Project must be made available to the public before the decision for the Bitterroot Front Project is signed. The biological assessment has not been disclosed in the Draft EA even though it has been completed and sent to the USFWS.

Finally, the Draft EA claims that Project activities will contribute to beneficial cumulative impacts because, "the proposed action **is intended** to reduce the risk of uncharacteristically severe wildfires, and, therefore, widespread vegetation loss that could otherwise expose bare soil and increase water yield and sediment delivery" (Draft EA, pp. 107-108) (emphasis added). Such good intentions, while admirable, are not guaranteed. Extreme fire conditions are caused by global warming. Logging and road building will not decrease warming. Bull trout are adapted to fire disturbance of all levels of severity. Bull trout are not adapted to landscape scale logging activities.

B. Grizzly Bear

There is solid documentation of recent and ongoing grizzly bear occupancy in the Bitterroot National Forest.[59]

The area covered by the Bitterroot Front Project encompasses almost the entire Bitterroot Range. That area has been shown to contain suitable grizzly bear denning habitat and provides an area of demographic connectivity, something necessary for the continued genetic health of the grizzly bear population.[60]

No adequate explanation is offered by the Draft EA regarding exactly how this proposed Project will proceed without harming grizzly bears, their habitat, and demographic connectivity. (See below **XIII. The Forest Service must Disclose and Analyze the Environmental Consequences to Grizzly Bears Including Connectivity and Recovery,** pp. 62-69)

[continued on next page]

[59] See newspaper articles "Wandering grizzly leaves Bitterroot, returns to Idaho" and "Grizzly bear captured Saturday at golf course near Stevensville" (See Exhibit 12)

[60] Bader,M. and Sieracki, P. (2022) Grizzly Bear Denning Habitat and Demographic Connectivity in Northern Idaho And Western Montana. Northwestern Naturalist103(3)

Path to recovery: Modeled movement paths of male grizzly bears between recovery areas (black outlined polygons). Red stars signify bear observations outside recovery zones. Colors range from red (lowest predicted bear use) to blue (highest predicted bear use). Note bear observations and predicted use of the Missoula and Bitterroot Valleys. NCDE: Northern Continental Divide Ecosystem. BE = Bitterroot Ecosystem. GYE = Greater Yellowstone Ecosystem. From Sells et al. (2023).

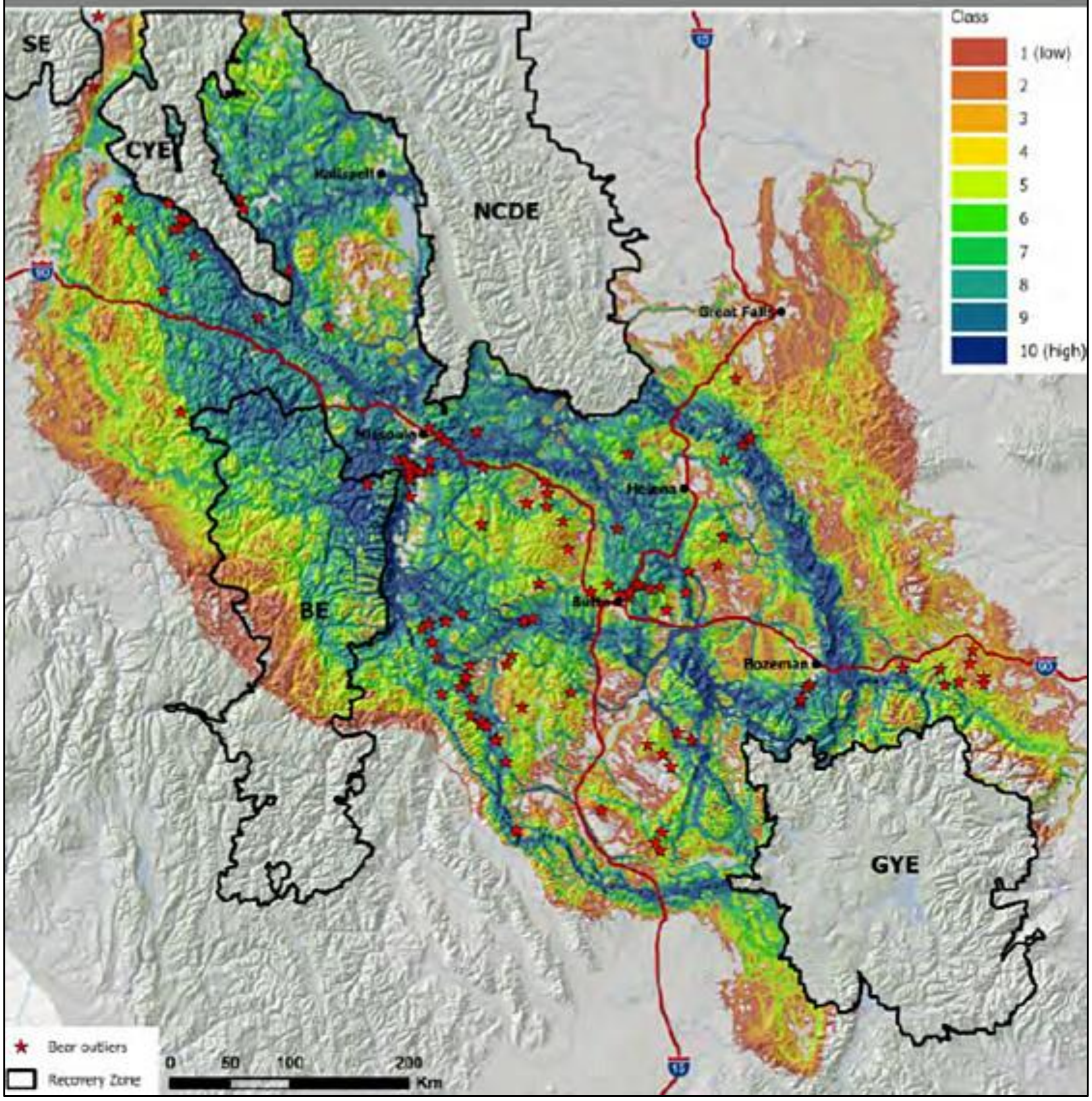

Figure 6 – see Jonkel, J. (2023) Wildlife Corridors: Finding a way through a changing landscape. Montana Fish Wildlife and Parks, Region 2 Technical Bulletin, Vol 9, Issue 37

C. Black Bear

Black bears over-winter (den) within the area encompassed by this proposed Project.

Disturbance of bears while denning has been shown to be detrimental, especially to females with cubs.[61]

Please provide a list of the exact measures that will be taken to ensure that those den sites and their inhabitants will not be disturbed by management activities.

D. Wolverine, Lynx, and Fisher

We discussed wolverine, lynx, and fisher in FOB scoping comments (pp. 29-35) which were not addressed in the Draft EA and carry them forward to this comment. FOB scoping comments requested all consultation information and assessments, but this not been included in the Draft EA or Project files. FOB also requested all monitoring information, maps of habitat, and monitoring results, dates, times, and protocols. These have not been supplied.

Wolverine are present in the Project area and are now a proposed species. Past monitoring is inadequate, and effects of Project activities have not been disclosed or analyzed in Project documentation. Fisher have been found in the area, and lynx habitat is prevalent in the area.

The Draft EA does not analyze the effects from the activities included in this proposed Project on wolverine (e.g., widely spaced trees, opening overgrown roads, and closed roads to both non-motorized and motorized recreational use). Scrafford et al 2017 found "roads, regardless of traffic volume, reduce the quality of wolverine habitats (at 534)." That study discovered that even those roads which were scarcely used by vehicles were deleterious to wolverine habitat suitability. Barrueto 2022 found "detection [of wolverine] probability also decreased with human recreational activity (at 1)." The proposed Project activities will expand both motorized and non-motorized human access. Heinemeyer 2019 found "significant avoidance of areas used by backcountry winter recreationists and that this results in habitat degradation, particularly for female wolverines. Given the low density and fragmented nature of wolverines in the contiguous United States, impacts to the relatively few reproductive females should be of concern (at 19)."

Illegal use has not been disclosed or analyzed. According to Scarpato 2013, even though most off-road vehicle "users know and understand that staying on-trail is an important limit on their activity, a majority of users prefer breaking new trail, most do so from time to time, and as many as one-fifth do so on a regular basis (at 143)." How many enforcement officers are available, how many off-road citations have been written, and how many off-road violations have been reported in the last 10 years in the Project area? Illegal motorized use is common in the Project area. One example is over-snow use in elk winter range near the non-motorized Coulee trail. (Figure 7)

[continued on next page]

[61] Linnell, J.D.C. et al (2000) How vulnerable are denning bears to disturbance - https://www.jstor.org/stable/3783698?origin=JSTOR-pdf&seq=1

Figure 7 - Illegal over-snow vehicle track along non-motorized trail and then veering off to a ridge. Photo 12/2022

Considering the deleterious effects of linear features to wolverine and countless wildlife, it is surprising that Project documentation neither considers nor analyzes an alternative with no road building or re-opening of overgrown roads. Therefore, the public is unable to discern whether a no-roads alternative would be as beneficial as the current proposal. Fisher et al 2022 found, "Wolverines are vulnerable to multiple, widespread, increasing forms of human activity." And "In the Ontario boreal forest, Ray et al 2018 suggested both road density and climate warming (thawing degree days had a negative effect on the probability of wolverine occupancy)" (at 9).

Another effect of more access and more people in wolverine habitat was discovered by Chow-Fraser 2022.

> Wolverines failed to successfully occupy areas with linear features as these entrain unsustainable competition via the coyotes that exploit them. Thus, landscape management aimed at minimizing linear feature density, decommissioning roads, and trails, and restoring linear features (Tattersall et al 2020b) are likely needed to conserve wolverine (at 7).

That study found that even snowshoe paths, backcountry ski tracks, and snowmobile trails packed the snow enough to allow coyotes into areas where they would not normally venture due to deep snow. These are places where wolverine had the advantage but must now compete for prey with coyotes. Figure 8 shows the rate of species concurrence with linear feature densities.

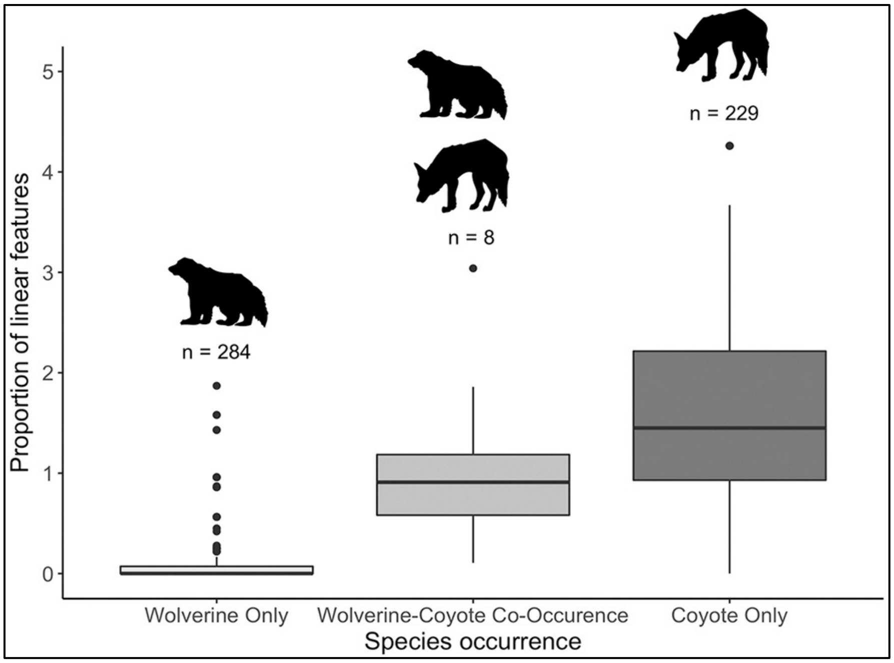

Figure 8 - Chow-Fraser 2022 species occurrence vs proportion of linear features.

New travel technology is another factor not analyzed in the Draft EA. Motorized recreation continues to evolve into highly powerful and maneuverable vehicles that access high-elevation areas with deep snow (i.e., wolverine maternal habitat). Snow motorcycles can weave through tightly packed trees providing easy motorized access to remote areas. Project activities would add roads, skid trails, and widely space trees for easy travel into higher areas of untreated forests occupied by female wolverine.[62] Motorized snow bikes are an increasing threat to wolverine persistence and should be analyzed. Heinemeyer 2019 found, "winter recreation should be considered when assessing wolverine habitat suitability, cumulative effects, and conservation" (p 19).

The increased length of trapping seasons in Montana will affect wolverine in the Project area but are not mentioned in Project analysis. Though trapping of wolverine is not legal in the state, non-target captures are common. Incidental capture in Montana included 5 wolverines over a 6-year period from 2012 -2017 (Incidental Captures of Wildlife and Domestic Dogs in Montana 2012-2017, June 2018). That count was before the trapping season was extended in 2021 and trapping regulations were made more liberal on private lands. It should be assumed that more wolverines will be inadvertently trapped in the Project area with increased access and checkerboard private lands. Montana does not have a 24-hour mandatory trap check, so it is highly probable that incidental captures will result in mortality.

Recent court proceedings showed that global warming and lack of regulatory mechanisms to curtail are the greatest threats to wolverine. This Project proposal calls for cutting of mature and old-growth forests. A recent letter to congress by hundreds of scientists stated, logging in U.S. forests emits 617 million tons of CO_2 annually (Harris et al 2016). Further,

[62] This video gives an idea of the capabilities https://www.youtube.com/watch?v=R_byTMZY0xw&t=89s.

logging involves transportation of trucks and machinery over long distances between the forest and the mill. For every ton of carbon emitted from logging, an additional 17.2% (106 million tons of CO_2) is emitted from fossil fuel consumption to support transportation, extraction, and processing of wood (Ingerson 2007). In fact, annual CO_2 emissions from logging in U.S. forests are comparable to yearly U.S. emissions from the residential and commercial sectors combined (https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks) (Moomaw 2020, at 1). The Draft EA does not analyze these effects on wolverine and other sensitive species.

According to Ruggiero et al 2007, Wolverine persistence is "vitally dependent on regular, or at least intermittent, dispersal of individuals between habitat islands to facilitate gene flow between sub-populations." Carroll et al 2021 emphasizes the need for private land conservation to enhance wolverine dispersal, "for many species, such as wolverines (*Gulo gulo*), species persistence and continued recovery to historical range hinge on successful dispersers or migrants crossing low-elevation private lands (Cegelski et al., 2006) (at 1)." Carroll removes public lands from analysis assuming that they are better protected, but increased land management activities will fragment and affect wolverine in the Project area.

With decreasing snowpack, McKelvey et al 2011 finds "By the late 21st century, dispersal modeling indicates that habitat isolation at or above levels associated with genetic isolation of wolverine populations becomes (at 2882)". It is abundantly clear that dispersal areas on public lands are vitally important to the persistence of the species.

Carroll 2021 found,

> In the Rocky Mountain West (RMW), protected conservation areas and long-term wildlife conservation have historically focused on high-elevation systems with little economic or agricultural value (Scott et al 2001; Joppa and Pfaff 2009). This focus has resulted in conservation areas being unbalanced, with well-represented high-elevation ecosystems but less well-represented low-elevation ecosystems (Scott et al 2001; Dietz and Czech 2005; Aycrigg et al 2013).

Lower- to mid-elevation public lands like those in the Project area are as vital to wolverine as lower elevation private lands. Saura et al 2013 found "the loss of intermediate and sufficiently large stepping-stone habitat patches can cause a sharp decline in the distance that can be traversed by species (critical spatial thresholds) that cannot be effectively compensated by other factors previously regarded as crucial for long-distance dispersal (at 1)." And Fisher et al 2022 discussed the need for "increased flexibility in wolverine selection during dispersal movements" because "it is important for metapopulation connectivity in this highly fragmented system. Unfortunately, there is some threshold at which wolverine dispersal movements are constrained that requires further investigation (at 11)." Without further investigation and evidence, it is irresponsible to assume that Project activities do not create constraints on wolverine movement in dispersal areas. As Carroll emphasized, "Successful dispersal is critical for the species to continue occupying the available habitats and maintaining genetic diversity in the conterminous US (Kyle and Strobeck 2001; Cegelski et al 2006) (at 2)."

Project activities will produce a variety of linear features including skid trails, yarding, firelines, roads, both temporary and permanent, and decommissioned roads. Fisher 2022 found, "wolverine occurrence declined with density of anthropogenic landscape features, including roads, seismic lines, harvest cutblocks, and other industrial footprint (Heim et al., 2017) – with linear features the most pervasive feature driving wolverine occurrence (pp. 10-11)." Project activities are not benign to wolverine survival because they produce linear features.

The proposed site-specific coarse woody debris (CWD) amendment would be detrimental to wolverine, fisher, and lynx. Keisker 2000 provides charts describing the reliance of wolverine and many other species in the Project area to CWD. The loss of CWD would be detrimental to wolverine, but Project documentation does not analyze the effects. Nor does Project documentation explain how often in the future maintenance burns would be required.

The Draft EA does not analyze the direct, indirect, and cumulative effects to lynx and lynx habitat. For example, the Draft EA does not analyze the effects of daylighting white bark pine on snowshoe hare and lynx habitat. Project documentation does not include a map of snowshoe hare habitat. Lynx occupy neighboring areas on the Lolo National Forest and, as Saura 2013 makes clear.

> The loss of intermediate and sufficiently large stepping-stone habitat patches can cause a sharp decline in the distance that can be traversed by species (critical spatial thresholds) that cannot be effectively compensated by other factors previously regarded as crucial for long-distance dispersal.

And Fisher et al 2022 discussed the need for "increased flexibility in wolverine selection during dispersal movements" because "it is important for metapopulation connectivity in this highly fragmented system. Unfortunately, there is some threshold at which wolverine dispersal movements are constrained that requires further investigation." Without further investigation and evidence, it is irresponsible to assume that land management activities do not create constraints on wolverine movement in dispersal areas. As Carroll emphasized, "Successful dispersal is critical for the species to continue occupying the available habitats and maintaining genetic diversity in the conterminous US (Kyle and Strobeck 2001; Cegelski et al 2006) (at 171).

Additionally, the Draft EA does not analyze the direct, indirect, and cumulative effects to fisher which are present in the Project area.

E. Sensitive Species

Boreal toads, flammulated owls, grey wolves, Coeur d' Alene salamanders, and numerous other Sensitive Species are known to live and breed in the Project area.

Please provide a list of the exact measures that will be taken to assure Project activities will not disturb sensitive species or destroy the habitat on which they currently depend. Please include in the Project file all monitoring of sensitive species in the Project area.

F. Indicator Species

Pileated woodpeckers, Pine marten, Westslope cutthroat trout, and elk are indicator species.

Please analyze how these species and their habitat will be protected during this multi-year Project. Please include all Project area monitoring of these species in the Project file.

G. Prescribed Fire vs. Wildfire

Prescribed fire has recently been shown to be less effective than wildfire at maintaining highly nutritious ungulate forage. [63]

Proposed activities could disturb and displace elk temporarily through noise, human activities, or prescribed fire. Indirect effects would be largely beneficial. Targeted treatment areas for prescribed fire and invasive species would enhance forage" (Draft EA, at 118)

Please justify, using the most recent scientific research, why this proposed Project includes using prescribed fire as a major treatment.

H. Grazing

There is a long record of cattle trespassing (illegal grazing) into some portions of the BNF. Please provide a map showing places within the Project area that are available for grazing. Please list what measures the Agency will implement to eliminate cattle encroachment in the Project area.

To the extent that the proposed treatments would fall within active and vacant livestock grazing allotments, the Forest Service must disclose this information. The Draft EA documents make the unfounded assumption that the proposed management actions will "increase the quality of grazing forage in allotments where treatments overlap." (PF-RANGE-0001, at 4). However, it is well understood that livestock significantly displace certain native ungulates.[64] In fact, research has found that some deer species are known to avoid cattle.[65] Additional research has found that elk and deer densities can decline by as much as 92 percent in response to the introduction of livestock.[66] A southwestern Montana study found that "elk generally avoided pastures being grazed, making relatively greater use of rested pastures and grazed pastures before and after grazing. Elk also used steeper slopes than cattle, apparently as a response to the presence of cattle. Elk avoided meadow

[63] Proffitt, K.M. (2019) A century of changing fire management alters ungulate forage in a wildfire-dominated landscape - https://academic.oup.com/forestry/article/92/5/523/5448926

[64] Wallace, Mark C. and Paul R. Krausman (1987) Elk, Mule Deer, and Cattle Habitats in Central Arizona. Journal of Range Management, Vol. 40, No. 1 (Jan. 1987), pp. 80-83. Society for Range Management. Stable URL: http://www.jstor.org/stable/3899367

[65] Krämer, August (1973) Interspecific Behavior and Dispersion of Two Sympatric Deer Species The Journal of Wildlife Management, Vol. 37, No. 3 (Jul. 1973), pp. 288-300. Wiley on behalf of the Wildlife Society Stable URL: http://www.jstor.org/stable/3800119

[66] Clegg, Kenneth, "Density and Feeding Habits of Elk and Deer in Relation to Livestock Disturbance." (1994) All Graduate Theses and Dissertations. 969. https://digitalcommons.usu.edu/etd/969

sites heavily used by cattle during the previous year during the early summer. Elk were rarely observed in close proximity to cattle."[67] All of this describes the social displacement of elk by cattle, a likelihood that must be analyzed in upcoming NEPA documents.

Cattle impacts on streams are well documented and therefore a potential expansion of the species in areas where streams hold sensitive and important native trout species must be thoroughly analyzed. Although riparian areas account for less than 2% of the West's total land area, they provide habitat for approximately one-third of the plant species. In the arid Southwest and similarly arid regions approximately 60% of vertebrate species and 70% of threatened and endangered species are riparian obligates.[68] Yet these are the areas most impacted by livestock grazing, largely because as much as 81% of the forage in an allotment can come from 2% of the area occupied by a riparian zone.[69]

These impacts must be analyzed cumulatively with any additional riparian area impacts expected from the proposed treatments. In addition, drought is increasing across the west and must be considered. Drought and climate change are expected to decrease populations of bull trout and cutthroat trout through several mechanisms[70] and because of the presence of these species on the Forest and within several streams crossing active and vacant grazing allotments in the Project area, the impacts of expanded grazing on these species and their habitats must be thoroughly considered in upcoming NEPA documents.

The Forest Service must also analyze the cumulative impacts of expanded livestock grazing on bighorn sheep. While the only allotment that borders bighorn sheep habitat is currently vacant, if it were to be restocked due to an increase in forage provided by the Project, what impact would this have on those sheep? Cattle have been implicated in pneumonia-related die-offs of bighorn sheep as well as in outbreaks of Bovine Viral Diarrhea and other diseases impacting wild sheep.[71] Bovine respiratory syncytial virus (BRSV) and bovine parainfluenza virus 3 have been identified as co-agents in pneumonia outbreaks in bighorn sheep populations, affecting bighorn herds exposed to primary agents *Mycoplasma ovipneumoniae* and *Mannheimia haemolytica*.[72] *Mannheimia haemolytica* originating in

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[67] Gniadek, Steve (1987) Elk and cattle relationships on summer range in southwestern Montana. Master's Thesis U of Montana.

[68] Poff, Boris; Koestner, Karen A.; Neary, Daniel G.; Merritt, Da (2012) Threats to western United States riparian ecosystems: A bibliography. Gen. Tech. Rep. RMRS-GTR-269. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 78 p.

[69] Kauffman, Boone (2002) Lifeblood of the West—Riparian Zones, Biodiversity, and Degradation by Livestock. In Welfare Ranching: The Subsidized Destruction of the American West Edited by George Wuerthner and Mollie Matteson.

[70] Bell, D. A., Kovach, R. P., Muhlfeld, C. C., Al-Chokhachy, R., Cline, T. J., Whited, D. C., ... & Whiteley, A.R. (2021) Climate change and expanding invasive species drive widespread declines of native trout in the northern Rocky Mountains, USA. *Science advances*, *7*(52), eabj5471.

[71] Spraker, T., Collins, J., Adrian, W., Otterman, J (1986) Isolation and serologic evidence of a Respiratory Syncytial Virus in bighorn sheep from Colorado. Journal of Wildlife Diseases, 22(3), 416-418

[72] Dassanayakea, R., Shanthalingam, S., Herndon, C., Subramaniam, R. Paulraj K. Lawrence, Bavananthasivam, J., Cassirer, F., Haldorson, G., Foreyt, W., Rurangirwaa, F., Knowles, D., Besser, T., Srikumaran, S. (2010. Mycoplasma ovipneumoniae can predispose bighorn sheep to fatal Mannheimia haemolytica pneumonia. Veterinary Microbiology, 145, 354–359.

cattle is believed to have been a primary respiratory disease agent in at least one bighorn sheep pneumonia outbreak.[73] In addition to the potential for transmission of pneumonia-causing bacteria and other pathogens to bighorn sheep, cattle may displace bighorn sheep through habitat degradation or direct competition for resources, and they may spread noxious weeds that deteriorate native plant communities on which bighorn sheep depend. Do the management areas focused on improving livestock forage fall within the currently vacant Trapper Peak allotment? These impacts must be disclosed and analyzed.

Finally, the potential expansion of livestock grazing due to increased forage availability might have impacts on grizzly bears that are returning to the Bitterroot ecosystem. These impacts must be analyzed as conflicts with livestock is a leading cause of mortality for grizzly bears.

Increased forage that is likely to result from these treatments will mean more cows in more places, which must be analyzed in upcoming NEPA documents not only because of the potential impact of this livestock expansion on big game, but also the impacts on other species of wildlife in the area. The Forest Service must consider whether the potential for livestock to use new and different areas as a result of this Project will impact bull trout, westslope cutthroat trout, Canada lynx, bighorn sheep, and potential grizzly bear denning habitat.

I. Invasive Plants and Weeds

Most on-the-ground management activities have been shown to spread invasive plants and weeds into previously uninfected areas.[74]

The spread of invasive plants and weeds typically has a detrimental impact on the wellbeing of many wildlife species.

But, contrary to an abundance of research, the Draft EA documents assume that “Compared with the no-action alternative, implementing treatments to reduce the risk of high-severity wildfire would decrease the potential spread or potential increase in abundance of invasive and noxious weeds that have been associated with high-severity wildfire (Sutherland 2004).” (PF-RANGE-0001, at 4).

That assumption appears to be supported by a single source (Sutherland 2004). An abundance of research and on-the-ground observations contradict such conjecture. Thus, support for that support that declaration.

[continued on next page]

[73] Wolfe, L. Diamond, B., Spraker, T., Sirochman, M., Walsh, D., Machin, C., Bade, D., Miller, M. (2010) A bighorn sheep die-off in southern Colorado involving a Pasteurellaceae strain that may have originated from syntopic cattle. Journal of Wildlife Diseases, 46(4), 1262-8.

[74] Dodson, E.K. and Fielder, C.E. (2006) Impacts of restoration treatments on alien plant invasion in ponderosa pine - https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/j.1365-2664.2006.01206.x

J. Elk

The list of References attached to the Project documentation includes, “Cook, J. G., L. L. Irwin, L. D. Bryant, R. A. Riggs, and J. W. Thomas. 1998. Relations of forest cover and condition of elk: a test of the thermal cover hypothesis in summer and winter. Wildlife Monographs 141:1-61.”

That study is an outlier among the many thermal-cover studies that have been completed. Unlike most of the scientific research establishing the importance of thermal cover for elk and other big game, Cook, et al 1998 asserts their study of captive elk shows a conflicting result.

In addition, as the pace of global warming accelerates, thermal cover during the hottest months of the year to protect elk from overheating is an important factor which the Draft EA documents completely ignore.

K. Migratory Birds

Little mention of protection for bird species is included in the Project documentation. The Migratory Bird Act (1918) prohibits the “taking” of migratory birds. Several listed species are known to nest in the area of this proposed Project. Courts have determined that “taking” does not have to be intentional. Therefore, destruction of migratory bird habitat, though unintended, is illegal.

Many wildlife species will be impacted by management activities during the Project’s very lengthy duration and very large area. A few of the avian species that will be impacted are the Flammulated Owl, Pileated Woodpecker, and Northern Goshawk. All are Montana Species of Concern, “native animals breeding in the state that are considered to be ‘at risk’ due to declining population trends, threats to their habitats, and/or restricted distribution” (“Montana’s Species of Interest”). The Flammulated Owl is priority Level I on the Montana Priority Bird Species List, based on the Partners in Flight prioritization process. Level I species are those that “generally exhibit declining population trends and warrant immediate conservation action” (Marks et al, at 4). In addition, the owls are listed by the USFWS as BCC10, which means they “are likely to become candidates under the Endangered Species Act” unless more conservation actions are undertaken (“Flammulated”). Pileated Woodpecker and Northern Goshawks are priority Level II, species that are “not thought to be at as high a risk as those at Level I but nonetheless are in need of monitoring to assess population status” (Marks et al, at 4).

Have surveys of these three species been conducted in the recent past? If so, please provide the survey results including times and dates. If not, please conduct surveys before implementation planning, before implementation public comment, and before starting treatments.

The species discussed above will be impacted if the Forest logs mature, large, and/or old-growth trees. President Biden has made a commitment to safeguarding them. Here the focus is on the importance of old growth and other large trees to avian and other species.

L. Flammulated Owls

Both the Montana Field Guide and Cornell Lab of Ornithology suggest that Flammulated Owls may suffer from any logging that occurs in old-growth stands in the Bitterroot Front Project. The Montana Field Guide says, "No specific management activities for Flammulated Owls are currently occurring in Montana, however, management for old-growth ponderosa pine habitats is ongoing by a number of land management agencies. Management for the maintenance of this habitat type will be beneficial for Flammulated Owls in Montana." According to Cornell Lab of Ornithology, the "Flammulated Owl has a low reproductive rate and is found mostly in older forests, which can be under pressure for logging" ("Conservation").

In response to commenters on the Mud Creek Project, the Agency suggested that an article by Linkhart and Reynolds on the territories used by Flammulated Owls does not tie breeding success to numbers of old-growth trees but to mature and over-mature stands. The article does identify a forest type it calls "old" consisting of ponderosa pine and Douglas-fir from 200 to 400 years old. Linkhart and Reynolds find that territories occupied 12 or more years (out of 16 years in the study) had "more than 75 percent old ponderosa pine/Douglas-fir." Yes, Linkhart and Reynolds use "old" and not "old growth," but is that a difference that really matters here? Ponderosa pine and Douglas-fir ranging from 200-400 years old will, most likely, be considered old growth. Indeed, like the commenters, The Montana Field Guide interprets Linkhart and Reynolds' use of "old" trees to mean old-growth trees: "Territories consistently occupied by breeding pairs were those containing the largest portion (more than 75 percent) of *old-growth* [emphasis added] (200 to 400 years), whereas territories occupied by unpaired males and rarely by breeding pairs contained 27 to 68 percent *old-growth* [emphasis added] (Linkhart and Reynolds 1997 cited in "Flammulated Owl"). Further, while Linkhart and Reynolds use the term "mature," the term "over-mature" does not appear in the article. Linkhart and Reynolds should stand as a relevant source when the Forest is considering cuts in old-growth habitat. The Forest Service's amendment on old growth uses the standard promoted by Green et al. In most circumstances, Green et. al.'s minimum of eight old-growth trees per acre clashes with the needs of Flammulated Owls, particularly breeding pairs.

Please provide recent survey information on Flammulated Owls throughout the Project area including dates, times, and moon phases. Avoid harvesting old growth, old, mature, or very large trees.

M. Pileated Woodpeckers

Protections for Pileated Woodpeckers ripple across the forest, as these woodpeckers excavate a new nest hole every year. Aubry, K., and C. Raley point out that Pileated Woodpeckers function as important primary nest cavity excavators and have been fittingly labeled as "ecosystem engineers" by the United States Forest Service (Aubry & Raley 2003). Each season, pileated woodpeckers create new nests, leaving vacant cavities throughout the forest that many other species of animals use. This influence, combined with their creation of large foraging cavities, constitutes their placement as a keystone species throughout their range (Hartwig et al 2004).

Included in the species that use the old nest cavities are the Flammulated Owl, Boreal Owl, Northern Saw-whet Owl, songbirds, bats, squirrels, and other small mammals. Kathy Martin, a professor in the Faculty of Forestry at the University of British Columbia, points out how often cavities are used, over and over, by various species: "Some of the tree cavities in Canada were used 17 times in 13 years by up to five different species," says Martin. “One tree cavity can sustain a lot of wildlife over its lifetime” (qtd. in University of British Columbia). In his Ph.D. dissertation at the University of Montana, B.R. McClelland says, “The Pileated can be considered as key to the welfare of most hole-nesting species. If suitable habitat for its perpetuation is provided, most other hole-nesting species will be accommodated” (qtd. in Marks et al 325).

Just as protections for Pileated Woodpeckers translate into protections for other species, forest management practices that negatively impact these birds harm other species as well. Marks et al. explains that the Pileated Woodpecker is categorized as Level II Priority and a Species of Concern “because of its reliance on large tracts of mature and old-growth forest” (324). According to the Montana Field Guide, “Timber harvest has the most significant impact on habitat and populations. Removal of large-diameter live and dead trees, downed woody material, and of canopy closure eliminates nest and roost sites, foraging habitat, and cover” (“Pileated”). Kathy Martin, of the University of British Columbia also points to forest management that cuts too many old trees and therefore threatens woodpeckers and other species: "Most forest policies help protect younger trees but promote the harvest of older, larger, living trees -- the very trees needed by cavity-nesting animals” (qtd. in University of British Columbia).

In addition to relying on large, mature, and/or old-growth trees, the Montana Field Guide, in referencing important work by McClelland and McClelland 1999, says, “The Pileated Woodpecker in western larch forests of Montana is closely associated with forest values (fire, insects, and heartwood decay) often considered characteristic of ‘unhealthy’ forest conditions. … Forest management that benefits Pileated Woodpeckers will need to recognize these components as important parts of a truely [sic] healthy forest ecosystem (“Pileated”). And as we’ve seen, management that benefits Pileated Woodpeckers benefits many other species.

Please avoid harvesting old growth, old, mature, or very large trees.

N. Northern Goshawks

The dependence of Northern Goshawks on old growth does not appear to be as strong as that of Flammulated Owls and Pileated Woodpeckers. Goshawks do favor “mature and old-growth stands, and they are classified as a Species of Concern and a Level II Priority on the Montana Priority Bird Species List “because of its selective use of mature and old-growth forest in some parts of its range” (Marks et al, at 166). In a literature review on habitat use by Northern Goshawks, R.T. Reynolds finds: “Despite the wide diversity of habitats occupied by goshawks, the reports reviewed showed that mature and older forests (including but not limited to, old growth) consistently comprised the habitat in goshawk areas" (at 2). However, Marks et al says, "On balance, more information is needed on population trends and habitat relations, especially with regard to how forestry practices influence these issues" (at 166). If the Forest avoids old growth harvesting to benefit Flammulated Owls, Pileated Woodpeckers, and the ecosystem as a whole, Northern Goshawks will benefit as they will have more access to their preferred nesting habitat.

The Bald and Golden Eagle Protection Act (1940) offers similar protection for eagles. Both Bald and Golden Eagles are known to nest in the area covered by this proposed Project.

Please explain how the drastic changes to the existing habitat for bird species proposed by this Project do not conflict with the Migratory Bird and Bald and Golden Eagle Protection Acts.

XIII. The Forest Service must Disclose and Analyze the Environmental Consequences to Grizzly Bears Including Connectivity and Recovery

Grizzly bears (*Ursus arctos*) once ranged throughout most of western North American, from the high Arctic to the Sierra Madre Occidental of Mexico, and from the coast of California across most of the Great Plains. Prior to European settlement, scientists believed that approximately 50,000 grizzly bears occupied the western United States between Canada and Mexico. With European settlement of the American West and a federally funded bounty program aimed at eradication, grizzly bears were shot, trapped, and poisoned, reducing the population to just 2 percent of their historic range (Mattson, 2021[75]). As a result of its precipitous decline, FWS listed the grizzly bear as a threatened species in the lower 48 states under the Endangered Species Act in 1975. Today scientists estimate there are approximately 1,800 grizzly bears left in the lower 48 states, occupying five isolated populations. The Grizzly Bear was listed partially due to isolation and populations in the contiguous U.S. remain isolated (USFWS 2021). None of the Recovery Areas are large enough to independently support a viable population so that linkage of the isolated grizzly bear populations into a genetically-diverse metapopulation (as defined by Hanski and Gilpin 1991) would increase the probability of long-term survival (Allendorf et al 2019; Boyce and others 2001; Servheen and others 2001; Craighead and Vyse 1996).

The Selway-Bitterroot Wilderness borders the Project area. This area was designated as part of the Bitterroot Grizzly Bear Recovery Area by the U.S. Fish & Wildlife Service as part of the 1993 Grizzly Bear Recovery Plan. This is the largest Recovery Area but has very few verified grizzly bear observations. To reach viable population numbers, the Bitterroot Ecosystem must be occupied by resident grizzly bears. In other words, grizzly bear recovery in the lower 48 states is not possible without a sustainable grizzly bear population in the Bitterroot Ecosystem. Commercial logging and other vegetative management actions, along with connected activities

[75] Mattson, D. (2021) The Grizzly Bear Promised Land: Past, Present & Future of Grizzly Bears in the Bitterroot, Clearwater, Salmon & Selway Country. Livingston, MT (See Exhibit 13)

(such as road use in the Project area's nearly 50,000 acres of roadless terrain), will fragment grizzly bear habitat, reduce connectivity opportunities, degrade denning areas, and encourage human access. In fact, biologists "found that motorized access affected grizzly bears at the individual and population levels through effects on bears' habitat use, home range selection, movements, population fragmentation, survival, and reproductive rates that ultimately were reflected in population density, trend, and conservation status." (Proctor et al 2020). Thus, the Bitterroot Front Project, with its changes in motorized access, is likely to harm grizzly bear survival and recovery in the area, which in turn harms overall grizzly bear recovery goals for the lower 48 states.

The recent history of verified and likely observations of grizzly bears within and near the Project Area requires in depth analysis. Recent verified grizzly bear observations have been confirmed in the eastern and northern sections of the Bitterroot National Forest and in adjacent areas including Lolo, Lolo Hot Springs, Lolo Pass, and many areas within the Sapphire Mountains that are within known female dispersal distances to the Bitterroot Front (Jonkel 2022; Bader and Sieracki 2022). Likely visual observations from qualified observers including a former Forest Service District Ranger have come from St. Mary Peak and the head of Bass Creek. Moreover, these are just the verified and likely observations, which certainly underrepresent actual presence. No DNA hair traps or wildlife camera surveys have been done in this area so the information on residential occupancy is incomplete (Fortin-Noreus 2022). The Bitterroot National Forest through its capacity as a member of the IGBC Bitterroot Subcommittee has made an erroneous assumption that these bears either have all died or left the area resulting in no resident grizzly bears. This faulty assumption cannot be part of the analysis. The assumption must be that grizzly bears are present on the Bitterroot Face and adjacent areas and that more are likely in the near future.

The BNF must take a hard look and fully analyze potential impacts to grizzly bears, both resident and transient. This includes temporary displacement that could hinder or prevent natural recolonization. It also includes a hard look at impacts on grizzly bear landscape level connectivity of the Project.

The Action Area, as defined by the Endangered Species Act, is the entire area to be affected directly or indirectly by the federal action and not merely the immediate area involved in the action. The Forest Service must consider the cumulative effects of past, present, and reasonably foreseeable federal actions that in sum will lower the probability of female grizzly bear immigration into the Bitterroot Ecosystem. This is an important aspect of the issue before the Agency required by the APA, NEPA, and the ESA.

The BNF must also fully analyze impacts on grizzly bear denning habitat based on the best available scientific information [See Bader and Sieracki (2022) Grizzly Bear Denning Habitat and Demographic Connectivity]. Please also see Exhibit 16, for denning habitat on the BNF. To facilitate this detailed analysis, grizzly bear proponents contracted with experts to develop proposed Grizzly Bear Management Units (BMUs) that we urge the Forest Service to utilize in evaluating the proposed action and a reasonable range of alternatives. Our proposed BMUs will enable the Forest Service to assess the existing baseline condition and changes under the proposed actions for grizzly bear habitat within the Project area, including calculating baselines for roads, secure core, habitat productivity, denning habitat, and other resources (See Bader and Sieracki, 2022[76]).

One need look no further than the proposed timber harvest to see the need for analyzing potential impacts to grizzly bear denning habitat as the broad scale, artificial manipulation of the Project area is likely to negatively impact grizzly bears in the short-term and long-term. Areas that receive the regeneration harvest treatment will appear as openings in the forest. The Lolo National Forest acknowledges such action will “not likely provide sufficient hiding cover until the vegetation regrows to a point that would conceal a bear (about 15 years).” Grizzly bears are likely to avoid these areas in the long-term because grizzly bears select regenerating cut-blocks significantly less often than other habitats during all seasons (McLellan & Hovey 2001). And when grizzlies do use these areas, they may be more susceptible to poaching because they will not be easily concealed. The Forest Service must analyze the increased risk of poaching on new roads or on areas where timber and hiding cover will be removed. This Project as proposed will degrade grizzly bear use and movement, and the Forest Service must fully analyze how this Project is likely to impede and significantly delay grizzly bear recovery.

These complex issues, combined with the immense Action Area can only be properly addressed through completion of a full Environmental Impact Statement and substantive Section 7 consultation with the U.S. Fish & Wildlife Service.

In addition, the Project area includes a major predicted linkage zone from the Greater Yellowstone Ecosystem (GYE) population to the Bitterroot Recovery Area and to the Northern Continental Divide Ecosystem to the North (Figure 9). In fact, grizzly bear biologists have found that “Pathways connecting the NCDE and BE were well distributed within the Reservation Divide, Rattlesnake, Garnet, Bitterroot, and Sapphire Mountains, but were relatively sparse in the Missoula and Bitterroot Valleys” (Sells et al 2023). To be clear, the project activities would occur within areas of high connectivity value (Figure 9). The courts have found that connectivity of the GYE population to other populations is necessary for recovery of the grizzly bear under the Endangered Species Act Crow Indian Tribe v. United States of America, No. 18-36079 (9th Circuit, 2020).

[continued on next page]

[76] Bader, M. and Sieracki, P. (2022) Proposed Grizzly Bear Management Units on the Lolo, Bitterroot and Select Portions of the Beaverhead-Deerlodge National Forests, Montana, USA. Exhibit 15. See also Exhibit 16 (Map of the Proposed Grizzly Bear BMUs, South Half)

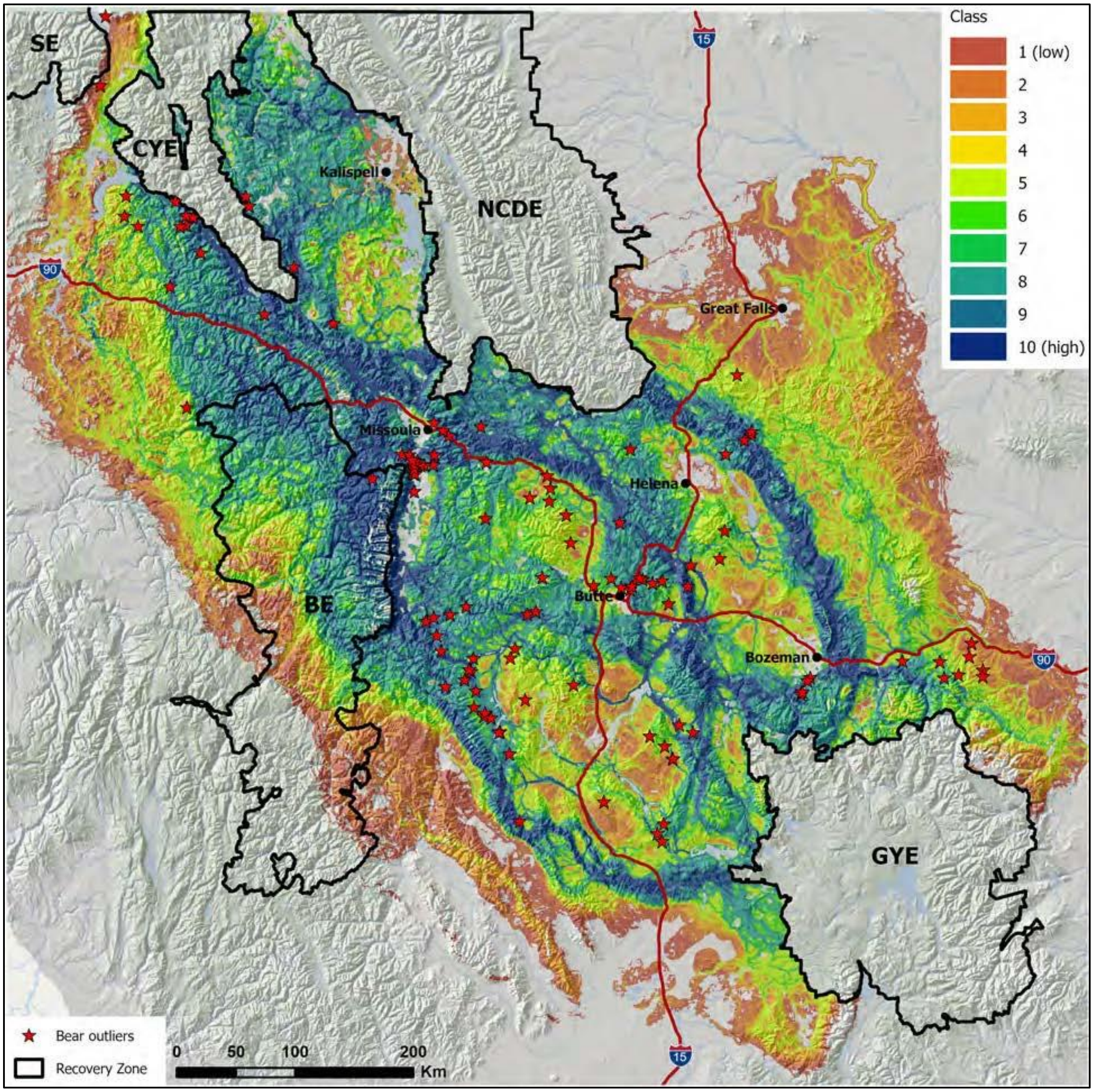

Figure 9 - "Predicted connectivity pathways between grizzly bear ecosystems in Western Montana." Sells et al., 2023.

"Prediction of female grizzly bear connectivity pathways in western Montana, summarized from 5 sets of directed (randomized shortest path) movement simulations using start and end nodes associated with routes of NCDE-CYE, NCDE-BE, NCDE-GYE, CYE-BE, and GYE-BE (Fig. 1). Class 1 = lowest relative predicted use, whereas class 10 = highest relative predicted use. Simulations were based on 46 individual iSSFs for NCDE females. These simulations employed the lowest ϑ value of 0.0001, which resulted in the highest correlation with independent grizzly bear outlier observations (Table 1). Results from other ϑ values shown in the Appendix." Id.

Recent studies authored by Inter-Agency Grizzly Bear Study Team scientists indicate that major portions of the Project area could function as a linkage area with the Greater Yellowstone Ecosystem- a key element of grizzly bear recovery across the Northern US Rockies. The van

Manen et al[77] and Peck et al[78] studies show that a part of the Project area is a key linkage area (Map 4). Peck et al made the following comments about the probability of grizzly bear use in these zones: "[t]herefore, with the exception of areas with low numbers of predicted passages (e.g., wide open valleys), we anticipate that sporadic bear sightings and possible interactions with humans may occur almost anywhere along the gradient of our model predictions." Connectivity is an essential element of both survival and recovery of ESA listed species. Specific, appropriate Project requirements that are clear and affirmative boundaries are needed to achieve the duty imposed by Section 7 of the ESA. Thus, connectivity for grizzly must be explained and supported by the best available science (36 CFR §219.3 and §219.4).

Moreover, the 2012 USFS Planning Rules require maintenance and restoration of wildlife connectivity, including that of grizzly bears (36 CFR Sec 219.8(a) and Sec 219.9(a)(1)). Therefore, independent of any conservation duty under the Endangered Species Act Section 7, the BNF has an obligation to plan the project and do the analysis necessary to support maintenance of the connectivity value mapped by government scientists and others.

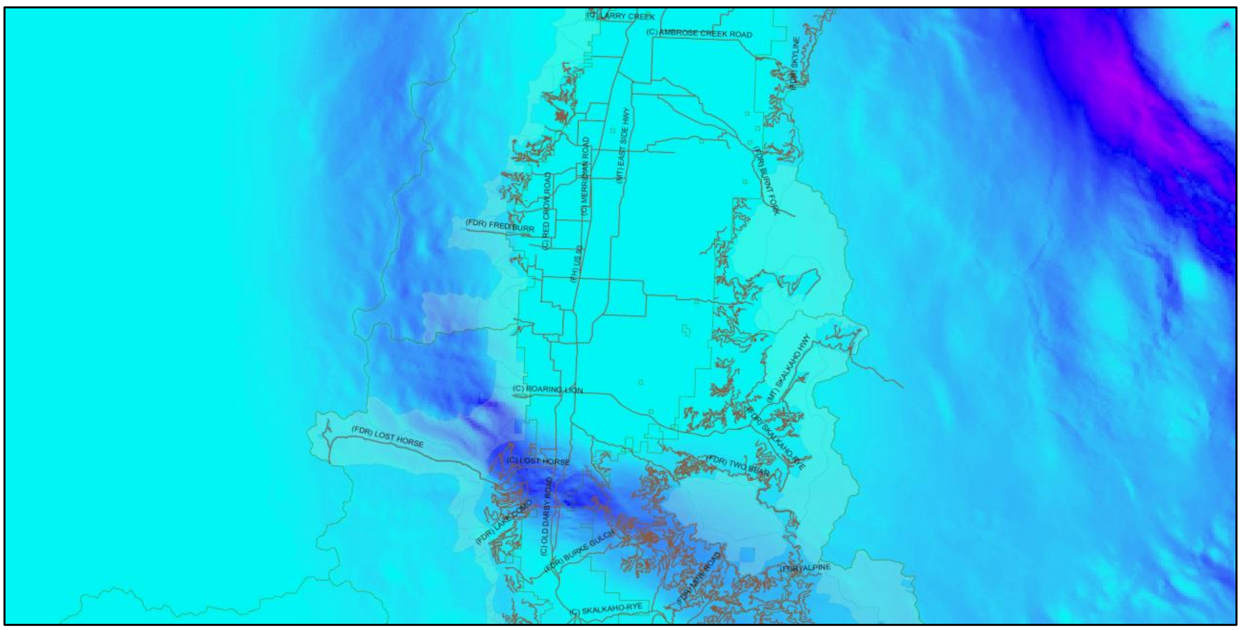

Figure 10 - Bitterroot Front Area and van Mannen et al (2017) Grizzly Bear Connectivity Areas. The BNF Ranger District Boundaries in the Bitterroot Front area that correspond to the Project boundary are mapped on grizzly connectivity areas with increasing connectivity probability as the color darkens from aquamarine to blue as modeled initially by van Mannen et al and subsequently reported by Peck et al as well. Data for the grizzly connectivity areas found at: https://www.sciencebase.gov/catalog/item/59149ee6e4b0e541a03e9a58

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[77] van Manen, F.T., Peck, C.P., Costello, C.M., Haroldson, M.A., Landenburger, L.A., Roberts, L.L., Bjornlie, D.D., and Mace, R.D., (2017) Potential movement paths for male grizzly bear (*Ursus arctos*) dispersal between the Northern Continental Divide and Greater Yellowstone Ecosystems, 2000-2015: U.S. Geological Survey data release, https://doi.org/10.5066/F72V2F2W

[78] Peck, CP, van Manen, FT, Costello, CM, Haroldson, MA, Landenburger, LA, Roberts, LL, Bjornlie, DD, Mace, RD (2017) Potential paths for male-mediated gene flow to and from an isolated grizzly bear population. Ecosphere 8(10): e01969. Doi.org/10.1002/ecs2.1929

Clearly, the project area includes areas crucial for grizzly bears successfully returning to the Bitterroot Ecosystem, which is necessary if the species is ever to recover sustainable populations within the Northern Rockies. Yet, the Forest Service fails to properly analyze the effects the proposed action will have on individual grizzly bears and overall recovery within the Bitterroot Ecosystem. In fact, the agency states:

> The project area is contained within the Bitterroot Grizzly Bear Experimental Population Area and is adjacent to the Bitterroot Grizzly Bear Recovery Area. Grizzly bears may be present as transient individuals. One transient male was confirmed within the recovery area, but not within the project area, in summer 2019. However, the latest USFWS grizzly bear "may-be-present" habitat modeling has some overlap with the project area. (Draft EA, at 110, Table 26.)

To be clear, if grizzly bears are ever to repopulate the Bitterroot Ecosystem, it will be because transient grizzly bears successfully establish new home ranges that includes portions of the project area. The Forest Service appears to dismiss the importance of such bears, characterizing them as transients, (the same derogatory term as Missoula's unhoused population). Whether or not grizzly bears are "residents" is irrelevant. Strong steps must be taken to remove the human impediments to natural recovery. Recovery of the grizzly requires its population to grow and expand its range, especially in anticipation of the impending risks associated with the climate crisis. We do not believe the grizzly bear must leap high, arbitrary, agency-established hurdles to receive adequate habitat protections.

The false and misleading depiction of grizzly bears in the project area as transients is part of the agency's reasoning that the proposed industrialization of the forest lands in the project area is "not likely to adversely affect" grizzly bears (Draft EA, Wildlife Report, at 9). In the report titled, "Grizzly Bear Promised Land," renown grizzly bear biologist Dr. David Mattson discussed habitat security on the Nez Perce-Clearwater National Forests (NPCNF) that includes portions of the Bitterroot Recovery Area, specifically how to calculate road densities and core security in proposed Bear Management Units (BMUs) for the NPCNF (*Id.* pp. 56-59; Exhibit 13). The same method can be applied to the proposed BMUs we provided the Forest Service in our scoping comments. Here we explained that the Forest Service must analyze impacts on suitable grizzly bear denning habitat based on the best available scientific information published by Bader and Sieracki, 2022. To facilitate this detailed analysis, we provided proposed Grizzly Bear Management Units for the Bitterroot National Forest, urging the Forest Service to utilize them in evaluating the proposed action and a reasonable range of alternatives. The agency failed to do so, and did not indicate it used any other BMU to analyze grizzly bear effects. Our proposed BMUs would enable the Forest Service to assess the existing baseline condition and changes under the proposed actions for grizzly bear habitat within the project area, including calculating baselines for roads, secure core, habitat productivity, denning habitat, and other resources.

The effects to grizzly bears from the proposed action include potential long-term disturbance or displacement due to human presence, road construction and use, motorized use and other mechanized equipment. The presence of these activities and the presence of roads could lead grizzly bears to avoid otherwise suitable habitat and areas of connectivity. Absent this level of detailed analysis, the Forest Service fails to take a hard look at the potential environmental consequences of its proposed action.

Here it is important to note that the agency cannot play shell games with its roads and overall motorized route densities. Specifically, the agency asserts that "Any new permanent roads constructed would only be open to administrative access, and temporary roads would be restored after activities have been completed. Therefore, the proposed action may affect, but is not likely to adversely affect, the grizzly bear." (Draft EA, Wildlife Report, at 9). Such conclusory statements are arbitrary and capricious for several reasons. First, the Forest Service fails to demonstrate that only open roads have the potential to adversely affect grizzly bears. In fact, the US Fish & Wildlife Service explained the following:

> Some grizzly bears avoided areas with a high total road density even when the roads were closed to public travel. If human-related disturbances such as high levels of road use continue in preferred habitats for extended periods of time, grizzly bear use of the area may be significantly limited, particularly use by female grizzly bears and/or their dependent offspring. (BIOLOGICAL OPINION on the Effects of the Lolo National Forest Plan on Grizzly Bears, 2023, at 42; Exhibit 17).

The Forest Service fails to consider the harmful effects closed roads have on grizzly bears and how they affect the ability of bears attempting to return to the Bitterroot Ecosystem. Further, the agency fails to consider the issue of unauthorized motorized use within the project area and how changes in the road system may facilitate more illegal use. The Forest Service also fails to distinguish between open and total motorized routes, and instead only considers open roads, even while failing to disclose the number of motorized trails in the project area. Finally, under the proposed action, the Forest Service will construct 1.98 miles of new permanent roads and 27 miles of temporary roads, but the agency fails to disclose or discuss how the new construction could affect areas of connectivity where the construction occurs. Rather, the Forest Service asserts that there will be a benefit to grizzly bears because there will be a total reduction in the miles of road because the number of so-called "undetermined roads" that will be decommissioned. (Draft EA, at 18, Table 7). Yet, "[t]he condition of these roads varies depending on their location on the landscape and the last management entry. Some are completely grown in, while others can be accessible with minimal work." (*Id.,* at 20).

The Forest Service cannot claim a net benefit to grizzly bear habitat while counting roads that are not part of the official road system and not being utilized for motorized access. Moreover, the Forest Service suggests there will be a reduction in road network by decommissioning 10.08 miles of system roads, but it is unclear how many will be physically removed: "Oftentimes, roads proposed for decommissioning have not been used in years and have already revegetated to a condition where they are not producing sediment runoff and are functionally closed to motorized use. In these cases, no physical treatment may be needed." *Id.* The on-the-ground effect is unclear at best, and the agency needs to disclose the roads that will be physically removed in order to count as a reduction in total motorized route densities. This is especially important given the agency proposes to add 8.54 miles of "undetermined" roads to the road system. Here, the Forest Service claims a reduction of 1.54 miles of system roads, even while disclosing that decommissioning will simply be abandoning system roads and changing their status in the INFRA database. Altogether, it is entirely likely the proposed action will not result in the net 25.48-mile decrease in the road network. It is also important to note there are already 373.53 miles of road in the project area (*Id.,* at 19, Table 8). Since the Forest Service did not calculate total and open motorized route densities by BMUs, it cannot reasonably assert there will be a benefit to grizzly bear recovery or habitat security as a result of the proposed road actions. Yet, this is precisely what the agency does in this statement:

> Open road densities would remain within recommended ranges, project activities would improve cover and forage ratios, and a project design would require that a food storage order would apply to contractors implementing this project. (Draft EA, Wildlife Report, at 9)

In fact, the Forest Service erroneously asserts that "Implementation of the proposed action and design features would minimize effects on grizzly bears." Yet, nowhere in the design features does the agency even mention grizzly bears (Appendix A – Bitterroot Front Environmental Assessment – Design Features and Activity Cards). The agency cannot reasonably assert food storage orders for contractors is an applicable design feature that will ensure grizzly bear habitat security.

In addition to the fatal flaws in the analysis we described above, the Forest Service seems to contradict itself. As we noted, the agency states "grizzly bears may be present as transient individuals…" (Draft EA, at 110, Table 26). Yet, the Forest Service also states "Grizzly bears are not known to occur in the area." (Draft EA, Wildlife Report, at 9). Certainly, there should be no dispute that grizzly bears are making their way back to the Bitterroot Ecosystem and it is likely they will need and utilize portions of the project area to do so. As such, the Forest Service must consider the trade-off between proposed "treatments" and habitat security for grizzlies, especially the hazards associated with road access as per Proctor et al (2017). Further, Schwartz et al (2010) noted that management for grizzly bears requires provisions for security areas and limits of road densities between security areas. Otherwise, grizzly bear mortality risks will be high as bears attempt to move across highly roaded landscapes to other security areas.

The Forest Service is aware of the best programmatic agency direction it has adopted to date, that established in Flathead Forest Plan Amendment 19. It established Open Motorized Route Density (OMRD)/Total Motorized Route Density (TMRD)/Security Core indices. These are based upon the scientific information concerning security from roads and road density requirements for grizzly bears as found in Mace and Manley, 1993 and Mace et al 1996. The Forest Service must establish similar security and motorized route density thresholds for BMUs across the project area if it is going to assert the proposed action will not likely adversely affect grizzly bears or grizzly bear recovery.

Finally, it is unclear if the Forest Service will properly consult with the USFWS under Section 7 of the Endangered Species Act. To be clear, it must. The Forest Service arbitrarily asserts "the proposed action may affect, but is not likely to adversely affect, the grizzly bear." (Draft EA, Wildlife Report, at 9). But then, the agency recognizes that portions of the project area fall within areas where grizzly bears may be present (Draft EA , at 110, Table 26). Further, the Forest Service references a biological assessment, but it did not make that publicly accessible, as such we are not afforded the opportunity to provide meaningful public input on the assessment.

XIV. The Forest Service Must Disclose and Analyze the Environmental Consequences of Roads in the Project Area

The best available science shows that roads cause significant adverse impacts to National Forest resources. WildEarth Guardians issued a 2020 report (Exhibit 5) that provides a scientific literature review—including the Forest Service's General Technical Report synthesizing the scientific information on forest roads (Gucinski 2001)—on a wide range of road-related impacts to ecosystem processes and integrity on National Forest lands. Erosion, compaction, and other alterations in forest geomorphology and hydrology associated with roads seriously impair water quality and aquatic species viability. Roads disturb and fragment wildlife habitat, altering species distribution, interfering with critical life functions such as feeding, breeding, and nesting, and resulting in loss of biodiversity. Roads facilitate increased human intrusion into sensitive areas, resulting in poaching of rare plants and animals, human-ignited wildfires, introduction of exotic species, and damage to archaeological resources. Here, the Forest Service must consider how the proposed actions may cause direct, indirect, and further exacerbate cumulative impacts within the planning area as it relates to road maintenance, reconstruction, and use, particularly in regard to unauthorized and closed roads.

Our scoping comments urged the Forest Service to disclose the status of road segments in subsequent environmental analysis, along with the current environmental consequences from under-maintained or abandoned roads. In addition, we asked the Agency to disclose how many "road prisms" are in fact unauthorized roads such as remnants of temporary roads, user-created roads, or even untreated decommissioned roads. The Forest Service must also disclose the road management objectives for each system road within the Project area. Such disclosures are necessary to provide a baseline for proper analysis, and to determine the potential environmental consequences of future road construction and road use. Further, we cautioned against relying on BMPs or design features as a rationale for not conducting the hard-look analysis NEPA requires, or for arbitrarily asserting that potential environmental impacts are not significant.

Overall, the Forest Service failed to respond to these comments or provide the requisite analysis NEPA requires. While the Forest Service did provide an updated project specific travel analysis, the agency still failed to provide the requisite analysis. For example, the agency disclosed there are 478.3 miles of system and non-system roads in the project area with a total road density of 2.14 mi/mi^2 (PF-TRANSPORTATION-002 at 4, Table 1). Yet, the road density was "[c]alculated using the project area of 225 square miles." The agency failed to disclose the road densities within specific wildlife habitats, such as in suitable grizzly bear habitat or grizzly bear areas of connectivity or specific grizzly bear management units. Similarly, the agency failed to determine road densities within summer elk habitat or elk herd units. Further, the Forest Service only considered road actions within 100 ft of a stream when analyzing the potential for sedimentation and the potential effects on bull trout, along with other fish species. *Id.* at 4.

Yet, the agency explains that "RHCAs would be established with buffers ranging from 100 feet on intermittent streams (the narrowest), to 300 feet on fish-bearing streams (the widest)." *Id.* at 21. It would reason that calculating road and motorized trail densities within 300 ft of fish-bearing streams is necessary to estimate the potential for sedimentation and potential impacts to aquatic species. This would be in line with the buffers required under the Inland Native Fish Strategy (INFISH). In fact, the Forest Service lists the INFISH standards and uses simple "Yes" or "No" responses as a demonstration of compliance with them, but the agency fails to provide the requisite analysis to support these determinations (Draft EA, Appendix F). Rather, the Forest Service only provides a table of risks and benefits in the project's travel analysis report (PF-Transportation-02). This report fails to demonstrate consistency with the INFISH standards and fails to take a hard look at the potential environmental impacts required under NEPA. For example, standard RF-5 directs the agency to "[p]rovide and maintain fish passage at all road crossings of existing and potential fish-bearing streams." (Draft EA, Appendix F at 20). The agency then asserts that this standard is not applicable: "No culvert replacements on live streams are planned for this project." There is a fundamental disconnect in this assertion as the standard requires the agency to ensure there is sufficient fish passages, but the analysis fails to disclose the status of those crossings for existing and potential fish-bearing streams. If fish passages are blocked, then a culvert replacement would be necessary absent another action to provide for fish passage. Further, the agency's response conflicts with the another section that reads "Yes, the project proposed replacement of several culverts that are fish passage barriers." *Id.* at 16. Precisely how many fish passage barriers exist in the project area and how many would the proposed action replace? The analysis fails to disclose this information even though in another section the agency states "Yes, the project included an analysis that considered the current condition of each road and its potential effects on resources, including aquatics." *Id.* at 19. We failed to find such an analysis. In fact, the most detailed information we found was in the project's travel analysis report, but even here the risk-benefit methods used to assess water risks failed to meet the agency's requirements under NEPA, and thus demonstrate compliance with the Forest Plan standards. Specifically, the agency states,

> Resource specialists on the interdisciplinary team used the table to rank road segments as high, medium, or low risk or benefit. A risk-benefit key above the table in Attachment A defines high, medium, and low in the context of each resource. (PF-Transportation-002 at 6)

To be clear, the specialists used the table to display each road's rankings, but the actual methods are absent. Rather, the table simply provides a key with the following:

> Important to improve or close for watershed (water and soils):
> H = Contributing area paralleling stream, known sediment source, high road density, fire severity, high risk sediment production.
> M = Contributing area at stream crossings, known sediment source, high rd density, moderate risk of sediment production.
> L = Low risk of sediment reaching streams (PF-Transportation-002)

The Forest Service failed to provide the exact methods used to assign these rankings. Further, it failed to explain why stream crossings were only considered for moderate risks. In fact, it seems "contributing" is in reference to potential sedimentation and that blocked fish passages is not a risk factor at all. The omission precludes the agency from asserting it is in compliance with the RF-5 standard. Further, standard RF-2(c) requires "[i]nitiating development and implementation of a road management plan or a transportation management plan." *Id.* at 19. Such a plan must address a number of items, including "[i]mplementation and effectiveness monitoring plans for road stability, drainage, and erosion control." *Id.* The Forest Service failed to provide such plans. Rather, the agency states: "Yes, the project included an analysis that considered the current condition of each road and its potential effects on resources, including aquatics." (Draft EA, Appendix F at 19). Providing an analysis is not the same as providing an implementation and effectiveness monitoring plan.

In sum, the Forest Service has failed to provide sufficient analysis to meet its requirements under NEPA or demonstrate compliance with Forest Plan standards.

XV. Consider the Role of Mycorrhizal Fungi in Maintaining Ecological Integrity

Study after study has revealed that soil biota, particularly fungi that form symbioses with plant roots (mycorrhizae), provide a suite of ecosystem services that support the integrity and resiliency of natural and human communities (Markovchick et al 2023), especially forests. Mycorrhizae are known to reduce erosion and nutrient loss (e.g., Burri et al 2013; Mardhiah et al. 2016), increase plant water use efficiency and water retention and cooling capacity in the landscape (Querejeta et al 2006; Gehring et al 2017; Wu & Xia 2005), store carbon in the ground (e.g., Orwin et al 2011; Nautiyal et al 2019), help plants adapt changes in climate (Gehring et al 2017; Patterson et al 2019), and resist pests and pathogens (Reddy et al 2006; Rinaudo et al 2010).

Many reports suggest that beneficial native fungi, including native mycorrhizae are rare and frequently in decline. The Survey and Manage Standards and Guidelines of the Northwest Forest Plan found that 55% of the 234 fungal taxa in the program were found at fewer than 20 locations, and 42% were found at 10 or fewer sites (Molina 2008). For comparison, the Eastern prairie fringed orchid (*Platanthera leucophaea*) is extant in 59 populations and listed as threatened (USFWS 2019), while its relative, the chaparral rein orchid (*Platanthera cooperi*) is found at 162 locations and is considered vulnerable (The Calflora Database 2022).

The decline of mycorrhizal fungi can be more difficult to assess because this category includes fungi that do not form large fruiting bodies above ground, such as with Arbuscular mycorrhizal fungi (AMF). However, many studies report declines in mycorrhizal fungi due to various causes including land use change, invasive species, pollution deposition, and herbicide use (e.g., Meinhardt & Gehring 2012; Swaty et al 2016; Lilleskov et al 2019). Global warming also appears to be threatening the type of mycorrhizal fungi known to best support carbon sequestration called ectomycorrhizal fungi (EMF)(Baird & Pope 2021).

In some cases, the dangers facing beneficial fungi mirror those for other species, and the same conservation strategies could benefit fungi (Minter 2011). For example, Clemmensen et al (2013) found that habitat fragmentation, a common threat to biodiversity, is also a concern for mycorrhizal fungi and conservation mycology. Thus, conservation programs targeting the mitigation of fragmentation could benefit both charismatic taxa and lesser-known taxa like mycorrhizal fungi. Unfortunately, Cameron et al (2019) documented geographic mismatches between terrestrial aboveground and soil (including mycorrhizal) biodiversity, finding that these mismatches cover 27% of the earth's terrestrial surface. So, efforts to protect areas of aboveground biodiversity may not sufficiently reduce threats to soil biodiversity (Cameron et al 2019).

Even within areas that are protected, disturbances such as logging and thinning (Wiensczyk et al 2002), the treatment of invasive vegetation with pesticide (Helander et al 2018), or self-reinforcing soil legacies left after invasion by exotic vegetation (e.g., Meinhardt & Gehring 2012), may quietly continue to reduce beneficial fungi. These impacts must be recognized and specifically addressed (Davoodian 2015; May et al 2018; Willis 2018; Markovchick et al 2023). These effects are not short-term, and ripple throughout the ecosystem, as evidenced by study after study that shows the need for and effectiveness of restoring diverse native mycorrhizal communities after various kinds of disturbance. For example, Pankova et al (2018) found that a single fungicide application left mycorrhizal inoculum and plant outcomes far from reference levels even after five years.

While much of the science demonstrating the importance of mycorrhizal interactions is recent, the concepts are not new. For example, the Forest Service's own scientists (Harvey et al 1994) invoked the relationship between chemical properties and biological properties: "Productivity of forest and rangeland soils is based on a combination of diverse physical, chemical and biological properties." Due to its biodiversity, soil, far from being an inert, non-biological substrate, has been called the "poor man's tropical rainforest" (Giller 1996). The soil microbial world is known to be a foundational driver determining the habitat type, health, resiliency, and ecosystem services of natural areas (e.g., Singh & Gupta 2018; Cameron 2010; Wubs et al. 2016; Peay et al. 2016). Over 1,000 scientists and 70 institutions have urged agencies to recognize the broad relevance of the microbial world to sustaining healthy ecosystems, life on earth, and protect and harness this utility in responding to global warming (Cavicchioli et al 2019). Yet, the USFS continues to ignore microbial communities when considering the tools available to support and enhance forest resilience, and when considering the impacts of their actions.

A. Mycorrhizal Ecosystem Services

Forest Service Ecosystem Services Policy & Direction

In 2005, the United Nations issued a report titled, "The Millennium Ecosystem Assessment" that significantly advanced the concepts and definitions of ecosystem services. The report identified four main categories:

1. Provisioning Services such as food, clean water, fuel, timber, and other goods;
2. Regulating Services such as climate, water, and disease regulation as well as pollination;
3. Supporting Services such as soil formation and nutrient cycling; and

4. Cultural Services such as educational, aesthetic, and cultural heritage values, recreation, and tourism.

Importantly, the Forest Service adopted these categories and definitions in its 2012 National Forest System Land Management Planning Rule. (36 C.F.R. § 219.10, § 219.19)

(a) Integrated resource management for multiple use. The plan must include plan components, including standards or guidelines, for integrated resource management to provide for ecosystem services and multiple uses in the plan area. …

- Ecosystem services. Benefits people obtain from ecosystems, including:
    - Provisioning services, such as clean air and fresh water, energy, fuel, for- age, fiber, and minerals;
    - Regulating services, such as long-term storage of carbon; climate regulation; water filtration, purification, and storage; soil stabilization; flood control; and disease regulation;
    - Supporting services, such as pollination, seed dispersal, soil formation, and nutrient cycling; and
    - Cultural services, such as educational, aesthetic, spiritual and cultural heritage values, recreational experiences, and tourism opportunities.
    - When defining soil function, the Forest Service internal directives provides the following:
- Soil biology. The presence of roots, fungi, and micro-organisms in the upper sections of the soil.
- Soil hydrology. The ability of the soil to absorb, store, and transmit water, both vertically and horizontally.
- Nutrient cycling. Soil stores, moderates the release of, and cycles nutrients and other elements.
- Carbon storage. The ability of the soil to store carbon.
- Soil stability and support. Soil has a porous structure to allow passage of air and water, withstand erosive forces, and provide a medium for plant roots. Soils also provide anchoring support for human structures and protect archeological treasures.
- Filtering and buffering. Soil acts as a filter to protect the quality of water, air, and other resources. Toxic compounds or excess nutrients can be degraded or otherwise made unavailable to plants and animals.

Forest Service Manual 2550.5 at 8-9. As detailed in the following section, ecosystem services provided by mycorrhizal fungi directly relate to those identified by the Forest Service as important soil functions, and the significant benefits provided by mycorrhizal fungi must be considered in detailed environmental analysis.

Scientific Background on Mycorrhizal Ecosystem Services

Ecosystem services are defined as ecological functions and processes that contribute to human wellbeing (Costanza et al 1997). Available data highlight the many and meaningful contributions of mycorrhizae to ecosystem services and integrity, ranging from drought resilience to pest control to climate stabilization (e.g., Christensen, 1989; Peay et al 2016).

In the following sections, we include the definitions for each category from Costanza et al (1997) and briefly review the fungal contributions. In Figure 11, we highlight many of these studies and provide examples of some of the magnitudes of effects seen due to mycorrhizae (see effect sizes and percent changes).

Figure 11 - Some examples of mycorrhizal ecosystem services and effects sizes.

Ecosystem Service Category	Study	Effect Type	% Change[2]	Effect Size[3]
Climate	Clemmensen et al 2013	carbon storage	50-70%	
Climate	Orwin et al 2011	carbon storage	14%	
Climate	Nautiyal et al 2019	carbon storage	82%	
Disturbance regulation	Auge et al 2015	drought adaptation	111%	0.75
Disturbance regulation	Auge et al 2015	drought adaptation	49%	0.4
Disturbance regulation	Auge et al 2015	drought adaptation	24%	0.2
Disturbance regulation	Miozzi et al 2020	reduction in disease severity	200%	
Disturbance regulation	Ruiz-Lozano & Azcón 1995	support plant growth	938%	2.34
Disturbance regulation	Ruiz-Lozano & Azcón 1995	support plant growth	3542%	3.60
Disturbance regulation	Stella et al 2017	remove soil toxins	19%	
Disturbance regulation	Stella et al 2017	remove soil toxins	41%	
Disturbance regulation	Stella et al 2017	remove soil toxins	51%	

Ecosystem Service Category	Study	Effect Type	% Change[2]	Effect Size[3]
Disturbance regulation	Wulandari et al 2016	increase plant health & growth at toxic site	125%	0.81
Disturbance regulation	Wulandari et al 2016	increase plant health & growth at toxic site	200%	1.10
Disturbance regulation (Restoration)	Koziol & Bever 2017	support plant survival	40%	
Disturbance regulation (Restoration)	Koziol & Bever 2017	support plant growth/health	300%	
Disturbance regulation (Restoration)	Koziol & Bever 2017	increased leaves/tillers	200%	
Disturbance regulation (Restoration)	Koziol & Bever 2017	increased species richness	55%	
Disturbance regulation (Restoration)	Koziol & Bever 2027	increased species diversity	70%	
Disturbance regulation (Restoration)	Maltz & Treseder 2015	support plant growth/health		0.63
Disturbance regulation (Restoration)	Neuenkamp et al 2019	boost species richness	30%	
Disturbance regulation (Restoration)	Neuenkamp et al 2020	boost restoration plant growth		1.70
Disturbance regulation (Restoration)	Rua et al 2016	support plant growth/health		0.25 to 1.25

Ecosystem Service Category	Study	Effect Type	% Change[2]	Effect Size[3]
Disturbance regulation, Pollination	Botham et al 2009	support plant growth/health	30%	
Disturbance regulation, Pollination	Botham et al 2009	support plant growth/health	23%	
Disturbance regulation, Water	Egerton-Warburton et al 2008	support water uptake/movement	up to 7 μmol/m/hr	
Disturbance regulation, Water	Egerton-Warburton et al 2008	support water uptake/movement	up to 6.5 μmol/m/hr	
Disturbance regulation, Water	Querejeta et al 2006	drought adaptation	111%	0.75
Erosion control	Burri et al 2013	reduce erosion & increase soil stability	74%	0.94
Erosion control	Graf and Frei 2013	reduce erosion & increase soil stability	533%	1.85
Erosion control	Mardhiah et al 2016	reduce erosion & increase soil stability	16%	
Erosion control	Rillig et al 2010	reduce erosion & increase soil stability	116%	0.77
Erosion control	Rillig et al 2010	reduce erosion & increase soil stability	18%	0.17
Erosion control	Zheng et al 2014	reduce erosion & increase soil stability	267%	1.30

Ecosystem Service Category	Study	Effect Type	% Change[2]	Effect Size[3]
Erosion control	Zheng et al 2014	reduce erosion & increase soil stability	13%	0.12
Erosion control, Water	Andrade et al 1998	reduce erosion & increase soil stability	14%	0.13
Genetic resources	Ina et al 2013	medical contributions by EMF	54%	0.43
Genetic resources	Ina et al 2013	medical contributions by EMF	39%	0.33
Genetic resources	Ina et al 2013	medical contributions by EMF	10%	
Genetic resources	Zeng et al 2013	medical contributions by AMF	84-270%	
Habitat & biodiversity	Stevens et al 2018	ecosystem abundance/diversity from AMF-contributed phosphorus	48%	
Habitat & biodiversity	Tracy & Markovchick 2020	habitat suitability for endangered bird	1.2 hectares	
Habitat & biodiversity	van der Heijden et al 2015	land plants that rely on native mycorrhizae	86%	
Nutrient cycling	Bonneville et al 2009	mineral weathering & supply	50-75%	1.61
Nutrient cycling	Quirk et al 2015	mineral weathering & supply	400%	1.61

Ecosystem Service Category	Study	Effect Type	% Change[2]	Effect Size[3]
Nutrient cycling	Taylor et al 2012	mineral weathering & supply	100%	0.69
Pest regulation	Abdalla & Abdel-Fattah 2000	pathogen reduction by AMF	80%	
Pest regulation	Babikova et al 2013	residence time of pest controls	333%	
Pest regulation	Babikova et al 2013	residence time of pests	186%	
Pest regulation	Karst et al 2015	tree growth after pests	700%	2.08
Pest regulation	Karst et al 2015	monoterpene production	500%	1.79
Pest regulation	Reddy et al 2006	AMF reduction of pathogen	70%	-1.20
Pest regulation	Reddy et al 2006	AMF reduction of pathogen	75%	-1.39
Pest regulation	Rinaudo et al 2010	AMF reduction of invasive vegetation	45%	-0.60
Pest regulation	Rinaudo et al 2010	AMF reduction of invasive vegetation	25%	-0.29
Pest regulation	Waller et al 2016	AMF reduction of invasive vegetation	29%	-0.34
Pollination	Aguilar-Chama and Guevara 2012	flower mass	100%	0.69
Pollination	Cahill et al 2008	pollinator visitation rates	193%	1.08

Ecosystem Service Category	Study	Effect Type	% Change[2]	Effect Size[3]
Pollination	Cahill et al 2008	type of pollinators	shifted pollinator species	
Pollination	Gange and Smith 2005	flower number	63%	0.49
Pollination	Gange and Smith 2005	flower nectar sugar content	55%	0.44
Pollination	Gange and Smith 2005	pollinator visitation rates	33%	0.29
Pollination	Gange and Smith 2005	pollinator visitation rates	200%	1.10
Pollination	Gange and Smith 2005	pollinator visitation rates	100%	0.69
Pollination	Gange and Smith 2005	nectar production	50%	0.41
Pollination	Gange and Smith 2005	nectar production	81%	0.60
Pollination	Lu and Koide 1994	days to flowering	23%	0.26
Pollination	Lu and Koide 1994	flowering duration	76%	0.57
Pollination	Lu and Koide 1994	fruits produced	200%	1.10
Pollination	Lu and Koide 1994	fruits produced	350%	1.50
Pollination	Lu and Koide 1994	fruits produced	20%	0.18
Pollination	Poulton et al 2001	flowers per plant	113%	0.75
Pollination	Poulton et al 2001	flowers per plant	90%	0.64
Pollination	Wolfe et al 2005	pollinator visitation rates	100%	0.69

Ecosystem Service Category	Study	Effect Type	% Change[2]	Effect Size[3]
Pollination	Wolfe et al 2005	seed set	167%	0.98
Food & Raw materials	Elliot et al 2020	small mammal diet	80%	
Food & Raw materials	Willis 2018	edible mushroom market	US$42B/yr	
Water	van der Heijden 2010	reduction in nutrient leaching due to AMF	60%	

Figure 11 Notes:

1) See Markovchick et al 2023 Supplement S1 for an expanded list of studies and more detailed explanation. Ecosystem service categories are abbreviated from Costanza et al 1997, see Markovchick et al 2023 for details.
2) Absolute value of percent change seen (always an improvement, but sometimes the improvement is an increase, and sometimes it is a decrease, for example in disease severity).
3) Effect size is either the statistic provided in the paper (there are various ways of calculating this and not all mean the same thing, see Sullivan and Feinn (2012) for a summary), or calculated as ln(mycorrhizal mean / control) from the statistics provided in the publication (if no effect size was calculated in the paper). This measure of effect size has the advantage of being directly related to percent change (Pustejovsky 2017), which can be calculated using the following equation: $(e^{\ln(R)} - 1) \times 100\%$. For example, an effect size of 0 indicates a 0% change, 0.5 indicates a 65% change, and 0.75 indicates a 110% change in the mean between treatment and control (Pustejovsky 2017).

Disturbance Regulation & Response

This category includes boosting the ability of ecosystems to respond to environmental fluctuations and dampening the influence of disturbances on the integrity of the ecosystem. Mycorrhizas assist in site clean-up, vegetation return, and protection of plants against toxins at polluted sites (e.g., Wulandari et al 2016). They reduce invasive vegetation (e.g., Rinaudo et al 2010). Mycorrhizal fungi enhance plant water status, survival, and productivity, including during and after droughts (e.g., Querejeta et al 2006; Kivlin et al 2013).

Erosion Control & Sediment Retention

This service category includes retaining soil within an ecosystem. Mycorrhizas increase the stability of soils through entangling soil particles in a “sticky string bag” to form soil aggregates. These aggregates are structured by hyphae and enhanced by stabilizing substances that hyphae secrete, such as glomalin (Rillig & Mummey 2006; Nautiyal et al 2019). As a result, mycorrhizas play critical roles in stabilizing soil and protecting it from surface water flows (Mardhiah et al 2016) and wind erosion (Burri et al 2013).

Food & Raw Materials

This category includes the portion of gross primary production consisting of food and raw materials. In addition to their use to promote crop production (Reddy et al 2006; Rinaudo et al 2010), 350 species of mushrooms (many of which are mycorrhizal fungi) are known to be used for food (Willis 2018). Many kinds of fungi, including some that are mycorrhizal, are used to create medicines, enzymes used in industry, and sustainable clothing, packaging, and construction materials (e.g., Bhat, 2000; Willis 2018).

Gas & Climate Regulation

This category includes regulating the chemical composition of the atmosphere, global temperature, and other climatic processes mediated by organisms. Clemmensen et al (2013) found that a majority of boreal forest soil-stored carbon is in roots and root-associated microorganisms (including mycorrhizal fungi). Orwin et al (2011) found that improved plant nutrient access due to mycorrhizal symbioses increased carbon sequestration. Fungal hyphae also produce exudates that promote the formation of soil aggregates, stabilizing soil and supporting continued carbon sequestration in the soil (e.g., Nautiyal et al 2019). Mycorrhizas compete with saprotrophs (decomposers) for soil nutrients, reducing decomposition (decomposition releases carbon) and increasing soil carbon storage (Read & Perez-Moreno 2003; Fernandez & Kennedy 2016).

Genetic Resources

This category includes unique biological materials and products, and their sources. An enormous variety of medical compounds are derived from or produced by fungi (see Markovchick et al Supplement S1). Mycorrhizal symbioses improve plant nutrition and enhance the active ingredients of medicinal plants (Zeng et al 2013). The effects of fungal genetics likely cascade through ecosystems. For example, ectomycorrhizal fungi are linked via plant genetics to insects, lichens, pathogens, endophytes, and soil decomposing fungi and bacteria (Lamit et al 2015). Given the role of fungi as foundational taxa that help to structure ecosystems (e.g., Tedersoo et al 2014), their genetic diversity may be crucial to conserving and supporting the genetic diversity at other community levels and stabilizing our ecosystems (e.g., Hazard et al 2017).

Habitat & Biodiversity

This category includes habitat for resident and migratory populations, a refuge for species and biodiversity. Nearly all plants depend on the presence of mycorrhizal fungi (van der Heijden et al 2015). Fungal contributions to plant nutrition and performance cascade through ecosystems, influencing habitat quality and resource quantity for most terrestrial species. One recent modeling effort suggests that the biomass of organisms in the Serengeti would be reduced by half without just the phosphorus provided by arbuscular mycorrhizal fungi (Stevens et al 2018). Another preliminary, smaller-scale model indicated that simply including appropriate mycorrhizal inoculation in restoration efforts could increase the useable habitat for an endangered bird from 0 to 1.2 hectares six years after restoration (Tracy & Markovchick 2020; Exhibit 19 [79])

Nutrient Cycling & Soil Formation

This service category includes the processes involved in forming, cycling, storing, and processing soil and nutrients. With complex enzymatic capabilities that allow them to access nutrients bound in recalcitrant forms, mycorrhizal fungi can forage for nutrients and mine them (e.g., Fernandez & Kennedy 2016). They may also indirectly facilitate decomposition by free-living soil microbes as they forage for nutrients in soil organic matter (e.g., Talbot et al 2008). Mycorrhizal fungi also structure soils and reduce nutrient losses (Rillig & Mummey 2006; Parihar et al 2019), permitting retention of nutrients necessary to build fertile soils (van der Heijden 2010).

Pest & Insect Regulation

This category includes regulation of populations, such as insect pests, invasive vegetation, and disease. Mycorrhizas and endophytes play key roles in this area. For example, Karst et al (2015) found that mycorrhizas increase monoterpene production, a key chemical defense against herbivory. Mycorrhizal fungi also reduce viral symptoms, disease and invasive vegetation (e.g., Miozzi et al 2020; Reddy et al 2006; Rinaudo et al 2010). Mycorrhizal fungi also appear to share pest warning signals through underground networks, permitting a coordinated call that attracts insects that control plant pests (e.g., attracting parasitoids that reduce aphids in Babikova et al 2013).

Pollination

This category is defined as moving and assisting floral reproduction. Our knowledge of fungal impacts on plant-pollinator interactions remains limited, and largely focused on arbuscular mycorrhizal fungi (Barber & Gorden 2015). However, these mycorrhizas can increase average flower number, flower mass, pollen tube length, seed production, nectar production and sugar content, pollinator visitation rates, and the number of fruits produced per plant (Aguilar-Chama and Guevara, 2012; Cahill et al 2008; Gange & Smith 2005; Lu & Koide 1994; Poulton et al 2001; Wolfe et al 2005). Mycorrhizas could also assist plant reproduction under climate change in two ways: 1) they can decrease time to initial flowering and increase flowering duration, reducing potential mismatches between flowering and pollinator activity (Barber & Gordon 2015; Lu & Koide 1994), and 2) they can encourage clonal growth, which could assist plant survival if pollination is reduced or impossible (Botham et al 2009).

Water Quality & Supply

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[79] Tracy J, Markovchick L (2020) Using mycorrhizal fungi in restoration to improve habitat suitability for an endangered bird. RiversEdge West Riparian Restoration Conference; February 4-6; Grand Junction, Colorado, United States

This combined service category includes the regulation, retention, and cleansing of water. Mycorrhizas enhance nutrient retention in vegetation, mycelium, and soils—decreasing leaching that negatively affects water quality (van der Heijden 2010). Mycorrhizal mycelia aggregate soil particles, improving soil porosity, and enhancing water infiltration and moisture retention (e.g., Augé et al 2001; Rillig & Mummey 2006). They mediate hydrological functioning by modulating surface soil-to-water attraction and repellency (e.g., Rillig et al 2010; Zheng et al 2014). Mycorrhizal hyphae infiltrate bedrock and tiny soil pores to access water and contribute to the soil-plant-atmospheric-continuum of water dynamics and nocturnal hydraulic lift of water to upper soil layers (Allen, 2009; Bornyasz et al 2005; Querejeta et al 2007).

B. A Special Note on Common mycorrhizal networks

Although the exact function of common mycorrhizal networks (the roots of separate plants linked by a network of fungal strands) is challenging to ascertain under field conditions, even critics recognize their existence in the field and demonstrated functions under controlled conditions (e.g., Karst et al 2023). For example, these underground networks are known to share resources between trees, shrubs, and other understory plants in the field, with some plants known as mycoheterotrophs being entirely dependent on this setup (e.g., Karst et al 2023; Selosse et al 2006). Under laboratory conditions, the use of autoradiography, dye tracers, and air gap treatments provide convincing evidence that resources are shared via the connections between plants provided by mycorrhizal fungi, including carbon (e.g., Finlay et al 1986; Brownlee et al 1983; Wu et al 2001), phosphorus (e.g., Finlay 1989), water (e.g., Warren et al 2008; Plamboeck et al 2007; Egerton-Warburton et al 2007), and defense signals (Babikova et al 2013). This ability to spread resources (Peay et al 2016) in the field would reduce risk and increase the inherent stability of ecosystems the way that financial portfolios reduce the risk of investing (Schindler et al 2015).

While trees communicate chemically all the time through the volatile organic chemicals they produce wafting through the air, research indicating communications and resources are shared through soil, root systems, and common mycorrhizal networks (e.g., Babikova et al 2013; Bingham & Simard 2011; Simard et al 2015) poses special new questions for the land and natural resources communities, due to the ability of land management actions to impact the soil community. If the ability of trees to communally send stronger insect control signals or share resources in times of need is impacted by current tree density reduction practices, as suggested by the scientific literature referenced herein, then the government would be liable for ignoring this large body of science, and the impact of its actions. Even the critics of the available current technologies acknowledge that given what we know about plant and fungal biology, these underground linkages, “should be common” (Karst et al 2023), and the indications of the science are clear - this issue is not constrained to one or a few environments or biomes.

C. To comply with NEPA, the Forest Service must consider soil function, mycorrhizal interactions and impacts to mycorrhizal assisted ecosystem services in a detailed environmental analysis

Many kinds of activities and disturbance can harm soil biota, including mycorrhizal fungi. Examples include the changes to microclimates and soil compaction caused by logging and thinning activities, the application of herbicides and pesticides, pollution deposition, and the presence of, and soil legacy left behind by, non-native vegetation (Wiensczyk et al 2002; Hartmann et al 2014; Meinhardt & Gehring 2012; Koziol & Bever 2017; Helander et al 2018). Appropriately protecting and restoring native mycorrhizal diversity and abundance offers a crucial tool to support forest resiliency. Conversely, when mycorrhizae are not protected from these effects, or are not appropriately restored, this can negatively impact forest regeneration and resiliency for many years. Unfortunately, soil biota like mycorrhizal fungi is frequently ignored in forest planning and projects, despite Forest Service policies requiring their protection (Markovchick et al 2023), and a regulatory and legal framework requiring their consideration and mitigation of impacts to them.

The Forest Service may not ignore topics if the information is uncertain or unknown. Where information is lacking or uncertain, the agency must make clear that the information is lacking, the relevance of the information to the evaluation of foreseeable significant adverse effects, summarize the existing science, and provide its own evaluation based on theoretical approaches. Thus, the Forest Service has a mandatory duty to analyze the direct, indirect, and cumulative impacts of the proposed action on soil function, mycorrhizal interactions and impacts to mycorrhizal related ecosystem services in a detailed environmental analysis.

D. Cumulative Effects

In addition to providing robust analysis that discloses the site-specific direct and indirect effects, the agency must also take a hard look at cumulative impacts. Toward this end, it is vital that the results of past monitoring be incorporated into Project analysis and planning. We request the following be disclosed.

- A list of all past projects (completed or ongoing) implemented in the analysis area.
- A list of the monitoring commitments made in all previous NEPA documents covering the analysis area, and the monitoring results.
- A description of any monitoring, specified in those past projects for the analysis area, which has yet to be gathered and/or reported.
- A summary of all monitoring of resources and conditions relevant to the proposal or analysis area as a part of the Forest Plan monitoring and evaluation effort.
- A cumulative effects analysis that includes the results from the monitoring required by the Forest Plan.
- A list of approved watershed and wildlife improvement actions from past NEPA decisions that remain incomplete due to a lack of funding.

Please provide an analysis of how well those past Forest Service projects met the goals, objectives, desired conditions, etc. stated in the corresponding NEPA documents, and how well the projects conformed to forest plan standards and guidelines. Such an analysis is critical for validating the agency's current proposed action under the Bitterroot Front Project. Without analyzing the accuracy and validity of the assumptions used in previous NEPA processes one has no way to judge the accuracy and validity of the current proposal. The predictions made in previous NEPA processes also must be disclosed and analyzed. If these were not accurate, and the agency is making similar decisions, then the process will lead to failure. For instance, if in previous processes the agency said they were going to do a certain monitoring plan or implement a certain type of management and these were never effectively implemented, it is important for the public and the decision maker to know. If there have been problems with Forest Service implementation in the past, it is not logical to assume that implementation will be proper this time. If prior logging, prescribed fire and other "forest health treatments" have not been monitored appropriately, the agency must demonstrate how it can ensure the beneficial results it asserts will in fact occur. The agency has an obligation to demonstrate consistency with all the applicable directions in the Forest Plan, and to provide robust cumulative effects analysis as NEPA requires.

XVI. The Current (1987) Forest Plan States That Beavers Will Be Introduced in the BNF

The East Fork Bitterroot Research Natural Area (RNA) appears to have been established by a Forest Plan (FP) amendment.

The FP indicates that RNA would "serve as a reference for ecological monitoring, especially the short- and long-term vegetation dynamics associated with a beaver-influenced river system."

Please provide all the results regarding beaver impact that have been gathered from the East Fork RNA.

A different section of the current FP states that "Beaver will be introduced into suitable riparian habitat." (FP at II-20)

Recent research indicates that the presence of beavers increases the landscape health, improves biodiversity, controls water flow, reduces downstream water temperatures, and provides increased breeding habitat for of native fish.[80] [81] [82] [83] [84]

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[80] Pershouse,D. (2020) Other Species are Essential Workers, Whose Economies Enfold Our Own - https://medium.com/the-regenerative-economy-collaborative/other-species-are-essential-workers-whose-economies-enfold-our-own-50deaa2f649f

[81] Goldfarb, B. (2020) How beavers became North America's best firefighter - https://www.nationalgeographic.com/animals/article/beavers-firefighters-wildfires-california-oregon

[82] Thomson environmental consultants (2020) The biodiversity benefits of beavers - https://www.thomsonec.com/news/biodiversity-benefits-beavers/

Given the FP directive and the substantial number of suitable areas in the proposed Project area and the recent research that confirms beavers benefit the environment in many ways, please explain why beaver introduction is not included as one of the goals for this proposed Project.

The Draft EA offers no explanation as to why there is no effort to introduce beavers into the many suitable riparian habitats in the area covered by this proposed Project. Given the purpose and need of this proposed Project is to "address the wildfire risk to the nearby communities and promote forest restoration using a wide range of tools," (Draft EA, at 4**), it is inconceivable that the introduction of beaver into all available and applicable sites within the Project area is not included as part of the Project.**

XVII. The Agency Ignores Cumulative Impacts from Multiple Projects

Given the gigantic size of this proposed Project and the large size and number of other (past, current, and foreseeable future) projects within the BNF and in close proximity, it is unacceptable that there is only cursory coverage of the Project's cumulative impact. In fact, after the Draft EA for this Project was released to the public, the Forest Service announced four additional projects which are intended to create miles of fuel breaks on the Bitterroot National Forest. Although these projects were in the planning stages and were well-known to those crafting the Draft EA for this Project, no mention was included for those four projects not the cumulative impact they would cause.

The Draft EA documentation includes plenty of verbiage but little meaningful informative information about the cumulative impact this proposed Project would have on the environment or its contribution to global warming.

CEQ adopted new regulations implementing NEPA in July 2020, 85 Fed. Reg. 43304 (July 16, 2020), and those regulations became effective for projects "begun" after September 14, 2020. However, those regulations have been challenged as illegal in numerous courts and are likely to be vacated. *See Environmental Justice Health Alliance v. CEQ*, Case 1:20-cv-06143 (S.D.N.Y. Aug. 6, 2020); *Wild Virginia v. CEQ*, Case 3:20-cv-00045-NKM (W.D. Va. July 29, 2020); *Alaska Community Action on Toxics v. CEQ*, Case 3:20-cv-05199-RS (N.D. Ca. July 29, 2020); *State of California v. Council on Environmental Quality*, Case No. 3:20-cv-06057 (N.D. Cal. Aug. 28, 2020)

On October 7, 2021, the Federal Register published CEQ's intent to restore regulatory provisions which were in effect for decades before being modified in 2020.

Please provide thorough and complete research that reveals the cumulative impact from this proposed Project and, given the recent (2021) Presidential Directive, justify why ignoring or ignoring that impact should be acceptable to the public.

[83] Parks Canada - Beavers: 5 ways beavers keep our ecosystems healthy - https://www.pc.gc.ca/en/pn-np/mb/riding/nature/animals/mammals/castors-beavers
[84] Davey, C. (2020) Flood and pollution reduction, biodiversity boost - The ecological benefits of beavers - https://earth.org/ecological-benefits-of-beavers/

XVIII. The Agency Asserts the Bitterroot Front Project Will Protect the Area from Natural Disturbance

The Agency's assumes, without confirmation, that the proposed Project will improve landscape resilience to natural disturbance.

First, insects. The Forest Service (FS) has insisted for years that when insects begin damaging a patch of forest they must be stopped because infestations increase the risk of more insect invasions and promote catastrophic wildfire. The FS's tools are always logging, thinning, and prescribed fire. Recent research contradicts FS claims that those tools work. A study by Meigs, G.W. et al (2016) indicates that not only do insect infestations not increase the likelihood of wildfire but that in the event of wildfire the severity is not increased.[85]

Other research by Hart, S.J. et al (2015) revealed that widespread and severe insect infestation restrict subsequent invasions.[86] This conclusion conflicts with current FS claims.

Later research by Six, D.L. et al (2018) suggests that Hart's finding of infestations restricting subsequent invasions may be the result of beetle choice and may result in a strong selection of trees for greater resistance to attack.[87]

The most recent research by Six, D.L. et al (2021) strongly suggests that thinning—the standard FS prescription for insects—has, at least for whitebark pine, "little-to-no effect on enhancing constitutive defense against the insect" and that, "… results also indicate thinning prescriptions aimed at increasing tree growth in whitebark pine should be applied with considerable caution."[88]

Contrary to repeated FS assertions that a mountain pine beetle outbreak increases wildfire risk, spatial overlay analysis shows no effect from outbreaks on subsequent area burned during years of extreme burning across the West. These results refute the assumption that increased bark beetle activity increased the area burned.[89] [90]

Weather, not insects, is what determines wildfire behavior.[91]

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[85] Meigs, G. W. et al (2016) Do insect outbreaks reduce the severity of subsequent forest fires - https://iopscience.iop.org/article/10.1088/1748-9326/11/4/045008/meta

[86] Hart, S.J. et al (2015) Negative feedbacks on bark beetle outbreaks: widespread and severe spruce beetle infestation restricts subsequent infestation. - https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0127975

[87] Six, D.L. et al (2018) Are Survivors Different? Genetic-Based Selection of Trees by Mountain Pine Beetle During a Climate Change-Driven Outbreak in a High-Elevation Pine Forest - https://www.frontiersin.org/articles/10.3389/fpls.2018.00993/full

[88] Six, D.L. et al (2021) Growth, Chemistry, and Genetic Profiles of Whitebark Pine Forests Affected by Climate-Driven Mountain Pine Beetle Outbreaks - https://www.frontiersin.org/articles/10.3389/ffgc.2021.671510/full

[89] Meigs, G. W. et al (2016) Ibid.

[90] Hart, S.J. et al (2014) Area burned in the western United States is unaffected by recent mountain pine beetle outbreaks - https://www.pnas.org/content/112/14/4375

[91] Hart, S.J. and Preston, D.L. (2020) Fire weather drives daily area burned and observations of fire behavior in mountain pine beetle affected landscapes - https://iopscience.iop.org/article/10.1088/1748-9326/ab7953

Using the most recent scientific research, please justify the declaration that insects can and must be controlled by management activities to improve forest resilience.

Second, disease. Mistletoe is the disease which seems to be the most troubling to the FS. Reduction or eradication is given as a goal in almost every Agency project on the BNF. Interestingly, a FS leaflet explains that "It is a pest ONLY (emphasis added) where it interferes with management objectives, such as timber production." [92]

That same pamphlet points out that dwarf mistletoe is important to wildlife.

> "Some rodents, such as porcupines and squirrels, feed on bark tissues at infection sites because of the accumulations of starch and nutrients at these locations. The large witches' brooms caused by the parasite are used for hiding, thermal cover, and nesting sites by grouse, hawks, owls, squirrels, porcupines, martens, and other wildlife. Northern spotted owls east of the Cascades show an attraction to Douglas-fir witches' brooms for nest sites."[93]

A study by Watson, D.M. and Herring, M. (2012) confirmed mistletoe as a keystone resource that when removed by management treatments, significantly reduces species richness of both birds and other wood-land dependent residents.[94]

The fact that the FS continually insists on reducing/eradicating dwarf mistletoe gives substance to the widely held belief that the focus of this Project (and most others) is timber production even when detrimental to certain wildlife species.

Please explain why mistletoe should be "controlled" when it provides vital habitat and the likelihood it is a keystone resource needed to ensure species richness.

Third, wildfire. In project after project, the FS claims the forest is primed for catastrophic wildfire. The oft-repeated assertion is made that the forest is too thick, overstocked with small trees, and contains an overabundance of ladder fuels. Those issues are blamed on long-term wildfire suppression by previous FS management actions that, ironically, must now be overcome using current FS management activities.

Those FS claims related to the history of wildfire rely heavily on research performed by Arno (1976) more than 45 years ago. That study focused on an extremely small portion of the Bitterroot Forest and findings extrapolated to the entire Bitterroot National Forest (BNF). The assumption was made that approximately 4% of the BNF, which should have experienced multiple fires over the past 129 years, even burned once. That postulation is problematic and statistically unsound. Arno's sample was too small to support such an hypothesis.[95]

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[92] Hadfield, J.S. (2000), Douglas Fir Dwarf Mistletoe: Forest Insect and Disease Leaflet https://www.fs.fed.us/foresthealth/docs/fidls/FIDL-54-DouglasFirDwarfMistletoe.pdf

[93] Hadfield, J.S. (2000) Ibid.

[94] Watson, D.M. and Herring, M. (2012) Mistletoe as a keystone resource - an experimental test - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3415901/

[95] Arno, S. F. (1976) The historical role of fire on the Bitterroot National Forest - https://forest.moscowfsl.wsu.edu/smp/solo/documents/RPs/Arno_RP-INT-187_1976.pdf

The fact is ignored that over the past 129 years ~4% of the BNF burned one or more times was mainly determined by climatic conditions that existed during that period. Claiming that a larger percentage of the BNF "should have burned one or more times" during that period is subjective and not based upon the body of research which reached a different conclusion.

As shown by numerable studies, the frequency and severity of wildfire is driven mostly by climate (high temperature, drought, and wind) and not by the availability of fuels.[96] [97]

It is not logical to presume that thinning will reduce the possibility of catastrophic wildfire.[98] Nor is the assertion by the Draft EA documents that the thinning proposed as part of this Project will produce a more desirable forest. That belief is outdated and not based upon the latest research.[99] [100] [101]

Please provide the most recent research that justifies how thinning, the removal of ladder fuels, and the use of prescribed fire reduces catastrophic wildfire and how the reduction of wildfire of any intensity is better for forest health and resilience than allowing nature to take its course.

XIX. Inventoried Roadless Areas (IRA)

The U.S. Forest Service adopted the Roadless Area Conservation Rule (Roadless Rule) in 2001 "to protect and conserve inventoried roadless areas on National Forest System lands." Forest Service, Special Areas, Roadless Area Conservation, Final Rule, 66 Fed. Reg. 3244 (Jan. 12, 2001). The rule observed:

> The Department of Agriculture is adopting this final rule to establish prohibitions on road construction, road reconstruction, and timber harvesting in inventoried roadless areas on National Forest System lands. <u>The intent of this final rule is to provide lasting protection for inventoried roadless areas within the National Forest System in the context of multiple-use management.</u> (emphasis added)
>
> This final rule prohibits road construction, reconstruction, and timber harvest in inventoried roadless areas because they have the greatest likelihood of altering and fragmenting landscapes, resulting in immediate, long-term loss of roadless area values and characteristics. (Federal Register, Vol. 66, No. 9, at 3244)

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[96] Hart, S.J. et al (2015) ibid.

[97] Abatzoglou, J.T., and A.P. Williams. 2016. Impact of anthropogenic climate change on wildfire across western US forests. PNAS https://www.pnas.org/content/113/42/11770

[98] Bradley, C.M., et al (2016) Does increased forest protection correspond to higher fire severity in frequent-fire forests of the western United States? https://esajournals.onlinelibrary.wiley.com/doi/full/10.1002/ecs2.1492

[99] Harris, N.L. (2016) Attribution of net carbon change by disturbance type across forest lands in conterminous US - https://cbmjournal.biomedcentral.com/track/pdf/10.1186/s13021-016-0066-5.pdf

[100] Buotte, P.C. et al (2019) Carbon sequestration and biodiversity co-benefits of preserving forests in the western United States - https://esajournals.onlinelibrary.wiley.com/doi/full/10.1002/eap.2039

[101] McNulty, S.G. et al (2014) The rise of the mediocre forest - why chronically stressed trees may better survive extreme episodic climate variability - https://www.srs.fs.usda.gov/pubs/ja/2014/ja_2014_mcnulty_001.pdf

> At the national level, Forest Service officials have the responsibility to consider the ''whole picture" regarding the management of the National Forest System, including inventoried roadless areas. Local land management planning efforts may not always recognize the national significance of inventoried roadless areas and the values they represent in an increasingly developed landscape. If management decisions for these areas were made on a case-by-case basis at a forest or regional level, inventoried roadless areas and their ecological characteristics and social values could be incrementally reduced through road construction and certain forms of timber harvest. Added together, the nation-wide results of these reductions could be a substantial loss of quality and quantity of roadless area values and characteristics over time. (Federal Register, Vol. 66, No. 9, at 3246)

Despite the institutional command that the Forest Service safeguard and conserve these areas, the Bitterroot Front Project proposed action would attempt to use the Roadless Rule's narrow exceptions to approve approximately 11,970 acres of logging within portions of the Lolo Creek and Selway-Bitterroot IRAs (Draft EA, at 53). The Forest Service does so without providing the site-specific analysis the agency required and expected when it adopted the Roadless Rule. Because the Forest Service's proposal and analysis of roadless area logging violates the Roadless Rule and NEPA, or at least, fails to demonstrate compliance with those laws, the Forest Service must correct these errors in any subsequently prepared NEPA document.

<u>The Forest Service's proposed action does not comply with the Roadless Rule.</u>

Given the clearly stated "intent" of the roadless rule and the limitations it imposes on roads, timber harvesting, and other activities, it is difficult to imagine how commercial harvesting in an Inventoried Roadless Area (IRA) can occur without running afoul of the Roadless Rule.

The Forest Service states that "[t]wo of the four circumstances applicable to the Bitterroot Front project that result in potential exceptions to the 2001 Roadless Rule are as follows:

The cutting, sale, or removal of generally small-diameter timber is needed for one of the following purposes and will maintain one or more of the roadless area characteristics as defined in 36 CFR 294.11:

- To maintain or restore the characteristics of the ecosystem composition and structure, such as to reduce the risk of uncharacteristic wildfire effects, within the range of variability that would be expected to occur under natural disturbance regimes of the current climate period.
- The cutting, sale, or removal of timber is incidental to the implementation of a management activity not otherwise prohibited by 36 CFR 294.11.

Existing roads that are overgrown with trees and shrubs be "bladed" to allow for the passage of logging traffic. That could easily be determined to be "road reconstruction" and must not be allowed. Commercial harvesting and other Project activities must be restricted so they do not run afoul of the Roadless Rule. (See the BNF IRA map [Figure 12] below for applicable restrictions.) Treatment in IRAs must not be detrimental to roadless characteristics to such an extent that the areas will no longer qualify as IRAs.

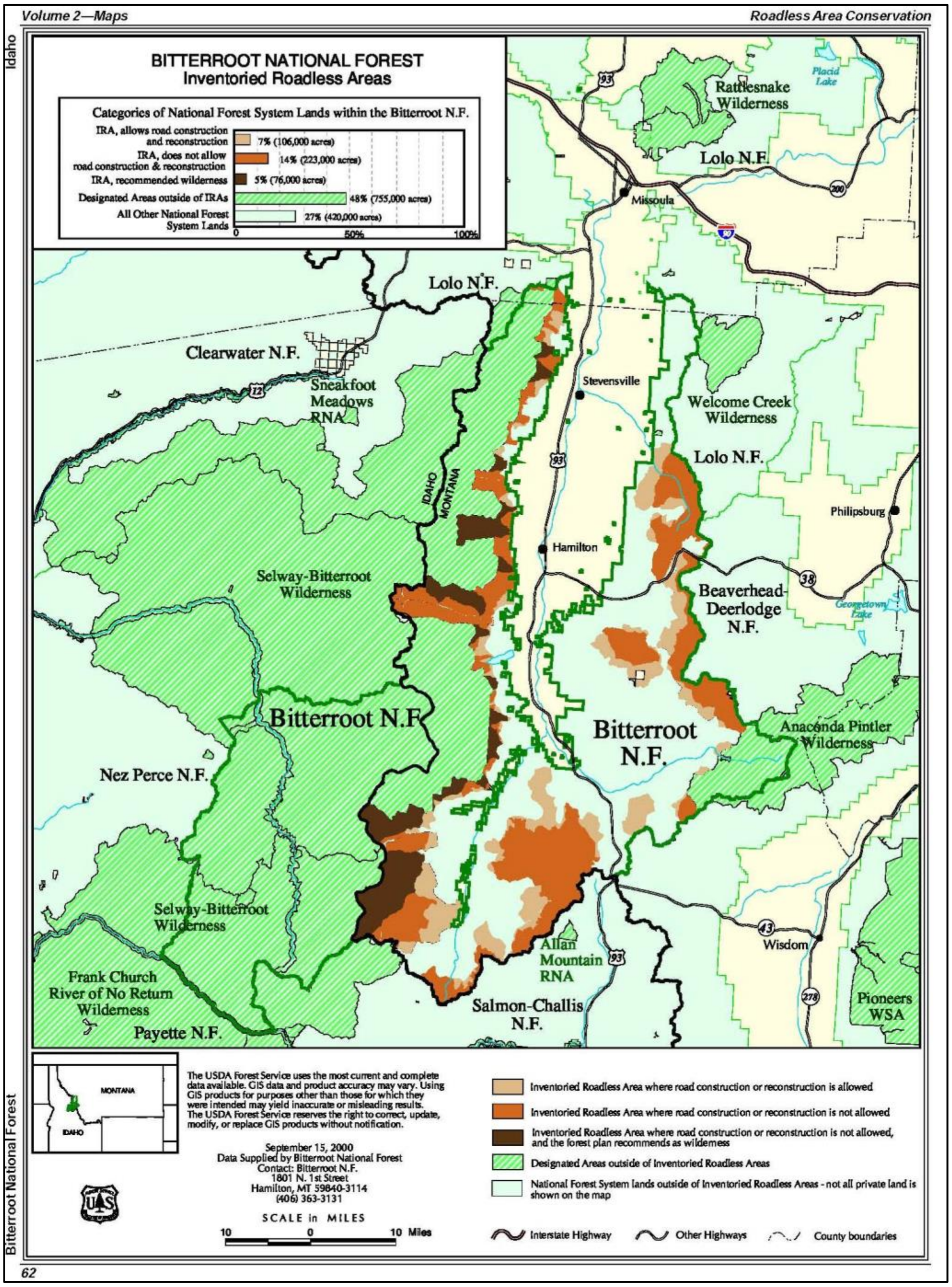

Figure 12 - Bitterroot National Forest Inventoried Roadless Areas

XX. Management Activities

There is no suggestion in the scoping or Draft EA documentations for the possibility that performing no management activities in the current forest and allowing natural forest succession to occur is likely to produce a more natural forest.[102] Whether by oversight or design, this proposed Project is sacrificing natural forest succession.

[102] Pearce, F. (2020) ibid.

A forest and its multiple ecosystems can never reach a natural equilibrium if not left alone. Any management activities will disrupt naturally occurring processes and certainly cause unwished-for and unintended consequences.[103] Far too many ecosystem components and their interconnectivity exist in a forest for anyone to gain a complete understanding. It is best to observe and study with the only intent being to gain knowledge. Interference with nature by humans has yet to produce positive results. Assuming that "this time will be different" is presumptuous, short sighted, and displays an amazingly high level of hubris.

Given the preponderance of recent, contradictory research, it is difficult to believe any forest treatment is necessary to prevent catastrophic wildfire or increase forest health by removing understory plants, opening the canopy, or removing certain tree species for the benefit of "preferred" trees. All suggested treatments are designed to "hopefully" produce a forest that represents an unproven, unrealistic historical condition, <u>a silviculturist-imagined, perfect-world forest</u> which yields an endless supply of readily marketable timber to industry.

Please justify, using the most recent scientific research, why any management activities are required in the area covered by this proposed Project.

As suggested in an April 2021 article, "A better handle on all processes that affect microbial biodiversity and their net balance is needed. Lack of insight into the dynamics of evolution of microbial biodiversity is arguably the single most profound and consequential unknown with regard to human knowledge of the biosphere." [104] Although focused on microbial biodiversity, the article points out that humans lack insight into the impact of their actions on the planet's ecosystems. That insight is certainly applicable to the management actions contained in the Draft EA documentation.

Please explain, given the Agency's inability to identify and understand all of the consequences resulting from this proposed Project, how BNF management reached the conclusion that this proposal should move forward.

Available from a USDA/FS website is an article, Wildfire and Salvage Logging (Beschta, R. L., 1995) which contains specific recommendations from a group of experts—mostly PhDs—for forest managers to follow.[105] The authors concluded that:

> "Land management practices in the interior Columbia and upper Missouri basins have profoundly impacted forest, grassland, and aquatic ecosystems. Watersheds and forests have been degraded (e.g., ecosystems fragmented, habitats simplified or lost, disturbance regimes altered). At every level of biological organization - within populations, within assemblages, within species, and across the landscape--the integrity of biological systems has been severely degraded. This degradation is best seen in the marked reduction in the biological diversity in the region.

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[103] For example, the FS now claims that a century of fire suppression has resulted in unanticipated and unintended overgrown forests.

[104] Thaler, D.S. (2021) Is global microbial biodiversity increasing, decreasing, or staying the same - https://www.frontiersin.org/articles/10.3389/fevo.2021.565649/full

[105] Beschta, R.L. et al (1995) Wildfire and Salvage Logging - https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsm91_050057.pdf

"The entire range of land management practices is implicated in this regionwide decline. Streamside development, logging, grazing, mining, fire suppression, removal of beaver and large predators, water withdrawals, introduction of exotic species, and chronic effects of roadbuilding have cumulatively altered landscapes to the point where local extirpation of sensitive species is widespread and likely to continue. Areas dominated by healthy populations of native species of vertebrates are exceptional. Many of these changes began long before the establishment of wilderness areas and other protections, and therefore, the majority of the region has been impacted."

The authors' findings and advice included:

- Ongoing human activity and the residual effect of past activity continue to threaten watershed ecosystem integrity.
- Fires are an inherent part of the disturbance and recovery patterns to which native species have adapted.
- There is no ecological need for immediate intervention on the post-fire landscape.
- Existing conditions should not be used as "baseline" or "desired" conditions upon which to base management objectives.
- Fire suppression throughout forest ecosystems should not automatically be a management goal of the highest priority. The overall management goal must be to preserve (and reestablish) the fire and other disturbance regimes that maintain ecological systems and processes, while protecting human life and property.
- Fire suppression activities should be conducted only when absolutely necessary and with utmost care for the long-term integrity of the ecosystem and the protection of natural recovery processes.
- The region's ecosystems, not just forests, are under severe strain.

In relation to post-fire principles, the authors advise:

- Allow natural recovery and recognize the temporal scales involved with ecosystem evolution. Human intervention should not be permitted unless and until it is determined that natural recovery processes are not occurring.
- Protect soils. No management activity should be undertaken which does not protect soil integrity.
- Preserve capabilities of species to naturally regenerate.
- Do not take actions which impede natural recovery of disturbed systems.
- Salvage logging should be prohibited in sensitive areas.
- On portions of the post-fire landscape determined to be suitable for salvage logging, limitations aimed at maintaining species and natural recovery processes should apply.
- Because of the wide range of chronic ecological effects associated with roadbuilding, the building of new roads in the burned landscape should be prohibited.
- Active reseeding and replanting should be conducted only under limited conditions.
- Structural post-fire restoration is generally to be discouraged.

That paper, which offered a clear, well-defined scientific framework of principles and practices, was published in 1995 and has been available to FS personnel for more than 25 years. Yet, as is readily apparent from this Project proposal, the Agency refuses to accept the guidance of its own experts. Forest Service management remains stuck in the distant past, pursuing the singular objective of extracting timber from forested, public lands. To continue chasing a goal which has caused the degradation of public lands and contributed to global warming is outrageous.

Please explain in detail why Agency management continues to ignore the best available science, much of it produced by FS specialists, as it proposes this Project which is likely to cause harm on many levels.

We noted that the following references were not included in scoping and asked that they be considered analysis of this Project.

> DiMarco et al (2019) Wilderness areas halve the extinction risk of terrestrial diversity; Law et al (2022) Creating Strategic Reserves to Protect Forest Carbon and Reduce Biodiversity Losses in the United States; and Miller et al (2022) Can landscape fuel treatments enhance both protection and resource management objectives.

We even offered to supply copies if you were unable to access these or any other references we cited in our scoping comments. We note that none of those references were requested nor are they included in the list of references for the Draft EA. Thus, we can only conclude that the Agency has predetermined the outcome for this Project and is uninterested in Public input which may diverge with that predestined outcome.

XXI. General Forest Plan Compliance

According to the Forest Plan, “Elk population status will be used as an indicator of commonly hunted ungulate species and the status of their habitat.” (FP at II-17) The Bitterroot Front documents do not analyze or mention elk population status which meet or are above Fish Wildlife and Parks (FWP) objectives throughout the Project area. It is clear the elk population has not been used to determine the need for habitat improvement as specified in the FP. The Forest Plan also states, “(t)he habitat need of sensitive species, as listed by the Regional Forester, will be considered in all project planning.” (FP at II-21) It cannot be discerned from the Draft EA whether sensitive species were carefully considered. There is no analysis that shows the reopening of roads, road construction and reconstruction, and mechanical procedures used to thin and burn will follow management goals to “(p)rovide habitat to support viable populations of native and desirable non-native wildlife and fish.” (FP at II-3). Endangered bull trout are present in the area as well as sensitive cutthroat trout.

Project analysis should demonstrate to the public that the Project and Project activities comply with Forest Plan standards and objectives in accordance with NFMA.

The Forest Service must clearly commit to following the 1987 forest plan criteria for old growth in this Project as you modify the forest structure. The definition of old growth in the FP is 15 trees greater than 20-inch dbh (6 inches in lodgepole), 75% of site potential canopy closure, multistoried or uneven age, 1.5 snags/acre greater than 6 dbh, .5 snags 20dbh/acre, 25 tons per acre of down material greater than 6dbh. The standard criteria for identifying old growth is large trees, generally 15 per acre greater than 20 inches dbh for species other than lodgepole pine and 6 inches for lodgepole pine, canopy closure at 75 percent of site potential, stand structure usually uneven-aged or multistoried; snags, generally 1.5 per acre greater than 6 inches dbh and .5 per acre greater than 20 inches; more than 25 tons per acre of down material greater than 6 inches diameter, heart rot and broken tops in large trees are common; and mosses and lichens are present.

Insufficient Draft EA information makes it unclear what, if any old growth trees/stands of any species will be impacted. To comply with the forest plan, current old growth status should be mapped using stand exams and quantitative data and overlaid with proposed action areas in high resolution and in a form that the public can access. Old growth should be mapped using both Forest Plan criteria as stated in Forest Plan standards and the proposed amended criteria, ground-truthed and compared in Project documentation. All methods and criteria used should be explained in detail.

The impact of removing or restructuring old growth stands of any tree species on nesting sites and home range habitat for Bald Eagle, Boreal Owl, Flammulated Owl, Great Grey Owl and Northern Goshawk must be included in the Project analysis. What is the potential impact on other wildlife species associated with old growth forests such as Northern Fisher, Pine Martin, Brown Creeper, Snowshoe Hare, and Moose?

XXII. Cost of the Project is not disclosed.

Please include a detailed accounting of Project costs in the Project analysis. What will be the costs of this large, multi-year Project and how will it be funded? How will the costs of repairing damage to county roads from log hauling and other Project-related transportation be funded?

XXIII. The Agencies Must Demonstrate Compliance with the Endangered Species Act.

Section 7 of the ESA imposes a substantive obligation on federal agencies to "insure that any action authorized, funded, or carried out by such agency . . . is not likely to jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modification of" habitat that has been designated as critical for the species. 16 U.S.C. § 1536(a)(2); *Nat'l Wildlife Fed'n v. Nat'l Marine Fisheries Serv*., 524 F.3d 917, 924 (9th Cir. 2008). The Forest Service must consult with the U.S. Fish and Wildlife Service under section 7 of the ESA as to the impacts of the project on species listed under the ESA and designated critical habitat, including grizzly bear, Canada lynx, bull trout and whitebark pine. While wolverines are a candidate species and therefore formal consultation is not required, the Forest Service must still conference with USFWS. The Forest Service must ensure the proposed road construction and timber harvest will not harm listed wildlife or degrade its critical habitat.

We encourage the Forest Service to be transparent about any consultation process and affirmatively post online all consultation documents, including any Biological Evaluations or

Assessments by the Forest Service, any letters seeking concurrence, and any responses or Biological Opinions from FWS. We request that the Forest Service do so at the time the Forest Service sends or receives the documents. Without these records, we (and the public) are unable to assess the agency's analysis of impacts to wildlife and habitat in light of FWS's expert opinion. Publicly posting this information will allow the public to view these critical documents, and other documents in the project record, without the need to submit a formal Freedom of Information Act request. Because the Forest Service has not made this information publicly available during the notice and comment period, we are unable to meaningfully comment on the Forest Service's (or Fish & Wildlife Service's) determinations or analysis.

XXIV. Conclusion

The primary purpose of this proposed Project "is to reduce the risk of a stand-replacing wildfire and return the forest to a healthy and resilient ecosystem, …" (Draft EA, at 1)

> The United States Forest Service Bitterroot National Forest Stevensville and Darby-Sula Ranger Districts propose conducting **forest management activities** in the Bitterroot Front project area to **address the wildfire risk** to the nearby communities and **promote forest restoration**. The forest management activities include a variety of actions that mostly fall within the categories of vegetation management, fuels reduction, and transportation system management. The project's primary purpose is to reduce the risk of a stand-replacing wildfire and return the forest to a healthy and resilient ecosystem, which includes high-frequency and low-intensity fire.

Despite its extremely large size, almost 144,000 acres, the proposed Project is intended to move forward using conditions-based analysis under an Environmental Analysis (EA).

The possible, even likely, negative impacts to the forest, its many interconnected ecosystems, and to the human environment are mostly ignored in the currently available documentation.

Emerging research appears to support a long-held belief that managed forests are less able to adapt to changing conditions than unmanaged forests. (Faison, E. K. et al, 2023, The importance of natural forest stewardship in adaptation)

Without proper scientific justification, which must be based on the most recent scientific research, this proposed Project should not move forward.

If the Agency insists on implementing a project on the proposed area, it must be done under an Environmental Impact Statement (EIS) including adequate documentation, site-specific information, and the support of recent scientific research.

Respectfully,

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On the following pages are a List of the Exhibits, a list of the Cited References, and the Exhibits.

Two CDs containing copies of all supplemental files, the Individual Exhibits, the References cited herein, and files from previous Bitterroot National Forest projects were delivered at 3:08 p.m. on September 15, 2023, to the Hamilton, MT Supervisor's Office of Matt Anderson

Exhibits

1. Powell, Hugh. Old Flames: The Tangled History of Forest Fires, Wildlife, and People. Living Bird, Summer 2019
2. Despite What the Logging Industry Says, Cutting Down Trees Isn't Stopping Catastrophic Wildfires. ProPublica, December 2020; Colorado's Troublesome megafire. Mountain Town News, November 2, 2020
3. Missoula Current. 2022. Part 1 & Part 2: Scientists, Missoula County shift wildfire focus to home ignition zone.; Missoulian. Aug. 2020. DAVE STROHMAIER and JACK COHEN Guest Column: Community destruction during extreme wildfires is a home ignition problem.
4. Coalition Comments Re: Request for CEQ-Issued Guidance and/or Regulatory Change Addressing Federal Land Management Agency Attempts to Avoid Site-Specific NEPA Analysis and Disclosure ("Condition-Based Management")
5. A Dilapidated Web of Roads - The USFS's Departure From a Sustainable Forest Road System. Jan 2021_WildEarth Guardians
6. Environmental Consequences of Forest Roads - WildEarth Guardians - March 2020
7. Potyondy, J.P and Geier, T. W. 2011. Watershed Condition Classification Technical Guide. USDA Forest Service FS-978
8. Juel, J. (2021) Management of Old Growth In The U.S. Northern Rocky Mountains Debasing the concept and subverting science to plunder national forests.
9. Mature and Old-Growth Forests: Definition, Identification, and Initial Inventory on Lands Managed by the Forest Service and Bureau of Land Management (MOG Report).
10. Article 38 of the UNFCCC COP26 Glasgow Climate Pact
11. B. Law et al., 2020 The Status of Science on Forest Carbon Management to Mitigate Climate Change.
12. Newspaper articles "Wandering grizzly leaves Bitterroot, returns to Idaho" and "Grizzly bear captured Saturday at golf course near Stevensville
13. Mattson, D. (2021) The Grizzly Bear Promised Land: Past, Present & Future of Grizzly Bears in the Bitterroot, Clearwater, Salmon & Selway Country. Livingston, MT
14. Pearce, F. (2020) Do Forests Grow Better With Our Help or Without
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16. Id. Map of Proposed Grizzly Bear BMUs, South Half.
17. BIOLOGICAL OPINION on the Effects of the Lolo National Forest Plan on Grizzly Bears, 2023
18. Intergovernmental Panel on Climate Change, AR6 WG1 (2021): Forster, Piers; Storelvmo, Trude (2021). "Chapter 7: The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity."
19. Tracy J, Markovchick L (2020) Using mycorrhizal fungi in restoration to improve habitat suitability for an endangered bird. RiversEdge West Riparian Restoration Conference; February 4-6; Grand Junction, Colorado, United States

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Old Flames: The Tangled History of Forest Fires, Wildlife, and People

Story By Hugh Powell; Photographs by Jeremy Roberts

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A yellow plastic sign stapled to a skinny black tree warned ENTERING BURN: STAY ON ROADS AND TRAILS. It was a classic June day in western Montana: 50 degrees and you judge how good the weather is by how hard the rain is beating against the windshield. I was in the passenger seat of a Jeep Grand Cherokee, and Richard Hutto, a professor emeritus at the University of Montana, was leading me into the heart of the Rice Ridge Fire burn area in the foothills of the Swan mountain range.

Nine months earlier, in September 2017, this burn was the nation’s top firefighting priority during the second-most-expensive fire season on record. Rice Ridge eventually consumed 160,000 acres of forest and cost the U.S. Forest Service $49 million to fight. Smoke levels in nearby Seeley Lake went off the charts (actually exceeding what the air quality sensors could measure). An evacuation order was issued, and the local high school had to move its classes to a nearby dude ranch.

“You couldn’t have asked for a better fire,” Hutto said, and as an ecologist he was serious. He drove on past the sign and into what he calls “nature’s best-kept secret,” a young burned forest.

In every direction bare trees reached up into the low gray sky, their naked branches pinwheeling off trunks as black as chainsaw oil. Yet on the ground, tiny starbursts of beargrass were already creeping out of fireproof stems, singed at the tips but otherwise brilliant green against the black soil. Off in the distance, a swath of burned trees swept down a valley and up the next slope, the red-needled edges forming huge paisleys on the green mountainside.

Severely burned forests can look barren, but beetles, birds, and other wildlife begin returning as soon as the flames go out. *Photo by Hugh Powell.*

Birds were everywhere. Western Tanagers chirruped and Western Wood-Pewees buzzed. A Mountain Bluebird the color of movie-star eyes gleamed from a jet-black spar of larch. A Hermit Thrush sang, and everywhere woodpeckers—Hairy, Downy, American Three-toed, Northern Flicker—rattled, cackled, and whinnied.

There was one other splash of color: blue flagging tape tied around the black trees. It was there to mark areas slated for salvage logging, which is the industry term for cutting dead wood in order to capitalize on its economic value.

Here on this muddy Forest Service road, two conflicting views of fire were meeting head-on. One view, currently prevailing among society at large, regards Rice Ridge as a costly and tragic “megafire,” a catastrophe that endangered homes and destroyed valuable forest that would take decades to recover. If you buy this view—of burned forest as ruined forest—then salvage logging seems only prudent, a way to temper the losses the fire inflicted.

Because of increased sunshine and available nutrients, wildflowers grow abundantly in burned forests for the first decade or more after a fire.

But many fire ecologists have long had an alternate perspective on large, severe fires like Rice Ridge: that they are inevitable and largely unstoppable, like a hurricane. Far from destroying forests, these fires touch off a frenzy of ecological activity—a tumult of new plants, mushrooms, insects, amphibians, birds, and mammals—that’s unlike anything that happens in the quiet shade of a green forest.

“This is a habitat that’s like no other habitat on Planet Earth,” Hutto says, and salvage logging is just about the worst thing that could be done to it. “If you take the [burned] trees out, all these special things go away.”

It was exploring this dichotomy—wildfire as disaster versus wildfire as essential natural process—that drew me back out West last June, back into the burned forests I’d fallen in love with 20 years ago. Back then I was one of Hutto’s graduate students, and I studied the Black-backed Woodpecker, a bird that is intimately adapted to burned forests. I spent three years covered in soot and camping among the jet-black trees, watching the forest come back to life.

Today the fire season is longer than it was during my grad school days. The long-term trends show fire seasons are nearly three months longer than they were in the 1970s. And 100,000-acre megafires are burning more frequently. Yet little has changed in how the U.S. government approaches fire, besides the price tag. From 1985 to 1995 the U.S. spent just over $4 billion fighting fires; from 2008 to 2018 it spent nearly $20 billion.

Meanwhile, more homes are being built in harm’s way, in the spaces where towns and forest intermingle and where fires will eventually burn as surely as hurricanes will strike the Gulf Coast. More than 12.7 million new homes went up in this “wildland-urban interface” just between 1990 and 2010. And with each new fire, journalists and politicians repeat the same three misconceptions—about fuel accumulation, the need to suppress fire, and the need to salvage log—all built on the mistaken impression that fire is unnatural.

“You’d be hard-pressed to find any patch of forest in the Northern Rockies that isn’t in one stage or another of succession following a severe fire event,” Hutto says. “If you want to use [fire] funding to save a house from burning down, fine. That’s a disaster. But a fire burning out in the middle of nowhere is not a disaster.”

Back at Rice Ridge, we wandered off the roadside in search of an American Three-toed Woodpecker that was tattooing the tippy-top of a charred Douglas-fir. This was a stand-replacement or crown fire—the terrifying kind that leaps into the canopy, sends up walls of flame, and rips across the landscape. It’s precisely this most powerful, least tameable kind of fire that Hutto says people need to make peace with.

It only takes one visit to a burned forest to realize it’s much more than a pile of ash at the bottom of a charcoal grill. A burned forest is more like a bank vault with the door blown wide open. Fire knocks out a tree’s chemical defenses but barely touches its nutritious interior. Far from being dried husks, fire-killed trees stay so insulated you can still squeeze water out of the inner bark a year after a fire.

University of Montana professor emeritus Richard Hutto has been studying the ecology of wildfires since the 1980s. *Photo by Jeremy Roberts/Conservation Media.*

The burn area of the 160,000-acre Rice Ridge Fire displays the classic mosaic pattern that's created by forest fires in the West. Patches of green, brown, and black add to the landscape's habitat diversity in the years following the fire. Photo by Jeremy Roberts/Conservation Media.

With the bank vault open, the bugs come rushing in. One group of beetles uses special heat-sensing organs to colonize a forest fire before it even cools off; another type does the same thing by following smoke plumes. These are some of the most stupendous beetles I've ever seen—some are glittering green-and-gold; some the color of cinders and highlighted with orange; others with black-and-white antennae three times as long as their bodies.

The beetles lay eggs, and their larvae tunnel through the tree eating everything in sight. Predatory beetles and parasitic wasps flood in to feed off the larvae, and the food web takes off from there.

Morel mushrooms come up in carpets, enough to fuel a ragtag foraging industry in burns that's worth up to $10 million annually. In some areas, boreal toads move in to breed in ponds warmed under the open canopy; and plants such as beargrass, fireweed, mariposa lilies, lupine, and geraniums spring up into the abundant sunshine.

This flush of food brings in woodpeckers, flycatchers, thrushes, swallows, and finches. To demonstrate, Hutto cocks an ear and gives a running commentary on what he hears:

Western Wood-Pewee: "It always amazes me. This is a cottonwood bottomland bird, and then it shows up in these fires, far away from where it 'ought' to be."

Tree Swallows: "Nothing, no other bird, likes it as severely burned as Tree Swallows. When it's toasty and completely black, they love it."

With abundant food, plentiful nest sites, and few predators, burned forests are an ideal habitat for Black-backed Woodpeckers. Black-backed Woodpeckers use burned forests for up to about eight years after a fire. *Photo by Jeremy Roberts/Conservation Media.*

Mountain Bluebirds: “If you had been standing here this time last year, I guarantee there would not have been a Mountain Bluebird here. They are all about burns. The higher the severity, the more of them you find.”

Nowadays Hutto can back up claims like these with piles of data from more than 16,000 monitoring sites throughout the Northern Rockies. But all his work began with a small paper published in *Conservation Biology*, on the famous 1988 Yellowstone fires, when 1.4 million acres in and out of the park burned in a single season.

His key realization was that birds don’t just make do with whatever’s left after a fire—they seek out burns for their unique mix of rich food supplies, abundant nest sites, and relative lack of predators. After visiting 34 burns in the first two years after the Yellowstone fires, he found 15 species that were nowhere more abundant in the Northern Rockies than in young burns. As if to prove his point, we saw 11 of these

Hutto says the Black-backed Woodpeckers are “As well camouflaged against burned trees as a ptarmigan is in the snow.” This male uses the fire-hardened snag to drum and proclaim his territory. *Photo by Jeremy Roberts/Conservation Media.*

Both the male and the female care for the chicks, which fledge after about 24 days. *Photo by Jeremy Roberts/Conservation Media.*

15 birds on our first day at Rice Ridge, including Olive-sided Flycatcher, Cassin's Finch, and Townsend's Solitaire.

Chief among these fire-adapted species is the Black-backed Woodpecker, which Hutto found in 78% of the burns he surveyed and almost nowhere else. In the Northern Rockies, he says, "they are as restricted to burns as a Belted Kingfisher is to rivers."

But Hutto cautions against focusing on a single species as a poster child for burn areas: "It's not about Black-backed Woodpeckers. They're an indicator. They're just whispering in my ear about the bigger issue, the need for natural fire in these mountains."

The larger point, he argued in a 2008 paper published in *Ecological Applications*, is that the abundance of life after a forest fire is no accident. If crown fires are an anomaly, a lapse of proper forest management, he asked, then how can there be so many examples of animals that over millennia have evolved ways to find and capitalize on them?

The United States got off on the wrong foot with fire back in 1910, during what is still the West's worst fire season on record. Over just two days in August, a complex of fires across Montana and Idaho burned 3 million acres and killed 78 firefighters.

In response, the U.S. Forest Service doubled down on firefighting, eventually enacting a policy goal of putting out all fires by 10 a.m. the day after they were spotted. In 1944 the Forest Service invented Smokey Bear, and Smokey began a campaign of pulling heartstrings, pointing fingers, and driving home a message that no fire is acceptable. It was well-intentioned, but it was disastrously successful in shaping the public's view of wildfire.

"We as a society only see [burned forest] as destroyed forest, because we've been conditioned to believe that forests should be green and they shouldn't change," says Tania Schoennagel, a fire scientist at the University of Colorado. "But that high-severity fire that burns like hell and is terrifying, that is business as usual for [many] forests."

Starting in the 1970s, studies of the comparatively gentle fires in Southwestern ponderosa pine softened Smokey's viewpoint somewhat, and a new conventional wisdom emerged: Understory burns are good, but severe fires are bad. Understory burns make forests healthy and safe by keeping fuels in check, or so the argument goes, while severe fires are disasters that happen only because a century of fire suppression has allowed fuel to build up.

“The problem is [the public has] over-learned that story,” Schoennagel says, “because it’s so tractable and appealing, and they now see that story everywhere.”

Those dry ponderosa pine forests turned out to be a special case, not a general rule. They’re so dry that barely enough fuel can grow in a year to allow a fire to spread. In almost every other Western forest type, from mixed conifer to lodgepole pine to spruce-fir, the climate is cooler and moister. Plenty of fuel grows each year, but it takes a major drought to dry it out enough to burn. Before climate change, this happened every 50 to 200 years or so, depending on the forest type.

In other words, what fire scientists call a forest’s “fuel load” is not the main cause of large, unstoppable fires; it’s climate factors such as temperature, humidity, and especially wind. But weather is ephemeral and invisible, while thick underbrush is easy to see and photograph. So in wider society, the conversations are still all about fuels. From President George W. Bush’s Healthy Forests Initiative of 2003 straight through to California governor Gavin Newsom’s emergency declaration in 2019, the fixation on reducing fuels through thinning and prescribed burning spans decades and political parties.

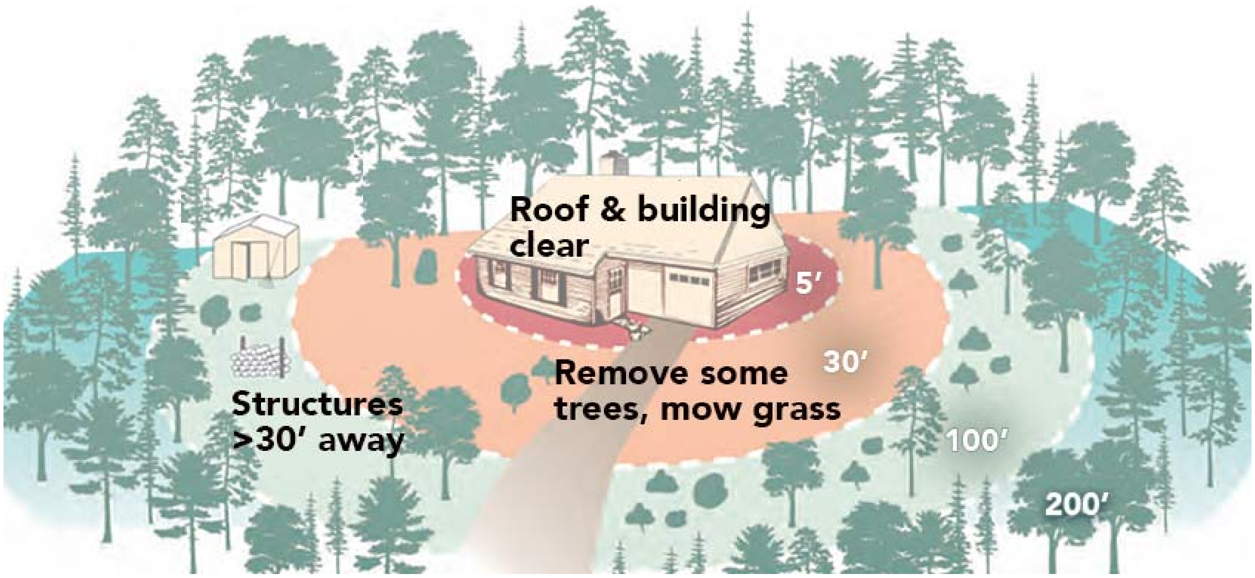
Large fires happen during periods of unusual drought and high wind. When those ingredients come together—as they have been doing increasingly with the effects of climate change—there’s almost always enough fuel to keep a fire going. In fact, because firefighters put out so many fires, it virtually guarantees that when fires do break out of control, it’s only when conditions are dry, windy, and primed for very dangerous, rapidly spreading fires—a phenomenon dubbed the “wildfire paradox” by three fire scientists in a 2014 paper published in *Proceedings of the National Academy of Sciences*.

“Lost is the legacy of smaller fires that likely burned outside extreme weather and fuel conditions and resulted in less severe impacts,” wrote Michael Dombeck, former chief of the U.S. Forest Service, in *Conservation Biology* in 2004, adding that “projects that reduce fuel loads but compromise the integrity of soil, water supplies, or watersheds will do more harm than good in the long run.”

While fire crews are extremely good at putting out small fires, at 1,000 acres or larger, all bets are off. Large fires cost $1 million per day to fight, and still they don’t go out until the wind changes or rain starts to fall, according to a report by the General Accounting Office. Worse, firefighters lose their lives in this uphill battle—an average of 17 deaths per year since 2000. And in light of the wildfire paradox, even fires they do control seem less like victories and more like postponements.

Of course, forest fires do pose a grave threat to people and property within the wildland-urban interface, giving fire managers plenty of incentive to throw everything they have at every fire. But long-term research by Jack Cohen, a researcher with the U.S. Forest Service's Fire Sciences Lab, suggests there are better ways to safeguard houses than taking the fight into the forest.

I tracked down a phone number for Cohen, who had practically vanished after retiring from the fire science lab. (He'd grown frustrated after many years of talking to reporters and policymakers while seeing more and more second homes built in flammable locales.) To my surprise, he returned my call.



Fire scientist Jack Cohen's research on the **Home Ignition Zone** laid the groundwork for safety recommendations for homeowners, like these from the Wisconsin Dept. of Natural Resources. The zone contains three regions: **5 feet:** Keep roof clear of leaves, needles, and other debris. Keep burnable materials from under and around all structures. Siding and decks should be constructed with fire-resistant material. **30 feet:** Remove all but scattered trees and keep grass mowed. **Over 30 feet:** Keep woodpiles and sheds 30 feet from structures. *Illustration from the Wisconsin DNR, used with permission.*

"Bottom line, home ignitions are determined by very, very local conditions," he said. Early in his career, he was puzzled to see houses survive near the edge of a fire, while homes a few blocks farther away burned to the ground. Homes that did burn down often were gone before the fire front even came close to the building. He realized, and subsequently proved in experiments, that walls of flame aren't what light homes on fire. It's firebrands—burning embers that get lofted on hot air and blown hundreds of yards downwind. These can lodge in a needle-choked gutter or a corner of a wooden deck and smolder for 20 minutes, like a curl of newspaper under a pile of charcoal.

Cohen's research led to the idea of safeguarding the "home ignition zone." He discovered that a set of fairly simple actions in a 100-foot-radius around a home can greatly improve its chance of surviving a forest fire. Homeowners can't stop firebrands from landing on their houses, but they can move their woodpile, clear brush within 60 feet, sweep up fallen pine needles, clean gutters, and make sure they have a nonflammable roof and deck. In a 2000 study, Cohen found that actions such as these would result in a 90% chance of a house remaining unburned during a forest fire.

The work is “pretty much a once a year kind of thing,” Cohen says—and much more manageable than trying to keep the entire surrounding forest from burning. In 2014, he and two colleagues advocated for this kind of shift in thinking.

“Wildfires are inevitable,” they wrote, in *Proceedings of the National Academy of Sciences,* “but the destruction of homes, ecosystems, and lives is not.”

Hutto was tooling through a section of the Rice Ridge burn known as Morrell Creek, driving with his knee while pinching and zooming a fire map on a tablet. We rounded a corner and entered a stand of larger trees with tan splotches running up the black trunks, where flakes of bark had been knocked aside to reveal fresh bark beneath.

Peppering the splotches were dozens of neat, round holes, each one patiently drilled by a woodpecker and leading precisely to the former hiding place of a beetle larva. I tried it myself on a larch, peeling back a section of bark, and found an inch-long jewel beetle larva, still wriggling, with shreds of half-digested bark visible in its guts.

Hutto says the Black-backed Woodpeckers are “As well camouflaged against burned trees as a ptarmigan is in the snow." This male uses the fire-hardened snag to drum and proclaim his territory. *Photo by Jeremy Roberts/Conservation Media.*

Both the male and the female care for the chicks, which fledge after about 24 days. *Photo by Jeremy Roberts/Conservation Media.*

Moments later came a scolding, mewling sound, as if a wren was mugging a cat. That's the Black-backed Woodpecker's giveaway call. A glossy, blue-black male flew in carrying a larva as long as his bill, and dipped his head into his nest hole.

These birds are handsome in a classic, black-will-never-go-out-of-style way. This one had a military bearing with his martial yellow crown, a nearly all-black face with a white slash on the cheek, and fine gray barring on the flanks. He flew off into the black forest and almost disappeared.

"As well camouflaged against burned trees as a ptarmigan is in the snow," as Hutto likes to say.

Over the next hour we watched as male and female took turns carrying larvae to their young. The nest was a classic of the Black-backed Woodpecker style: low—just above head height—in a small, fire-hardened larch. On the lower edge of the nest entrance, the male had chipped out a neat beveled doorstep, now smudged a soft ash-gray from woodpecker tummies squeezing in and out all day. Nesting in such hard wood helps the chicks stay safe from predators such as woodpeckers, jays, bears, and squirrels. (It's even been suggested that their unusual three-toed feet are an adaptation to help them deliver more powerful thwacks of the bill when excavating flame-tempered trees.)

This area was prime real estate. We found an additional two American Three-toed Woodpecker nests within a hundred yards, and watched a female Tree Swallow visit the Black-backed nest. Lacking any excavatory abilities of her own, the swallow was leaning inside to check whether the cavity was free for the taking.

Next to one of the three-toed nests was another blue-flagged tree marking the edge of a salvage-logging plot. Hutto gave half a chuckle.

"That's what I always say, you want a model of where Black-backed Woodpecker abundance is? Show me your model of where you want to salvage log," he said. "I bet it's not that different."

He paused to clarify: "I'm not against cutting trees. This is not a tree-hugger thing. But let's just be smart about where we do it."

Instead of salvage logging, Hutto wants the Forest Service to think about ecotourism, as they already do when they provide maps and permits to morel pickers after fires. "Why not give out maps of where to go see Black-backed Woodpeckers?" he says. "Where's the most amazing wildflower show you're ever going to see in your life, and it's going to be going on for the next 10 years? They ought to be taking out ads in every bird-watching magazine in the country."

Hutto relishes throwing suggestions out of left field like this, but he acknowledges that forest supervisors have a harder line to walk. “The Lolo [National Forest] is probably the most progressive district in the nation,” he said. “But as soon as a fire burns, those letters are going to start pouring in demanding that you do some logging.”

U.S. Forest Service biologist Victoria Saab stands in an Oregon forest that was salvage logged following the Canyon Creek Fire in 2015. Saab studies whether salvage logging and bird habitat can be compatible in fragile postfire ecosystems. *Photo by Hugh Powell.*

While Hutto approaches fire policy and salvage logging with intensely logical arguments made from an academic remove, scientists in the U.S. Forest Service—such as research wildlife biologist Victoria Saab—have to consider real-world situations.

“Most of the time when a fire happens, salvage logging is considered,” Saab says, “so let’s try to learn what we can. If I thought it was going to end, I wouldn’t have put this study together.”

To see Saab’s study, I had driven overnight from Montana to the high-desert town of John Day, Oregon, where the 2015 Canyon Creek megafire burned 110,000 acres and destroyed 43 homes, despite the efforts of some 900 firefighters. She’s been studying burned forests since 1994, when she became one of the first biologists to examine the effects of salvage logging on birds. Over the course of 11 years, working among 350,000 acres of burned forest in Idaho, she found some bird species did well in salvage logged plots—one of the highest nest densities ever recorded of Lewis's Woodpeckers, for instance. But Black-backed Woodpecker nests were rare in the logged areas, and more than five times more abundant in the intact plots.

Now, Saab is trying to refine that understanding: "We know Black-backed Woodpeckers will persist where you don't have any [salvage] logging," she says. "But can we have some logging and still have population persistence for Black-backed Woodpeckers?" (Her project is exploring similar questions for Lewis's and White-headed Woodpeckers.)

We were visiting one of the sites in her new study, where she's comparing three differing levels of logging against a control of no logging. Behind Saab loomed a minor mountain of logs that had been cut but never made it to the mill. A Common Nighthawk was buzzing in the sky, and a White-headed Woodpecker was bringing food to a youngster in a single snag left among the stumps.

These are the most fragile moments in fragile ecosystems, and to go in there with heavy machinery and remove logs is probably the most damaging thing you can do.~Tania Schoennagel

In separate discussions, Hutto, Saab, and Schoennagel had each stressed that salvage logging delivers no ecological benefits, just economic ones.

"These are the most fragile moments in fragile ecosystems, and to go in there with heavy machinery and remove logs is probably the most damaging thing you can do," Schoennagel said. "I can see why there might be an economic interest in salvage logging, but there's no argument that can be made that there's an ecological benefit."

"In the short term, it can create habitat for Lewis's that wouldn't be there till later, when trees start falling," Saab said. Fallen trees open up the airspace for these oddball woodpeckers, which do most of their foraging by catching insects in midair. "But eventually [in 10 to 30 years] those conditions would be created by the fire on its own."

Salvage logging doesn't improve the habitat, it just speeds up the disappearance of the burned forest.

Still, the U.S. Forest Service's motto is "Land of Many Uses," and one of the major uses is timber harvest. As long as burned forests are seen as lifeless areas, the monetary return of salvage logging will be an attractive option. In the first couple of years after a burn, salvage-logged timber is just as valuable as green timber, and the large trees can be very valuable. Because dead trees quickly degrade (the work of all those wood-boring beetles), environmental regulations are sometimes waived under emergency orders to speed up the logging process. And very large dead trees, which are far more valuable as wood than smaller trees, aren't always protected by the same regulations that cap the harvest of big live trees.

All told, salvage logging made up only about 11% of all the wood harvested on Forest Service land in the 2018 fiscal year. And all the logging on Forest Service land, burned or unburned, accounts for only about 10% of all the wood logged in the United States each year; the rest comes from private timber lands. If salvage logging is a drop in the bucket, Hutto had asked, back in Montana, then why do it at all?

"A burned forest isn't the first place you should cut, it's the last place," he said. "If it's about wood, let's look at the green forest. There's a billion acres of green forest that's not nearly as special as this forest right here."

Landscapes across the mountainous West are a patchwork of forest types—and in most cases, forest fire is the agent that creates those mosaics. *Section of the Rice Ridge fire, Montana, photo by Jeremy Roberts/Conservation Media.*

While the debates continue over how to handle postfire forests and whether to fight forest fires in the first place, climate change is upping the ante by drying out forests and making fire seasons longer.

“Ten years ago, scientists were very hedgey when talking about climate change,” Schoennagel told me. “Now it’s front and center.” In a 2017 *Proceedings of the National Academy of Sciences* paper, Schoennagel put this idea right into the title: “Adapt to More Wildfire in Western North American Forests as Climate Changes.”

The evolution in attitudes is apparent in the *Quadrennial Fire Review*, a joint publication of U.S. Forest Service Fire and Aviation Management and the Department of the Interior Office of Wildland Fire. The most recent one, published in 2015, went so far as to envision a change in philosophy “from war on fire to living with fire.”

The report even suggested, in very polite language, the possibility of adjusting Smokey Bear’s attitude. “Core messaging,” the report said, “would emphasize that fire is a natural, necessary, and productive occurrence.” (Back in 2000, I had briefly tried to promote a new sidekick for Smokey. I called him Smudgy the Black-backed Woodpecker, but he never caught on.)

Additionally, many Western communities have begun to encourage landowners to make their homes more fire resistant, using Cohen’s research as a jumping-off point. Two federal initiatives, FireWise and Fire Adapted Communities, help organize these public information campaigns and help homeowners, fire departments, and local authorities work together.

The goal is to get people to understand that they live next to a recurring natural hazard, not too different from living in a beach house during hurricane season. Instead of logging burned forests, why not meet timber needs by thinning the forests around towns and along predetermined evacuation routes, like the ones we already have for people fleeing hurricanes? That’s a step that could actually save lives when a crown fire does strike.

From the Canyon Creek burn I drove west to the city of Bend, which sits beneath a trio of 10,000-foot volcanoes known as the Three Sisters, to spend a day off with friends. In this adventure-sports town, we decided to skip all the mountain biking, trail running, sport climbing, river rafting, and fly-fishing to do something really spectacular: go hiking in a forest burned during the 2017 Milli Fire.

We wound lazily up the trail, my friends’ Australian shepherd, Taz, running up ahead and coming back to report on the situation. As we gained elevation, we moved out of Douglas-fir and lodgepole pine into a hushed stand of mountain hemlock, burned black but with a shock of red-singed needles still drifting gently onto the forest floor. A Townsend’s Solitaire was singing.

Farther still, we emerged onto a hillside of subalpine fir that had burned as severely as anything I've ever seen. This was one of those fully gothic stands, where the trunks are powdery black and the ground is an unrelenting gray.

We were in the Three Sisters Wilderness by now, where logging isn't allowed due to Wilderness Act protections. This was that rare scene in today's outdoors where nothing was the matter. The forest was already pursuing its own course of action. Trees that had spent the last two centuries storing up the energy of the sun were about to turn it all loose again in one great years-long exhale, and push life—beetles, woodpeckers, bluebirds—out of their sturdy bodies one last time.

A bird skittered its nails on the bark of a fir. There was some tentative pecking, and a pause to listen for beetles. A flash of soft, gray-barred flanks, a flash of yellow. Almost too appropriately, it was a Black-backed Woodpecker. It turned its back to me and disappeared.

I thought of Hutto, walking along the road at Rice Ridge, falling silent as he reflected on his 30 years of research in burned forests.

“Basically, it's just a magical place,” he had told me. “That's the bottom line.”

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As thousands of Oregon homes burned to rubble last month, the state's politicians joined the timber industry in blaming worsening wildfires on the lack of logging.

Echoing a long-standing belief in the state that public forests are the problem, U.S. Rep. Greg Walden, a Republican who represents eastern Oregon, equated the federal government's management to that of "a slum lord." And Democratic Gov. Kate Brown on "Face the Nation" accused Republicans in the state's Legislature of blocking measures, proposed by a wildfire council, that would have increased logging on public lands.

In the decades since government restrictions reduced logging on federal lands, the timber industry has promoted the idea that private lands are less prone to wildfires, saying that forests thick with trees fuel bigger, more destructive blazes. But an analysis by OPB and ProPublica shows last month's fires burned as intensely on private forests with large-scale logging operations as they did, on average, on federal lands that cut fewer trees.

In fact, private lands that were clear-cut in the past five years, with thousands of trees removed at once, burned slightly hotter than federal lands, on average. On public lands, areas that were logged within the past five years burned with the same intensity as those that hadn't been cut, according to the analysis.

"The belief people have is that somehow or another we can thin our way to low-intensity fire that will be easy to suppress, easy to contain, easy to control. Nothing could be further from the truth," said Jack Cohen, a retired U.S. Forest Service scientist who pioneered research on how homes catch fire.

The timber industry has sought to frame logging as the alternative to catastrophic wildfires through advertising, legislative lobbying and attempts to undermine research that has shown forests burn more severely under industrial management, according to documents obtained by OPB, The Oregonian/OregonLive and ProPublica.

This year's wildfires were among the worst that Oregon has experienced. They destroyed more than 4,000 homes across the state and consumed about 1 million acres of public and private land, nearly double the acreage as in previous years. Extreme winds drove fires across federal forest and industrial timber plantations, down through canyons and into populated areas like Sam Drevo's community of Gates, about 45 minutes east of Salem.

Drevo stepped outside of his home Labor Day evening and saw flames racing across a clear-cut hillside a quarter mile away. He and his mother had time only to grab a bag of clothes before evacuating.

"I'm still kind of spinning. It's hard to believe what just happened," Drevo, a 44-year-old river guide, said. "The devastation of the loss, everything we lost in the house, everything that was sentimental to me. It's just really hard to cope with that."

Sam Drevo walks through wildfire damage in the town of Gates, Oregon, where he owned a home and river guide business. (Tyler Westfall for OPB)

As fires continue to threaten communities from California to Colorado, state and federal lawmakers have prioritized logging ahead of methods scientists say provide the best chance for limiting damage from wildfires, including prescribed use of fire to clear brush and programs that could help make homes like Drevo's more resistant to wildfire.

"This country has a huge amount of money," Cohen said, noting that annual firefighting costs have surpassed $3 billion nationally. "But if you have a misperception of what the problem is, if you continually define it as a wildfire control problem, then that money largely goes into ineffective kinds of uses."

After last month's fires, the Oregon Forest & Industries Council, a statewide timber lobbying organization, spent thousands of dollars on Facebook advertisements promoting forest management to reduce wildfire risks. Four industry groups, including the council, published an opinion piece calling for the state to unite around logging, thinning and prescribed burns to reduce the buildup of dead and diseased trees on federal lands.

Sara Duncan, spokeswoman for the council, said logging is an effective tool for slowing wildfires. She said that this year's fires, which burned more than 275,000 acres of logged industrial timberland in Western Oregon, should be treated as an outlier because of winds that fueled unanticipated damage.

"In such an extreme event, any land would have burned, managed or not," Duncan said in an email.

The Campaign for Logging

The idea of managing forests to prevent wildfires began gaining popularity in the 1990s, after logging on public lands plummeted following court battles that led to protections for threatened species like the northern spotted owl.

Proponents of more logging have argued that a rise in the number of large fires in recent decades coincided with the slowdown in timber sales on federal lands.

In 2018, the Oregon Forest & Industries Council launched a campaign that featured a simple message: "Managed Forests Do Good Things. Catastrophic Wildfires Do Bad Things." The campaign aims to "build a high-quality, on-line community of activists who will advocate for the industry to policymakers and elected officials," according to an internal strategy document obtained by OPB, ProPublica and The Oregonian/Oregonlive.

Over the past decade, 80% of the acres burned in the state have been on federal land, according to data from Oregon's Department of Forestry. The disparity in acres burned is in part because 60% of Oregon forests are managed by the federal government. Most of those forestlands are in drier, remote areas prone to more frequent fire, compared with private forest lands.

Fires on private industrial timberlands can be more quickly suppressed because firefighters have more access through roads, making data that shows the intensity or severity of fires an incomplete metric for damage, industry groups said.

"More important is how the fire spreads and how easy it is to control," Duncan said in an email. "Fires on private forestlands are easier to put out because fuels are more receptive to suppression efforts, and access is maintained through roads."

A stretch of private industrial timberland that burned in the Holiday Farm Fire. (Jes Burns/OPB)

Because the state and federal governments have tried to put out every wildfire for decades, forests that would have been cleared of vegetation by frequent, naturally occurring fires became overgrown. Logging or thinning could provide jobs and wood for local mills, but scientists say it won't prevent destructive wildfires like the ones the state experienced this year.

Logging doesn't eliminate the underbrush, twigs and tree needles that fire feeds on. Removing brush and debris requires fire. That includes "prescribed fire," using drip torches to safely burn across the forest floor during cooler weather.

A forest that is thinned must then be purposely burned to reduce wildfire spread. But in Oregon, more than 1 million acres of federal land have been thinned in the past 10 years, while landscape burning has been completed on less than half that amount, according to data from the Forest Service and Bureau of Land Management.

Homes most often ignite from flying embers, not flames, and research from the U.S. Geological Survey found vegetation levels on public lands were a poor predictor of home destruction in a wildfire.

Scientists with the U.S. Forest Service and wildfire insurance industry say adapting communities to withstand wildfire by clearing vegetation and using fire-resistant construction like closed eaves, covered vents and double-pane windows provide the best chance to prevent home losses.

In Oregon, neither the state nor federal government track money spent on preventing home ignitions.

Matt Donegan, a former timber investor and consultant who led Brown's Wildfire Response Council, acknowledged thinning may not be effective in the rainy forests of western Oregon because the trees would grow back before wildfire.

Donegan said the damage caused by wildfires this year, which was almost entirely on the west side of the state, will likely prompt a special legislative session. He expects a debate over how much state funding should go toward fireproofing private residences.

"I think one of the most vexing topics Oregon will face is what do you do with the west side forests?" Donegan said. Wildfire there is "not going to happen often but when it does, my heavens, the impacts are so great."

The governor's wildfire council put forth a set of recommendations this year that

included increasing the state's firefighting capacity, creating a buffer around homes and requiring electric companies to shut down power lines during high winds.

The council's most expensive recommendation called for the state to spend $4 billion over the next 20 years on forest management, primarily on thinning. Funding for the proposal would have covered fewer than half of the total acres in Oregon considered at high risk of wildfire.

The cost estimate didn't include maintenance treatments of prescribed fire, which the council acknowledged are "essential for maintaining risk reduction over time."

"Researchers and Their BS Study"

About an hour east of Eugene in a patchwork of heavily managed public and private timberland, with hundreds of acres of clear-cutting and thinning in every direction, the community of Blue River was completely leveled by September's 173,000-acre Holiday Farm Fire.

Picking through the burned husks of buildings and cars, researcher Chris Dunn pointed to a nearby hillside that had been logged before the fire.

"That kind of management clearly didn't provide community protection," said Dunn, who spent eight years as a wildland firefighter. He now studies fire behavior and risk for Oregon State University and the Forest Service.

In 2018, Dunn co-authored a study with Humboldt State University's Harold Zald that found the 2013 Douglas Complex Fire in southern Oregon burned 30% more severely on private industrial timber plantations than on federal forestlands.

Dunn said the research wasn't intended to target the timber industry. It was meant to explain why the fire burned in a particular pattern. He thought perhaps industry leaders might use the study to push for better fire protection funding for their lands, which provide society's wood supply and could be susceptible to burning.

But the findings challenged a report by the Oregon Forest Resources Institute, a tax-funded forest education agency overseen by timber companies. The institute's report had pointed to the same fire to caution that unlogged public lands contributed to damage on private lands.

"While the study is not receiving attention, enviros are using it, and it is out there as a matter of record," then-director Paul Barnum wrote to staff in 2018 in an email obtained by The Oregonian/Oregonlive, OPB and ProPublica. "Without someone challenging the study, those accessing it in the future may assume it's legit."

Barnum declined to answer specific questions about the study by Dunn and Zald. He said his emails were not relevant to this year's fires.

The institute drafted a guest opinion refuting the study and sought input from industry groups before submitting it to a local newspaper.

"From beginning to end I would keep the focus on these two specific researchers and their BS study," advised Nick Smith, a lobbyist for the national timber group American Forest Resources Council.

In response to emailed questions, Smith said he took issue with the researchers' "broad policy conclusions" and thought the study didn't contribute much to the protection of forest values or communities.

The institute's opinion piece ran nearly two months after the study was published, under the heading "Replanted forests don't increase intensity of wildfire."

Dunn said no one from the industry reached out to him before criticizing his findings.

"Why wouldn't someone just email me and ask me about it and talk," Dunn said. "It's like creating a false perception of me being against them or them being against me, and that's completely incorrect."

Land Managed, Homes Lost

Days after the September fires wreaked havoc in Oregon communities, Congress had a hearing on a comprehensive wildfire bill.

In the Senate, Democrat Dianne Feinstein of California and Republican Steve Daines of Montana introduced a wildfire bill focused primarily on expanding logging. The bill, which also includes prescribed burning and funding for home construction, would provide additional exemptions on environmental and legal reviews for logging to help mitigate wildfire.

Logging didn't help Drevo's community of Gates. Five of the nine houses on his street survived because they were built to be fire resistant or their owners doused them with sprinklers during the blaze. Drevo, who didn't learn he could fortify his home until it burned down, said politicians should focus on making communities more fire-resistant.

"You look at what happened in my little microcosm," Drevo said, "and the fact that there was an area that was heavily logged, and it was a huge inferno that helped add to the destruction of our community."

Late last year, Sen. Kamala Harris, a California Democrat and her party's nominee for vice president, sponsored a bill to create a $1 billion grant program for making homes more resistant to wildfires. Oregon Democratic Sen. Ron Wyden co-sponsored the bill in September. He also filed a separate bill seeking a $300 million federal investment in the use of prescribed fire.

Neither bill has received a hearing.

Jes Burns of OPB and Rob Davis of The Oregonian/Oregonlive contributed reporting.

Colorado’s Troublesome megafire

November 2, 2020 by Allen Best

Troublesome questions about where we’re headed during our hotter, drier, longer summers in Colorado

by Allen Best/Top photo by Brad White

East Troublesome, now the second largest fire in Colorado as defined by acreage, appears to have started on Oct. 14 within a mile or so of my first backpack trip 40 years ago.

My days of backpacking have ended. These very large, very strange fires such as East Troublesome will almost certainly become more common in coming decades. For about a decade, wildfire specialists have been using a new word to describe those of another dimension:

megafires. Colorado this year has had three wildfires that crossed the threshold of the simplest metric, 100,000 acres in size.

East Troublesome hurtled past that metric in less than 90 minutes. Like at least one other fire, it appears to have created its own weather. And then there's the weirdness of the timing. It started in mid-October, traditionally a time of down comforters and, if not every year, most years in the mountains, snow on the ground.

The largest fire in Colorado history is now the Cameron Peak Fire. It started Aug. 15 and has now reached 209,000 acres. The East Troublesome Fire is second at 194,000 acres. Both remain lives fires. The third largest fire, Pine Gulch, north of Grand Junction, also occurred this year, covering 139,000 acres before being declared completely contained in September. Partly in Colorado, but mostly in Wyoming, is the Mullen Fire, at 177,000 acres.

Smoke from the Mullen Fire along the Wyoming-Colorado border as seen from the Snowy Range in Wyoming on Oct. 6. *Photo/Allen Best*

But first, about that backpack trip. In 1980, I was living in Kremmling, a small town with a blue collar and cowboy boots. The busiest bar was called the Hoof 'n' Horn. Most people worked at the Edwards Hines sawmill, one of several sawmills in the region, or at the Amax Henderson molybdenum mill, which was "up" the Williams Fork Valley 25 miles away.

About backpacking, I knew nothing. My equipment was laughable, more suitable for a city park than a stretch of country rarely visited by people except cowboys during roundup time. A girlfriend drove me up Colorado 125, the road between Granby and Walden, and then onto a Forest Service road, and dropped me off.

It rained hard that night, lightning crashing fiercely, and there were bumps in the night, probably cattle and maybe elk, but I thought for sure bears. Then the sun came up. I had caught the bug. Exploring places beyond the roads became a passion. A decade later I had become an avid backpacker and a pretty good backcountry skier, too.

The East Troublesome fire started Oct. 14 and would have been a record fire in the 20th century and, by 21st century standards it was still respectably large. But in the dull, gray sky along Front Range, it was indistinct from the smoke of the Cameron Peak Fire and then the fire near Boulder called CalWood.

We had watched the CalWood fire that Saturday evening from a restaurant in Boulder, the last one along Broadway before it joins Highway 36. The fire had started about seven hours before and was already, I believe, the largest in Boulder County history. Sitting outside at the restaurant, we could see the fire flaring in the distance, maybe 10 miles away. I didn't realize how personal it was to people in the next socially distanced table until later. Cathy, my companion, who still has good hearing, said they were people who had homes in the fire area. One was calling his insurance agent.

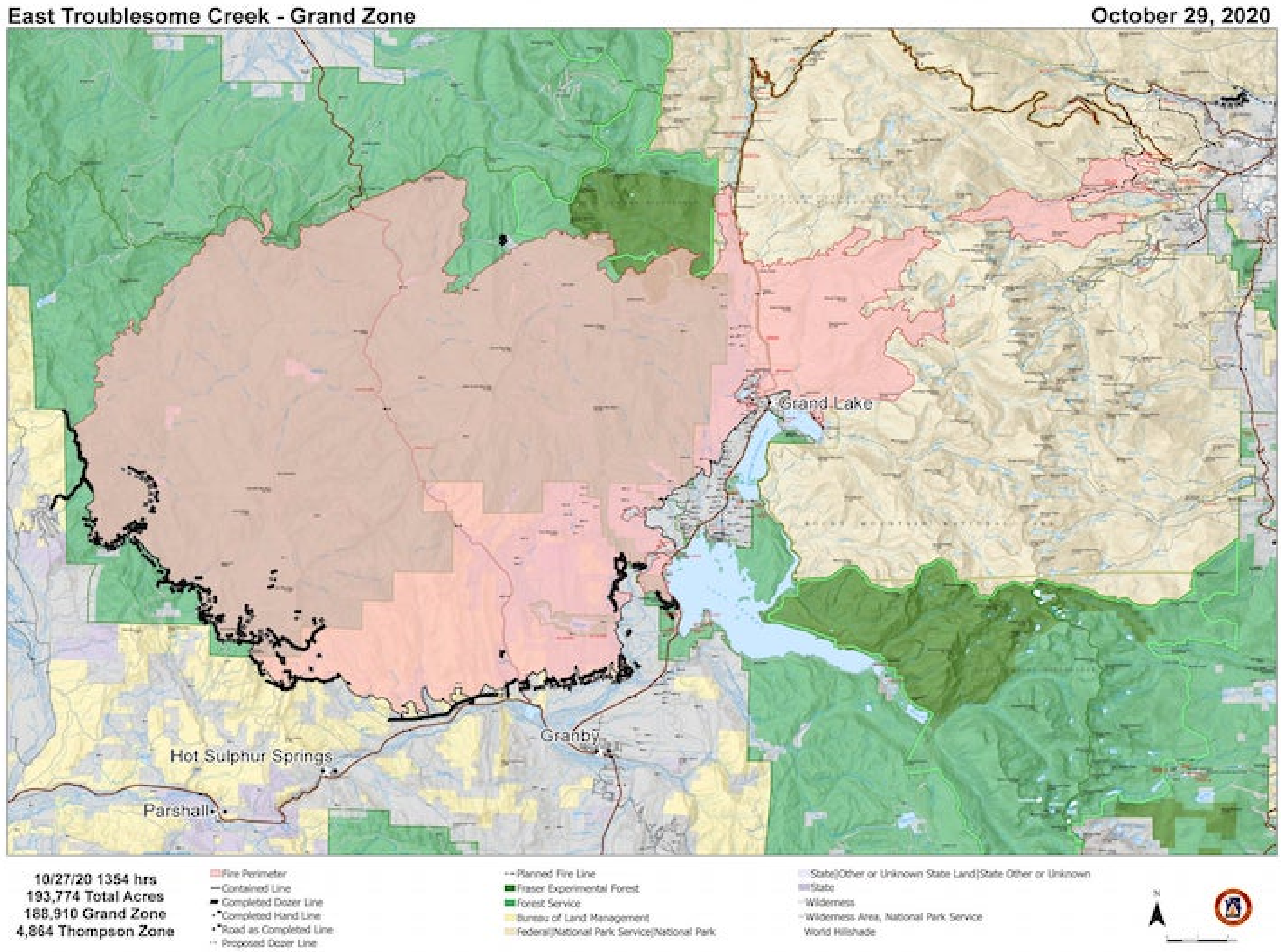
Like a volcanic eruption

On Oct. 21, a week to the day after East Troublesome had started, I saw a Facebook post showing a giant plume of smoke as seen from Park Meadows, in Denver's South Metro area. I assumed one of these Front Range fires had blown up. It had been another unseasonably warm day. The person who posted the photo compared it to Mt. Vesuvius erupting.

Later, the story has been pieced together. The fire had advanced to northeast of Hot Sulphur Springs but still east of Colorado 125, the highway that goes from Windy Gap—west of Granby a few miles—north to Willow Creek Pass and to Walden.

Brad White, the fire chief for Grand County Fire Protection District No. 1, whose service territory includes most of the affected area other than Grand Lake, says the fire made a run toward evening, as the sun was getting low in the sky. The fire had been burning a mixture of live and dead trees in the Kinney Creek area northeast of Hot Sulphur Springs. In 90 minutes, pushed by winds from the southwest, the fire rushed to Rocky Mountain National Park and across Trail Ridge Road. By White's calculation, that's a distance of 17 miles.

Slow-burning fires spread by the ground, often from tree crown to tree crown. This fire, during its runs, leaped great distances, a process called spotting. Visiting the charred remains of Columbine Lake, a housing development west of Grand Lake, White and others found a burning fist-sized ember—a piece of burning tree that they believe was hurled into the sky and came down miles away, like hail.



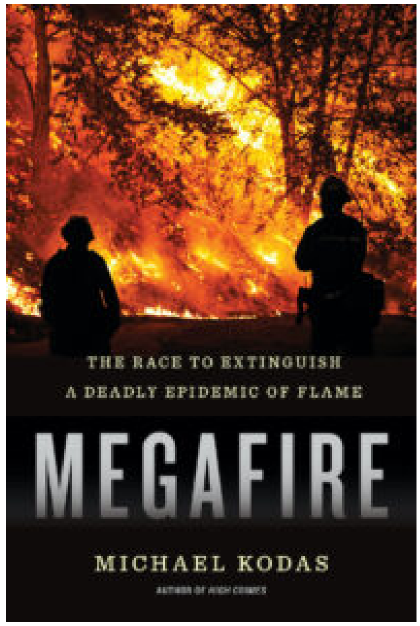
The East Troublesome fire was large by conventional Colorado standards, having covered a large area north of Hot Sulphur Springs. Then, in one evening it sprinted past Grand Lake and across the Continental Divide.

The current issue of Wired magazine tells of something similar, but set in Redding, Calif. An employee of the Forest Service, Eric Knapp, barely escaped a fire alive. The assumption he had made was that the fire would spread in typical fashion, on the ground. It instead created a giant column of fire and smoke, like a tornado, and then spread ashes and embers. That is what nearly killed the Forest Service fire expert and many of his neighbors. It sounds like something similar happened with the East Troublesome fire.

A key paragraph from that story:

“Knapp knew this could signal a once rare and dangerous phenomenon known as plume-driven fire, in which a fire’s own convective column of rising heat becomes hot enough and big enough to redirect wind and weather in ways that can make the fire burn much hotter and, with little warning, spread fast enough to trap people as they flee.”

See, “The West’s Infernos Are Melting Our Sense of How Fire Works.”



Michael Kodas, the Boulder-based author of a 2017 book called "Megafire," says Cameron Peak, East Troublesome and Pine Gulch fires all produced what are called pyrocumulus clouds, basically thunderheads. In the case of Pine Gulch, it produced lightning. Lightning from such smoke-born clouds can make the fire worse or spread it.

So far, though, Colorado has escaped what has now been observed in California: tornadoes caused by wildfires. They've been nicknamed firenadoes.

But the East Troublesome fire had enough wind to sprint hard across Grand County. I heard statements about hurricane-type winds capable of forcing cars off roads. Another report from a second-hand source was of "pine cones on fire blowing in the wind that were like missiles in the air."

White's estimate bears repeating: This fire ran 17 miles in 90 minutes. And 105,000 acres in an evening. To put that into perspective, Colorado's largest forest fire until 2020 was the Hayman Fire of 2002, which covered 138,000 acres. It's largest single-day run was 60,000 acres.

The Troublesome fire got big and did so fast in a month when fires are rare. It also leaped across the Continental Divide. In some areas, where the Continental Divide in Colorado is forested and relatively low, that wouldn't be all that notable. But in this case it leaped across two miles of rock and tundra to start a fire that quickly forced the evacuation of the east side of Estes Park, including the downtown area, and eventually the entire valley. In published reports, firefighting experts described it as so rare as to cause head-scratching.

It may have created its own weather, as big fires can do. Some anecdotal reports gleaned second-hand describe intense winds. From Fraser, about 30 miles to the south, Andy Miller, with whom I worked almost 40 years ago at the now-defunct Winter Park Manifest, said he saw tall columns of smoke, thunderhead-type formations. Atop this cloud of smoke were lenticulars, which commonly are at 40,000 feet.

On the outskirts of Granby, Patrick Brower and his wife and children had packed their car that Wednesday. The town was under a pre-evacuation order, but some areas on the mesa north of the high school were ordered to evacuate. That afternoon, there had been a steady stream of evacuees flowing through Granby—people from Grand Lake and the Three Lakes area—driving by his former office at the Sky-Hi News. Police did a good job of getting people out of harm's way, he says, just as they had in Granby in 2004.

"It was scary for sure, because there were massive, massive clouds of smoke," he says. "But the fire was still west and north of Granby."

Brower has a habit of sticking around until the last minute. In 2004, when he was still editor and publisher of the newspaper, Brower fled through the back door of the newspaper office just as the bulldozer of the small-town terrorist Marvin Heemeyer crashed through the front door.

Heemeyer nursed his grudges against the world in Grand Lake, the town of knotty-pine-sided buildings at the entrance to Rocky Mountain National Park. It mostly escaped the fire.

Despite the greenery evident in the foreground of this photo, there was a stench all around such as being amid 10,000 smoldering campfires. ***Photo/Allen Best***

On Saturday, 11 days after East Troublesome made its big run, I drove to Granby and then Grand Lake. An electric sign at the entrance said, "Locals only please." My companion and I instead followed Highway 34 to the blockade at the entrance to Rocky Mountain National Park. In the background of Grand Lake were giant hillsides of charred, dead trees. Immediately along the highway, only a few areas had burned. Nearly all the houses remained standing. The Grand County Sheriff reported 300 houses wee lost, not counting outbuildings. I suspect considerable luck. Easily, hundreds of houses could have burned if the wind had been in a slightly different direction.

Munching on our ham sandwiches, the car windows open, because it was warm, almost hot, we smelled the stench, the stink of being in a landscape of 10,000 campfires. It became unpleasant, almost sickening. We wondered what it would be like to live amid that strench for days, even weeks.

This is from the Nov. 2, 2020, issue of Big Pivots. To join the mailing list go to BigPivots.com

President Trump famously blamed environmentalists in the case of California's fires this summer with his comment that "you gotta clean your floors, you gotta clean the forest." The general grievance that I heard in Trump comments was that it's those darned environmentalists wanting nature pure and pristine. If only the logging industry were allowed to get out the harvest.

In fact, sawmills in Colorado during the 20th century did cut a lot of wood. The mill in Kremmling when I was there ran 12 to 14 million board-feet a year. When Louisiana-Pacific came in, it did 20 million board feet. I assume the mill in Walden had some comparable numbers to the earlier Kremmling mill. These mills would mostly have had access to the wood on national forest lands in the East Troublesome fire area.

Then came the beetle epidemic. There had been a fairly significant epidemic in the lodgepole pine that dominates that country in the early 1980s. Then, in 1996, a much, much bigger epidemic, first along Keyser Creek, near the molybdenum mill where I had once worked, then spreading outward: the Fraser Valley and Winter Park, Grand Lake, Summit County and Vail, Steamboat Springs and along I-70 near the Eisenhower Tunnel.

Some of this wood has been harvested, such as for wood pellets at a new mill in Kremmling. More in recent years has been used to produce electricity at a plant at Gypsum.

Mostly it was left standing or it fell down. The economics of wood in Colorado just aren't that good. To make electricity, for example, requires a subsidy. Even so, it makes no sense to haul the wood more than 70 miles. And the dimensional timber from Colorado's mostly scrawny lodgepole pine just isn't worth that much. Bigger trees in the Pacific Northwest and British Columbia, that's where the money is. As for the beetle killed trees, they begin twisting and cracking fairly soon after they've died.

Suppressed fires

A century of fire suppression also mattered. Fires had been big in the 19th century in Colorado. There were big fires in the 1850s and then again in 1878. The latter fires were attributed to Ute Indians and were called spite fires. Maybe, maybe not. Better authenticated are the fires set by prospectors to study the rock outcrops more easily. We do know that Vail's famous Back Bowls lost their trees in 1878.

This federal policy of fire suppression in landscapes that are fire prone has been written about often, and in various ways. In "The Big Burn," Timothy Egan wrote about the fire in northern Idaho that covered three million acres in 1910 and triggered the fire-suppression policy in the new federal agency created to manage the forest reserves. In his delightful novel "English Creek," Ivan Doig created a central figure who was dogged by a disquieting past that never comes out until late in the book. He had, we learned, let a fire get out of hand.

The East Troublesome fire burned to the shores of Granby Reservoir in one or two places but more generally had a northeasterly trajectory. ***Photo/Allen Best***

In 1988, by which time I was in Vail, the harm of fire suppression had become apparent. That was the year that Yellowstone was "lost." But – the ecologists insisted – fire is natural in forests, even if the scale in Yellowstone was mind boggling: 1.2 million acres. Colorado that summer was smoked up by the I Do fire west of Craig, named because a firefighter got married the day lightning caused the fire. It covered 15,000 acres. At the time, it was Colorado's record.

In Vail in the 1990s, the Forest Service tried to reintroduce fire to improve game habitat. There was bitter opposition, although fire did occur after I left. Trees were cut, mostly with more thought to aesthetics and biology, along Red Sandstone Road north of Vail and in the Buffehr Creek area. And swathes of forest on the south—think ski mountain—side of Vail were thinned of wood in the first decade of this century after the big drought, the big fires of 2002, and the bark beetle left forests red and then needle-less.

In Summit County, the pivot may have been even greater. I greatly oversimplify here, but think of public policy that went from thou-shalt-cut-no-trees to thou-shalt-cut-trees.

Climate change matters, too—immensely so. During my years in Kremmling, it routinely got to 20 and 30 below. Most memorable was the January morning in 1979 when the thermometer at the Phillips 66 gas station next to where I lived registered 62 below. That wasn't an official record temperature, but it's as cold as it gets on Colorado's record books. Nowadays, In Fraser, the self-described "icebox of the nation," it got to 14 below last week. During mid-winter it can get to 30 below. But that's not routine, like in the good, cold days.

Then add to that warming trend this year's exceptional heat. It wasn't particularly a dry winter at the headwaters of the Colorado River where the East Troublesome fire began. But spring came early, and summer turned hot.

Many homes along Highway 34 and west of Granby Reservoir were spared, perhaps the result of the luck of winds. ***Photo/Allen Best***

This August was the driest and hottest on record in much of Colorado. By mid-month, several fires were raging: The Williams Fork fire began almost precisely at the epicenter of the bark beetle epidemic from 1996, near where I had worked during that year of my first backpack trip. There was Grizzly Creek above Glenwood Canyon, which shut down Interstate 70 for two weeks, causing bumper-to-bumper traffic across South Park as people took the long, long detour through Gunnison to get to Denver. But after a a snowstorm in early September, it got hot again. I was in the Steamboat area a few days before that East Troublesome fire began, and it had been 85 degrees at an elevation of almost 8,000 feet. Yikes.

The current issue of Foreign Affairs has an article by Michal Oppenheimer of Princeton University titled: "As the World Burns: Climate Change's Dangerous Next Phase." He talked about wildfires and cyclones, disparate, but alike in important ways, and increasingly common:

"Soon, some once-in-a-lifetime catastrophes will become annual debacles. As temperatures rise, the odds that such events will occur at any specific location in a given year are growing quickly, particularly in coastal areas," wrote Oppenheimer. He went on to make the case for adaptation getting equal billing with mitigation.

Bruce Finley, writing in The Denver Post, riffed on the same theme of accelerating impacts of climate change. The headline was: As Colorado wildfires burn, fears that climate change is causing "multi-level emergency" mount.

A heavy wool blanket

Megafires—including 2020's Cameron Peak, East Troublesome, and Pine Gulch—are burning hotter and longer, with record destruction this year of 700,000 acres in Colorado and 6 million acres around the West. The smoke that exposed tens of millions of people to heavy particulates, health researchers say, will pose an even greater risk to public health in years to come.

The U.S. Interagency Fire Center defines a megafire by its size: more than 100,000 acres. By that count, Colorado has had three alone this year after having just one before in 2002.

Kodas, the "Megafire" author, dislikes a simple metric of size in deciding when to apply mega to a fire. Impacts also matter, and by that measure none of this year's fires caused near as much damage as those along the Front Range in years past: Waldo Canyon at Colorado Springs, Four Mile west of Boulder and High Park west of Fort Collins.

Colorado, he agrees, has entered a new era of wildfires: a time of larger fires more resistant to suppression and fires outside what has typically been considered wildfire season. In this, Colorado has company with California but also other parts of the world, he says. Next year may not be as bad as this year. Every year won't look the same. But the trend is clear.

There's also something else, as was hinted by the October fire near Boulder.

"We will see bigger fires and I think we will also see fires closer to and more threatening to our infrastructure, our communities, our homes," he says. "That's when these fires will really become mega."

Fires, some of them very big, have always been a part of our ecosystems. In the early 1600s, for example, there was a giant, stand-replacing fire in the Fraser Valley. But in the 20th century, it was still possible to describe the high-elevation forests on the Western Slope as "asbestos forests," the threat of fire was so remote. We've lost that illusion. Now we have the unnatural created by accumulating greenhouse gases like a heavy wool blanket on top of what is natural.

In 1980, during my first backpack trip, the accumulation of greenhouse gases measured at Mauna Loa stood at 338 parts per million. This year we hit 411 ppm.
East Troublesome, foremost among the several giant fires in Colorado during 2020, tells me we've entered a new era. Call it a Big Pivot.

Author Recent Posts

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Part 1: Scientists, Missoula County shift wildfire focus to home ignition zone

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A crowd gathers to watch a fire burn on Mount Sentinel in this file photo. Recent fires around the West have demonstrated the potential fo

Editor's note: This is part one of a two-part story on urban fires. Part 2 can be read by following this link.

It's been called an "urban firestorm" or "urban conflagration." Regardless of the title, the citizens of Superior and Louisville, Colo., all agree that the Dec. 30 fire that burned more than 1,000 homes and businesses nearly to the ground was an urban disaster.

The Marshall Fire started in the grasslands west of the two suburbs as residents were going about their business, some no doubt preparing for New Year's Eve festivities. They likely wouldn't have been aware of the fire on an average day when fire departments could snuff out the flames.

But the winds of Dec. 30 were extreme, accelerating down the Rocky Mountain Front with some gusts topping 105 mph. Grassfires burn fast anyway, but this caused the fire to race toward the towns, spitting burning embers ahead of it that then caused several buildings on the edge of town to begin to burn.

From there, the structures themselves started a domino effect, the embers of each penetrating nearby houses, causing entire neighborhoods to burn at about the same time.

Video shows residents emerging from stores, confused and scared, as wind and smoke enveloped the towns. Trying to flee the parking lots, people ended up in bumper-to-bumper traffic as debris bounced off their vehicles. Amazingly, only two people remain unaccounted for.

Post-fire photos show neighborhoods with houses reduced to ash piles, and only the concrete stairwells remain of the four-story Element Hotel. A snowstorm finally blew through on New Year's Eve, a day too late for the thousands who suddenly found themselves homeless.

Some in Missoula may see the fire as another sad but distant event of 2021. But some fire experts hope people take it as a warning to improve plans for evacuation and home defense.

"Could it happen? Missoula doesn't have that extent of development yet. But the answer is yes, to a limited extent," said retired U.S. Forest Service fire behaviorist Jack Cohen.

Dissecting an urban conflagration

Understanding what caused the Colorado disaster is key to reducing the extent of the next one. Four factors played a role, Cohen said: high winds, a wildfire with a wide leading edge and non-fire-resistant structures in relatively dense neighborhoods. And these four led to a final factor: firefighters unable to deal with such an overwhelming situation so buildings burned.

Unlike a point source like a bonfire, a wildfire with a wide fire front can send multiple burning embers into a community, causing a number of house fires to start simultaneously. But those embers aren't likely to sail far away from the flame front without a good wind blowing them. And stronger winds can create a "blizzard of burning embers."

"And it doesn't have to be 100 mph," Cohen said. "It was 30 to 40 mph winds that spread the West Wind Fire into Denton. And it was the same thing for the Lytton, British Columbia, fire where winds were 25 to 30 mph. And that was a grassfire too."

The sun sets over Montana in a blanket of smoke. (William Munoz/Missoula Current file)

While it's not unusual to have high winds along places like the Colorado Front or the plains of eastern Montana, climate scientists are hypothesizing that a warming climate creates conditions that favor more severe storms accompanied by strong winds, which could end up in uncharacteristic places.

Though Missoula isn't historically a windy town, throughout the night of Nov. 15 , winds toppled trees and power lines in the Missoula area, with the Missoula Airport registering gusts of more than 65 mph while Point Six above Snowbowl hit 75 mph.

If the burning embers rain on a fire-resistant house with a clear "home ignition zone" – an area 100 to 200 feet around the house – little damage is likely to result. But a house with wood siding, large windows and flammable items next to the house, such as leaf litter or firewood, could be in trouble, because the flames will work their way inside the house. A fire department might be able to limit the destruction of one such fire. But put a bunch of similar homes right next to each other, and they'll not only catch fire but also create their own embers that winds will shower on nearby houses.

"At that point, the community spreads the fire and the wildfire has nothing to do with it," Cohen said. "Multiple ignitions simultaneously result in fire-involved structures and are completely destroyed because at that point, there's no fire suppression. What I've been trying to get people to understand is fire protection is overwhelmed. And that's when a community disaster happens."

Solutions

Cohen has investigated multiple community disasters, carefully observing the scene, noting details that firefighters cannot because they're too busy trying to save buildings. After seeing similarities in each case, he worked with other fire scientists to devise a more effective fire risk analysis for communities, compared the ability to control wildfire to the ability to control community vulnerability. In essence, they compared trying to control thousands of acres to improving a half-acre of property.

"The ability to be effective is intractable when we define the problem as wildfire," Cohen said.

In western Montana, residents tend to think of forest fires as the danger to communities. However, as Cohen noted, several recent firestorm disasters have been initiated by grassfires. He can rattle off several such incidents, from the fires last month that ravaged Denton and Gibson Flats near Great Falls to the January 2006 prairie fires in Oklahoma and Texas that burned more than 200 homes. With the Santa Rosa fire in 2017, the Tubbs Fire ran out of stubby vegetation before it reached Coffee Park, but the embers had already inundated the dense subdivisions of Coffee Park.

This is why fire scientists argue that forest thinning does little to nothing to stop wildfire in extreme conditions. Firefighters are pulled back for their safety and firebrands can leap thinned areas. That's also when urban disasters occur. When conditions aren't extreme, wildland firefighters can usually put fires out before they reach communities.

The Boulder 2700 fire on Flathead Lake. (Trevon Baker photo)

In 2021, Montana had 2,555 fires, but crews dealt with most of them. Only 48 grew large enough to be named. But some forest managers still justify logging as a way to reduce community wildfire risk. Cohen said such efforts aren't effective.

"We're already successful at stopping 95-98% of wildfires. But if we're not doing preparatory projects to handle the 3% of the fires that are causing us 80-95% of the problems, particularly in light of climate change, then don't do it. Because it won't work," Cohen said. "That seems to be the hard sell."

When it comes to controlling community vulnerability, it's a matter of convincing people that all they need to do is improve the conditions in their home ignition zone. And if Missoula wants higher density, then houses need to be built of tougher stuff and designed differently. That's a lot easier and better for ecosystems than having to clear-cut the forest.

"We need to start thinking in terms of engineering our design and materials, and this can be done with codes," Cohen said. "And the greater the density, the more important those kind of codes become."

Part 2: Scientists, Missoula County shift wildfire focus to home ignition zone

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In Part 1, fire behaviorist Jack Cohen compared the Dec. 30 fire in Superior and Louisville, Colo., to other urban fire disasters to identify the causes and propose solutions for communities wanting to avoid the same fate. Here in Part 2, Missoula County starts looking at what it can do and a potential wildfire hazard challenges the residents of Grant Creek.

Missoula County Changes

Proposing new zoning tends to garner public opposition. Some people don't like to be told what they can't do on their property. Building codes aren't popular either.

However, Missoula County Commissioner Dave Strohmaier said there's a high likelihood that the county will be creating new building codes and zones this year to deal with wildfire risk, based upon the recent lessons of Colorado, Denton and Lytton, British Columbia.

"What we have learned over the years is the critical nature of the home ignition zone to averting community disaster," Strohmaier said. "We've not done ourselves any great service on focusing our attention on areas beyond the first 100 feet of one's home. Because ultimately, that's going to determine whether a structure is saved or not. Not whether you've done fuel treatments some distance from the community."

Since the county has yet to discuss what zoning to apply and what building codes might be required, Strohmaier couldn't go into much detail, particularly with codes. The challenge with building codes is the county has to have enough staff to enforce the codes.

But commissioners and staff have already pondered the possibility of creating "donuts" of zoning around more populous areas where regulations would change to prevent the urban chain reaction of houses burning simultaneously.

"There may be areas in the urban core that are within a couple miles of an ember shower, but we wouldn't include those in regulations. Then you go out a little ways and there's this zone that has enough proximity to wildland fuels and enough density of development that once fire starts, it could propagate from one property to another, unless those property owners have addressed the home ignition zone."

Smoke from burnout operations rises above the Madison River during the Maple Fire in Yellowstone National Park, September 10, 2016.

Outside the donut would be the "live-and-let-live zone," Strohmaier said, where houses are so sparse that they can burn down without setting their neighbors' homes on fire.

The county will also begin working on updating the Community Wildfire Protection Plan, even though its last revision was in 2018. The Protection Plan identifies the wildfire risk in regions of the county and the actions that agencies and property owners should take to first prevent and then respond to wildfire. But the wildfire hazard map is a little limited, being based on flame length, a measurement more applicable to trees than grass.

"It's yet to be determined how we'll use the existing mapping," Strohmaier said. "What is it that ignites people's homes? It is not the wall of flames that we see in dramatic images. Even though it looks scary and pretty awesome, that's not what starts structures on fire. It's predominantly the firebrands that cause fire to start in the home ignition zone, whether we're talking grassfires or heavier forest fuels. We've gone astray focusing on fire intensity."

The county is referencing protection plans being used elsewhere, including ironically, Boulder County, Colo., to get ideas on what to update in Missoula County's plan.

Case study: Grant Creek

The Missoula County Community Wildfire Protection Plan is a useful guide for the county. But there's too much area to cover for the plan to really get down to the nitty-gritty of what individual neighborhoods or smaller communities should consider if they want to address risk.

That's where the Wildfire Risk Task Force comes in for the Friends of Grant Creek, a neighborhood organization. A year ago, the Friends of Grant Creek recruited a handful of neighbors, some of whom have firefighting experience, to form the task force to evaluate the drainage and propose a wildfire protection plan tailored for Grant Creek.

The Roaring Lion fire near Hamilton.

Mike Cole, Wildfire Risk Task Force leader who works for Type 1 Wildfire Incident teams in the summer, said the task force spent the summer inventorying the properties throughout the drainage, looking at forest stands and property condition. Now, it's time to sit down and flesh out the plan.

"If you have a site-specific plan, you have more options working with the agencies," Cole said. "The city and county don't have resources to do something like this for every drainage, so it's up to local residents. We had enough concern from residents that we volunteered to take this on."

Some of the concern was sparked when Ken Ault of KJA Development bought a former rock quarry at the bottom of Grant Creek and announced in February 2020 his intent to build four-story apartment buildings with 960 units on the 44 acres. Current zoning, however, would allow only three-story buildings with 500 units.

Even so, Friends of Grant Creek worried about adding at least 500 more vehicles to the traffic at the bottom of Grant Creek Road. The big problem is Grant Creek Road is one-way-in and one-way-out. If a wildfire sparked along Grant Creek, in particular a wildfire in extreme conditions, could evacuation be hindered by a traffic jam or accident near the development?

Is that a possible scenario? Cole said yes.

"If you look at the lower end of Grant Creek, it's got a lot of grass surrounding subdivisions," Cole said. "Then you look at Louisville and the surrounding grasslands. Compare that to (the Prospect Drive development). Does this look like your neighborhood? It certainly does."

When Cohen read about the proposed high-density apartment development, he immediately hoped it would have interior sprinklers and nonflammable siding on the exterior, including the ceilings of the balconies and alcoves.

He pointed to the remains of the four-story Element Hotel and two-story fourplexes in Superior, Colo, and said such buildings often burn in independent parts during firestorms. Each unit catches fire at different times as flammable furniture and other items on the balconies or in alcoves catch fire. Then nearby windows fracture and collapse, allowing the fire inside.

"We're going to have to recognize the primary vulnerability is particularly with multi-story structures where it becomes extremely difficult to suppress fires. Particularly if there's more than one," Cohen said.

Friends of Grant Creek have asked the City of Missoula to do a traffic study to assess the current situation before adding another 500-plus cars. Cole said they may have to wait months, maybe years, because traffic studies are expensive. In the meantime, the City of Missoula reported five injury accidents, not counting fender-benders, on the lower section of road between January and September 2021.

That's the kind of situation the Wildfire Risk Task Force will have to compensate for in their plan. But they don't know that there's much they can do to stave off disaster, especially if reaction times have to speed up.

"If you're looking at new construction projects, you need to look at what the fire environment is going to look like 30 or 50 years from now," Cole said. "The information and models we used to base evacuations on, with the climate influencing fire behavior, are we going to have to reduce the time we'd normally take to evacuate people. And are we going to have fewer options?"

Contact reporter Laura Lundquist at lundquist@missoulacurrent.com.

https://missoulian.com/opinion/columnists/community-destruction-during-extreme-wildfires-is-a-home-ignition-problem/article_ef8aa717-99f1-5300-a137-3ebb25d6db00.html

Guest column

Community destruction during extreme wildfires is a home ignition problem

DAVE STROHMAIER and JACK COHEN

Aug 9, 2020

We must abandon our expectation that we can suppress 100% of wildfires and reject the false narrative that community protection requires wildfire control. Community wildfire disasters have only occurred during extreme wildfire burning intensities, when high wind speed, low relative humidity, and flammable vegetation result in rapid fire growth rates and showers of burning embers (firebrands) starting new fires. Under these conditions, wildfire suppression, the principal method used for protecting communities, quickly becomes overwhelmed.

But wildfires are inevitable and wildland fuel treatments don't stop extreme wildfires. Does that mean wildland-urban (WU) fire disasters are inevitable as well? Absolutely not! Wildfire research has shown that homeowners can create ignition resistant homes to prevent community wildfire disasters. How can this be possible?

Recall the destruction of Paradise, Calif., during the extreme 2018 Camp Fire. Most of the totally destroyed homes in Paradise were surrounded by unconsumed tree canopies. Although many journalists and public officials believe this outcome was unusual, the pattern of unconsumed vegetation adjacent to and surrounding total home destruction is typical of WU fire disasters. Home destruction with adjacent unconsumed shrub and tree vegetation indicates the following:

• High intensity wildfire does not continuously spread through the residential area as a tsunami or flood of flame.

• Unconsumed shrub and tree canopies adjacent to homes do not produce high intensity flames that ignite the homes; ignitions can only be from burning embers and low intensity surface fires.

• The "big flames" of high intensity wildfires are not causing total home destruction.

Surprisingly, home ignitions during extreme wildfires result from conditions local to a home. A home's ignition vulnerabilities in relation to nearby burning materials within 100 feet principally determine home ignitions. This area of a home and its immediate surroundings is called the home ignition zone (HIZ). Typically, lofted burning embers initiate ignitions within the HIZ. Although an intense wildfire can loft firebrands more than one-half mile to start fires, the miniscule local conditions where the burning embers land and accumulate determine the ignitions. Importantly, most home destruction during extreme wildfires occurs hours after the wildfire has ceased intense burning near the community; the residential "fuels" — homes, other structures and vegetation — continue fire spread within the community.

Given the inevitability of extreme wildfires and home ignitions determined by conditions within the HIZ, community wildfire risk should be defined as a home ignition problem, not a wildfire control problem. Unfortunately, protecting communities by creating ignition resistant homes runs counter to established orthodoxy.

There are good reasons to reduce fuels or "treat" vegetation for ecological and commercial objectives. But fuel treatments are most effective on wildfire behavior within a fuel treatment. They do not stop extreme wildfires. So let's call a spade a spade and not pretend that most of these projects truly reduce home ignition risk during extreme wildfires. The most effective "fuel treatment" addressing community wildfire risk reduces home ignition potential and occurs within HIZs and the community, which is to say, we can prevent WU fire disasters without necessarily controlling wildfires.

To make this shift, land managers, elected officials, and members of the public must question some of our most deeply ingrained assumptions regarding wildfire. For the sake of fiscal responsibility, scientific integrity and effective outcomes, it's high time we abandon the tired and disingenuous policies of our century-old all-out war on wildfire and fuel treatments conducted under the guise of protecting communities. Instead, let's focus on mitigating WU fire risk where ignitions are determined — within the home ignition zone.

Dave Strohmaier is Missoula County Commissioner. He previously worked for both the Bureau of Land Management and U.S. Forest Service in fire management, and has published two books on the subject of wildfire in the West.

Jack Cohen, PhD, retired from U.S. Forest Service Research after 40 years as a research physical scientist where he conducted experimental and theoretical wildland fire research. In addition, he developed operational fire models for management applications and served operationally as a fire behavior analyst.

For more information:

- Fire Adapted Missoula County, https://sites.google.com/view/famcounty/home

- "Your Home Can Survive a Wildfire," https://www.nfpa.org/Public-Education/Fire-causes-and-risks/Wildfire/Preparing-homes-for-wildfire
- Preparing your home ignition zone for wildfire, https://www.nfpa.org/Public-Education/Fire-causes-and-risks/Wildfire/Preparing-homes-for-wildfire

February 3, 2022

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Submitted via email

RE: Request for CEQ-Issued Guidance and/or Regulatory Change Addressing Federal Land Management Agency Attempts to Avoid Site-Specific NEPA Analysis and Disclosure ("Condition-Based Management")

Dear Chair Mallory, Ms. Hein, and Mr. Pidot:

On behalf of the undersigned organizations and individuals, we write to request that the Council on Environmental Quality ("CEQ") take action to preserve the integrity of the National Environmental Policy Act ("NEPA") and correct unlawful federal agency efforts to avoid site-specific NEPA analysis and disclosure before they make decisions with site-specific consequences. NEPA commands federal agencies to look before they leap and tell the public what they see, but the Forest Service and other federal land managers are at the forefront of an unlawful trend of agencies attempting to sidestep NEPA by deploying an analytical framework commonly known as "condition-based management." These emerging practices are unlawful, unwise, and undermine basic NEPA principles.

The attached report details the legal violations and on-the-ground harms that result when agencies try to avoid their NEPA obligations through condition-based management schemes and other related practices. Site-specific NEPA analysis and disclosure is required by law, leads to better outcomes, and is critical to promoting administration priorities like advancing the cause of environmental justice and combatting climate change.

Unfortunately, the Forest Service and other land managers have not gotten the message, and it is time for CEQ to step in. We respectfully request that CEQ issue guidance and/or regulations that reaffirm the fundamental importance of site-specific NEPA analysis when agencies make site-specific choices, correct agency practices contrary to that rule, and identify NEPA-compliant ways for agencies to responsibly implement their mandates, including their NEPA obligations. We also request a meeting with you to discuss the issue further. If you have questions about this request or the attached report, or to schedule a meeting, please contact Susan Jane Brown (brown@westernlaw.org) or Sam Evans (sevans@selcnc.org).

With regards on behalf of the undersigned organizations and individuals,

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REQUEST FOR CEQ-ISSUED GUIDANCE AND/OR REGULATORY CHANGE: ADDRESSING FEDERAL LAND MANAGEMENT AGENCY ATTEMPTS TO AVOID SITE-SPECIFIC NEPA ANALYSIS AND DISCLOSURE ("CONDITION-BASED MANAGEMENT")

INTRODUCTION

The undersigned have major concerns about a growing trend of federal agency efforts to avoid site-specific analysis under the National Environmental Policy Act ("NEPA"). While this trend cuts across agencies, the bulk of examples included here relate to NEPA analyses from federal land management agencies, and primarily the Forest Service, with which our organizations have the most familiarity. The environmental reviews of federal land management agencies, especially the Forest Service, provide uniquely valuable opportunities for understanding the challenges and opportunities in implementing NEPA because of the breadth of statutory duties and interests these agencies must balance, the diversity of public values that attach to federal lands, and the sheer number of environmentally consequential land management decisions to be made. The Forest Service is also currently the most prolific in its attempts to skip site-specific NEPA analysis, pioneering a practice known as condition-based management ("CBM"), which, as shown in the attached case studies,[1] is explicitly intended to cut off the NEPA process before the agency gathers the site-specific information or public input needed to inform its decision.

As discussed below, agency efforts to avoid site-specific NEPA analysis through CBM and other related practices are unlawful, unwise, divisive, and unnecessary. We respectfully request that the Council on Environmental Quality ("CEQ") issue guidance and/or regulations that reaffirm the fundamental importance of site-specific NEPA analysis when agencies make site-specific choices, correct agency practices contrary to that rule, and identify NEPA-compliant ways for agencies to responsibly implement their mandates, including their NEPA obligations.

I. NEPA requires agencies to undertake site-specific NEPA analysis before making project-level decisions.

CEQ should reaffirm that site-specific analysis is central to NEPA's action-forcing mandate whenever agencies propose to make project-level decisions with site-specific consequences for the environment, and that NEPA requires these consequences be evaluated and disclosed to the public *before* agencies decide to act. This obligation and this sequence are legally required by statute and confirmed by decades of judicial decisions. And as a practical matter, site-specific NEPA analysis is an effective and important tool for improving decisions and for promoting administration priorities like advancing environmental justice and combating climate change.

A. NEPA requires site-specific analysis for all project-level decisions with site-specific consequences for the environment.

[1] *See* Appendix 1.

NEPA famously has "twin aims":[2] (1) the statute commands each agency to consider the environmental impacts of its proposed actions; and (2) to ensure that "the relevant information will be made available to the larger audience that may also play a role in both the decision-making process and the implementation of that decision."[3] Although the Supreme Court has interpreted NEPA's enforceable requirements to be procedural, its goals and its benefits are unambiguously substantive. Environmental analysis and public scrutiny are intended to produce "better decisions,"[4] and, indeed, are "almost certain to affect [an] agency's substantive decision."[5] "Simply by focusing [an] agency's attention on the environmental consequences of a proposed project, NEPA ensures that important effects will not be overlooked or underestimated only to be discovered after resources have been committed or the die otherwise cast."[6]

To this end, NEPA requires that agencies must undertake and disclose site-specific analysis before making decisions with site-specific impacts.[7] In other words, whenever an agency proposes to choose among options that have different site-specific environmental consequences—like logging in one area versus another—the agency must provide site-specific analysis of those environmental consequences during the NEPA process before making a final decision.[8] Specifically, when an agency prepares a site-specific analysis for a project-level action, it must include "a reasonably thorough discussion of the distinguishing characteristics and unique attributes of each area affected by the proposed action."[9] Moreover, in order to "facilitate public discussion," the project's "proposed activities must be sufficiently correlated with environmental factors" and values—such as the presence of plant and wildlife species, for example—in each area that will be affected by the project.[10] The same rule applies when the

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[2] Baltimore Gas & Elec. Co. v. Nat. Res. Def. Council, Inc., 462 U.S. 87, 97 (1983).

[3] Robertson v. Methow Valley Citizens Council, 490 U.S. 332, 349 (1989).

[4] *See* Nat'l Audubon Soc'y v. Dep't of Navy, 422 F.3d 174, 206 (quoting 40 C.F.R. § 1500.1(c) (1978)).

[5] *Robertson,* 490 U.S. at 350.

[6] *Id.* at 349.

[7] *E.g.,* California v. Block, 690 F.2d 753, 761 (9th Cir. 1982) (holding that site-specific impacts must be "fully evaluated" when an agency proposes to make an "irreversible and irretrievable commitment" of resources to a project at a particular site). Congress alone may make exceptions to this rule. *E.g.,* 16 U.S.C. §§ 6591a(b)(2), 6591b(a)(1), 6591(d) (allowing the Forest Service to skip NEPA for site-specific actions that otherwise would require an EA or EIS, provided that all the requirements for eligibility are met. Such exceptions are narrow and rare).

[8] *See, e.g.*, Western Watersheds Project v. Abbey, 719 F.3d 1035, 1049 (9th Cir. 2013) (internal citation omitted) (holding that BLM has a "critical duty to 'fully evaluate[ ]' site-specific impacts" even after issuing a programmatic EIS); City of Tenakee Springs v. Block, 778 F.2d 1402, 1407 (9th Cir. 1985) (finding that "NEPA requires both a programmatic and a site-specific EIS," and that agencies do not have discretion "to determine the specificity required by NEPA" in a site-specific EIS but must instead adhere to the statute); Wilderness Soc'y v. U.S. Forest Serv., 850 F. Supp. 2d 1144, 1150, 1157 (D. Idaho 2012) (holding that the U.S. Forest Service was required to "take a 'hard look'" at the impact of 94 miles of roads under NEPA "before making them a part of the designated route system in the area" despite the roads having been used unofficially for years); Klamath-Siskiyou Wildlands Ctr. v. U.S. Forest Serv., No. 2:05-CV-0299, 2006 WL 1991414, at *9–10 (E.D. Cal. July 14, 2006) (invalidating the use of an EA without site-specific analysis for project locations).

[9] Stein v. Barton, 740 F. Supp. 743, 749 (D. Alaska 1990); *see Klamath-Siskiyou Wildlands Ctr.*, 2006 WL 1991414, at *9–10.

[10] *Stein*, 740 F. Supp. at 749; *see* Ayers v. Espy, 873 F. Supp. 455 (D. Colo. 1994) (holding that where the Forest Service's EA for a timber sale in the Arapaho and Roosevelt National Forests selected an alternative despite "grossly inadequate" soil data, the agency was required to conduct a soils inventory and analysis providing site-specific information sufficient to properly evaluate each proposed alternative and the reasons for each alternative's selection or rejection).

choice of the timing of implementation is environmentally consequential. In such cases, the time-dependent impacts must be considered during the NEPA process.[11]

Site-specific analysis and public input are required to assess environmental baselines,[12] develop and compare differences among alternatives,[13] and develop site-appropriate mitigation measures.[14] The obligation to undertake and disclose this sort of analysis during the NEPA process is set forth by NEPA's plain terms. For on-the-ground or otherwise project-level actions that require preparation of an environmental impact statement ("EIS"), the obligation to evaluate site-specific impacts arises from the "detailed statement" requirement of Section 102(2)(C) of NEPA and the requirement that agencies consider all reasonable alternatives.[15] A "detailed statement" of effects must include analysis of impacts that depend on location or timing.[16] An agency cannot take a hard look at impacts to wildlife, for example, without first understanding exactly where the action will take place and which wildlife species are using the affected area. In addition, an EIS must evaluate alternatives to the proposed action—a requirement that has long been understood as the "heart" of the NEPA process.[17] Where alternatives involve choices between locations or timing, the comparison must account for those site-specific or time-dependent differences.[18] In addition, agencies must understand the type and degree of site- and time-specific impacts in order to identify mitigation measures.[19]

For on-the-ground or otherwise project-level actions that do not require preparation of an EIS, NEPA nevertheless requires site-specific analysis in environmental assessments ("EAs") for agency actions where the choice of sites is environmentally consequential. An EA is not solely a tool for deciding whether an EIS is needed; it is also the mechanism required to comply with Section 102(2)(E) of NEPA,[20] which requires agencies to develop and consider alternatives when there are "unresolved conflicts concerning alternative uses of available resources"—an obligation that exists independent of Section 102(2)(C)'s "detailed statement" requirement. The

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[11] *Cf.* Marsh v. Oregon Nat. Res. Council, 490 U.S. 360, 374 (1989) (holding that a supplemental EIS is required whenever the passage of time or subsequent events might "'affec[t] the quality of the human environment' in a significant manner or to a significant extent not already considered") (quoting 42 U.S.C. § 4332(2)(C)); Oregon Nat. Desert Ass'n v. Bureau of Land Mgmt., WL 5830435, at *6 (D. Or. 2011) (finding that "the regulatory definition of 'significantly' requires the BLM to consider the context and intensity of the proposed project and its impacts.").
[12] Oregon Nat. Desert Ass'n v. Jewell, 840 F.3d 562, 568 (9th Cir. 2016) (holding that an accurate baseline is a "practical requirement" of NEPA and that environmental data must be made "available to public officials and citizens *before* decisions are made and *before* actions are taken.") (emphasis in original) (internal citations omitted).
[13] 40 C.F.R. § 1502.14 (2020).
[14] *Id.* at § 1502.16.
[15] 42 U.S.C. § 4332(2)(C)(iii).
[16] *See* Southeast Alaska Conservation Council v. U.S. Forest Serv., 443 F. Supp. 3d 995, 1013 (D. Alaska 2020) (holding that condition-based management project on the Tongass National Forest violated NEPA's hard-look standard because the Forest Service did not analyze where and when logging and road construction would occur).
[17] Robertson v. Methow Valley Citizens Council, 490 U.S. 332, 352 (1989).
[18] *See, e.g.*, New Mexico *ex rel*. Richardson v. Bureau of Land Mgmt., 565 F.3d 683, 705–07 (10th Cir. 2009) (requiring BLM to conduct additional site-specific NEPA analysis when it significantly modified chosen alternative without completing any additional analysis).
[19] *Robertson*, 490 U.S. at 351 (holding that a discussion of mitigation measures is an "essential ingredient" of an EIS which "flows both from the language of the [Clean Water] Act and . . . from CEQ's implementing regulations."); *see also* 42 U.S.C. § 4332(C)(ii) (requiring a detailed statement for "any adverse environmental effects which cannot be avoided should the proposal be implemented").
[20] 40 C.F.R. § 1508.9 (1978); 40 C.F.R. § 1501.5(c)(2) (2020).

requirement to consider alternatives arises when the choice is environmentally consequential—i.e., whenever an agency's objective "can be achieved in one of two or more ways that will have differing impacts on the environment."[21] Accordingly, if an agency's purpose can be met by acting in different locations (or at different times or in different ways) with different environmental consequences and the agency is exercising discretion to choose among those places or times, an EA must consider the different effects corresponding to those location or timing options.[22] For example, where and how to conduct logging or build roads are the sorts of decisions explicitly left "unresolved" in forest plans and deferred to future project-level decisions, requiring site-specific analysis at the project level.[23] In addition, the requirement to consider site-specific impacts is inherent in the EA's role of assisting decisionmakers to determine whether an EIS is required. Without site-specific analysis, an agency cannot credibly justify a finding of no significant impact ("FONSI") for a site-specific project.

This is not to say that agencies must spend considerable time analyzing nonsignificant issues. If, based on agency experience and monitoring, an action will not individually or cumulatively cause significant impacts *no matter where or when it occurs*, an agency may develop a categorical exclusion ("CE") for that category of action.[24] On the other hand, if an agency's proposed action may individually or cumulatively lead to significant impacts *depending on where or when it occurs*, the agency must at least prepare an EA that considers whether the particular action will occur at a place or time that makes its impacts environmentally significant.

B. Site-specific analysis of project-level decisions is effective and important.

In addition to being legally required, site-specific NEPA analysis is effective and important as a practical matter.

First, site-specific analysis during the deliberative NEPA process is critical to ensuring informed and effective public participation, formulating and evaluating alternatives, and avoiding or mitigating adverse project impacts. Site-specific information related to, for example, where logging will occur or new roads will be built, is essential for an agency and the public to understand and evaluate the reasonably foreseeable impacts of a proposal.[25]

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[21] 42 U.S.C. § 4332(2)(E); Trinity Episcopal Sch. Corp. v. Romney, 523 F.2d 88, 93 (2d Cir. 1975).
[22] *Trinity Episcopal*, 523 F.2d at 93.
[23] *E.g.,* U.S. DEP'T OF AGRIC., U.S. FOREST SERV., FINAL ENVIRONMENTAL IMPACT STATEMENT FOR THE REVISED LAND AND RESOURCE MANAGEMENT PLAN FOR THE NATIONAL FORESTS IN FLORIDA ch. 3, at 1 (1999), https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd500375.pdf; U.S. DEP'T OF AGRIC., U.S. FOREST SERV., FINAL ENVIRONMENTAL IMPACT STATEMENT FOR THE LAND AND RESOURCE MANAGEMENT PLAN: CHATTAHOOCHEE-OCONEE NATIONAL FORESTS: APPENDIX G: RESPONSE TO PUBLIC COMMENTS 40, 108 (2004), https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsm9_028731.pdf; U.S. DEP'T OF AGRIC., U.S. FOREST SERV., PISGAH-NANTAHALA FOREST PLAN ENVIRONMENTAL IMPACT STATEMENT: FINAL SUPPLEMENT TO THE FINAL ENVIRONMENTAL IMPACT STATEMENT: VOLUME II, at app. N-68 (1994).
[24] *See* Heartwood v. U.S. Forest Serv., 230 F.3d 947, 954 (7th Cir. 2000) (holding that categorical exclusions "by definition" are for actions which do not have any "significant environmental impact").
[25] *See, e.g.*, Southeast Alaska Conservation Council v. U.S. Forest Serv., 443 F. Supp. 3d 995, 1014 (D. Alaska 2020) (explaining where a project analysis "identified a total acreage of potential timber harvest, but not the distribution of the specific acreage authorized by each alternative within these areas" "[t]his omission is meaningful given the duration and scale of the project" and "fails to provide a meaningful comparison of alternatives.").

An informed public is empowered to correct agencies' mistakes, offer alternative means by which to accomplish the purpose and need of a project, provide additional relevant information, and persuade agencies that some impacts may simply be unacceptable. Project improvements are driven by public input, usually centering on concerns about site-specific impacts. As CEQ has previously recognized, site-specific NEPA analysis leads to better outcomes, period.[26]

Recent experience reinforces CEQ's conclusions about the importance of site-specific analysis when reviewing project-level decisions. In connection with its November 2020 NEPA rulemaking, the Forest Service identified 68 vegetation management projects (encompassing a range of activities, from prescribed fire to timber production), which the agency believed were representative of its routine EA-level work, and which all resulted in FONSIs. Of those 68 projects, 40 were modified after preparation of an EA—33 at least partly in response to informed public comments, and another 7 due to internal review.[27] During the EA process, the sampled projects shrank by approximately 20% in terms of total acreage treated, but project improvements were much more varied than merely dropping high-risk acres. Other improvements included changing harvest locations and types, reducing mileage or changing locations of permanent or temporary roads, and adding site-specific mitigation measures such as retention of old trees and protections for rare species.[28] Similarly, an analysis of vegetation management projects in the Southern Appalachian national forests showed that NEPA comments regarding site-specific impacts resulted in project modifications to avoid potentially significant impacts to old growth forest, roadless areas, water quality, soil, rare species, and rare and exemplary natural communities.[29]

The following examples of Forest Service projects from across the country, which improved during the NEPA process based on site-specific information, further illustrate why a NEPA process with site-specific analysis and public input is important:

- ***Stoney Creek***[30] ***and Clarke Mountain***[31] ***Projects (Watauga District, Cherokee NF)***: While modestly sized, these projects would nonetheless have caused significant impacts

[26] Memorandum from Michael Boots, Acting Director of Council on Env't Quality, to Heads of Fed. Dep'ts and Agencies 5 (Dec. 18, 2014), https://obamawhitehouse.archives.gov/sites/default/files/docs/effective_use_of_programmatic_nepa_reviews_final_dec2014_searchable.pdf (Memorandum is entitled "Effective Use of Programmatic NEPA Reviews," and states that the NEPA process of using programmatic and site-specific analysis "leads to better outcomes" for the environment, public engagement, and government decisionmaking).
[27] *See* Appendix 2, at 10–16. These tables and charts analyze the projects that the Forest Service identified in an appendix to the supporting statement for several proposed CEs, available at https://www.fs.fed.us/emc/nepa/revisions/includes/docs/SupportingStatementAppxA-D.pdf.
[28] *Id.*
[29] *See* Appendix 2, at 17–25.
[30] U.S. DEP'T OF AGRIC., U.S. FOREST SERV., ENVIRONMENTAL ASSESSMENT: STONY CREEK PROJECT (2013), https://www.fs.usda.gov/nfs/11558/www/nepa/92055_FSPLT3_1448898.pdf; *see also* S. Env't L. Ctr., W. Env't L. Ctr., The Wilderness Soc'y, Comment Letter on Proposed Rule, National Environmental Policy Act (NEPA) Compliance (84 Fed. Reg. 27,544, June 13, 2019) at 168 (Aug. 25, 2019) [hereinafter SELC Comments on Proposed NEPA Rule], https://westernlaw.org/wp-content/uploads/2020/04/USFS-NEPA-Rulemaking-Comments-FINAL.pdf.
[31] U.S. DEP'T OF AGRIC., U.S. FOREST SERV., DECISION NOTICE AND FINDING OF NO SIGNIFICANT IMPACT: CLARKE MOUNTAIN PROJECT (2012), https://www.fs.usda.gov/nfs/11558/www/nepa/64492_FSPLT2_117679.pdf.

to old growth forests—an extremely rare resource in the Southern Appalachian ecoregion. Of the 613 acres proposed for commercial harvest in the combined projects, 174 were old growth (119 in Stoney Creek and 55 in Clarke Mountain). In both projects, District staff either did not recognize the stands at issue as old growth or resisted acknowledging that they were old growth. Because of EA comments submitted by citizen scientists with tree core data and field visits with Forest Service staff, the agency excluded old growth stands from logging, and more ecologically appropriate harvest locations were substituted.

- ***Somerset Integrated Resource Project***[32] (***Manchester District, Green Mountain NF***): This project originally proposed 9,630 acres of timber harvest, over 31 miles of road construction, and other proposed activities in the Deerfield River and Lye Brook-Batten Kill watersheds in south-central Vermont. Based on input from stakeholders and natural resource experts through the NEPA process, including supplemental input on site-specific impacts disclosed in the draft EA, the Forest Service issued a final decision that reduced temporary road construction by 45% to mitigate negative effects associated with water quality from sedimentation and overall hydrological watershed functions. In addition, the Forest Service eliminated timber harvests and road building in areas with sensitive soils, reducing detrimental impacts to wetlands and soil productivity by 67%.

- ***Modoc Restoration Project***[33] ***(Chemult District, Fremont-Winema NF)***: This project proposed an aggressive logging of white fir that would have resulted in virtual clear-cuts on Yamsay Mountain, a scenic feature of eastern Oregon that is central to the mythology of the Klamath people. Through the NEPA process, conservationists were able to convince the Forest Service to modify the heavy-handed treatments to culture individual legacy trees and thin the white fir on about 252 acres of the project, fewer acres than initially proposed. The project went forward under a decision notice and FONSI.

In sum, site-specific analysis is essential to informed review, and to enable the public to persuade agency decisionmakers to modify their proposals to avoid harm or to add mitigation measures. Even though NEPA does not require agencies to select the least harmful alternative, public input does shape agency incentives at all scales of decision-making. In addition, to avoid the necessity of preparing an EIS, agencies have strong incentives to modify or mitigate their actions to justify a FONSI.[34] Transparency regarding site-specific impacts is fundamental to ensuring that agencies are responsive and accountable to the members of the public most immediately affected. If agencies are permitted to make consequential project-level decisions without analysis, public scrutiny, or informed local input, the agencies will not have the

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[32] U.S. DEP'T OF AGRIC., U.S. FOREST SERV., DECISION NOTICE AND FINDING OF NO SIGNIFICANT IMPACT: SOMERSET INTEGRATED RESOURCE PROJECT (2020), https://www.fs.usda.gov/nfs/11558/www/nepa/108977_FSPLT3_5540552.pdf.

[33] U.S. DEP'T OF AGRIC., U.S. FOREST SERV., DECISION NOTICE AND FINDING OF NO SIGNIFICANT IMPACT: MODOC RESTORATION PROJECT (2011), https://www.fs.usda.gov/nfs/11558/www/nepa/1864_FSPLT2_057340.pdf.

[34] CEQ guidance recognizes and encourages these "mitigated FONSIs." *See* memorandum from Nancy H. Sutley, Chair of Council on Env't Quality, to Heads of Fed. Dep'ts and Agencies 7 (Jan. 14, 2011), https://ceq.doe.gov/docs/ceq-regulations-and-guidance/Mitigation_and_Monitoring_Guidance_14Jan2011.pdf (Memorandum entitled "Appropriate Use of Mitigation and Monitoring and Clarifying the Appropriate Use of Mitigated Findings of No Significant Impact").

information or incentive to address public concerns and avoid or mitigate risks. This result defies congressional intent behind our environmental laws.

Second, site-specific NEPA analysis is critical to promoting administration priorities, including advancing environmental justice and combating climate change. With respect to environmental justice, agencies cannot adequately analyze potential localized impacts to environmental justice communities without site-specific analysis. EPA's environmental justice guidance recommends that "an effort should be made to correlate the demographic analysis to the area most likely to bear environmental effects."[35] This is an impossible task for projects unless the agency discloses where an action is proposed to occur and draws a rational boundary for its effects analysis.[36] Furthermore, it is unfair and unrealistic to expect members of the public to anticipate how a generalized decision untethered from site-specific information will affect them in the future. This is particularly true of environmental justice communities, which often lack access to technical resources and face barriers to access the public participation process.[37]

With respect to climate change, site-specific choices at the project level add up to profound differences in the extent to which carbon storage potential is realized and the extent to which rare species' habitats are protected on national forest lands. While a single project may appear to have only a minor impact in light of the gravity of the climate and biodiversity crises, inherently site-specific differences between project options have significant cumulative implications for carbon storage. For example, there is a substantial difference between logging in moist and productive older forests versus removing small diameter material from dry and fire-prone ecosystems. The Forest Service routinely asserts that forest fuel treatments reduce the risk of high-intensity wildfire and carbon emissions from fire.[38] Yet the agency typically makes decisions about fuel removal on a project-by-project basis without properly analyzing the individual and cumulative impacts of these inherently site-specific choices. The result: the agency may in fact be liquidating resilient and carbon-sequestering forests in the name of climate change mitigation. Allowing the agency to duck the site-specific analysis requirement altogether simply amplifies the problem.

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[35] EPA, FINAL GUIDANCE FOR INCORPORATING ENVIRONMENTAL JUSTICE CONCERNS IN EPA'S NEPA COMPLIANCE ANALYSES § 3.2.1 (1998) [hereinafter EPA ENVIRONMENTAL JUSTICE GUIDANCE], https://bit.ly/3r7w7zj.

[36] *See* Vecinos para el Bienestar de la Comunidad Costera v. FERC, No. 20-1045, 2021 WL 3354747 at *5 (D.C. Cir. Aug. 3, 2021) ("When conducting an environmental justice analysis, an agency's delineation of the area potentially affected must but reasonable and adequately explained and include a rational connection between the facts found and the decision made.") (citations and internal quotation marks omitted).

[37] EPA ENVIRONMENTAL JUSTICE GUIDANCE, *supra* note 35, at §§ 4.0–4.2.

[38] *Cf.* U.S. DEP'T OF AGRIC., ACTION PLAN FOR CLIMATE ADAPTATION AND RESILIENCE 11–12 (2021), https://www.usda.gov/sites/default/files/documents/climate-smart-ag-forestry-strategy-90-day-progress-report.pdf (listing as a key Forest Service strategy to address climate change, "[i]ncrease the rate of fuels reduction to reduce the risk of severe wildfire," asserting that high-intensity wildfire "can move forests from being a solution to address our changing climate to a significant emitter of GHGs."). *See also* U.S. DEP'T OF AGRIC., CLIMATE-SMART AGRICULTURE AND FORESTRY STRATEGY: 90-DAY PROGRESS REPORT 17 (2021), https://www.sustainability.gov/pdfs/usda-2021-cap.pdf ("[Forest Service] will scale up its activities to accelerate the strategic implementation of hazardous fuel treatments and prescribed fire to reduce wildfire risks and to increase forest restoration and reforestation.").

To be sure, the Forest Service could analyze the balance between fuels treatments and carbon storage more efficiently at the programmatic or policy level, limiting its project-level discretion and focusing on priorities that are less likely to degrade carbon stocks and rare habitats. But site-specific analysis serves as an essential backstop, especially when the agency does not consider these tradeoffs at a higher level. Indeed, the requirement to conduct site-specific analysis of unresolved issues (like the balance between fuels reduction and carbon storage) creates a strong contextual incentive to zoom out and assess the problem programmatically. In short, analysis of carbon implications must occur *somewhere*. If analysis at the site-specific level is cumbersome, the Forest Service can make it more efficient by resolving issues at a higher level. But it simply cannot close its eyes to the problem in the name of "efficiency." Any perceived gains of omitting site-specific analysis now and rushing through ill-reviewed projects are dwarfed by the potentially damaging cumulative impacts of implementing those decisions.[39]

II. Agencies are failing to perform site-specific analysis where it is required and essential for informed decision-making.

Site-specific analysis of project-level decisions is a crucial aspect of nearly every federal agency's decision-making process—and certainly of those federal agencies tasked with managing America's public lands. This imperative has never been more apparent than today: when ecosystems are facing unprecedented stressors, agencies cannot blindly assume that they will be resilient to extractive management practices that in the past were considered routine.

Without considered and transparent site-specific analysis, agencies simply cannot make the informed decisions Congress and the courts have demanded of them. In recent years, agencies have not been meeting this obligation, particularly the Forest Service. For example, the Forest Service has aggressively proposed projects under the banner of "condition-based management" or "CBM," in which the disclosure of site-specific information and evaluation of those site-specific factors is deferred until after the NEPA process is complete. The use of CBM and other related practices discussed below demonstrate that guidance from CEQ is necessary to remind agencies of NEPA's essential obligations.

A. Condition-Based Management.

Condition-based management, as employed by the Forest Service for forest vegetation management projects,[40] represents an alarming and unlawful trend[41] that violates NEPA. At its

[39] CEQ has long warned of this phenomenon, calling it "the tyranny of small decisions." COUNCIL ON ENVIRONMENTAL QUALITY, CONSIDERING CUMULATIVE EFFECTS UNDER THE NATIONAL ENVIRONMENTAL POLICY ACT 1 (1997) (quoting William Odum, *Environmental Degradation and the Tyranny of Small Decisions,* 32 BIOSCIENCE 728 (1984)), https://www.energy.gov/sites/prod/files/nepapub/nepa_documents/RedDont/G-CEQ-ConsidCumulEffects.pdf; *see also* Kern v. Bureau of Land Mgmt., 284 F.3d 1062, 1078 (9th Cir. 2002) (quoting Odum).
[40] By focusing on vegetation management projects in this letter, we do not mean to minimize the importance of other contexts where condition-based management and related practices are occurring. Rather, these types of projects are clear examples where site-specific choices inherenrly carry different environmental consequences that are obscured by condition-based management.
[41] *See generally* Appendix 1.

core, CBM is a decision-making approach in which an agency postpones identifying or disclosing site-specific information in its analysis and instead purports to identify the conditions that will characterize the *types* of sites on which the agency wishes to act, without disclosing (or even knowing) where those actions may later be approved. The Forest Service proposed to codify this practice in 2019, explaining that CBM allows NEPA decisions to be made before the local characteristics (or impacts) are known or disclosed.[42] The proposal was abandoned, but the practice continues. To be sure, setting priorities by identifying common conditions in need of treatment can be both lawful and beneficial, but not at the expense of analyzing and disclosing site-specific impacts. For example, an agency could decide to focus on particular conditions in a programmatic NEPA decision and later analyze site-specific proposals in slimmer NEPA analyses that tier to the programmatic decision.[43] CBM, however, skips over the tiered decisions and proceeds to implementation without site-specific information and analysis during the NEPA process, violating NEPA.

Using the CBM "methodology" for vegetation management decisions (i.e., timber harvest for any purpose) the Forest Service generally: (1) proposes an action consisting of a set of loosely applicable project variables and possible mitigation techniques; (2) conducts a NEPA lookalike without disclosing where or when actions will occur; (3) approves the general proposal; and (4) only later, during project implementation and well after the NEPA decision has been made, identifies the specific locations to be managed, the specific management that will occur, and actual mitigation measures (if any). For this reason, documents available during NEPA's public participation opportunities do not provide site-specific information, analysis, comparison of alternatives, or mitigation because none exists at the time the document is issued. Put differently, the Forest Service's use of CBM deprives the public of critical opportunities to understand the precise nature of the agency's action and its potential environmental impacts, much less provide informed input to influence the decision based on site-specific impacts before project approval. In such scenarios, the "ambiguity about the actual location, concentration, and timing" of actions such as timber harvest and road construction "fails to provide a meaningful comparison of alternatives."[44]

Outside the context of vegetation management projects, to which CBM has so far been confined, the use of CBM would be rejected on its face as ridiculous. Imagine, for example, that the Department of Transportation identified "traffic congestion" as a condition warranting road capacity expansion, then declined to conduct analysis of the site-specific impacts of new road construction on particular communities and environmental resources. Or imagine that the Bureau of Land Management identified "windy areas" as conditions where windmills may be permitted, but then declined to consider site-specific impacts to bird migration paths. Such a process would not be tolerated by CEQ or the courts. Yet CBM is quietly becoming the new normal for Forest Service timber sales and other vegetation management projects.

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[42] *See* 84 Fed. Reg. 27,544 at 27,545, 27,553.
[43] *See* Appendix 1, Case Study: Dry Forests Restoration Project.
[44] Southeast Alaska Conservation Council v. U.S. Forest Serv., 443 F. Supp. 3d 995, 1014 (D. Alaska 2020).

As practiced by the Forest Service, CBM is incompatible with NEPA because the Forest Service never takes the requisite "hard look at the environmental consequences."[45] By failing to focus "agency and public attention on the environmental effects of proposed agency action,"[46] the Forest Service acts on "incomplete information" and risks "regret[ting] its decision after it is too late to correct."[47] Vague statements and conclusions about the environmental impacts of a project—lasting in some cases for 15 years or more[48]—and "deferring siting decisions to the future with no additional NEPA review . . . violates NEPA."[49]

One recent project demonstrates how a CBM approach violates NEPA's basic tenets. In 2017, the Forest Service identified 125,000 acres where timber harvest might occur on Prince of Wales Island in the Tongass National Forest ("Prince of Wales"), including 48,140 old-growth acres, and over 600 miles of potential new and temporary road construction.[50] The Forest Service subsequently authorized 40,000 acres of logging within this 125,000-acre area, including over 23,000 acres of old-growth forest, and over 160 miles of road construction.[51] The project would have been the largest single timber sale approved on the Forest in at least three decades. The Final EIS and record of decision ("ROD") authorizing the project's implementation did not include site-specific information on the "where" or "when" of road construction or logging. Indeed, the Service was explicit on this point: "[this p]roject proposes to harvest timber and build roads under all action alternatives, but it is *unknown at this time where on the landscape this would occur*,"[52] adding that "it is *not possible to determine* all of the direct, indirect, or cumulative impacts to wildlife habitat or connectivity that could result from this project before implementation."[53]

The Forest Service also attempted to use an ad hoc, post-decisional, implementation-phase public participation process that contained no formal, binding requirements on the agency, unlike the specific NEPA provisions for public participation.[54] The Forest Service proposed post-decisional, twice yearly "workshops" at which the public and Forest Service personnel would

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[45] Baltimore Gas & Elec. Co. v. Nat. Res. Def. Council, Inc., 462 U.S. 87, 97 (1983) (internal quotation marks omitted).
[46] Western Watersheds Project v. Kraayenbrink, 632 F.3d 472, 487 (9th Cir. 2011) (citing Marsh v. Oregon Nat. Res. Council, 490 U.S. 360, 371 (1989)).
[47] *Marsh*, 490 U.S. at 371.
[48] U.S. DEP'T OF AGRIC., U.S. FOREST SERV., EARLY SUCCESSIONAL HABITAT CREATION PROJECT: ENVIRONMENTAL ASSESSMENT 1 (2019), https://www.fs.usda.gov/nfs/11558/www/nepa/108891_FSPLT3_4658918.pdf.
[49] *Southeast Alaska Conservation Council*, 443 F. Supp. 3d at 1014.
[50] U.S. DEP'T OF AGRIC., U.S. FOREST SERV., PRINCE OF WALES LANDSCAPE LEVEL ANALYSIS PROJECT: FINAL ENVIRONMENTAL IMPACT STATEMENT 23 (2018), https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd601039.pdf.
[51] *Id.* at 5.
[52] *Id.* at 234 (emphasis added).
[53] U.S. FOREST SERV., APPENDIX D: RESPONSE TO COMMENTS ON THE DRAFT ENVIRONMENTAL IMPACT STATEMENT [FOR THE PRINCE OF WALES LANDSCAPE LEVEL ANALYSIS PROJECT DRAFT ENVIRONMENTAL IMPACT STATEMENT] 58 (2018), https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd601044.pdf (emphasis added).
[54] U.S. DEP'T OF AGRIC., U.S. FOREST SERV., PRINCE OF WALES LANDSCAPE LEVEL ANALYSIS PROJECT: RECORD OF DECISION: APPENDIX 2: IMPLEMENTATION PLAN (2018), https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd601049.pdf.

suggest "activities" to implement under the Project.[55] The Forest Service's plan, in other words, was that the public, even though deprived of meaningful site-specific information, would nevertheless be able to present:

> a wide array of activities for all resource areas . . . at these workshops, and that *those present* will help to *determine locations*, activity design components, methods, mitigation measures, and integration opportunities . . . . We will be requesting written substantive comments on changes to the activities listed, the locations, activity design components, methods, mitigation measures and integration opportunities . . . . The comment period will be 30 days. [The Forest Supervisor] will consider all comments received during workshops and comment periods to finalize activities for implementation that adhere to the FEIS, ROD, and Forest Plan.[56]

This public participation framework was entirely subjective and nonbinding because the Forest Supervisor would have the final decision regarding which activities to implement with no accountability during the life of the project. Moreover, the Forest Service and the Forest Supervisor were not actually bound to follow this voluntary process. Nor would the public be able to hold the agency accountable for failing to respond to public comments or ignoring contrary data or scientific studies, as would be required under NEPA.[57] Post-decisional participation schemes like this do not comport with the public procedural rights created by NEPA.[58]

Because the Forest Service did not provide any information—let alone formal analysis—of where, when, or how it would cut old-growth forest in the project area or construct logging roads, it failed to take the requisite "hard look" at the relevant impacts. Indeed, the agency could not meaningfully distinguish between alternatives, much less rationally select one. Following a challenge by conservation groups, the U.S. District Court for the District of Alaska ruled that the lack of site-specific analysis violated NEPA and vacated the roadbuilding and logging portions of the EIS.[59]

Although the Forest Service was prohibited from using CBM in the Prince of Wales project for logging and roadbuilding, the agency continues to pursue the practice elsewhere. On the Superior National Forest in Minnesota, the Tofte Landscape Project ("Tofte" or "Tofte Project") is a 333,470-acre, 15-year project designed to achieve certain silvicultural goals in the

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[55] U.S. DEP'T OF AGRIC., U.S. FOREST SERV., PRINCE OF WALES LANDSCAPE LEVEL ANALYSIS PROJECT: RECORD OF DECISION AND APPENDICES 1–4 at 30 (2019), https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd615347.pdf.
[56] *Id.* (emphasis added).
[57] Int'l Snowmobile Mfrs. Ass'n v. Norton, 340 F. Supp. 2d 1249, 1265 (D. Wyo. 2004) (holding that NPS acted in violation of NEPA where the agency gave minimal response to and "did not seriously consider" public comments); Ctr. for Biological Diversity v. U.S. Forest Serv., 349 F.3d 1157, 1167 (9th Cir. 2003).
(finding that USFS was "required to disclose and respond to" opposing scientific viewpoints in project FEIS); 40 C.F.R. § 1503.4 (2020).
[58] *Cf.* Sierra Club v. Marsh, 976 F.2d 763, 770 (1st Cir. 1992) ("Because public disclosure is a central purpose of NEPA, an EIS that does not include all that is required by NEPA may not be cured by memoranda or reports that are included in the administrative record but are not incorporated into the EIS itself.").
[59] Southeast Alaska Conservation Council v. U.S. Forest Serv., 443 F. Supp. 3d 995, 1011–12 (D. Alaska 2020).

2004 Forest Plan.[60] The project's draft EA also proposes 148 miles of new temporary road construction and an astonishing 2,305 miles of skid trail construction. The draft EA contains no site-specific analysis. Instead, it offers a non-binding, single scenario "estimated implementation plan," which the EA purports to analyze, but the draft EA reserves the agency's discretion to depart from the estimated plan at its election.[61]

As described more fully in the attached case study, the Tofte draft EA proposes a two-year "implementation cycle" in which the "where" (forest stands) and the "how" (stand treatments) of logging will be decided *after* the project is approved.[62] The agency says it will provide for a "30-day public participation period on proposed stand treatment list (published on website) with interactive online map," outside of the NEPA process, but does not spell out how, if at all, the agency will consider or respond to public comments during this post decisional process.[63]

This project—with its long-term implementation and unaccountable decision-making—is especially concerning because the project area abuts the Boundary Waters Canoe Area, one of the nation's iconic public land jewels. As with the Prince of Wales project, the Tofte Project involves an ersatz non-NEPA process that fails to ensure that environmental information is available to the public before decisions are made as the law requires.[64]

Our review of public participation opportunities associated with current and past CBM projects, like Prince of Wales and Tofte, indicates that the Forest Service is using *sui generis* post-decisional participation schemes as substitutes to the well-defined NEPA public participation mandate.[65] These post-decisional opportunities vary arbitrarily from project to project because they are designed on an ad hoc basis by lower-level staff in the absence of any regulation, handbook, or agency guidance. As CEQ understands, there is a serious danger when agencies even *paraphrase* NEPA's requirements,[66] and that danger is greater by orders of magnitude when local agency personnel make up their own unenforceable, and inconsistent, review processes from whole cloth. Because the public never gets to review "high quality"

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[60] Total project acreage is actually 435,327 acres, including non-Forest System lands. U.S. DEP'T OF AGRIC., U.S. FOREST SERV., TOFTE LANDSCAPE PROJECT: DRAFT ENVIRONMENTAL ASSESSMENT 5 (2021), https://www.fs.usda.gov/nfs/11558/www/nepa/110580_FSPLT3_5637846.pdf.
[61] *Id.* at 19; *see also id*., app. D, at 1–2, https://www.fs.usda.gov/nfs/11558/www/nepa/110580_FSPLT3_5637851.pdf.
[62] *Id.* at app. D.
[63] *Id*. at 3.
[64] Citizens for Better Forestry v. U.S. Dep't of Agric., 341 F.3d 961, 970–71 (9th Cir. 2003) ("[T]he very purpose of NEPA . . . is to 'ensure that federal agencies are informed of environmental consequences before making decisions and that the information is available to the public.'") (quoting Okanogan Highlands All. v. Williams, 236 F.3d 468, 473 (9th Cir. 2000)); *see also* 40 C.F.R. § 1500.1(b) (1978) ("NEPA procedures must insure that environmental information is available to public officials and citizens *before decisions are made* and before actions are taken.") (emphasis added).
[65] Weinberger v. Cath. Action of Haw./Peace Educ. Project, 454 U.S. 139, 143 (1981) ("The second aim [of NEPA] is to inform the public that the agency has considered environmental concerns in its decisionmaking process.").
[66] 40 C.F.R. § 1507.3(a) (1978) ("[E]ach agency shall as necessary adopt procedures to supplement these regulations. When the agency is a department, major subunits are encouraged (with the consent of the department) to adopt their own procedures. Such procedures shall not paraphrase these regulations. They shall confine themselves to implementing procedures.").

information during the planning process, the Forest Service's use of post-decisional participation opportunities in CBM projects is especially troublesome.

In addition to agency misapprehension of its public participation obligations under NEPA, the Forest Service appears to lack a clear understanding of the differences between programmatic, "adaptive," and more traditional planning methodologies such as tiering. CBM cherry-picks elements of each of these approaches but omits the core requirement that both broad-scale and site-specific impacts must be part of the NEPA review. For example, CBM bears resemblance to programmatic analysis, but omits or explicitly disclaims any commitment to future tiered, site-specific analyses and decisions under NEPA.

CBM also shares some commonality with adaptive management, in that it purports to make a final decision despite future uncertainty regarding the scope and impact of the decision. Adaptive management, however, is distinguishable as a tool that is utilized in the face of changing conditions that are not knowable at the time of decision. CBM projects on the other hand, involve inherent uncertainties that originate from the agency's own refusal to make choices and gather obtainable site-specific information before the agency makes decisions—a self-inflicted problem. Furthermore, the Forest Service's own regulations explain that adaptive management is not a blank check; it requires the agency to clearly identify the adjustments that may be made when monitoring during project implementation reveals the project is not having its intended effect, and that the NEPA analysis for the project must identify the monitoring that would inform an adjustment and disclose the effects of any adjustment.[67] In other words, under adaptive management, the NEPA process discloses the initial management strategy, the monitoring thresholds that would change that strategy, and the modified management strategy the agency may employ. But the Forest Service's CBM projects do not comport with its own understanding of adaptive management because all of those important decisions are not part of the NEPA process and are instead made unilaterally by the agency after the final decision.

CEQ has previously provided direction on "adaptive" NEPA approaches, recognizing that the traditional "one-time" NEPA analysis may not always be appropriate where changes in conditions may "negate any environmental protections in the original analysis."[68] In fact, in 2003, the NEPA Task Force issued a report that explicitly contemplated adaptive management strategies in the context of a programmatic approach.[69] In the 18 years since that report, however, federal agencies have begun to stray far from the adaptive frameworks CEQ has endorsed.

Compounding the problem, the Forest Service also seems to lack a consistent lexicon for describing its analytical creations. For example, in addition to CBM, the Forest Service has begun to recently employ what it variously calls "landscape vegetation analysis"[70] and

[67] *See* 36 C.F.R. §§ 220.5(e)(2) (EISs), 220.7(b)(2)(iv) (EAs).
[68] THE COUNCIL ON ENVIRONMENTAL QUALITY, THE NATIONAL ENVIRONMENTAL POLICY ACT: A STUDY OF ITS EFFECTIVENESS AFTER TWENTY-FIVE YEARS 32 (1997), https://ceq.doe.gov/docs/ceq-publications/nepa25fn.pdf.
[69] THE NEPA TASK FORCE, MODERNIZING NEPA IMPLEMENTATION 45 (2003), https://ceq.doe.gov/publications/modernizing_nepa_implementation.html (reporting to the CEQ).
[70] U.S. DEP'T OF AGRIC., U.S. FOREST SERV., *LaVA Project Implementation: Background and Implementation Information for the Medicine Bow Landscape Vegetation Analysis (LaVA) Project*, https://www.fs.usda.gov/detail/mbr/landmanagement/?cid=FSEPRD572816 (last visited Dec. 1, 2021).

"landscape-level analysis,"[71] among other descriptors. As a report from the Forest Service's Pacific Northwest Region recently described, "forest landscape analysis" can be applied in a variety of contexts because the Forest Service has no bright-line definition of "landscape."[72] Like integrated resource project analysis, "forest landscape analysis" contemplates project areas that are less than an entire forest unit (as captured in forest plans), but certainly more than "individual project area[s]" like traditional timber sales.[73] Of course, there is nothing inherent in conducting analysis at a landscape scale that is fundamentally incompatbible with NEPA, and landscape-level analyses can be site-specific and adaptive. On the other hand, the Forest Service has used the phrase as synonymous with CBM in projects such as Prince of Wales and the Medicine Bow Landscape Vegetation Analysis.[74] Regardless of what these CBM projects are called, their common thread is that the Forest Service plans projects on massive spatial and temporal scales, provides no site-specific analysis in the project-level documents, and provides no subsequent site-specific NEPA analysis at the implementation-level. This approach violates NEPA regardless of the terminology used.

Confusion about CBM has seeped into judicial decisions as well, including *WildEarth Guardians v. Conner* and *Southeast Alaska Conservation Council v. U.S. Forest Service* ("*SEACC*").[75] In brief, *Conner* upheld a CBM logging project authorized under an EA because the Forest Service concluded, and the court agreed, that site-specific choices about where timber harvests would occur were "not material" to whether the project would adversely affect threatened Canada lynx based on a worst-case-scenario analysis.[76] In *SEACC*, the court struck down the Prince of Wales project—also a CBM logging project—authorized under an EIS on the Tongass National Forest. The *SEACC* court reasoned that site-specific analysis was critical to discharging NEPA's mandate to fully evaluate alternatives in an EIS, and distinguished *Conner* because that case involved an EA rather than an EIS.[77]

SEACC is the only case to squarely address the illegality of CBM, and rightly concluded it was an unlawful violation of NEPA. Unfortunately, *SEACC's* dictum discussing *Conner* could be read to suggest that an EA may rely on CBM to forgo site-specific analysis for a condition-based project whereas an EIS cannot. Yet such a distinction would be inconsistent with the NEPA statute because EAs—just as EISs—must assess site-specific impacts as needed to

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[71] U.S. DEP'T OF AGRIC., U.S. FOREST SERV., *Prince of Wales Landscape Level Analysis Project* (*POW LLA*) *FAQs*, https://www.fs.usda.gov/detail/tongass/landmanagement/projects/?cid=fseprd628550 (last visited Dec. 1, 2021).
[72] U.S. DEP'T OF AGRIC., U.S. FOREST SERV., FOREST LANDSCAPE ANALYSIS AND DESIGN: A PROCESS FOR DEVELOPING AND IMPLEMENTING LAND MANAGEMENT OBJECTIVES FOR LANDSCAPE PATTERNS 3.1, https://www.fs.fed.us/pnw/pubs/flad/part_a.pdf (last visited Dec. 1, 2021).
[73] *Id.*
[74] *See supra* notes 70–71. Both projects are also discussed in attached case studies in Appendix 1.
[75] WildEarth Guardians v. Conner, 920 F.3d 1245 (10th Cir. 2019); Southeast Alaska Conservation Council v. U.S. Forest Serv., 443 F. Supp. 3d 995, 995 (D. Alaska 2020). Both cases and the underlying logging projects are discussed in attached case studies in Appendix 1.
[76] *Conner*, 920 F.3d at 1259.
[77] *Southeast Alaska Conservation Council*, 443 F. Supp. 3d at 1013 ("While an agency's analysis of a proposed action's maximum potential impacts may be appropriate for an EA, the Forest Service's analytical framework in this case is not sufficient to meet the requirements for an EIS.").

compare the differences in environmental consequences of alternatives,[78] an issue that was not briefed in *SEACC*.

Nor does *Conner* itself support reliance on CBM to forgo site-specific analysis in an EA where the decision has site-specific environmental consequences. *Conner* merely held that, as constrained by the Forest Service's decision, future site-specific choices were immaterial to the only issue raised by the plaintiffs—impacts to Canada lynx.[79] Like *SEACC*, *Conner* did not discuss NEPA's alternatives requirement under Section 102(2)(E), even though agency decisions like where to log or build roads are exactly the type of proposals that involve unresolved conflicts concerning alternatives uses of available resources. Furthermore, the *Conner* court was not asked to decide whether site-specific choices would have been material to these sorts of unresolved issues, such as impacts to forest health and composition, streams, or rare species other than Canada lynx. In litigation, plaintiffs sometimes focus on one or two key environmental resources, like sensitive species. And in such cases, it may be theoretically possible for an EA to withstand judicial review on the grounds that the proposed action would not have a significant impact on those one or two specific resources no matter where the action occurs. Such was the case with *Conner*. But *Conner* simply cannot be read as a blanket approval to make environmentally consequential site-specific decisions without site-specific information or analysis.

Although the holdings in both *SEACC* and *Conner* reinforce the fundamental requirement that site-specific analysis is needed where site-specific differences are material to an informed decision, the interplay between the decisions has clearly created confusion regarding the lawfulness of the CBM approach. This underscores the urgent need for CEQ to issue guidance. It is incumbent upon CEQ to preserve NEPA's integrity. If CEQ does not clarify that NEPA requires site-specific analysis in both EISs *and* EAs, there is a risk that *SEACC* and *Conner* will invite agencies to promote an EA versus EIS distinction that finds no support in the text or purpose of NEPA. This risk is all too real given that agencies are increasingly preparing EAs for projects that may in fact cause significant impacts.[80]

B. Other Related Problems.

The CBM approach outlined above is perhaps the most egregious way that agencies are avoiding the duty to analyze, disclose, and solicit public input on site-specific impacts when making project-level decisions, but it is not the only such failure. Other related practices share the same legal defects, and they are sometimes used in combination with CBM. These related practices further highlight the importance of CEQ guidance reaffirming the obligation to

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[78] 42 U.S.C. § 4332(2)(E); *see also* Greater Yellowstone Coal. v. Flowers, 359 F.3d 1257, 1277 (10th Cir. 2004) (quoting Highway J Citizens Group v. Mineta*,* 349 F.3d 938, 960 (7th Cir. 2003) ("An agency's obligation to consider reasonable alternatives is 'operative even if the agency finds no significant environmental impact.'"); ROBERT L. GLICKSMAN ET AL., NEPA LAW AND LITIGATION § 9:21 (2d ed. 2020) ("Alternatives must be considered in an environmental assessment as well as an environmental impact statement . . . .").

[79] *Conner,* 920 F.3d at 1258 (concluding that NEPA was not violated because "whatever sites [USFS] ultimately chooses (within the constraints imposed by the Project), there would not be a negative impact on the lynx").

[80] *E.g.,* Standing Rock Sioux Tribe v. U.S. Army Corps of Eng'rs, 440 F. Supp. 3d 1, 16–17 (D.D.C. 2020) (vacating pipeline easement and ordering agency to prepare EIS where agency argued EA was appropriate despite unrebutted expert testimony demonstrating safety of pipeline was "controversial" under NEPA).

consider a proposal's site-specific impacts before a decision is made. Brief descriptions of those practices are provided here.

1. *Worst-case Analysis.*

As *Conner* illustrates, land managers and other agencies have recently used a form of "worst-case analysis" that attempts to analyze the environmental consequences of the largest scale and most intensive activity potentially authorized by a project decision. Rather than comparing and contrasting the risks and benefits of site-specific alternatives, worst-case analysis shows only the maximum level of impact as a way to avoid comparing alternatives. Notably, this approach is very different from the worst-case analysis required by CEQ's 1978 regulations, which were amended to address this issue in 1985. In 1985, the question was whether an agency *must* use worst-case analysis to fill the gaps when data *are not* available or obtainable.[81] Here, the question is whether agencies *may* rely on a worst-case analysis to ignore site-specific differences among alternatives when data *are* available or obtainable. Obscuring knowable site-specific differences through a worst-case approach is inconsistent with an agency's obligation to transparently consider meaningful differences between site-specific alternatives when relevant data are available.

A NEPA process that "obscure[s] differences in impacts among alternatives" is facially unlawful.[82] In *Oak Ridge Environmental Peace Alliance v. Perry* ("*OREPA*"), the National Nuclear Security Administration ("NNSA") relied on what it called a "bounding" approach that "use[d] simplifying assumptions and analytical methods *that are certain to overestimate actual environmental impacts*."[83] Specifically, NNSA "bounded" its analysis of accident scenarios for each alternative considered by evaluating only what it considered the most likely possible accident (fire) and the accident with the most severe potential consequences (a plane striking the facility).[84] The agency did not, however, consider site-specific differences in risk, particularly the risk of earthquake.[85] Because information regarding those site-specific differences was obtainable, the reviewing court found that the agency must conduct further analysis.[86] As the court explained, NNSA's own parent agency the Department of Energy recognized that worst-case analysis in lieu of analyzing alternatives is impermissible "where more accurate and detailed assessment is possible and would better serve the purposes of NEPA," such as "where differences in impacts may help to decide among alternatives."[87]

The unlawful use of worst-case analysis to dodge site-specific analysis is not limited to condition-based projects, but it is a common element of such projects.[88] Where site-specific impacts will be materially affected by site-specific choices, *SEACC* and *OREPA* establish that

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[81] *See, e.g.*, Edwardsen v. U.S. Dep't of Interior, 268 F.3d 781, 785–86 (9th Cir. 2001) (holding that the agency properly used worst-case analysis to fill the gap where site-specific information (where an oil spill might actually occur) was not obtainable).
[82] Oak Ridge Env't Peace All. v. Perry, 412 F. Supp. 3d 786, 856 (E.D. Tenn. 2019).
[83] *Id.* at 855 (emphasis added).
[84] *Id.* at 820.
[85] *Id.* at 856–57 (emphasis in original) (internal citations omitted).
[86] *Id.* at 859.
[87] *Id.* at 857.
[88] *See, e.g.*, Appendix 1, Case Studies: Sage Hen Integrated Restoration Project and Tennessee Creek Project.

worst-case analysis cannot be used to obscure the differences between alternatives.[89] By statute, this limitation applies with equal force to EIS-level and EA-level decisions.[90]

2. *Best-case Analysis.*

Agencies have also failed to consider site-specific risks based on unfounded assertions that no environmental harm will occur so long as the agency uses best management practices (or project design criteria or similar mitigation measures) and professional judgment. In the South Red Bird Wildlife Enhancement Project in the Daniel Boone National Forest, for example, the Forest Service did identify specific locations for timber harvest, but provided no analysis of the site-specific *risk* associated with ground-disturbing timber harvest at those sites nor a comparison of lower risk in a scaled-down alternative, which excluded areas known to be at extreme risk of landslides. Instead, the agency stated in its EA and decision notice that it would follow best management practices and consult with specialists on site-specific design criteria during implementation—the same internal procedures that failed to prevent landslides in an earlier phase of the same project.[91]

NEPA requires agencies to consider actual project impacts and risks prior to a decision; they may not merely provide empty assurances —unsupported by analysis, untested by public review, and unaccompanied by site-specific mitigation commitments—that all will go according to the agency's plan. As the *OREPA* court explained, "the mere assertion that overall environmental consequences may be reduced if all goes according to plan does not allow [an agency] to avoid conducting a transparent and complete analysis in a timely fashion. To hold otherwise would turn NEPA into a dead letter."[92]

3. *Single-Scenario Analysis.*

Recent Forest Service projects have analyzed the site-specific impacts of a single possible implementation scenario, but leave the agency so much discretion at the implementation stage that the actual project may have far different environmental impacts than were evaluated in the

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[89] See appended case study for discussion of the Prince of Wales timber sale at issue in *SEACC*, in which the Forest Service opted for a worst-case analysis that assumed all forest included in the project would be clearcut while admitting that the "total acres estimated to be needed to meet timber needs are likely over-estimated and therefore the effects are likely over-estimated as well." This approach blurred potentially meaningful differences between alternatives in a similar way to *OREPA*; for example, the EIS's analysis of effects on wildlife stated that the effects "are similar between all alternatives because all alternatives assume that all acres proposed for timber harvest will be harvested." The District of Alaska held that this worst-case approach violated NEPA: "By focusing on the Project's maximum potential impacts for all alternatives rather than its actual or foreseeable impacts for each alternative, the EIS falls short of NEPA's directive to 'contain[] a reasonably thorough discussion of the significant aspects of the probable environmental consequences' for each alternative." Se. Alaska Conservation Council v. U.S. Forest Serv., 443 F. Supp. 3d 995, 1013 (D. Alaska 2020) (quoting WildEarth Guardians v. Montana Snowmobile Ass'n, 790 F.3d 920, 924 (9th Cir. 2015)).
[90] 42 U.S.C. § 4332(2)(C), (E).
[91] U.S. DEP'T OF AGRIC., U.S. FOREST SERV., DECISION NOTICE AND FINDING OF NO SIGNIFICANT IMPACT: SOUTH RED BIRD WILDLIFE HABITAT ENHANCEMENT PROJECT 2 (2021), https://www.fs.usda.gov/nfs/11558/www/nepa/107498_FSPLT3_5598895.pdf; U.S. DEP'T OF AGRIC., U.S. FOREST SERV., SOUTH RED BIRD WILDLIFE HABITAT ENHANCEMENT PROJECT ENVIRONMENTAL ASSESSMENT (2020), https://www.fs.usda.gov/nfs/11558/www/nepa/107498_FSPLT3_5237672.pdf.
[92] *Oak Ridge Env't Peace All. v. Perry*, 412 F. Supp. 3d 786, 858 (E.D. Tenn. 2019).

NEPA analysis. For example, the Tofte Project purports to provide some degree of site-specific analysis in an Estimated Implementation Plan ("EIP"), which identifies a default set of forest stands (small forested areas) for logging.[93] However, the Forest Service would retain full discretion to depart from the EIP based on a "flexible toolbox."[94] In addition, in the Francis Marion National Forest's Prescribed Burning Adaptive Management Strategy, the Forest Service analyzed one set of possible locations for dozer-created firelines, while retaining discretion to locate those firelines elsewhere.[95] NEPA requires pre-decision analysis of the sites where the project *will* occur, not merely where the project *may* occur.

4. *Determinations of NEPA Adequacy* (*DNAs*).

Determinations of NEPA Adequacy ("DNAs") are technically authorized by some agencies' regulations implementing NEPA,[96] but as applied are often an unlawful NEPA substitute. A DNA is an agency's determination that a new action has previously been adequately analyzed in an existing NEPA document, and a conclusion that no further environmental review is required.[97] Agencies tout DNAs to responsible officials as a "means by which you can use existing NEPA to cover your proposed action without doing additional NEPA analysis."[98]

Courts have upheld use of DNAs in narrow circumstances where the new action is in fact nearly identical to a prior action, like putting back up for sale the same lease parcel a year after it went no-bid and where there were no changes in environmental impacts in the meantime.[99] But if any circumstances on the ground change or new information becomes available, a DNA cannot be used as a substitute for NEPA analysis where there are site- or time-dependent differences, and especially not when a DNA would purport to authorize a new action in a new place.[100] In

[93] U.S. DEP'T OF AGRIC., U.S. FOREST SERV., TOFTE LANDSCAPE PROJECT: DRAFT ENVIRONMENTAL ASSESSMENT 10–11 (2021), https://www.fs.usda.gov/nfs/11558/www/nepa/110580_FSPLT3_5637846.pdf.
[94] *Id.* at 11.
[95] U.S. DEP'T OF AGRIC., FOREST SERV., PRESCRIBED FIRE MANAGEMENT ENVIRONMENTAL ASSESSMENT: FRANCIS MARION RANGER DISTRICT, FRANCIS MARION NATIONAL FOREST 8, 12, app. A (2020), https://www.fs.usda.gov/nfs/11558/www/nepa/109253_FSPLT3_5221545.pdf.
[96] Interior Department regulations require that, before using existing NEPA documentation for a new action, the agency support a finding that the prior analysis "adequately assesses the environmental effects of the proposed action and reasonable alternatives" and evaluate whether "new circumstances, new information or changes in the action or its impacts not previously analyzed may result in significantly different environmental effects." 43 C.F.R. § 46.120(c). Forest Service regulations require that the new proposed action be "substantially the same as a previously analyzed proposed action," with further requirements that the DNA be subject to scoping and include issuance of a new decision document when approved. 36 C.F.R. § 220.4(j). While the Forest Service authority has not yet been widely used, it invites the same kinds of abuses as Interior's DNAs.
[97] *See* Bureau of Land Mgmt., *Presentation on Determination of NEPA Adequacy*, #1620-16 at 5, https://www.ntc.blm.gov/krc/uploads/456/1620-16_PPTs+Exercises.pdf (last visited Dec. 1, 2021).
[98] *Id.*
[99] *See* Rocky Mtn. Wild v. Bernhardt, 506 F. Supp. 3d 1169, 1188–89 (D. Utah 2020) (upholding BLM's reliance on a DNA for issuing oil and gas leases where it had performed an EA on those same lease parcels the prior year but the parcels had not sold); Friends of Animals v. BLM, 232 F. Supp. 3d 53, 60–61 (D.D.C. 2017) (finding that BLM's 2008 EA analyzing the gathering of 573 wild horses for a fertility control vaccine and removing 447 was sufficient without further NEPA analysis to support a 2016 plan to gather up to 700 horses and permanently remove up to 300).
[100] *See* Rocky Mountain Wild v. Haaland, No. 18-cv-02468-MSK, 2021 WL 4438032, at *6 (D. Colo. Sept. 29, 2021) (holding that BLM violated NEPA because DNA failed to consider impacts to wilderness characteristics that

practice, however, DNAs create an overbroad process that encourages just that kind of abuse. The BLM Handbook gives discretion to the BLM officer to decide whether public involvement is necessary and what form it should take.[101] BLM encourages its field officials that "[a] public comment period may be unnecessary . . . if site specific analysis is rarely commented on and there is no or minimal public or stakeholder engagement for routine or similar EAs."[102] An agency cannot foreclose future opportunities for public comment mandated by NEPA simply because past projects—which, even if for a similar action, could have substantially different environmental impacts depending on the site at which they occurred—were not controversial. Such an approach begs the question whether the different location involves different environmental consequences, which is unknown without analysis and informed public input.

5. *Unfinished Proposals.*

The Forest Service sometimes proposes projects that violate NEPA simply because the agency barrels ahead before finishing its analysis. These proposals are especially baffling because the agency ostensibly intends to develop a traditional, site-specific proposal, but local agency personnel's haste to sign decisions leads to omission of site-specific analysis just the same. Unlike typical CBM projects in which the agency defers choosing where or how it will act until after the conclusion of the NEPA process, unfinished proposals tend to involve situations where the agency has identified where it proposes to act but has not identified what resources are present at those locations or how they will be impacted.

For example, in the Sandy Ridge Short Leaf Pine Restoration Project on the George Washington National Forest,[103] the Forest Service identified a general area where some acres would receive heavy timber harvest, some thinning, and some left as a "control" with no logging.[104] The EA acknowledges that when the decision was final, the "distribution of thinning and regeneration" and the "specific location" of treatments and roads would remain indeterminate.[105] Like CBM projects, the deferred choices will have different results depending on the ultimate locations chosen for the various actions. Unlike most CBM projects, however, the agency does not argue that it needs future flexibility to respond to changing conditions; it

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were not accounted for by prior NEPA decision concerning a different area); Triumvirate, LLC v. Bernhardt, 367 F. Supp. 3d 1011, 1027 (D. Alaska 2019) (finding that BLM improperly relied on a DNA for a permit that would allow three heli-ski operators to make 390 landings per season where a prior EA only considered the impacts of one heli-ski operator making 130 landings per season); WildEarth Guardians v. Bernhardt, 423 F. Supp. 3d 1083, 1103–04 (D. Colo. 2019) (finding that DOI's decision to find an existing EIS adequate in a DNA was arbitrary and capricious where the EIS assumed no perennial springs or streams existed in the project area but information contradicting that assumption became available between the EIS and DNA); Friends of Animals v. BLM, No. 3:15-CV-0057, 2015 WL 555980, at *3–4 (D. Nev. Feb. 11, 2015) (finding that BLM's 2010 EA analyzing the gathering of 199 wild horses for a fertility control vaccine and removing 67 could not support a 2014 plan to gather 322 horses and permanently remove 200).

[101] BUREAU OF LAND MGMT., NATIONAL ENVIRONMENTAL POLICY ACT HANDBOOK H-1790-1 at 24 (2008), https://www.blm.gov/sites/blm.gov/files/uploads/Media_Library_BLM_Policy_Handbook_h1790-1.pdf.

[102] BUREAU OF LAND MANAGEMENT, NEPA EFFICIENCIES FOR OIL AND GAS DEVELOPMENT, Information Bulletin No. 2018-061 (June 6, 2018), https://www.blm.gov/policy/ib-2018-061.

[103] U.S. DEP'T OF AGRIC., U.S. FOREST SERV., SANDY RIDGE YELLOW PINE ENHANCEMENT PROJECT: ENVIRONMENTAL ASSESSMENT 10–12, 15 (2021), https://www.fs.usda.gov/nfs/11558/www/nepa/100648_FSPLT3_5659322.pdf.

[104] *Id.*

[105] *Id.* at 11, 62.

simply hasn't finished putting together what is otherwise a proposal for a very ordinary project. This is perplexing because the agency is clearly capable of gathering the missing location-specific data and completing the missing analysis, and indeed intends to do so before implementation. It simply failed to inform its decision and the public in its NEPA analysis.

Similarly, the National Forests in North Carolina recently issued a draft EA purporting to analyze broad-scale use of herbicides to maintain existing wildlife openings, with the promise that site-specific "maintenance plans" would be forthcoming.[106] As in the Sandy Ridge project, the agency expects to make traditional, site-specific choices before acting; it has just failed to give the public a chance to understand the impacts of those choices in the NEPA process.

III. An agency need not jettison site-specific NEPA analysis to achieve its mission.

Despite the importance of site-specific NEPA analysis and public input, agencies (and especially the federal land management agencies) are increasingly seeking to "innovate" in the NEPA process, but as discussed above, this often results in skipping site-specific detailed analysis and precludes meaningful and informed public engagement. In the following section, we address the agencies' asserted need to take these measures, explain why those assertions are misguided, and propose NEPA-compliant solutions to the proffered problems.

One important reason for the spread of inadequate analyses is a lack of agency guidance explaining which NEPA approaches are available and their comparative advantages and disadvantages. Indeed, because of a chronic lack of investment in structured NEPA training, practitioners often "learn NEPA" from their peers, very few of whom have ever had any kind of professional or legal NEPA training.[107] Moreover, this "peer learning" is often outdated and not based on recent case law or new federal law. As a result, NEPA processes follow fads or attempt to replicate processes from other places, despite contextual, practical, and legal differences. CEQ should reaffirm the appropriate approaches it has long endorsed, such as programmatic analysis, and clearly explain why current agency practices are inconsistent with those valid approaches and best practices.

Without intervention by CEQ, agencies will continue pushing the boundaries to avoid site-specific analysis. The Forest Service has been particularly upfront about its reasons for abandoning "traditional" NEPA planning:

> [T]raditional planning methods result in the inability to implement some of the treatments. Years may pass between the decision and the time of implementation. Changed conditions caused by disturbances . . . forest succession, or imperfect information at the time of analysis may result in situations where forest stands should not be treated as expected to move them toward desired conditions, and

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[106] U.S. DEP'T OF AGRIC., U.S. FOREST SERV., WILDLIFE OPENING MANAGEMENT ON THE NATIONAL FORESTS IN NORTH CAROLINA: ENVIRONMENTAL ASSESSMENT 8–9 (2021), https://www.fs.usda.gov/nfs/11558/www/nepa/110681_FSPLT3_5661301.pdf.

[107] *E.g.,* Chris French, *Environmental Analysis and Decision Making Workshop*, Phoenix, Arizona (2017).

> traditional planning does not allow the flexibility to modify the needed treatment.[108]

In other words, because of changing conditions or inaccurate information used in the NEPA process (or timber sale purchaser decisions to defer harvest for multiple years to "play the market" or harvest more lucrative timber elsewhere first), a site identified for a specific treatment may need a different treatment (or no treatment at all) by the time the Forest Service is ready to take action on the ground. Of course, the Forest Service always retains the discretion to take no action when it encounters changed conditions, and nothing prohibits the agency from analyzing a range of potential treatments that may be needed to achieve the desired future condition at a particular site, using adaptive management to tailor treatment based on monitoring triggers, or supplementing its original analysis when warranted by changed conditions. In recent decisions, however, the Forest Service is seeking increased post-decisional flexibility not only to adapt *treatment* to a particular site, but rather to pick and choose *sites* for a particular treatment or treatments.

This pursuit of unlawful "flexibility" is also driven in part by a desire to have more acres approved in the NEPA process so that they can be implemented when resources are available.[109] As Fleischman reports, the Forest Service is making fewer decisions overall, perhaps due to inadequate funding and staffing,[110] but the agency faces growing pressure to meet higher targets for timber production and fuels reduction regardless of available human and financial resources.[111] The only way to achieve higher outputs in fewer decisions is to propose larger projects. Unfortunately, the agency lacks the capacity to gather baseline data, generate site-specific prescriptions for action, and analyze site-specific and cumulative effects at those larger scales.[112] Thus, the Forest Service concluded for one project:

> A larger project area with a longer timeframe (15 years) for implementation calls for more flexibility to update treatment design in consideration of changing conditions. The condition based management approach on a larger project area would allow for greater progress . . . than would planning a static set of treatments and stands in a smaller project.[113]

Stated more simply, the agency believes it can cover more ground if it does not take the time to analyze site-specific impacts in the NEPA process. Even if true, NEPA's goal is *better*

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[108] U.S. DEP'T OF AGRIC., U.S. FOREST SERV., TOFTE LANDSCAPE PROJECT: DRAFT ENVIRONMENTAL ASSESSMENT 19–20 (2021), https://www.fs.usda.gov/nfs/11558/www/nepa/110580_FSPLT3_5637846.pdf.
[109] *See* SELC Comments on Proposed NEPA Rule, *supra* note 30, at 57.
[110] Forrest Fleischman et. al., *U.S. Forest Service Implementation of the National Environmental Policy Act: Fast, Variable, Rarely Litigated, and Declining*, 118 J. FORESTRY 403, 404-18 (2020), https://forestpolicypub.b-cdn.net/wp-content/uploads/2020/04/FleischmanEtAl.NEPA-JOF.pdf.
[111] SELC Comments on Proposed NEPA Rule*, supra* note 30, at 55; Letter from Shalanda D. Young, Acting Director of the Off. of Mgmt. & Budget, to Senator Patrick Leahy, Chairman of the Committee on Appropriations (Apr. 9, 2021), https://www.whitehouse.gov/wp-content/uploads/2021/04/FY2022-Discretionary-Request.pdf (requesting $1.7 billion for forest fuel reduction).
[112] *Id.* at 58.
[113] U.S. DEP'T OF AGRIC., U.S. FOREST SERV., TOFTE LANDSCAPE PROJECT: DRAFT ENVIRONMENTAL ASSESSMENT 20 (2021) [hereinafter TOFTE LANDSCAPE PROJECT DRAFT EA], https://www.fs.usda.gov/nfs/11558/www/nepa/110580_FSPLT3_5637846.pdf.

decisions, not simply *more action*.[114] "More action" comes from better resourced federal agencies, not circumvention of NEPA.

The Forest Service's novel approach to NEPA defers critical site-specific choices until after the decision has been made, "at time of implementation."[115] This is the key to understanding the problem: the Forest Service does not claim that gathering and considering site-specific information is wholly unnecessary; it admits that site-specific decisions need site-specific information *at some point*. Instead, it claims that the drag comes from making that information available in a transparent NEPA process that considers and is responsive to public input, and for which the agency can be held accountable if it ignores science or fails to respond to the public. CEQ should not turn a blind eye to what amounts to an existential threat to NEPA—the claim that the statute's procedural safeguards and informed public input are just *not worth the effort*.

As explained above, site-specific NEPA results in beneficial improvements to proposed actions, avoiding significant harms both in individual projects and cumulatively. These improvements come with a low cost. NEPA's procedural requirements do not themselves add considerable time to decision-making. Comment periods are typically 30 to 45 days, and project development can carry on while comments are solicited.[116] The Forest Service, in particular, is ahead of the pack when it comes to NEPA timelines, completing decisions faster than other agencies.[117]

Yet while most Forest Service projects move through the NEPA process quickly, a few projects encounter resistance and delay. Of course, speedy projects and slow projects are subject to the same NEPA rules, so the procedures themselves cannot take the blame. Instead, delays are attributable to not only inadequate funding and staffing, but also the substantive conflicts that the NEPA process sometimes brings to light (and indeed was designed to surface). CEQ's guidance should explain that agency strategies to avoid conflict should center around bringing forward and refining *better proposals* with broad public buy-in, not removing public scrutiny. In addition to early and iterative collaboration with interested stakeholders, the proven way to increase efficiency, at scale, consistent with NEPA requirements, is to employ programmatic analysis and decision-making prior to identifying and planning individual projects.

An agency may prepare a "programmatic" NEPA document broadly analyzing the cumulative effects of a program of work or set of connected actions, to which subsequent site-specific analyses may "tier."[118] Well-designed programmatic analysis can increase the efficiency in agency decision-making by deferring site-specific decisions for which site-specific information would be time consuming to obtain. NEPA analysis works like a funnel, where the mouth is the full breadth of the agency's discretion and the spout is concrete, on-the-ground

[114] *See* 40 C.F.R. § 1500.1(c) (1978) ("[I]t is not better documents but better decisions that count. NEPA's purpose is not to generate paperwork—even excellent paperwork—but to foster excellent action.").
[115] *See, e.g.*, TOFTE LANDSCAPE PROJECT DRAFT EA, *supra* note 113, at 20.
[116] *See, e.g.*, 36 C.F.R. § 218.25.
[117] Fleischman et al., *supra* note 110, at 404.
[118] Ventling v. Bergland, 479 F. Supp. 174, 179 (D.S.D. 1979), *aff'd*, 615 F.2d 1365 (8th Cir. 1979); Earth First v. Block, 569 F. Supp. 415 (D. Or. 1983) (holding that the Forest Service erred by relying on a programmatic EIS that was deemed insufficient by the Ninth Circuit to prepare a subsequent EIS for the same Wilderness Area).

action. If an agency is starting from scratch every time, its site-specific analyses will be unwieldy and duplicative. Programmatic analysis, however, moves the agency partway down the funnel, putting sideboards on future actions and commensurately reducing the complexity of site-specific analysis.

Land management agencies already use programmatic NEPA analysis in support of Forest Service Land and Resource Management Plans or BLM Resource Management Plans. However, these long-lived documents are often very broad and do not move the agency far down its decision-making funnel; indeed, increasingly, land management plans are so broad as to be meaningless in determining any type of environmental effect. Plans could do a better job setting priorities and sideboards that can make future site-specific analyses more efficient. Where they fail to do so, however, programmatic *projects* can take a middle step from land-management plans to site-level decisions. For example, the Cherokee National Forest Dry Forests Restoration project[119] sets forth a set of treatment priorities (conditions in need of vegetation management for ecological restoration) and establishes conservative sideboards to protect against cumulative impacts to soil, water, and roadless area values.[120] Future site-specific decisions will be made in concise EAs that are tiered to the programmatic document.[121] Because cumulative, repeating impacts were already analyzed at the programmatic stage, the site-specific EAs need only analyze issues unique to the particular sites.[122] This is how programmatic and tiered analysis *should* work.

Yet while programmatic analysis and tiered decision-making can increase agency efficiency, we note that it is not an exception to the requirement that site-specific analysis and public comment on that analysis precede site-specific decisions. In other words, agencies may not play a shell game. If site-specific impacts are not considered at the programmatic stage, they must be considered in a subsequent tiered analysis.[123] As courts have recognized, sometimes a "program may be so broad in scope that a site-specific EIS" for an action under that program "is the only manner in which the objectives of NEPA can be met."[124] But in those cases "a programmatic EIS will often be insufficient as it relates to site-specific actions," as these high-level analyses inherently lack site- and project-specific details that are required to satisfy NEPA's mandates.[125] Thus, subsequent tiered decisions must address site-specific impacts. On the other hand, where a programmatic decision *does* constrain future site-specific choices, site-specific analysis is sometimes required even at the programmatic stage.[126] Programmatic

[119] *See* Appendix 1, Case Study: Dry Forests Restoration Project.
[120] *Id.*
[121] *Id.*
[122] *Id.*
[123] *E.g.,* Western Watersheds Project v. Abbey, 719 F.3d 1035, 1035 (9th Cir. 2013).
[124] *Id.*; WildEarth Guardians v. Montana Snowmobile Ass'n, 790 F.3d 920 (9th Cir. 2015).
[125] Ventling v. Bergland, 479 F. Supp. 174, 180 (D.S.D. 1979).
[126] *See, e.g.*, California v. Block, 690 F.2d 753, 757–63 (9th Cir. 1982) (holding invalid a programmatic EIS that did not adequately consider the site-specific impacts of designating 36 million acres of roadless areas for "non-wilderness" because a Forest Service regulation required the agency to manage "non-wilderness" areas in a certain way such that future decisions concerning the areas would be constrained by the choice of designation); *see also Montana Snowmobile Ass'n*, 790 F.3d at 922–27 (holding invalid a programmatic EIS designating over 2 million acres of national forest land for use by snowmobiles and other winter motorized vehicles where the EIS did not provide site-specific analysis of how the designated acreage would overlap with moose range, whether the

analyses, like all analyses, must support the agency's decision by disclosing and considering the relevant impacts of that decision. When those impacts are site-specific, so too must be the analysis. No matter whether a decision is characterized as "condition-based," programmatic, or otherwise, site-specific analysis and disclosure is essential during the NEPA process when consequential site-specific decisions are being made.

CONCLUSION

We support agency efforts to improve their decision-making processes, including efforts (such as programmatic analyses and decisions) that set broad priorities and broad-scale sideboards for future action. But NEPA does not permit agencies to bypass the requisite detailed, site-specific analysis for project-level EAs or EISs. Recent approaches to NEPA like CBM undermine the public's ability to: (1) notify agencies of issues they may have overlooked; (2) encourage agencies to adopt different alternatives or mitigation measures; and (3) hold agencies accountable when they ignore public comments or contrary scientific evidence. These failures cannot be cured by ersatz, post-decisional public involvement processes.

We urge CEQ to provide guidance and/or regulations that clarify NEPA's requirements for site-specific analysis to restore public involvement in project-level decisions, improve agency transparency, and improve project design.

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designation would affect that range, and whether there were alternatives that would avoid adverse impacts to moose and other big game wildlife).

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Appendix 1: Case Studies

Condition-based Management Projects

Programmatic Project

Name of Project: Black Hills Resilient Landscapes ("BHRL") Project

Location: Black Hills National Forest ("BHNF"); South Dakota and Wyoming

Responsible Official: Mark Van Every, Forest Supervisor

Forest Service Stated Purpose & Need: To reduce "hazards," move forest structure and composition toward "objectives," and increase ecosystem resilience to disturbances such as severe wildfire and mountain pine beetle infestation.[1]

Proposed Activities:[2]

- 18 miles of new permanent road construction
- Up to 20 miles of existing unauthorized roads reconstructed
- Up to 39 miles of temporary road construction
- Up to 182 miles of existing unauthorized roads may be used as temporary roads
- Reconstruction of an estimated 375 miles of roads
- Mechanical and manual fuel reduction, prescribed fire, hazard tree removal
- Timber harvest and precommercial thinning

Timeline: Officially proposed in August 2016; DEIS published for comment in Sept. 2017; FEIS published in April 2018; Final ROD issued in July 2018.

Authorities Used: NEPA, NFMA, ESA, HFRA, NHPA, BHNF Land and Resource Management Plan Phase II Amendment, National Cohesive Wildland Fire Management Strategy

Summary of Analysis:

- The final EIS includes:
  - A project implementation framework using resource-specific "design features."[3] The EIS incorporates by reference several documents it represents "contain standard design features that apply to this project."[4]
  - The EIS represents that "[p]arties responsible for implementation of proposed activities would coordinate activity layout and design with managers of affected resources."[5]
- The final EIS failed to disclose:
  - Where new permanent and temporary roads would be constructed. This omission is crucial because the Forest Service could construct 18 miles of new permanent roads nearly anywhere in the BHNF. Because the Forest Service does

[1] Final Environmental Impact Statement for the Black Hills Resilient Landscapes Project at i.
[2] *Id.* at i, 37, 48.
[3] *Id.* at 51.
[4] *Id.* at 40.
[5] *Id.* at 17.

not know the locations of the roadbuilding, the Forest Service did not analyze site-specific impacts.
  - Where fuel treatments will specifically occur. Providing a pool of acres where the fuel treatments may occur is not the same as deciding and analyzing exactly where the treatments are going to occur. Therefore, BHNF did not make an informed decision about the impacts of fuel treatments.
  - Where logging will occur. The EIS represents that commercial timber harvesting will occur on up to 185,210 acres within a 300,000 acre area.[6] Without deciding and analyzing exactly where cuts will take place, and when, BHNF did not take the requisite hard look that NEPA requires.
  - How exactly the vaguely incorporated design criteria will translate into on-the-ground implementation for site-specific actions. In other words, the EIS took away any opportunity for meaningful public participation at the project-level analysis phase (the EIS) and during the project implementation phase.
- Values at risk: Loss of habitat for certain wildlife and plant species; soil and timber productivity lost where roads are built; air quality diminished from prescribed burn smoke and dust from road construction; increase in noxious weeds; scenic views temporarily diminished; recreation sites may be impaired and unavailable.

Status: Implementation Stage, Final ROD published on July 20, 2018.[7]

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[6] *Id.* at 26.
[7] Black Hills Resilient Landscapes Project Final Record of Decision, at https://www.fs.usda.gov/nfs/11558/www/nepa/103904_FSPLT3_4389333.pdf.

Name of Project: Early Successional Habitat Creation ("ESHC") Project

Location: Manchester Ranger District, Green Mountain National Forest ("GMNF"), Vermont

Forest Service Stated Purpose & Need: To create early successional habitat as provided for in 2006 Forest Plan; to improve neotropical migrant bird habitat.[1]

Proposed Activities: As originally conceived, the project authorized up to 15,000 acres of mostly even-aged management, and 17 miles of new permanent road construction, and 25 miles of total road construction, which exceeded the amount of road building authorized in the GMNF Land and Resource Management Plan. The project will last for 15 years.[2]

Timeline: The Green Mountain National Forest first proposed the project in May 2018; the EA issued in February 2019 (the public was not allowed to comment on the EA); the DN and FONSI were released in June 2019.

Authorities Used: NEPA, NFMA, ESA

Summary of Analysis:

- The EA adopts a fixed set of resource-specific "design criteria" to implement site-management objectives. The EA admits that "varying site-specific conditions [will] dictate which design criteria to apply depending on the type of harvest treatment method prescribed, level of road and location for access selected, and other site-specific factors."[3] Moreover, regarding roads, "the specific level, amount, and location of road infrastructure needed would be based upon site-specific conditions identified during project planning at the time of implementation."[4] In short, the project does not include site-specific NEPA analysis, and the public therefore cannot comment on site-specific impacts.
- The most troubling site-specific analysis omission is the failure to identify the specific location of roads, both new permanent roads and new temporary roads. The ESHC project is among the largest logging projects on the GMNF in recent years. Without disclosing site-specific road locations, the GMNF is unable to take the requisite hard look at the site-specific impacts of roadbuilding.
- Another omission is the failure to identify where exactly the harvests would take place. Though the harvest pool was identified as 17,274 acres, exactly which 15,000 acres will actually be harvested was not disclosed during the project analysis.[5] Several potential

[1] Early Successional Habitat Creation Project website at https://www.fs.usda.gov/project/?project=53629&exp=detail.
[2] Decision Notice and Finding of No Significant Impact for the Early Successional Habitat Creation Project at 4.
[3] Draft Environmental Assessment for the Early Successional Habitat Creation Project at 18.
[4] *Id.* at 15.
[5] Decision Notice and Finding of No Significant Impact for the Early Successional Habitat Creation Project at 4.

harvest units, including one unit in a completed timber sale, abut designated wilderness areas.

- The public has no way to meaningfully weigh in on what types of harvest treatments are going to be used, nor where the roads to facilitate the logging will ultimately end up. The project asks the public to trust the utilization of design criteria, while never doing the site-specific analysis required for a site-specific project.

Status: "Analysis completed"; four timber sales completed; a Supplemental Information Reports ("SIR") published related to road construction on the GMNF, which included elements of this project, and an additional SIR is expected to be released in late December 2021 or early January 2022 to make specific modifications to the project.

Name of Project: Landscape Vegetation Analysis ("LaVA") Project[1]

Location: Medicine Bow National Forest, Wyoming

Forest Service Stated Purpose & Need: Respond to changed forest vegetation conditions caused by the bark beetle epidemics on the Medicine Bow National Forest.[2]

Proposed Activities: Authorizes up to 288,000 acres of vegetation management (including up to 86,119 acres of clear-cutting), and up to 600 miles of temporary roads, somewhere within a project area of 850,000 acres over the next 15 years.

Timeline: Notice for scoping 2017; FEIS issued March 2019; Draft ROD withdrawn June 2019; Modified FEIS April 2020; Final ROD signed Aug. 2020, Fall 2020 Mullen fire and corresponding Aug. 2021 supplemental information report ("SIR").

Authorities Used: NFMA, NEPA, Healthy Forests Restoration Act and Farm Bill Amendment (2003 and 2014), 2003 Medicine Bow Forest Plan, Governor's Task Force on Forests (Bannon et al. 2015), Western Bark Beetle Strategy (USDA Forest Service 2011), and the Wyoming Statewide Forest Resource Strategy (Wyoming State Forestry Division 2010).

Summary of Analysis: The final ROD identified 288,000 acres of treatment opportunity areas, and excluded inventoried roadless areas from potential treatment. The Forest Service's analysis did not identify where within the 850,000-acre project area the agency intends to log or build roads. The analysis failed to disclose relevant site-specific details including the location, timing, and specific type of vegetation management (commercial thin, clear-cut, or other treatment) of treatment areas or particular units. It also failed to disclose the location and mileage of system and temporary roads necessary to accomplish the vegetation treatments.

As its "condition-based" analysis the Forest Service relies on an Adaptive Implementation and Monitoring Framework with five phases to identify, refine, field verify, implement, and monitor individual treatments over 15 years.[3] All phases occur after NEPA and a final decision. The agency invites public engagement via a web-based mapping application for the first two phases (identify and refine). There is no public feedback opportunity after field verification, when site-specific details will be disclosed, and no ability to hold the agency accountable for failing to respond to comments or scientific data.[4]

Without details on project implementation, it is impossible to determine how project activities relate to and may impact important factors such as: old growth, habitat for imperiled wildlife, at-risk watersheds, sources of drinking water, inventoried roadless areas, and recommended wilderness. Values at risk include 41,516 acres of old-growth forest identified for

[1] *See* Medicine Bow Landscape Vegetation Analysis Project website: https://www.fs.usda.gov/detail/mbr/landmanagement/?cid=FSEPRD572816 (last accessed Dec. 17, 2021).
[2] *See* U.S. Forest Service, Modified Final Environmental Impact Statement (April 2020), page 31.
[3] U.S. Forest Service, Medicine Bow Landscape Vegetation Analysis Project Record of Decision (Aug. 2020), pg 11.
[4] Per Forest Service response to questions during the project's first virtual public workshop on June 9, 2021.

logging, thinning, burning, and other "treatments." The project will destroy 29,870 acres of suitable lynx habitat, and degrade watershed conditions for impaired and at-risk watersheds.

Status: Forest Supervisor Bacon signed the ROD on Aug. 13, 2020. Nine individual treatments are in implementation phase, covering more than 2,500 acres.[5]

[5] *See* Aug. 2020 ROD at 43-33. *See also* LaVA Story Map, *available at* https://usfs.maps.arcgis.com/apps/MapSeries/index.html?appid=ca50896c133c414490f7255d01565aae (last accessed Dec. 17, 2021).

Name of Project: George Washington and Jefferson National Forests Oak and Woodland Restoration Project

Location: George Washington ("GW") and Jefferson National Forests, Virginia; Deputy Forest Supervisor Beth LeMaster

Forest Service Stated Purpose & Need: Manage white pine stands to promote growth of oaks, hickories, yellow pines, and other species

Proposed Activities: The project area is the entirety of both the George Washington and Jefferson National Forests.[1] The Forest Service is proposing to treat "approximately" 1,100 acres per year on the GW National Forest and 700 acres per year on the Jefferson National Forest.[2] Logging methods would range from clearcutting to thinning.[3] The project authorizes one mile of temporary road construction for each "implementation project."[4] The scoping letter does not state the expected duration of the project's implementation but agency personnel stated in a public meeting that they intended to continue implementation until the NEPA documentation becomes stale.

Timeline: Unclear. This project was scoped in October 2020, but no draft or final EA has been released. The project appears on the schedule of proposed actions, where it is denoted "on hold" as of December 2021.

Authorities Used: NEPA, NFMA, 2014 Revised GW National Forest Plan, 2004 Revised Jefferson National Forest Plan

Summary of Analysis: The process that the Forest Service is proposing for this project would be the most clearly unlawful version of condition-based management, and would defer all site-specific decisions until after completion of an EA. Instead, a "Project EA" would outline the process for how the Forest Service would select white pine-dominant stands to manage across the two National Forests and develop an "implementation checklist."[5] This Project EA and corresponding decision "would not allow for the explicit implementation of a treatment project."[6] Instead, subsequent site-specific "implementation projects" would be carried out in accordance with the process defined in the EA, subject to meeting all the implementation checklist's criteria. These "implementation projects" would not undergo further NEPA review.[7] As such, the only NEPA document prepared for the project would provide no information about the location, concentration, or timing of timber harvest and associated road construction.

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[1] Scoping Notice at 2–3.
[2] Scoping Notice at 3.
[3] Scoping Notice at 3–4.
[4] Scoping Notice at 3.
[5] Scoping Notice at 1.
[6] Scoping Notice at 1.
[7] Scoping Notice at 1.

Similarly, the scoping notice does not provide information about the project's duration or the actual amount of timber harvest that would occur in a given year or during the entire implementation—only an annual cap of 1,800 acres between the two national forests. The scoping notice contemplates clearcutting and commercial thinning and silvicultural prescriptions in between, but includes no details on when, where, and how much any technique will be used on the ground.[8]

The project purportedly would involve a substitute non-NEPA process for informal public comment. Agency staff stated in a public meeting that, once a year, the Forest Service would notify the public of stands that might be managed that coming year. Even under this substitute process, the project as scoped does not provide for public disclosure of, or comment on, the implementation checklists themselves.

Additional Concerns: The Forest Plans for both the GW and Jefferson National Forests require site-specific analysis. Both Plans provide that the "Forest Plan will be implemented through a series of project-level decisions based on appropriate site-specific environmental analysis and disclosure to assure compliance with [NEPA]."[9] The Jefferson Forest Plan further requires that "[a]ny decisions on projects to implement the [Forest Plan] are based on site-specific analysis in compliance with NEPA."[10]

Status: As of December 2021, this project appears on the schedule of proposed actions, where it is denoted "on hld."

Project Website: https://www.fs.usda.gov/project/?project=58928

[8] *See* Scoping Notice at 3–4.
[9] GW National Forest Plan at 5-1; Jefferson National Forest Plan at 5-1.
[10] Jefferson National Forest Plan at 2-1.

Name of Project: Prince of Wales Landscape Level Analysis

Location: Thorne Bay and Craig Ranger Districts, Prince of Wales Island, Tongass National Forest, Alaska; supervised by M. Earl Stewart

Forest Service Stated Purpose & Need: "The purpose is to help move the project area towards the desired conditions in the Forest Plan, and to meet multiple Forest Plan resource goals and objectives," including timber harvesting.[1]

Proposed Activities: The Forest Service identified over 125,000 acres of potential timber harvest on Prince of Wales Island, including 48,140 old-growth acres, and over 600 miles of potential new and temporary road construction.[2] It then selected a preferred alternative that would have authorized logging more than 40,000 acres within that broader area, including 24,000 acres of old growth forest, and over 160 miles of road construction, without disclosing which acres would be logged or where roads would be located.[3] This would have been the largest National Forest timber sale—and the largest single old-growth forest logging proposal—in at least 30 years. The project was scheduled for a 15-year implementation.[4]

Timeline: The Forest Service published a scoping notice in July 2017. It issued a final EIS in October 2018 and a decision in March 2019. In June 2020, the District of Alaska vacated the logging and roadbuilding portions of the Record of Decision (ROD) and EIS in *Southeast Alaska Conservation Council v. U.S. Forest Service*.[5] The agency has moved forward with implementing the much smaller watershed improvement and restoration project components. The agency also initiated a new project, the Twin Mountain II Timber Sale Project, which would allow for logging up to 3,000 acres of the old growth forest on Prince of Wales Island and construction of 14 miles of roads over five-to-ten years.[6] Twin Mountain II is in scoping as of September 2020.

Authorities Used: NEPA, NFMA, Alaska National Interest Lands Conservation Act (ANILCA), 2016 Amended Forest Plan for the Tongass

Summary of Analysis: The Final EIS did not disclose where, when, or how logging would occur within the 125,000-acre area and where roads would be built. It acknowledged that the "[p]roject proposes to harvest timber and build roads under all action alternatives, but it is *unknown at this time where on the landscape this would occur*,"[7] and that "it is *not possible to determine* all of the direct, indirect, or cumulative impacts to wildlife habitat or connectivity that could result from this project before implementation."[8] The Forest Service instead planned

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[1] Record of Decision at 6.
[2] Final EIS at 2-23.
[3] Final EIS at 2-23.
[4] Final EIS at 1-1.
[5] 443 F. Supp. 3d at 1022–23.
[6] *See* Scoping Information Twin Mountain II Timber Sale Project at 1.
[7] Final EIS at 3-234 (emphasis added).
[8] Final EIS, Appendix D at D-58 (emphasis added).

to determine site-specific project details based entirely on condition-based management ("CBM") performed after NEPA review concluded and implementation commenced.[9]

The District of Alaska held that the Forest Service's CBM approach violated NEPA. The court found that the project's EIS "d[id] not include a determination—or even an estimate—of when and where the harvest activities or road construction . . . w[ould] actually occur" within the much broader project area.[10] Because the project's CBM approach "create[d] ambiguity about the actual location, concentration, and timing of timber harvest and road construction on Prince of Wales Island," it "fail[ed] to provide a meaningful comparison of alternatives."[11] The court also found that, while CBM "may very well streamline management of the Tongass," NEPA requires that these site-specific determinations occur before project implementation commences to "ensure . . . that the agency will not act on incomplete information, only to regret its decision after it is too late to correct."[12]

The Prince of Wales EIS also failed to meaningfully evaluate actual or likely impacts because it opted for a worst-case analysis that assumed all forest would be clearcut.[13] The Forest Service admitted that the "total acres estimated to be needed to meet timber needs are likely over-estimated and therefore the effects are likely over-estimated as well."[14] This approach blurred potentially meaningful differences between alternatives; for example, the EIS's analysis of effects on wildlife stated that the effects "are similar between all alternatives because all alternatives assume that all acres proposed for timber harvest will be harvested."[15] The District of Alaska held that this worst-case approach further violated NEPA: "By focusing on the Project's maximum potential impacts for all alternatives rather than its actual or foreseeable impacts for each alternative, the EIS falls short of NEPA's directive to 'contain[] a reasonably thorough discussion of the significant aspects of the probable environmental consequences' for each alternative."[16] Together, the worst-case analysis and lack of site-specific information in the EIS prevent the public from having a remotely coherent understanding of the likely differences in impacts between project alternatives.[17]

Furthermore, the Forest Service substituted an informal "collaborative public process" for required NEPA notice and comment.[18] Once specific units and road locations were identified, the agency would make that information available online with an opportunity for public review and comment prior to the line officer's final decision.[19] Such informal provisions,

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[9] Record of Decision at 21.
[10] Southeast Alaska Conservation Council v. U.S. Forest Service, 443 F. Supp. 3d 995, 1009 (D. Alaska 2020).
[11] *Id.* at 1014.
[12] *Id.* at 1014–15 (quoting Protect Our Cmtys. Found., 939 F.3d 1029, 1035 (9th Cir. 2019)).
[13] *See, e.g.*, Final EIS at 3-171, 3-179.
[14] Final EIS at 3-176.
[15] *Id.*
[16] *Southeast Alaska Conservation Council*, 443 F. Supp. 3d at 1013 (quoting WildEarth Guardians v. Mont. Snowmobile Ass'n, 790 F.3d 920, 924 (9th Cir. 2015)).
[17] *See id.*
[18] Record of Decision at 21.
[19] Record of Decision at 21.

with no legal mechanism for ensuring accountability in the event that the agency did not take a hard look at impacts to old growth and associated values, do not substitute for the specific public comment procedures that NEPA requires upon the agency making site-specific determinations.

The logging that would have been authorized under the Prince of Wales Landscape Level Analysis would have destroyed tens of thousands of acres of remaining old-growth forest in America's largest temperate rain forest. The area targeted for logging included habitat for black bears and imperiled wildlife including the Alexander Archipelago wolf and the Queen Charlotte's goshawk. Forest slated for logging included important habitat for deer and salmon, which are critical to Southeast Alaska's billion-dollar tourism and fishing industries, and to native tribes who rely on those species for subsistence. The degree of these adverse impacts could have varied widely based on the specific locations where logging would occur, but the project plan failed to analyze these site-specific differences.

Additional Concerns: The 2016 Forest Plan deferred many unresolved issues to site-specific project planning. The Plan's timber harvest standards require that the Forest Service "[d]etermine operability based on site-specific project conditions."[20] It also directs the Forest Service to "[c]onsider silvicultural systems other than clearcutting to meet resource objectives at the project level" and to, "[a]s part of the project NEPA process, analyze current scientific information related to the applicability of alternative timber harvest methods."[21] The Prince of Wales EIS could not meaningfully evaluate whether alternatives to clearcutting would be appropriate without site-specific analysis. Likewise, the Forest Plan requires that the Forest Service, "[d]uring project planning, identify resource concerns and site-specific mitigation measures" for roads and other transportation infrastructure.[22] The Forest Plan even defines a "project" as "[o]ne or more *site-specific* activities designed to accomplish a *specific on-the-ground* purpose or result."[23]

Status: Logging and roadbuilding components of EIS vacated; watershed improvement and restoration components currently being implemented. Twin Mountain II Timber Sale Project, which covers a subset of the same project area, is in scoping but is described as currently "on hold."

Project Website:
https://www.fs.usda.gov/detail/tongass/landmanagement/projects/?cid=fseprd529245

[20] 2016 Tongass National Forest Land and Resource Management Plan at 4-68.
[21] *Id.*
[22] *Id.* at 4-77.
[23] *Id.* at 7-44 (emphasis added).

Name of Project: Sage Hen Integrated Restoration Project[1]

Location: Emmett Ranger District, Boise National Forest, ID.

Forest Service Stated Purpose & Need: To improve vegetation conditions to increase forest resiliency to uncharacteristic disturbances; conserve or restore habitat for wildlife species dependent on low-elevation, old forest habitats; restore watershed function to improve aquatic resources including bull trout habitat connectivity and diversity; improve and manage recreation opportunities and use; and support local and regional economies.[2]

Proposed Activities: Commercial harvest on up to 19,900 acres, construction of up to 83.1 miles of temporary roads, and reconstruction of 10.2 miles of system roads across a 67,800-acre project area for up to 20 years.

Timeline: Proposed Oct. 2019; request for comment April 2020; Final EA and FONSI, Draft Decision Notice, and objection period Nov. 13, 2020; Decision Notice issued April 2021.

Authorities Used: NEPA, NFMA, 2010 Boise Forest Plan.

Summary of Analysis: Decision Notice states condition-based management "allows managers to make landscape-level decisions while reserving flexibility and the ability to respond to change before implementing management activities."[3] The agency relied on "a conservative maximum impact analysis approach" to analyze impacts across all "potentially treatable project acres."[4] It committed to allowing additional public engagement and field trips during pauses between the three phases of project implementation, even though the Decision Notice approves all project activities.[5]

The Decision Notice disclosed the location and timing for logging units, system roads, and temporary roads for Phase 1 of implementation, and states that Phases 2 and 3 will focus on implementing condition-based management timber sales and vegetation treatment acres.[6] The analysis fails to disclose many site-specific details for Phases 2 and 3, relying on a Vegetation Condition-Based Management Guide to defer identification of specific vegetation treatments until project development, after signing the Decision Notice.[7] Lacking these site-specific details, it is impossible to determine how the project may impact important factors such as: habitat for imperiled wildlife, old growth stands, and water quality. The project will harm threatened bull trout by degrading water quality that includes designated bull trout

[1] Sage Hen Integrated Restoration Project website: https://www.fs.usda.gov/project/?project=56701 (last accessed Dec. 16, 2021).
[2] *See* U.S. Forest Service, Decision Notice for the Sage Hen Integrated Restoration Project (April 2021), page 1.
[3] Decision Notice at 2.
[4] Decision Notice at 4.
[5] *Id.*
[6] Decision Notice at 4-9.
[7] U.S. Forest Service, Sage Hen Integrated Restoration Project Environmental Assessment (Nov. 2020), page 2.

critical habitat, and will destroy Canada lynx habitat. Vegetation management activities may destroy multiple Northern goshawk nests in the project area.

<u>**Status**</u>**:** Boise Forest Supervisor Tawnya Brummett signed the Decision Notice on April 14, 2021. Three salvage sales scheduled for summer 2021.[8] On Nov. 11, 2021, a coalition of conservation groups filed a complaint challenging the decision, and specifically challenging the Forest Service's use of condition-based management as violating NEPA. *See WildLands Defense et al. v. Brummett et al.*, Case No. 1:21-cv-00425 (D. Idaho).[9]

[8] Decision Notice at 15.
[9] Complaint available at https://www.docketalarm.com/cases/Idaho_District_Court/1--21-cv-00425/Wildlands_Defense_et_al_v._Brummett_et_al/1/ (last visited Dec. 17, 2021).

Name of Project: Salmon-Challis Fuels Reduction and Restoration Project

Location: Salmon-Challis National Forest, Lemhi and Custer Counties, Idaho

Forest Service Stated Purpose & Need: "[T]o improve resiliency on the Salmon Challis National Forest by reducing existing natural fuels build-up, improving timber stand and wildlife habitat conditions, and restoring aspen and whitebark pine species."[1] The historical pace and "scale of prescribed fire and hand treatments of vegetation is not sufficient to maintain ecosystem health or to mitigate wildlife hazard."[2]

Proposed Activities: Prescribed burning activities including fireline construction, hand treatment of vegetation[3]; all activities would occur on "roughly" 2.4 million acres.[4]

Timeline: The Salmon-Challis National Forest released the scoping letter in October 2020

Authorities Used: NEPA, NFMA—Salmon-Challis LRMP

Summary of Analysis:

- The scoping letter for this categorical exclusion identifies three "programmatic considerations" to guide the Forest Service in implementing the project: (1) "Areas located with the Wildfire Protection Zone,"[5] (2) "[d]egree of departure from historic conditions using Vegetation Condition Class, with the highest departures given greater priority," and (3) "[a]bility to implement based on capacity, funding, complexity, local site conditions, and other relevant factors."[6]
- The scoping letter discloses several design criteria by resource type. For example, regarding the wildlife resource, the scoping letter represents that: "If active boreal owl, flammulated owl, great gray owl, or goshawk nests [sic] sites are identified in the burn area, preventative measures would be used to reduce nest abandonment."[7] "Preventative measures" and "Active" are not defined. Another example of a design criterion for the wildlife resource represents that fire crews "will strive to meet recommended burn plan objectives for old growth stands on lands subject to the Salmon LRMP."[8] "Strive" is undefined.
- The scoping letter does not provide any site-specific information—including any information on roadbuilding. In fact, the project is expected to be implemented forest-

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[1] Scoping Notice at 1.
[2] *Id.*
[3] *Id.*
[4] Legal Notice for Web at 1.
[5] Scoping Notice at 2. Areas where "high likelihood exists for wildfire impacts to infrastructure, private property and other identified socials [sic] and economic values within or near the Forest boundaries." *Id.*
[6] *Id.*
[7] *Id.* at 5.
[8] *Id.*

wide, or on about roughly 2.4 million acres.[9] The scoping letter also represents that the project will "fall within Idaho Roadless Areas."[10] The letter does not define which Idaho Roadless Areas. The lack of any site-specific information means the Forest Service not only does not know where, when, and how it will implement the project on 2.4 million acres, it does not know where, when, and how it will impact some of the most important ecosystems on the Forest. As noted above, the project's proposed design criteria are alarmingly vague and allow Forest Service staff a tremendous amount of flexibility for forest management without ever doing NEPA site-specific analysis.

Additional Concerns:

- ESA: the project area contains four listed species—Canada lynx, grizzly bear, yellow-billed cuckoo, and bull trout. The scoping letter contains no discussion of ESA-listed species, nor specific design criteria for mitigating impacts on them.

Status: Under analysis–NEPA or Forest Plan Amendment Decision Document estimated by 04/01/2022.[11]

[9] Legal Notice for Web at 1.
[10] *Id.*
[11] Salmon-Challis Fuels Reduction and Restoration Project at https://www.fs.usda.gov/project/?project=58813&exp=detail.

Name of Project: Spruce Beetle Epidemic and Aspen Decline Management Response ("SBEADMR") Project[1]

Location: Grand Mesa, Uncompahgre and Gunnison ("GMUG") National Forests, CO

Forest Service Stated Purpose & Need: Reduce the safety threats of falling, dead trees and of managing wildfires on the landscape; improve the resiliency of stands at risk of insect and disease; and treat affected stands via recovery of salvageable timber and subsequent re-establishment of desired forest conditions.[2]

Proposed Activities: Up to 60,000 acres commercial logging, up to 60,000 acres noncommercial treatment, and up to 178 miles of new road construction across a 207,600-acre project area for 8-12 years, pending funding.

Timeline: Pre-scoping map June 2013; Scoping July 2013; Draft EIS June 2015; Final EIS May 2016; Final Record of Decision July 2016.

Authorities Used: NEPA, NFMA, 1983 GMUG Forest Plan.

Summary of Analysis: The Forest Service identified acres for Priority Treatment Areas ("PTAs") for commercial and noncommercial timber harvest, potential hazard tree treatments outside of PTAs, and potential new road disturbance.[3] The agency noted that PTA boundaries may vary and "comprise more area than the total acres" approved "for treatment so that the Forest has more flexibility to implement the SBEADMR adaptively in response to evolving on-the-ground conditions over the life of the project," applying an Adaptive Implementation Framework.[4] The analysis failed to disclose site-specific details regarding the baseline environmental conditions within each of the PTAs, what types of vegetative treatments would occur where within the large PTA blocks, or where it would construct 178 miles of road. Major concerns included impacts to Canada lynx suitable habitat, impacts from the road system, and the impact of salvage logging on forest regeneration.

The Forest Service stated that it considered the project's maximum treatments, and that to comply with the Southern Rockies Lynx Amendment disturbance caps the agency would annually track implementation and report it to the U.S. Fish and Wildlife Service.[5] To address public concerns about the lack of specificity of proposed projects, areas to be treated, scope of impacts, and lack of public input, the Forest Service agreed to fund an independent science

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[1] SBEADMR Project website: https://www.fs.usda.gov/project/?project=42387 (last accessed Dec. 17, 2021).
[2] U.S. Forest Service, Spruce Beetle Epidemic and Aspen Decline Management Response Final Record of Decision (July 2016), page 3.
[3] Final ROD at 4-5.
[4] Final ROD at 5-6.
[5] Final Rod at 14.

advisory team to help identify treatment locations and inform the adaptive approach and management decision making.[6]
Status: Implementation stage.[7]

[6] SBEADMR Community Report, Fiscal Year 2020.
[7] SBEADMR Implementation website: https://www.fs.usda.gov/detail/gmug/landmanagement/resourcemanagement/?cid=fseprd497061 (last accessed Dec. 17, 2021).

Name of Project: South Plateau Area Landscape Treatment Project[1]

Location: Hebgen Lake Ranger District, Custer Gallatin National Forest, MT (on western boundary of Yellowstone National Park)

Forest Service Stated Purpose & Need: Reduce the risk or extent of, and increase the resiliency to insect and disease infestation, achieve an ecosystem that can better withstand future natural events such as wildfire, contribute to a sustained yield of timber products, and improve the productivity of forested timber stands.[2]

Proposed Activities: Clear-cutting up to 4,600 acres, thinning on up to 15,096 acres, and 56 miles of temporary roads across a 39,909-acre project area for the next 15 years.

Timeline: Combined scoping and draft EA in August 2020; Forest Service cancelled objection process May 12, 2021 pending the Custer-Gallatin Forest Plan Revision, expected summer 2021.

Authorities: NEPA, NFMA, 1987 Gallatin Forest Plan, (anticipate evaluating project under the forthcoming 2021 Revised Gallatin Forest Plan).

Summary of Analysis: The proposed action "preliminarily identified areas for treatment" on National Forest land adjacent to Yellowstone National Park, but "[t]he exact extent and location of treatments to be applied would be determined through the condition-based approach."[3] While the EA maps areas where specific types of treatments could be applied, those areas are far larger than where treatments will occur. For example, the EA states that "8,787 acres of clearcut harvest has been preliminarily identified in the project area," but clearcuts will be limited to 4,600 acres—and it does not identify the precise location of those acres.[4] During implementation the Forest Service will survey areas proposed for treatment to determine existing conditions and the appropriate treatment based on a Treatment Matrix.[5] The analysis omits the actual location of proposed timber harvest, location and mileage of temporary road construction, location and mileage of system roads for truck hauling, and the specific timeframe for each of these activities. The agency provides no role for public input when the agency designs specific logging treatments and road locations.

Without site-specific details it is impossible to determine how the project activities may impact important factors such as: habitat for imperiled wildlife, old growth stands, sources of drinking water, and watersheds functioning at-risk. The project will cut 56 miles of new temporary roads, displacing threatened grizzly bear and disrupting grizzly bear habitat in the

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[1] South Plateau Area Landscape Treatment Project website, https://www.fs.usda.gov/project/?project=57353 (last accessed Dec. 17, 2021).

[2] *See* U.S. Forest Service, South Plateau Area Landscape Treatment Project Final Environmental Assessment ("Final EA") (March 2021), page 1.

[3] Final EA at 6.

[4] Final EA at 57-58.

[5] *Id.* at 6.

Greater Yellowstone Ecosystem, and degrading watershed conditions for watersheds functioning at-risk.[6] It will destroy 4,600 acres of habitat for threatened Canada lynx.[7] The Forest Service concluded the project is "likely to adversely affect" both grizzlies and lynx.[8]

Status: Forest Service cancelled objection process May 12, 2021, and delayed issuance of a new draft Decision pending the release of the Custer Gallatin Forest Plan Revision (expected early 2022).

[6] Final EA at 46.
[7] Final EA at 77.
[8] Final EA at 42.

Name of Project: Tennessee Creek Project

Location: Leadville Ranger District, San Isabel National Forest and Eagle-Holy Cross Ranger District, White River National Forest, Colorado

Forest Service Stated Purpose & Need: "[T]o create forest conditions that are more resilient to insects, diseases, and fire; to improve or maintain habitat for threatened, endangered and sensitive species and other important wildlife species; and to provide for sustainable watershed conditions."[1]

Proposed Activities: The Forest Service identified a 16,450-acre project area, of which up to 13,580 were proposed for treatment.[2] The treatments include clearcutting 2,370 acres of lodgepole pine, thinning 6,765 acres of lodgepole pine, 6,040 acres of prescribed fire, and creating 20 miles of temporary roads and opening 1.5 miles of closed roads, but the location of the treatments was not disclosed[3] The project is scheduled to be implemented over a ten-to-fifteen year period.[4]

Timeline: The Forest Service published a scoping letter in November 2012. It approved the project with a FONSI in November 2014.[5] WildEarth Guardians sued in the District of Colorado in 2015. The court upheld the EA and FONSI in July 2017,[6] which the Tenth Circuit affirmed in April 2019.[7]

Authorities Used: NEPA; NFMA; ESA; Pike and San Isabel National Forests, Comanche and Cimarron National Grasslands Land and Resource Management Plan (1984) and Southern Rockies Lynx Amendment (SRLA) (2008); White River National Forest Land and Resource Management Plan (2002)

Summary of Analysis: The Tennessee Creek Project Final EA failed to disclose where and when each proposed treatment activity would occur. It instead made generalized, unconstrained predictions such as "[a]pproximately 20 miles of temporary road would be created and approximately 1.5 miles of closed roads would be open during the life of the project to access the project area, but mileage may vary during project implementation."[8] The project set up parameters such as "[t]reatments that result in openings would not exceed 25 percent of lodgepole pine stands,"[9] but provided no opportunity for public involvement, through the

[1] Final EA at 9.
[2] Final EA at 9.
[3] Decision Notice at 2.
[4] Final EA at 9.
[5] Decision Notice at 14.
[6] *See* WildEarth Guardians v. Conner, No.15-cv-00858, 2017 WL 5989046 (D. Colo. July 25, 2017).
[7] *See* WildEarth Guardians v. Conner, 920 F.3d 1245, 1251–52 (10th Cir. 2019).
[8] Final EA at 25.
[9] Final EA at 14.

formal NEPA process or otherwise, to monitor these requirements or challenge the site-specific decisions that are being made during implementation.

Instead of defining specific sites in the Tennessee Creek EA, the Forest Service applied a worst-case analysis assuming that the project would treat all 9,480 acres of lynx habitat in the project area, including clearcutting 2,485 acres, despite noting that "in reality the number of treated acres would be less, but it cannot be quantified at this time."[10] The Forest Service determined that even this worst-case scenario would fall below the SRLA's requirement that the Forest Service cut less than 15 percent of lynx habitat in each "Lynx Analysis Unit" within a ten-year period.[11] As such, the Forest Service concluded that effects on lynx would be "minimal" and "insignificant."[12]

In *WildEarth Guardians v. Conner*, the Tenth Circuit upheld the project's final EA and FONSI in a narrow ruling specific to the project's potential impacts on threatened Canada lynx.[13] Specifically, the court held that the choice of locations for future treatment was "not material" to whether lynx would be harmed.[14] The court did not address or approve condition-based management generally.

Additional Concerns: Both governing Forest Plans explicitly deferred site-specific analysis to the project level, but no such analysis occurred in the Tennessee Creek Project. The White River Forest Plan lists examples of "*site-specific* project decisions that require additional environmental analyses and disclosure," including timber harvesting, wildlife improvement projects, and prescribed burns.[15] Likewise, amendments to the Pike and San Isabel Forest Plan consistently recognize that the "actual decision to implement or not implement a project will be made after *site-specific* analysis and public involvement are completed."[16]

Status: Decision signed by Tamara Conner, District Ranger, Leadville Ranger District
Implementation ongoing

Project Website: https://www.fs.usda.gov/project/?project=30294

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[10] *See* Final EA at 82, 158.
[11] Final EA at 83.
[12] Final EA at 90.
[13] *See* WildEarth Guardians, 920 F.3d at 1251–52.
[14] *Id.* at 1259.
[15] White River National Forest Land and Resource Management Plan at P-5 (emphasis added).
[16] Pike and San Isabel National Forests and Comanche and Cimarron National Grasslands Land and Resource Management Plan, Amendment 11 at 2; *see also* Amendment 12 at 2; Amendment 20 at 2; Amendment 22 at 2.

Name of Project: Tofte Landscape Project

Location: Tofte Ranger District, Superior National Forest, Minnesota

Responsible Official: District Ranger Ellen Bogardus-Szymaniak

Forest Service Stated Purpose & Need: Achieve landscape ecosystem objectives for forest type and age; promote natural spatial patterns; promote habitat; increase resiliency; manage fuels; provide harvest materials.

Proposed Activities: The project area is 333,470 acres, but only a fraction of that area will actually be logged. The proposed action sets a maximum cap on acres logged and treated over a 15-year implementation period.[1] Yearly averages are listed for each activity, but "[a]verage acres and miles per year may be more or less than the stated amounts," so long as they do not exceed the caps over the full implementation period.[2] The 15-year caps include 25,500 acres of harvesting to "create young forest," 12,700 acres of thinning, 5,600 acres of uneven aged management, 6,830 acres of underburn, and 19,450 acres of understory mechanical fuel reduction.[3] Additional acreage for mosaic burns and salvage is provided but would count toward the 25,500-acre harvesting cap.[4] The proposal would also allow construction of up to 150 miles of temporary roads.

Timeline: The project's scoping notice is dated October 4, 2019. A draft EA was posted on May 27, 2021.

Authorities Used: NEPA, NFMA, ESA, 2004 Superior National Forest Land and Resource Management Plan

Summary of Analysis: At its core, the Tofte Landscape Project resembles other condition-based management ("CBM") case studies that employ the most clearly unlawful version of condition-based management, in which the agency proposes to make site-specific decisions about where and how to implement commercial timber harvest only outside the NEPA process. However, the Tofte Project is noteworthy because it includes a non-binding "estimated implementation plan" ("EIP") that purports to provide some degree of site-level analysis. The EIP includes the current proposed location of vegetation treatments and temporary roads.[5] It was created using "stand-level vegetation data" with "GIS analysis tools and professional judgment" to identify a "potential pool of stands to conduct treatments."[6] However, the EIP does not identify which specific silvicultural prescription the Forest Service will apply to each stand. It instead only includes a general treatment category for each stand, such as "Create Young" or "Uneven

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[1] Draft EA at 13–14.
[2] Draft EA at 13 n. 4.
[3] Draft EA at 13–14.
[4] *See* Draft EA at 13.
[5] Draft EA at 10–11.
[6] Draft EA at 43.

Aged."[7] These broad categories do not make clear which specific logging technique the Forest Service will apply to each stand, even though the differences between techniques in a given stand could have significant environmental differences.

Furthermore, the Draft EA still gives the Forest Service full discretion to change the EIP during the project's actual implementation through a broader CBM approach.[8] As with the EIP, the broader CBM analysis in the Draft EA does not provide site-specific designations or defined limits for specific treatment types. Instead, the project plans to use "landscape filters" to select logging sites after completion of NEPA review. These "landscape filters" may mitigate environmental effects in some way if applied, but without defining which 25,500 acres in the 333,470 acre project area will ultimately be logged, the Draft EA fails to give the public an understanding of the project's actual environmental effects.

The Draft EA's broader CBM approach also omits information about which specific logging method will be used on the 25,500 acres that it ends up selecting for logging. The Forest Service assures that not all areas allotted for harvesting to "create young forest" will be clearcut, but gives no indication of what proportion of that large total will be clearcut.[9] Several other logging techniques (e.g. clearcut with planting, seed tree harvest with natural regeneration or planting, shelterwood harvest with natural regeneration) are contemplated depending on the conditions without any binding determination of which specific sites of the 25,500 acres will undergo each respective technique.[10] Substantially different effects could result at a given site based on the logging technique applied and many other factors, but neither the EIP nor broader CBM approach adequately analyze site-specific impacts.

Ultimately, nothing in the EA limits the Forest Service's discretion to change the EIP so long as it remains within the EA's broad bounds, which renders the Tofte Landscape Project no different than any other CBM project. The EIP is merely a non-binding estimate of what the Forest Service might decide to do during implementation.

The Tofte Landscape Project would involve a substitute non-NEPA process for informal public comment. The Project Implementation Plan does not contemplate opportunities for the NEPA notice and comment process after the project is approved and implementation begins. It provides only for consultation with tribes and, once stands have been identified based on CBM, promises that it will consider public input before implementation.[11] These informal provisions do not substitute for the specific public comment procedures NEPA requires upon the agency making site-specific determinations.

Additional Concerns:

[7] *See generally* Draft EA, Appendix J.
[8] Draft EA at 11.
[9] Draft EA, Appendix A at A-1.
[10] Draft EA, Appendix A at A-4–A-6.
[11] *See generally* Draft EA, Appendix D.

- The 2004 Forest Plan notes that "'[i]mplementing the Forest Plan' means developing any implementing *site-level* forest management projects."[12] The Draft EA's analyses all occur at the landscape ecosystem ("LE") level despite the Forest Plan's directive that "[i]n designing projects that work toward reaching the desired conditions for a [management area ("MA")], managers will consider both MA direction and [LE] objectives" and requirement that "proposed projects must reflect the blend of both MA and LE direction."[13]
- The Draft EA only analyzes two alternatives: no-action and the proposed action.[14]

Status: Under analysis. Draft decision notice and objection period expected January 2022.

Project Website: https://www.fs.usda.gov/project/?project=55216

[12] Superior National Forest Land and Resource Management Plan at 1-10.
[13] *Id.* at 3-2.
[14] Draft EA at 23.

Name of Project: Dry Forests Restoration Project

Location: Ocoee/Hiwassee and Tellico Ranger Districts, Cherokee National Forest, Tennessee

Forest Service Stated Purpose & Need: Restore native tree species diversity in dry forest communities by removing off-site white pine and Virginia pine.[1]

Proposed Activities: The programmatic decision prioritizes logging approximately 62,000 acres dominated by off-site white and Virginia pine across a 300,000-acre landscape, subject to site-specific NEPA analysis and decisions, over an implementation period of at least ten years.[2] Cumulative effects are kept at non-significant levels by capping temporary road construction, limiting road length and requiring obliteration of temporary roads after use in certain unroaded areas, and prohibiting the use of ground-disturbing equipment on steep slopes. Effects unique to particular sites will be considered in the site-specific NEPA analyses.

The first tiered, site-specific decision approved 809 acres of regeneration harvest, 277 acres of commercial thinning, and 4,712 acres of manual tree release and improvement cuts.[3] A second site-specific proposal currently in scoping would allow another 624 acres of regeneration harvest, 1,237 acres of commercial thinning, and 4,463 acres of manual tree release and improvement cuts.[4] Because of the increase in pace and scale of timber harvest over recent levels, state forestry staff are providing assistance to implement the project.

Timeline: The project's scoping notice was issued in February 2019. A final programmatic EA with FONSI was published in July 2019, and the decision was signed in September 2019. The first site-specific project following the programmatic EA then had a scoping notice issued in April 2020, an EA with a FONSI published in September 2020, and a decision signed in October 2020. Scoping for a second site-specific project began in April 2021.

Authorities Used: NEPA, NFMA, Cherokee National Forest 2004 Revised Land and Resource Management Plan, CWA, ESA

Summary of Analysis: In contrast to other condition-based management ("CBM") case studies, the Dry Forests Restoration Project offers an example of a lawful programmatic approach and complies with NEPA. The Forest Service identified common conditions in the South Zone of the Forest for which a broad consensus favors active management. It then issued a programmatic EA and FONSI that did not authorize any timber harvest or make site-specific, on-the-ground decisions, but set forth a general (but not fully prescriptive) flowchart for addressing problematic conditions and established conservative sideboards to protect against cumulative impacts to soil, water, and roadless area values.[5] Then, unlike in other CBM projects that do not

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[1] Programmatic EA at 6.
[2] Programmatic Decision Notice at 4; Programmatic EA at 8.
[3] *See* 2020 Decision Notice at 3–11.
[4] *See* Unicoi Mountain Pre-Scoping Letter at 2–4.
[5] *See generally* Programmatic EA.

incorporate site-specific NEPA analysis, future site-specific decisions are each determined by a tailored EA that is tiered to the programmatic EA.[6] Because cumulative, repeating impacts were already analyzed at the programmatic stage, the site-specific EAs only analyze issues unique to that site, such as impacts to recreation and rare plants.[7] This programmatic approach gives the public formal, NEPA-compliant notice and comment opportunities before site-specific decisions are made and on-the-ground activity occurs, but each project can move forward quickly and efficiently.

Furthermore, the Forest Service's proactive collaboration on this project has allowed it to deliver on the efficiency goals that other CBM projects have been unable to achieve. The project supervisors sought input from a stakeholder group while developing the programmatic EA during the formal NEPA notice and comment process. Collaborating on project parameters and sideboards on the front end has saved the Forest Service time in its site-specific implementations. Within seven months of sending a scoping notice, the Forest Service finalized a decision on the programmatic EA without public objection. Just a year later, the first implementation project was signed—accompanied by its own "skinny" EA tiered to the programmatic EA—authorizing over 1,000 acres of commercial timber harvest, again without objection.[8]

Status: Decision signed by District Rangers Michael A. Wright & Stephanie Bland. Implementation, with one logging project in progress and a second in scoping.

Project Website: https://www.fs.usda.gov/project/?project=55303

[6] *See* Programmatic EA at 7.
[7] *Id.*
[8] *See* 2020 Decision Notice at 3–10.

Appendix 2

Excerpts of Appendices to S. Env’t L. Ctr., W. Env’t L. Ctr., The Wilderness Soc’y, Comment Letter on Proposed Rule, National Environmental Policy Act (NEPA) Compliance (84 Fed. Reg. 27,544, June 13, 2019) (Aug. 25, 2019)

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Submitted via public participation portal to: https://www.regulations.gov/document?D=FS-2019-0010-0001

RE: Comments on *Proposed Rule, National Environmental Policy Act (NEPA) Compliance* (84 Fed. Reg. 27,544, June 13, 2019)

Dear Chief Christensen, Deputy Chief French, Secretary Perdue, and Under Secretary Hubbard:

On behalf of the undersigned organizations and individuals, we are pleased to provide the Forest Service with the attached comments on the agency's proposed rule regarding National Environmental Policy Act (NEPA) compliance, 84 Fed. Reg. 27,544 (June 13, 2019), RIN 0596–AD31. Our organizations collectively represent decades of experience with the Forest Service's implementation of NEPA across the spectrum of land management actions, including forest planning, vegetation, wildlife, mineral, range, aquatic, travel, and recreation management decisions. Our organizations and members would be adversely affected by this proposal, which would immediately eliminate important procedural rights that we and other members of the public rely on. The proposal would have far-reaching effects to the places we advocate for and help to steward.

We have extensive expertise regarding the Council on Environmental Quality's (CEQ) NEPA regulations, the Forest Service's NEPA regulations and procedures, and the body of federal case law interpreting the agency's legal obligations under NEPA. Our experience in agency decision-making processes, collaborative efforts, and as plaintiffs in NEPA litigation lends us unique insight into the promises and pitfalls of the Forest Service's NEPA policies and practices.

Many of our organizations provided comments on the Advanced Notice of Proposed Rulemaking.[1] Unfortunately, it is clear from the proposed rule that the Forest Service failed to incorporate nearly all of our suggestions for efficient environmental analysis and decision-making that involves the public in decisions about how its lands will be managed. Instead, the agency has released a proposed rule that brazenly attempts to remove the public from public land management decisions, and seeks to expand the scope and scale of land management without sufficient environmental analysis: this is not the type of decision-making required by NEPA, which requires transparency, accurate scientific data and analysis, and inclusion of the public - including local communities, Tribes, local governments, scientists, and many others who use, enjoy, and rely upon the National Forests for a variety of values - in federal agency decision-making.

The proposed rule appears to be in service of the present Administration's deregulatory agenda that serves to elevate the interests of extractive industries above the interests of the public. This agenda is particularly inappropriate on the national forests, which are owned in common by all Americans, not just a privileged few. The proposed rule would drastically reduce or eliminate public involvement in the management of their national forests, curtail the role of science in land management planning, and will ultimately undermine the credibility of the Forest Service as the "expert scientists" in the eyes of the public it was created to serve.

In its environmental analysis and decision making efforts, the Forest Service created considerable momentum for positive change. This rule squanders the opportunity. The Forest Service has ignored its own analysis that concludes that funding, staffing, training, and internal personnel policies (particularly those related to promotion and staff transitions) are at the heart of inefficient planning and project implementation. It has also ignored the successful efforts of its most talented staff to accomplish more, high-quality work by accepting stakeholder contributions. Instead, it offers a rule meant to avoid accountability, with a rationale that is not supported by the information before the agency. The Forest Service simply offers no basis to believe that eliminating public input can improve the timeliness or quality of its decisions.

Because the Forest Service has failed to prepare a sufficient administrative record to support its proposed rule, we anticipate that the rule – should it be finalized – will not survive judicial review. We therefore recommend that the agency abandon this rulemaking effort and focus on immediate needs such as forest plan revision, science-based restoration, monitoring, and internal cultural changes.

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[1] *See*, Comments on *Advanced Notice of Proposed Rulemaking, Request for Comment, National Environmental Policy Act Compliance* (83 Fed. Reg. 302, Jan. 3, 2018) submitted by The Wilderness Society, Western Environmental Law Center, Southern Environmental Law Center, et al. (Feb. 1, 2018).

With regards on behalf of the undersigned organizations and individuals,

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TABLE OF CONTENTS

I. Introduction.[2]

NEPA is rightfully referred to as the "Magna Carta" of environmental laws. Like that famous charter, NEPA enshrines fundamental values into government decision-making. NEPA has been a proven bulwark against hasty or wasteful federal decisions by fostering government transparency and accountability. It has ensured that federal decisions are at their core democratic, by guaranteeing meaningful public involvement. And it has achieved its stated goal of improving the quality of the human environment by relying on sound science to reduce and mitigate harmful environmental impacts.

We have seen agencies, including the Forest Service, conduct highly efficient yet robust NEPA analysis. These successes demonstrate that NEPA is inherently flexible, and the current law, CEQ regulations, and Forest Service regulations and procedures provide significant authority to conduct efficient yet meaningful analysis, including through the use of tiering, mitigated findings of no significant impact, appropriate application of existing categorical exclusions, and other tools. At the same time, we agree that many Forest Service environmental analysis and decision-making processes could be more efficient and satisfying to stakeholders and the agency. However, as we described in our comments on the ANPR and reiterated below, the primary problems with – and solutions to – the Forest Service's NEPA process lie not with the agency's NEPA regulations and procedures but with funding and

[2] There are 8 key appendices to these comments, which are identified as "Appendix [number]" and are appended to these comments. Other popularly available references are identified in footnotes by author, title, year, and electronic database address, where available. Still other references that are not popularly available are attached alphabetically.

Appendix 1: Re-Analysis of Restoration CE Projects (the 68 Projects Included in Appendix A to the Supporting Statement for Proposed CE 26)

Table 1: Appendix A Data and Analytics

Project	Comm	Thinning and Fuels Reduction	Rx Burn	Reforest	Habitat & Watershed	Invasives	**Total harvest**	**Total project**
Arrowhawk	878	2618			118	2900	3496	6514
Bald Fire	8447		5499	12200			8447	26146
Barnyard South	1590			860			1590	2450
Bigelow-Newaygo	2256	952	1446			108	3208	4762
Biggie	1527	1008	256				2535	2791
Black Locust	23	23	23			23	46	92
Bucks Lake	1291	543	222				1834	2056
Charlie Preston	977	307	82	82			1284	1448
Cherokee Park	3124	2004					5128	5128
Davy Crockett			69000					69000
Deep Creek						11		11
Deer Pen	408	128				7	536	543
Dry Restoration	748						748	748
East Wedge	4976	695	4564				5671	10235
Elkhorn	2766		2191				2766	4957
Escalante	10525	11625					22150	22150
French Fire	3387	221		3000		32	3608	6640
Gooseberry	2246	126	2271				2372	4643
Gordon Hill	1466	1188	95				2654	2749
Grass Flat	200	1145	107	83			1345	1535
Grizzly Fire	3025			1837			3025	4862
Hams Fork	7892		730				7892	8622
Hopkins Prairie	1000						1000	1000
Interior	16638	106	3312		829		16744	20885
Iron Springs	4121	769		154			4890	5044
Julius Park	675	89					764	764
Junction	8964	12280	5738				21244	26982
Keola	371	401	139	11			772	922
Kidhaw	560	545	820				1105	1925
Larson	24574	1822	4906				26396	31302
Lemon Butte	603	43		55			646	701
Lower Skokomish	4484						4484	4484

Macedonia	8121						8121	8121
Marshall Woods	266	1178	1055	450			1444	2949
Martin Creek	774	338		929			1112	2041
Middle Bugs	705	114	642				819	1461
Millsteck	1989		1673	2956	160	70	1989	6848
Mitchell Spring	771	626		108			1397	1505
Morrison Run	1401	536	370	451		442	1937	3200
Mower Tract		6358			54		6358	6412
North Heber	3730						3730	3730
North Shore	3190	3785	20				6975	6995
Ocala		352					352	352
Pine Ridge	7496	10972	12708	400	1168		18468	32744
Pipeline	1944	952		461			2896	3357
Red Hill	1448	88					1536	1536
Reedy	1275						1275	1275
Renshaw	4970	457	663				5427	6090
Roy Creek	2550	865	5582			200	3415	9197
Sagehen		2627	2350				2627	4977
Salmon West	2529	819		1684		188	3348	5220
Sandbox	2185	2097	7465				4282	11747
Shores	1460	117					1577	1577
Smith Mountain	3032	2781	8970	572		50	5813	15405
Soldier Bay	2062	1434		243			3496	3739
South Bridger	250						250	250
South Summit II	2350	1000	6600				3350	9950
Southern Creek Ouachita River	1838	835	5460	225			2673	8358
Spring Gulch	256	66	229				322	551
Sulphur Forest	613						613	613
Telogia	1631	77					1708	1708
Toll Joe	944	139					1083	1083
Upper Lake Winona	2965	8097	15959	1555			11062	28576
Upper South Fork Skokomish	880						880	880
Watson Hill LLC	8116	268					8384	8384
West Slope		4546					4546	4546
Westside Collaborative	1349	978					2327	2327
Windy Project	2699	549	186				3248	3434
Average	**3153.7**	**1797.8**	**5039.2**	**1348.4**	**465.8**	**366.5**	**4351.8**	**7253.4**
Median	**1891.0**	**769.0**	**1559.5**	**451.0**	**160.0**	**70.0**	**2663.5**	**3734.5**

Table 8: Summary of Changes to Appendix A Projects

Project	Explicitly due to Public Comment	Due solely to Internal review or Unexplained	Non-substantive (Analysis or Informational)	Notes
Bald Fire	X			Adjusted treatment acres from SL to EA after fieldwork (see EA p.12). Added Alternative 3 to address public concern regarding commercial timber harvest (see EA p. 16).
Barnyard South	X			Reduced miles of road construction/reconstruction from SL to EA. Added alternatives in response to public concerns about road construction (Alt. 3), openings in forest canopy caused by logging (Alt. 4), and the need for "real restoration" (Alt. 5) (see EA p. 9-10). Analyzed Alts. 3, 4 in detail. Selected Alt. 2. Added documentation to project record in response to an objection (see DN p. 1).
Bigelow-Newaygo	X			Added Alternative 3 to address public concerns. Alternative 3 included the following: 1) Reduced acres of red pine stands proposed for conversion to prairie by changing treatment to thinning. 2) Dropped stands proposed for savanna restoration. 3) Dropped new road construction from southern part of project area; retained roads proposed for closure based solely on the fact the roads were duplicative (see EA p. 1-9 - 1-10). Selected Alt. 3 with some modifications (see DN p. 2). Modifications included adding 24 acres of savanna restoration (see DN p. 8-9).
Biggie	X			Changed 2 treatment areas from commercial to noncommercial treatment; changed follow-up fuels treatments of two treatment areas; dropped 772 acres of roadside hazard tree treatment (see EA p. 7). Updated timber volume and economic analysis as a result of internal review (see EA p. 7). From EA to DN, dropped hazard tree treatments, which reduced noncommercial harvest from 1,718 to 1,008 acres.
Black Locust		X		Reduced treatment area from original SL to EA (see EA p. 1-2).
Bucks Lake	X			Added Alternative D in response to scoping (EA p. 8). From EA to DN agency dropped 15.2 acres of mechanical thinning (590-574.8), dropped 5.4 acres of radial thinning (155.8-150.4), and added 22.2 acres of group selection treatments. USFS received two objections on the project (DN p. 12). Changed commercial harvest treatments in order to resolve objections.
Charlie Preston	X			From SL to EA: added public firewood gathering, provided more dispersed camping, reduced timber harvest along private property boundary, and provided more explanation. Added Alternative C to address public concerns about amount and types of timber harvest and amount of road construction (see EA p. 11). From EA to DN: selected Alternative C
Cherokee Park	X			Agency performed revised travel analysis in response to scoping. Agency added design criteria to address concerns about timber harvest impact on viewshed (see DN p. 3).
Davy Crockett		X		Dropped RX fire in all areas in which the management emphasis was not for red cockaded woodpecker, from 105,941 acres to 69,000 acres (see EA p. 1).
Deep Creek	X			Agency added project-specific design measures for monarch butterfly, sage grouse, and water quality (see DN p. 6).
Deer Pen	X			Removed used of herbicide, glyphosphate, in response to scoping comments. Resulted in 63-acre decrease in project size (see EA p. 32).
Dry Restoration			X	Added more information to descriptions of proposed activities in response to scoping.
East Wedge	X			From SL to EA: reduced commercial treatments and increased Rx fire. Agency added Alternative C, which reduced amount of treated acres in response to public comment. Selected Alternative C and modified it by

Project	Explicitly due to Public Comment	Due solely to Internal review or Unexplained	Non-substantive (Analysis or Informational)	Notes
				changing treatments and removing treatment acres from selected action (see DN p. 2-4). Removed Canada lynx habitat from areas proposed for commercial harvest. Agency removed all new road construction from proposed action. Removed areas along US-Canada border from areas proposed for commercial harvest. Removed re-designating a forest road from proposed action.
Elkhorn	X			Changed types of vegetation treatments applied to some areas. Modified travel management activities associated with project.
Escalante	X			Reanalyzed proposed timber management in unroaded and lightly roaded areas and excluded areas from consideration if accessing the areas would require "extensive temporary road construction."
French Fire	X			Developed Alternative 4 in response to public comments re. California Spotted Owl. Developed Alternative 5 in response to public comments. Developed Alternative 3 in response to public comments regarding hazards posed by herbicides. After EA released, removed herbicide treatment from one area in response to scoping comments provided by USFWS. USFWS comments pertained to California red-legged frog (see DN p. 5).
Gooseberry		X		Dropped construction of new temporary road in order to avoid a stream crossing (see DN p. 2).
Grass Flat	X			Agency's preferred alternative in EA was "Modified Alternative B," which was developed in response to public comment (EA Ch. 2.5, p. 10). EA Table 2.8 depicts difference in commercial harvest between original proposed action and modified Alternative B. Agency reduced total treatment acres from 1,808 to 1,602 (compare EA Table 2.2 to EA Table 2.5). Agency changed treatments in many areas, emphasizing more basal area retention for spotted owl. From EA to DN agency shifted 29 acres of mastication to hand-cut pile and burn treatment.
Grizzly Fire			X	Agency developed Alternative 3 in response to public comments on scoping notice (EA p. 12). Agency selected Alternative 2.
Hams Fork	X			Agency developed proposal that was presented in scoping letter with a collaborative working group (see DN p. 5-6). Original proposal was to treat 10,414 acres (see EA p 19), including 12 miles of roads (8 miles in Invent. Roadless Area). Collaborative group (w/ USFS) reduced size of proposed action to 8,622 acres in order to avoid constructing 8 miles of roads in an Invent. Roadless Area (see EA p. 19; DN p. 6). Received 4 objections to proposal (DN p. 4). Objection Reviewing Officer tasked District with explaining how the project complied with the 2001 Roadless Rule and with various exemptions from restrictions on timber harvest (DN p. 7). District's response at DN p. 7-10.
Interior	X			Released first scoping letter 12/20/2012. Released second scoping letter 07/25/2013. From first to second SL, prescribed fire reduced by 398 acres, timber harvest reduced by 326 acres, road construction increased by 5 miles, wildlife resource improvements reduced by 180 acres. From SL2 to EA, hazardous fuels treatments increased by 108 acres, timber harvest reduced by 141 acres. From EA to DN hazardous fuels treatments decreased by 16 acres.
Iron Springs	X			Changed proposed action treatment acres from SL to EA (compare SL p. 4 to EA Table 9). Created Alternative A in response to public comment on scoping letter (EA p. 7).
Junction	X			From SL to EA: maintained the same total acres treated: 16,034 (see SL Table 1; EA Table 2). Developed Alternative 3 in response to public comments on scoping notice (see EA, p. 12). Alternative 3 intended to favor habitat for three woodpecker species (see EA, p. 12). Selected Alternative 3 Modified (see DN, p. 1:

Project	Explicitly due to Public Comment	Due solely to Internal review or Unexplained	Non-substantive (Analysis or Informational)	Notes
				"Overstory, understory, and fuels treatments may occur on the same acres."). Modification to reduce commercial harvest from 9,864 (see EA p. 29) to 8,964 (see DN p. 2)
Kidhaw		X		Midstory control by mulching decreased from 600 acres in SL and EA to 545 acres in DN.
Larson	X			From SL to EA: added 2 miles of temporary road construction. Added Alternative 3 in response to public input on draft EA (see EA p. 12). Modified Alternative 3 in final EA to address public concern about mistletoe infected trees (see EA, p. 26). Selected Alternative 2, with modifications. Modified Alternative 2 by removing all temporary road construction from the proposal (see DN p. 4).
Lemon Butte	X			Prior to release of EA, reduced commercial harvest from 1650 acres to 603 acres. USFS dropped 6058 acre prescribed burn from SL to EA. Dropping prescribed burn was internal decision (see EA p. 21). Reduced commercial harvest from 1,650 acres to 603 acres in response to public input and internal review (see EA p. 17).
Lower Skokomish	X			Multiple modifications to treatment acres and treatment types from SL to EA. Original proposal had a 13,500 acre footprint. SL reduced that to 4,900. Proposed action in EA included 4,237 acres. SL included 5 miles road construction. EA included 15.6 miles construction and 3.1 reconstruction.
Macedonia			X	Developed a no herbicide alternative in response to public concern (see EA p. 10).
Marshall Woods	X			Developed Alternative N in response to public comment but did not analyze it in detail (see EA p. 27). Developed Alternatives C and D in response to public comment (see EA p. 26). Agency implemented a hybrid of Alternatives C and D (see DN p. 1).
Martin Creek	X			Developed Alternative C in response to public comment (see EA p. 2-1). Modified selected alternative in response to internal and public comment (see DN p. 8). Reduced total timber harvest acres, reduced precommercial thinning acres, reduced acres of tree planting (see DN Table 1).
Middle Bugs	X			SL proposed 712 acres commercial harvest. DN contained 705/114 commercial/noncommercial harvest. Within the commercial harvest acres, the DN included 642 acres of Rx burn. Developed Alternatives C-E in response to public comment (see EA p. 6-7). Implemented Alternative C (see DN p. 1).
Millsteck	X			SL included 2036 acres of even-age commercial harvest. EA reduced even-age commercial harvest to 2,033 acres. From SL to EA, prescribed fire changed from 1,727 to 1,795 acres. Reforestation changed from 3,114 to 3,090 acres from SL to EA.
Mitchell Spring	X			Removed pinyon-juniper treatment in response to public comment and agency fieldwork, resulting in a modified proposed action (see EA, p. 16). Developed Alternative 3 in response to public comment (see EA p. 27). Selected the modified proposed action for this project (see DN p. 1).
Morrison Run	X			From SL to EA to DN, commercial harvest changed from 1325 acres, to 1,399 acres, to 1,401 acres. RX Burn acres went from 429 to 370 to 370 acres. Developed Alternative 3 in response to public comment and IDT concerns regarding amount of timber harvest and associated road building (see EA p. 18).
Mower Tract	X			Scoped non-commercial treatments over 12,597 acres. Agency included 12.597 acres in the EA. Following EA release, agency engaged in ESA Sect. 7 consultation. As a result of consultation, the agency removed 6,239 acres from the project in order to avoid Cheat Mtn. Salamander habitat (see DN p. 11).
North Heber			X	Added alternative in response to public comments (see EA p. 13).
North Shore	X			From EA to DN: reduced size of prescribed burning by 40 acres.
Pine Ridge	X			From SL to EA: removed ponderosa pine planting from proposed action and refined design features for

Project	Explicitly due to Public Comment	Due solely to Internal review or Unexplained	Non-substantive (Analysis or Informational)	Notes
				proposed activities (see EA p. 4). Modified selected action (see DN p. 2).
Pipeline		X		Modified acres proposed for 4 types of treatment between Sl and EA. Comm Trt 1: 451 to 461 acres; Comm Trt 2: 1209 to 1142 acres; Comm Trt 3: 336 to 341 acres; Non-comm Trt 1: 1203 to 952 acres. Modifications from SL to EA.
Red Hill			X	Developed alternative in response to scoping (see EA p. 1-17).
Reedy		X		Scoped 1,350 acres and proposed 1,275 in EA. Added drum chopping in all treatment areas to be completed after commercial harvest and before herbicide treatments.
Renshaw	X			Added 13 acres of commercial harvest from SL to EA. Added 3 miles of road construction and 33 miles of road reconstruction from SL to EA.
Sagehen	X			Dropped one unit from project because of public comment regarding the effect of underburning on goshawk habitat (see EA p. 27).
Salmon West		X		Agency removed a 19-acre stand from selected action (see DN p. 2).
Sandbox	X			Developed Alt. 3 in response to scoping (comparison of SL to EA). Agency incorporated two elements from Alt. 3 into the selected action (Alt. 2) (see DN p. 1).
Shores		X		Dropped 48 acres of timber harvest and 0.4 miles of temp road construction between SL and EA (see EA p. 5, Sect. 1.4.1).
Smith Mountain			X	Developed no-herbicide alternative in response to scoping (see EA p. 21).
Soldier Bay	X			Dropped 500 acres - in 15 stands - of commercial harvest from EA to DN. Dropped all treatment from 8/15 stands (see DN Table 1). Decreased intensity of thinning from 40 BA to 50 BA for all commercial harvest. Dropped acres due to objection to EA (see DN p. 8). USFS received one objection to the EA/DN (DN p. 8). Changes described in DN Table 1 were made to resolve disagreement between agency and objector. Changes removed thinning treatment from 500 acres (234 acres treated with herbicide only; 266 acres removed from all treatment). Thinned density for all treated areas increased from 40 BA to 50 BA (DN p. 1 Table 1).
South Bridger	X			Added mitigation in response to objection (see DN p. 5).
South Summit II	X			Acres reduced from 2,350 proposed to 2,180 in DN (see DN p. 3).
Southern Creek Ouachita River		X		Added 18 acres commercial harvest and 60 acres RX fire.
Spring Gulch	X			USFS received 1 appeal on original EA (see DN p. 2-3). USFS withdrew DN in order to gather more information (see DN p. 3). Agency revised EA and released revised EA. From EA to DN: reduced noncommercial timber harvest and added prescribed burn.
Sulphur Forest	X			Modified proposed action due to internal scoping (EA p. 15). Modified selected action (DN p. 1). Total project area reduced from 1,700 to 1,677 acres.

Project	Explicitly due to Public Comment	Due solely to Internal review or Unexplained	Non-substantive (Analysis or Informational)	Notes
Telogia	X			Modified treatments from EA to DN based on public input and two objections. Changed from clearcut to firewood harvest and herbicides on 46 acres; dropped 20 acres from the project; changed 98 acres from clearcut to clearcut with reserves; and changed 79 acres from 'third-row harvest' to 'thin from below to 50 BA (see DN Table 1).
Toll Joe	X			Dropped 163 acres of commercial and 45 acres of noncommercial harvest. Reduced road construction from 1.5 to 1.3 but added 5.5 miles of reconstruction.
Upper Lake Winona		X		Reduced miles of fire line maintenance from 30 to 28.
Upper South Fork Skokomish	X			Reduced commercial harvest from 1,050 acres to 880 acres.
West Slope	X			Added two alternatives in response to scoping (see SL p. 2). The proposed action (Alt. 2) included 2,350 acres of mastication. Alternative 3, which the agency identified as its preferred alternative (see EA p. 12), included 4,546 acres of mastication because Alternative 3 dropped the use of herbicides in response to public comment (see SL p. 2; DN p. 4).
Westside	X			Commercial harvest in SL was 607/698/44 acres (see SL Table 1). In EA, agency adjusted commercial treatments to 506/799/44 acres (see EA p. 2-1). This change was described as Modified Alternative 2 in EA. From EA to DN the agency retained 0.68 miles of roads intended for decommissioning. Roads were retained due to public comment and subsequent agency fieldwork (see EA p. 1-15).
Windy	X			From EA to DN, commercial harvest was 3,958 to 2,699. Noncommercial treatment acres were 334 to 549. Burn acres were 390 to 186. Road construction went from 7.8 to 9 miles. Modified the selected Alternative (Alt. 3) by dropping 110 acres from the project and adding 112 of treatments to the project. Added reforestation to the selected action.
Total	**43**	**11**	**6**	

Chart: Relative Effect of Public Input on Appendix A Projects (n=68)

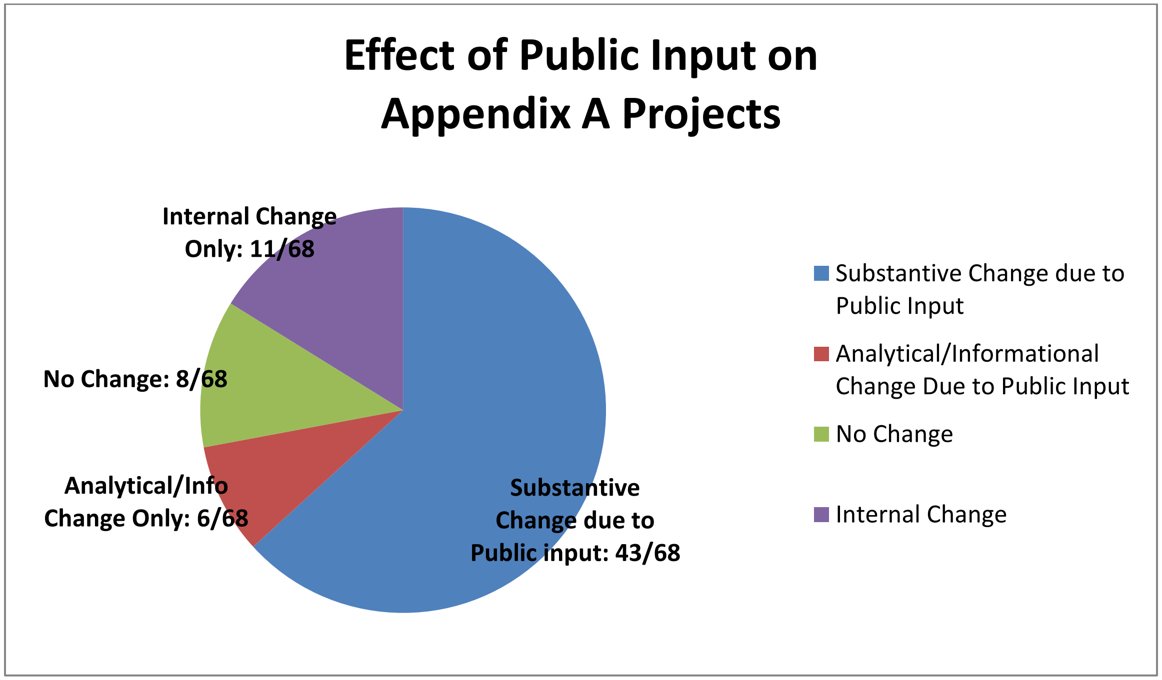


Chart: Number of Projects from Appendix A Modified in Response to Public Comment and due to Internal Review at Different Stages of Project Development

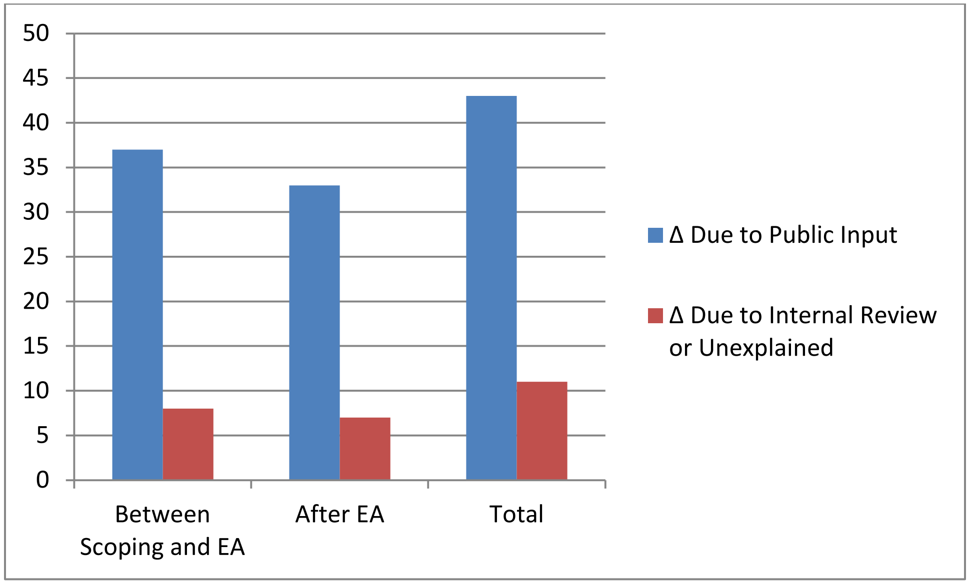


Table 1: Net Changes in Southern Appalachian Projects Completed with EAs (2009-2019)

Project (Forest/District)	Total Harvest Proposed Acres (A)	Total Harvest Decision Acres (B)	Δ Total Harvest Acres (B-A)	% Change Total Harvest [(B-A)/A]	Commercial Harvest Proposed Acres (A)	Commercial Harvest Decision Acres (B)	Δ Commercial Harvest Acres (B-A)	% Change Commercial Harvest [(B-A)/A]
04-136 - East Nottely Watershed Project (Chattahoochee / Blue Ridge)	1153	1108	-45	-3.90%	566	1108	542	95.76%
Cooper Creek Watershed Project (Chattahoochee / Blue Ridge)	3754	2058	-1696	-45.18%	2315	1397	-918	-39.65%
Forest Health Stewardship (Chattahoochee / Blue Ridge)	713	582	-131	-18.37%	713	528	-185	-25.95%
05-183 - Eastside Forest Health - Five Years (Chattahoochee / Chattooga River)	6800	6663	-137	-2.01%	6800	6663	-137	-2.06%
Upper Warwoman Landscape Management Project Proposal (Chattahoochee / Chattooga River)	1233	1115	-118	-9.57%	1168	785	-383	-32.79%
Sumac Creek Watershed Project (Chattahoochee / Conasauga)	1710	1951	241	14.09%	1681	1776	95	5.65%
Fightingtown Creek Wildlife Habitat Project (Chattahoochee / Conasauga)	436	394	-42	-9.63%	436	340	-96	-22.02%
Upper West Armuchee Creek Watershed (Chattahoochee / Conasauga)	1870	1813	-57	-3.05%	1870	1640	-230	-12.30%
Chattahoochee Totals	**17669**	**15684**	**-1985**	**-11.23%**	**15549**	**14237**	**-1312**	**-8.44%**
Dinkey (Cherokee / Ocoee)	1194.4	912	-282.4	-23.64%	751	428	-323	-43.01%
Spring Creek (Cherokee / Ocoee)	212	212	0	0.00%	212	212	0	0.00%
Conacat (Cherokee / Tellico)	1666	873	-793	-47.60%	13	29	16	123.08%
Greasy Creek (Cherokee / Tellico)	390	390	0	0.00%	390	390	0	0.00%
Middle Citico (Cherokee / Tellico)	971	872	-99	-10.20%	971	872	-99	-10.20%
Tellico (Cherokee / Tellico)	722	772	50	6.93%	622	622	0	0.00%
Clarke Mountain Project (Cherokee / Unaka)	230	230	0	0.00%	230	230	0	0.00%
Meadow Creek Environmental Assessment (Cherokee / Unaka)	831	784	-47	-5.66%	231	184	-47	-20.35%
Paint Creek Project (Cherokee / Unaka)	1298	1837	539	41.53%	529	623	94	17.77%
Doe Project (Cherokee / Watauga)	267	539	272	101.87%	257	357	100	38.91%

Project (Forest/District)	Total Harvest Proposed Acres (A)	Total Harvest Decision Acres (B)	Δ Total Harvest Acres (B-A)	% Change Total Harvest [(B-A)/A]	Commercial Harvest Proposed Acres (A)	Commercial Harvest Decision Acres (B)	Δ Commercial Harvest Acres (B-A)	% Change Commercial Harvest [(B-A)/A]
Offset Project (Cherokee / Watauga)	2185	2214	29	1.33%	696	723	27	3.88%
Pond Mountain II Project (Cherokee / Watauga)	825	809	-16	-1.94%	296	310	14	4.73%
Cherokee Totals	**10791.4**	**10444**	**-347.4**	**-3.22%**	**5198**	**4980**	**-218**	**-4.19%**
Harmon Den (NPNF / Appalachian)	1000	961	-39	-3.90%	306	267	-39	-12.75%
Franks Creek (NPNF / Cheoah)	1196	1128	-68	-5.69%	831	763	-68	-8.18%
Upper Santeetlah (NPNF / Cheoah)	1026	311	-715	-69.69%	442	292	-150	-33.94%
Armstrong (NPNF / Grandfather)	1269	1068	-201	-15.84%	563	362	-201	-35.70%
Roses Creek (NPNF / Grandfather)	535	535	0	0.00%	459	459	0	0.00%
Southside (NPNF / Nantahala)	371	317	-54	-14.56%	352	317	-35	-9.94%
Haystack (NPNF / Nantahala)	794.5	618	-176.5	-22.22%	462	384	-78	-16.88%
Copeland (NPNF / Nantahala)	389	371	-18	-4.63%	389	371	-18	-4.63%
Buckwheat (NPNF / Nantahala)	173	173	0	0.00%	173	173	0	0.00%
BBQ (NPNF / Nantahala)	279	234	-45	-16.13%	256	234	-22	-8.59%
Mossy Oak (NPNF / Nantahala)	323	298	-25	-7.74%	245	220	-25	-10.20%
Horse Bridge (NPNF / Nantahala)	197	197	0	0.00%	0	136	136	0.00%
Wetface (NPNF / Nantahala)	198	198	0	0.00%	157	157	0	0.00%
Fatback (NPNF / Nantahala)	632	538	-94	-14.87%	423	329	-94	-22.22%
Cane Pole (NPNF / Nantahala)	636	559.5	-76.5	-12.03%	334	323.5	-10.5	-3.14%
Brushy Ridge (NPNF / Pisgah)	1894	1666	-228	-12.04%	482	369	-113	-23.44%
Courthouse (NPNF / Pisgah)	1437	1351	-86	-5.98%	499	418	-81	-16.23%
Femelschlag (NPNF / Pisgah)	254	254	0	0.00%	145	145	0	0.00%
Lower End (NPNF / Tusquitee)*	735		-735		735		-735	
Brushy Flats (NPNF / Tusquitee)	242	242	0	0.00%	242	242	0	0.00%
Long Buck (NPNF / Tusquitee)	237	239	2	0.84%	237	239	2	0.84%
Prospect Hamby (NPNF / Tusquitee)	335	335	0	0.00%	320	320	0	0.00%
Thunderstruck (NPNF / Tusquitee)	335	290	-45	-13.43%	335	290	-45	-13.43%
Fontana (NPNF / Tusquitee)	1140	998	-142	-12.46%	721	579	-142	-19.69%
NPNF Totals	**15627.5**	**12881.5**	**-2746**	**-17.57%**	**9244**	**7389.5**	**-1854.5**	**-20.06%**
Wells Branch (GWJ / Clinch)	490	461	-29	-5.92%	490	461	-29	-5.92%
Hardwood Restoration (GWJ / Clinch)	100	92	-8	-8.00%	100	92	-8	-8.00%
Nettle Patch (GWJ / Clinch)	2622	1125	-1497	-57.09%	1449	577	-872	-60.18%
Tub Run (GWJ / ED)	769	766	-3	-0.39%	534	531	-3	-0.56%

Project (Forest/District)	Total Harvest Proposed Acres (A)	Total Harvest Decision Acres (B)	Δ Total Harvest Acres (B-A)	% Change Total Harvest [(B-A)/A]	Commercial Harvest Proposed Acres (A)	Commercial Harvest Decision Acres (B)	Δ Commercial Harvest Acres (B-A)	% Change Commercial Harvest [(B-A)/A]
Rich Mountain (GWJ / ED)	380	380	0	0.00%	380	380	0	0.00%
Fork Mountain (GWJ / ED)	635	635	0	0.00%	635	635	0	0.00%
White Rocks (GWJ / ED)	271	374	103	38.01%	239	342	103	43.10%
Pulaski (GWJ / GP)	402	393	-9	-2.24%	321	312	-9	-2.80%
Panther Mountain (GWJ / GP)	422	377	-45	-10.66%	422	377	-45	-10.66%
Gilmore Hollow (GWJ / GP)	674	669	-5	-0.74%	362	357	-5	-1.38%
Poplar Cove (GWJ / GP)	507	487	-20	-3.94%	143	123	-20	-13.99%
Tri County (GWJ / James River)	376	376	0	0.00%	376	376	0	0.00%
Little Mountain Mad Anne (GWJ / James River)	744	744	0	0.00%	220	220	0	0.00%
Brattons Run (GWJ / James River)	455	430	-25	-5.49%	455	430	-25	-5.49%
Humpback (GWJ / James River)	221	221	0	0.00%	221	221	0	0.00%
Lower Cowpasture (GWJ / James River)	3705	3422	-283	-7.64%	2207	1909	-298	-13.50%
Barb Gap (GWJ / Lee)	682	662	-20	-2.93%	537	517	-20	-3.72%
Church Mountain (GWJ / Lee)	75	75	0	0.00%	75	75	0	0.00%
SR 622 Bear (GWJ / Mt Rogers)	289	279	-10	-3.46%	114	104	-10	-8.77%
Woodpecker (GWJ / Mt Rogers)	250	285	35	14.00%	193	140	-53	-27.46%
Tom Lee Draft (GWJ / North River)	464	464	0	0.00%	292	292	0	0.00%
Hodges Draft (GWJ / North River)	182	182	0	0.00%	182	182	0	0.00%
Wall and Marshall Tracts (GWJ / North River)	185	185	0	0.00%	185	185	0	0.00%
West Side (GWJ / North River)	950	833	-117	-12.32%	750	633	-117	-15.60%
Moffett Creek Grouse (GWJ / North River)	591	591	0	0.00%	402	402	0	0.00%
Rocky Spur (GWJ / North River)	292	267	-25	-8.56%	245	220	-25	-10.20%
Back Draft (GWJ / North River)	866	805	-61	-7.04%	566	505	-61	-10.78%
Mares Run (GWJ / Warm Springs)	267	233	-34	-12.73%	203	169	-34	-16.75%
GWJ Totals	**17866**	**15813**	**-2053**	**-11.49%**	**12298**	**10767**	**-1531**	**-12.45%**
Southern Appalachian Totals	**61953.9**	**54822.5**	**-7131.4**	**-11.51%**	**42289**	**37373.5**	**-4915.5**	**-11.62%**

* The proposed Lower End project was split into three smaller projects (Brushy Flats, Long Buck, and Prospect Hamby) and was reduced by 735 acres of harvest based on concerns from environmental stakeholders that the District lacked the capacity to assess the impacts of such a large project. Lower End was not included as a separate project in this analysis because it did not go to a decision, but we document these acres in this table because the primary documents for the smaller projects do not otherwise show this change.

Table 2: Southern Appalachian Projects – Commercial and Total Harvest Acres and Analytics (n=71)

GW/Jeff comm.	GW/Jeff total	NPNF comm.	NPNF total	CNF comm.	CNF total	Chatt. comm.	Chatt. total
461	461	267	961	428	912	1108	1108
92	92	763	1128	212	212	1397	2058
577	1125	292	311	29	873	528	582
531	766	362	1068	390	390	6663	6663
380	380	459	535	872	872	785	1115
635	635	317	317	622	772	1776	1951
342	374	384	618	230	230	340	394
312	393	371	371	184	784	1640	1813
377	377	173	173	623	1837	**14237**	**15684**
357	669	234	234	357	539	**340**	**394**
123	487	220	298	723	2214	**6663**	**6663**
376	376	136	197	310	809	**1779.63**	**1960.50**
220	744	157	198	**4980**	**10444**	**1252.5**	**1464**
430	430	329	538	**29**	**212**		
221	221	323.5	559.5	**872**	**2214**		
1909	3422	369	1666	**415.00**	**870.33**		
517	662	418	1351	**373.5**	**796.5**		
75	75	145	254				
104	279	242	242				
140	285	239	239				
292	464	320	335				
182	182	290	290				
185	185	579	998				
633	833	**7389.5**	**12881.5**				
402	591	**136**	**173**				
220	267	**763**	**1666**				
505	805	**321.28**	**560.07**				
169	233	**304.5**	**326**			**All Comm**	**All Total**
10767	**15813**				**Total**	**37373.5**	**54822.5**
75	**75**				**Min**	**29**	**75**
1909	**3422**				**Max**	**6663**	**6663**
384.54	**564.75**				**Average**	**526.39**	**772.15**
349.5	**411.5**				**Median**	**357**	**535**

Table 3: Total Harvest (Comm. and Noncomm.) for Projects in the Southern Appalachians, 2009-2019, by Forest

Forest	Number of Projects	# Acres Min.	# Acres Max	#Acres Average	#Acres Median
GW/Jeff	28	75	3422	565	412
NPNF	23	173	1351	561	326
Chattahoochee	8	394	6663	1961	1464
Cherokee	12	212	2214	870	796.5
All	71	75	6663	772	535

Chart 1: Frequency Distribution of Project Sizes in the Southern Appalachians, 2009-2019

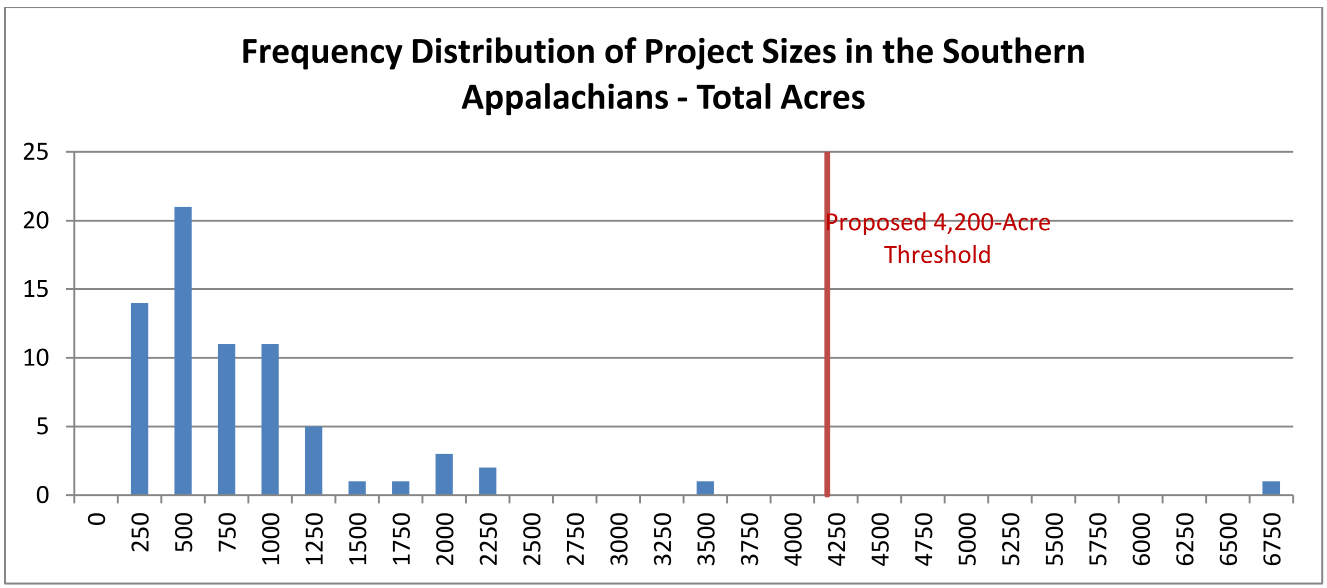


Table 4: Net Changes to Project Activities During EA Process by Forest

Forest	Δ Commercial Harvest (acres)		Δ Total Harvest (acres)		Δ Permanent Roads (miles)		Δ Temporary Roads (miles)	
GJ/Jeff	-1,531	-12.45%	-2,053	-11.49%	0.45	2.70%	-3.48	-8.20%
NPNF	-1,854.5	-20.06%	-2,746	-17.57%	-6.35	-74.1%	-1.97	-9.30%
Chattahoochee	-1,312	-8.44%	-1,985	-11.23%	0	0.00%	1.7	5.33%
Cherokee	-218	-4.19%	-347.4	-3.22%	1.2	22.86%	-0.5	-4.14%
Total	-4,915.5	-11.62%	-7,131.4	-11.51%	-4.7	11.03%	-4.25	-3.71%

Table 5: Net and Gross Changes in Total and Commercial Harvest by Forest

Forest	Combined Increases in Total Harvest	Combined Decreases in Total Harvest	Net Change Total Harvest	Gross Change Total Harvest	% Gross Change Total Harvest	Combined Increases in Commercial Harvest	Combined Decreases in Commercial Harvest	Net Change Commercial Harvest	Gross Change Commercial Harvest	% Gross Change Comm. Harvest
Chattahoochee	241	-2226	-1985	2467	14.0%	637	-1949	-1312	2586	16.2%
Cherokee	890	-1237.4	-347.4	2127.4	19.7%	251	-469	-218	720	13.9%
NPNF	2	-2748	-2746	2750	17.6%	2	-1856.5	-1854.5	1858.5	20.1%
GW/Jeff	138	-2191	-2053	2329	13.0%	103	-1634	-1531	1737	14.1%
All	**1271**	**-8402.4**	**-7131.4**	**9673.4**	**15.6%**	**993**	**-5908.5**	**-4915.5**	**6901.5**	**16.3%**

Chart 2: Acres Added and Dropped from Projects During EA Process

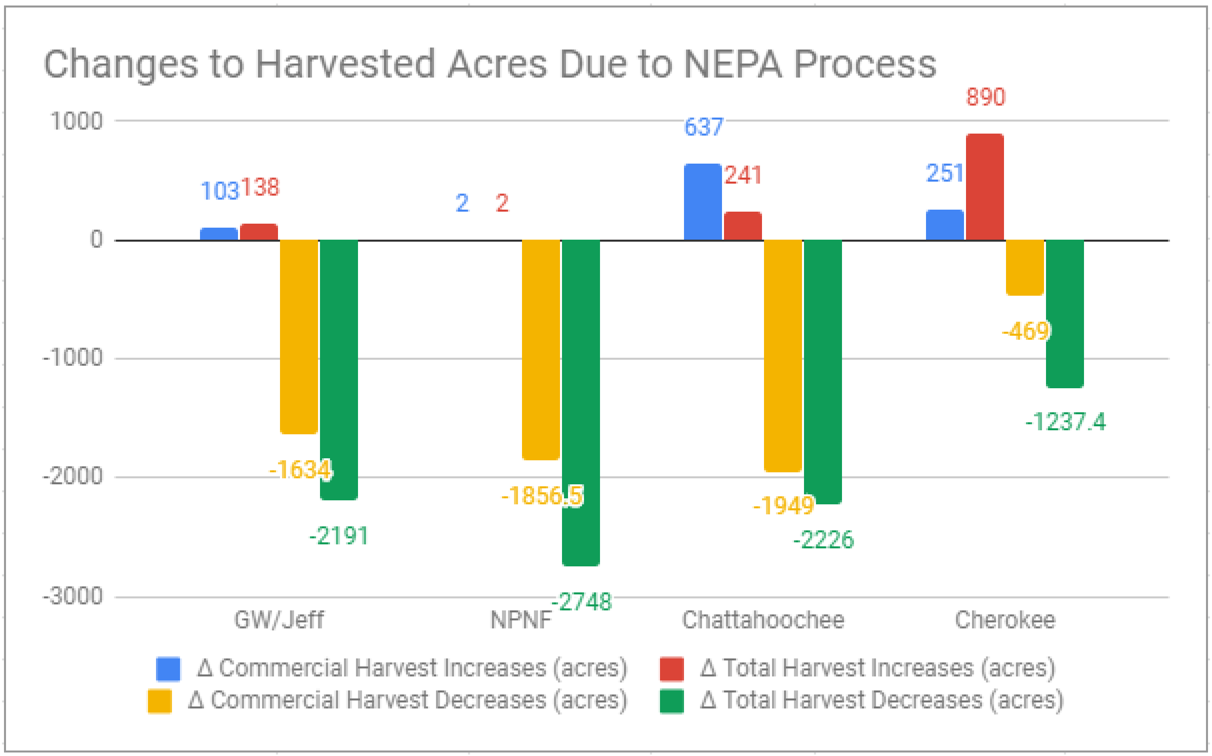


Table 6: Percent Net and Gross Changes in Total and Commercial Harvest by Forest

Forest	Δ Commercial Harvest Increases (acres)	% Δ Commercial Harvest Increases	Δ Total Harvest Increases (acres)	% Δ Total Harvest Increases	Δ Commercial Harvest Decreases (acres)	% Δ Commercial Harvest Decreases	Δ Total Harvest Decreases (acres)	% Δ Total Harvest Decreases
Chattahoochee	637	4.10%	241	1.36%	-1949	-12.53%	-2226	-12.60%
Cherokee	251	4.83%	890	8.25%	-469	-9.02%	-1237.4	-11.47%
NPNF	2	0.02%	2	0.01%	-1856.5	-20.66%	-2595	-18.42%
GW/Jeff	103	0.84%	138	0.77%	-1634	-13.29%	-2191	-12.26%
All	**993**	**2.38%**	**1,271**	**2.05%**	**-5908.5**	**-13.97%**	**-8402.4**	**-13.56%**

Chart 3: Percent Change in Acres (Dropped and Added) During EA Process

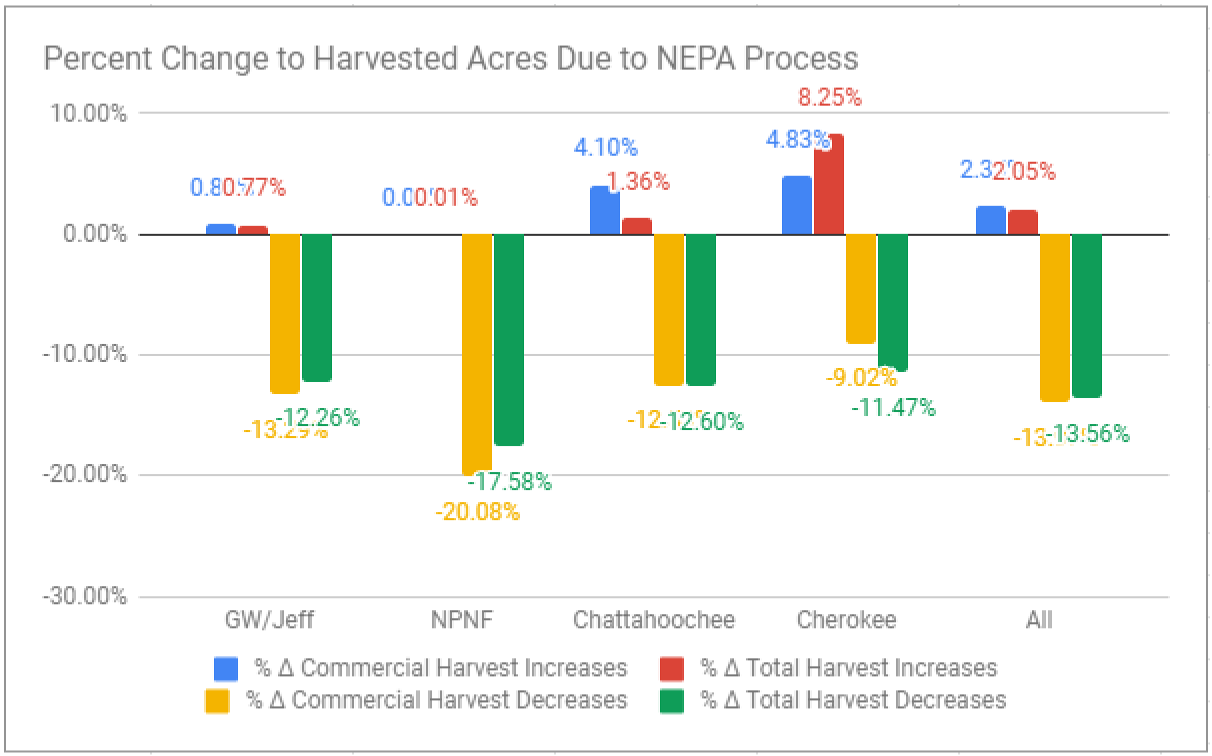


Table 7: Mitigation Added During EA Process (Number of Projects by Issue)

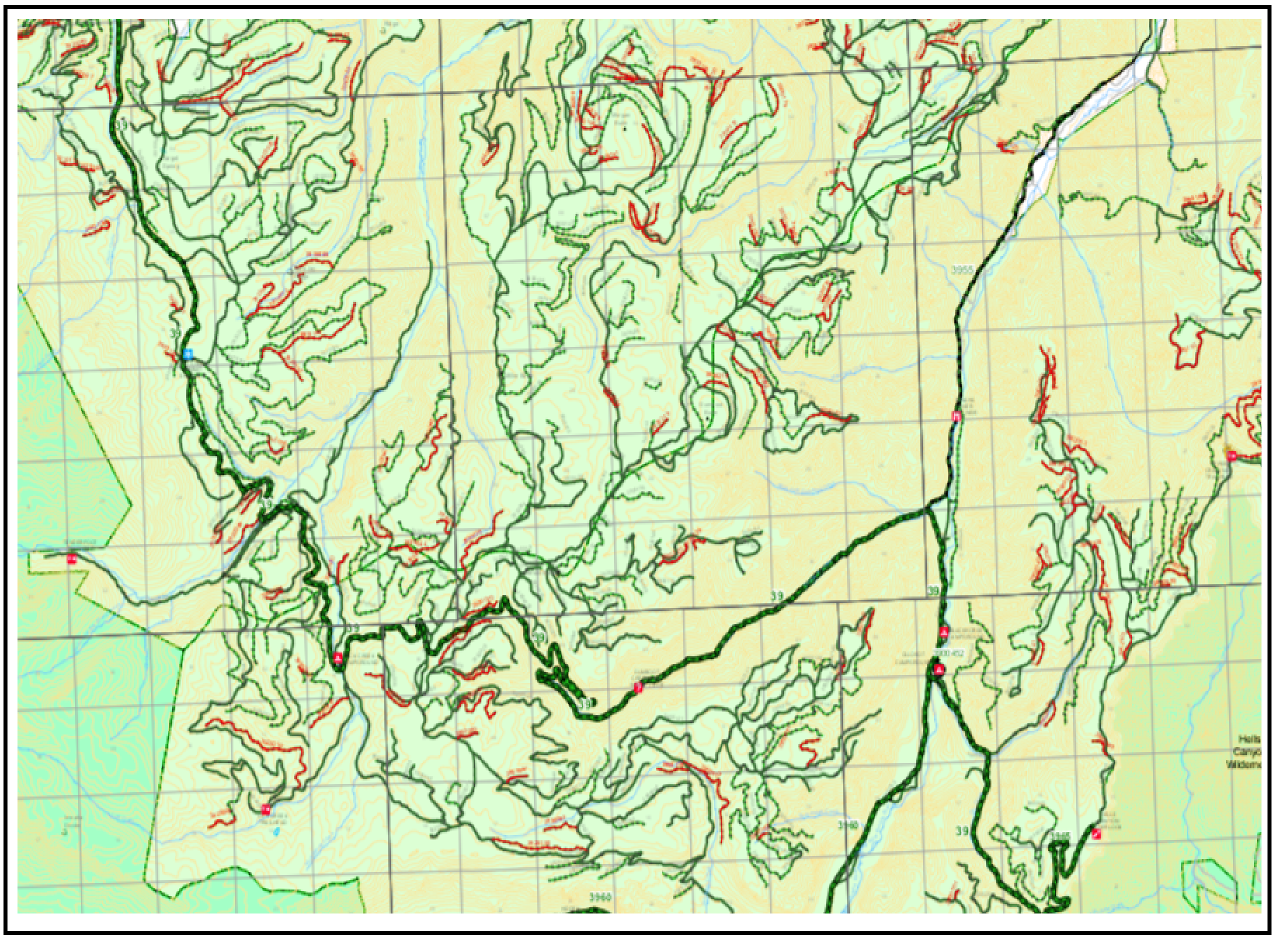
Forest	Ch. 70		Old growth		PETS		State nat. area		Water quality		Soil/Slope	
	Present	Mitigated	Present	Mitigated	Present	Mitigated	Present	Mitigated	Present	Mitigated	Present	Mitigated
GW/Jeff	4	2	6	6	5	4	1	1	9	9	9	9
NPNF	10	2	9	4	16	10	10	3	5	1	3	1
Chatt.	1	1	2	2	6	6	6	6	8	8	8	8
Cherokee	3	0	1	1	3	3	1	1	9	9	11	11
Total	18	5	18	18	30	23	18	11	31	27	31	29

Table 8: Summary of Potentially Significant Issues (PSIs) Present & Mitigated

Forest	Number of PSIs Present	Number of PSIs Mitigated	Percent of PSIs Mitigated
GW/Jeff	34	31	91%
NPNF	53	21	40%
Chattahoochee	31	31	100%
Cherokee	28	25	89%
All	**146**	**108**	**74%**

A Dilapidated Web of Roads -

The Forest Service's Departure From a "Sustainable" Forest Road System



January 2021

Cover image: Birds eye view of a typical network of roads on national forest lands. Green lines signify the roads that the agency determined are "needed" and red lines are those that are "unneeded". Significant "needed" roads remain.

WildEarth Guardians. A Dilapidated Web of Roads -The Forest Service's Departure From a "Sustainable" Forest Road System. January 2021.

Table of Contents

Introduction

National forests spread from coast to coast across 40 states, spanning 193 million acres. These forests provide habitat for over 30% of the threatened and endangered species in the U.S., supply 20% of the nation's water to rivers and streams, offer countless places for Americans to recreate and are essential for the cultural, spiritual and personal survival of tribal nations. How these millions of acres are managed - 1/12th of U.S. lands and waters – is vitally important, yet often overlooked.

The Forest Service (USFS), part of the U.S. Department of Agriculture, is the agency that has the responsibility to manage these forests – as set forth in the policy direction of the 1897 Organic Act:

> "…to improve and protect the forest within the reservation, or for the purpose of securing favorable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of citizens of the United States."

Later laws like the 1960 Multiple-Use Sustained Yield Act broadened policy and directed that lands and waters be managed "for outdoor recreation, range, timber, watershed, and wildlife and fish purposes."[2] Despite these policies, the Forest Service has a long history of heavily supporting, subsidizing, and prioritizing extractive uses like logging, grazing, and mining over water protection, wildlife recovery, and recreation. The result is a legacy of mismanagement that has degraded the ecological integrity of forests and grasslands, and left in its wake polluted streams and fragmented habitats.

In order to log, mine, and graze, the Forest Service carved and spliced a vast network of roads across millions of acres of national forest lands. The agency built many roads in poor locations and did not construct them to last. Today, with over 370,000 miles of roads and a draconian budget that leaves 90% of the roads unmaintained, the Forest Service is facing a severe crisis that is exponentially worsened due to climate change. The agency does not have the resources to repair or maintain the entire forest road system. Left unchecked, forest roads will continue to fall apart, bridges will keep collapsing, and access to public lands will further be unreliable at best and unsafe at worst.

The Forest Service, along with numerous conservation and recreation groups, recognized this problem decades ago and developed a blueprint for a sustainable road system through the 2001 Roads Rule.[3] The goal was to establish a road system that would provide access for recreation and management, is aligned with budget realities, while also reducing impacts to ecological functions and wildlife.

On the 20th Anniversary of the Roads Rule, it is important to review where the agency is today. This paper provides background on the rule, analysis of the progress to date and opens the door to a broader discussion on what is needed to truly meet the goals of the Roads Rule. As innocuous as forest roads may seem, healthy forests, waterways, wildlife are at risk, particularly as impacts from climate change become more pronounced.

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[1] Organic Administrative Act of 1897. 30 Stat. 34-36; codified U.S.C. vol. 16, sec. 551.

[2] Multiple Use Sustained Yield Act of 1960. 16 U.S.C. §§528-531 and U.S. Forest Service. "Managing Multiple Uses on National Forests, 1905-1985. A 90-year Learning Experience And It Isn't Finished Yet." Available: http://npshistory.com/publications/usfs/fs-628/chap1.htm (last accessed January 4, 2020).

[3] Road Management Policy. 2001. 36 CFR Parts 212, 261 and 295.

The 2001 Roads Rule - An Important Step Forward

Road construction across national forest lands always existed to support extractive industry demands, but rose exponentially after World War II. Housing demands created a large market for building supplies and lumber, which meant that forests were being cut at record paces. Congress supported the logging industry by dedicating millions of taxpayer dollars to the Forest Service to construct forest roads everywhere and anywhere. Roads were bulldozed through floodplains and up river valleys. Roads were cut along steep hillsides and over mountain tops. There was little thought or planning involved with the primary road construction driver being the need to cut trees. The figure below illustrates the rapid road construction over two decades.

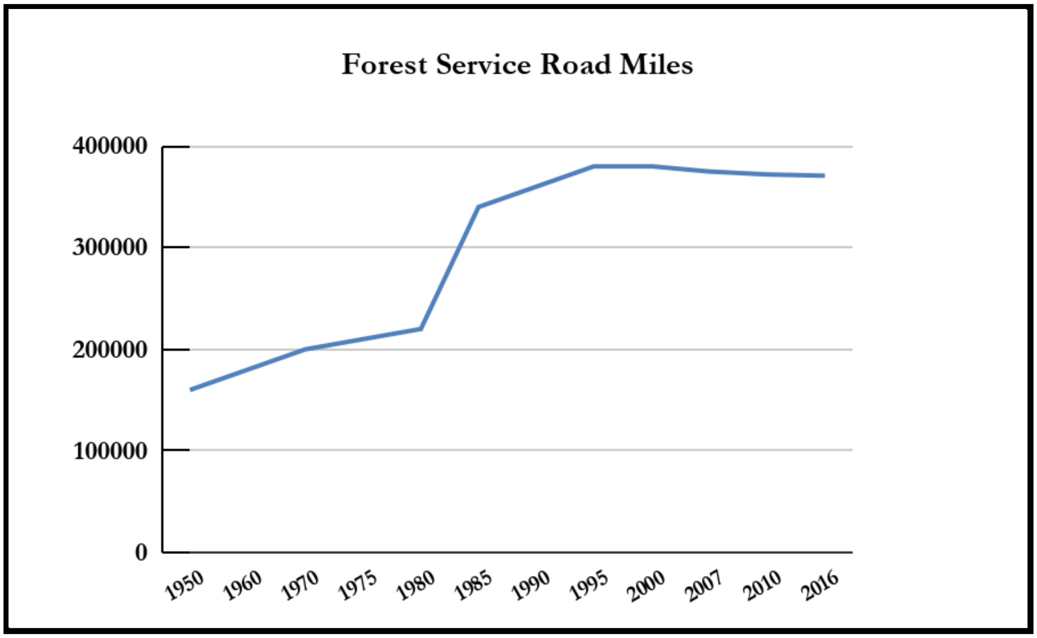

Figure 1. Growth of Forest Service road system from 1960-2016.[4]

By the late 1990's, as timber markets changed, the Forest Service began to acknowledge the growing body of evidence illustrating the harmful consequences from its poorly located, constructed, and managed forest road system. At the same time, the billions of dollars in Congressional appropriations that largely paid for building the road system were dropping at a rapid pace. Conservation groups, fueled by a groundswell of public support, pushed the agency to change. As a result, the Forest Service initiated a process to overhaul its road management policies. In 1998, the Forest Service issued an Advance Notice of Proposed Rulemaking announcing its intent to revise regulations concerning the management of the National Forest Transportation System.[5] The multi-year effort resulted in the landmark 2001 Roadless Rule, that most people are familiar with, protecting millions of acres of national forests from logging and road building. At the same time, then Forest Service Chief Mike Dombeck signed the Road Management Strategy Rule and Policy that went into effect on January 12, 2001, otherwise known as the "Roads Rule."[6]

[4] Adapted from Gerald Coghlan and Richard Sowa. *National Forest Road System and Use Draft Report.* USDA Forest Service. 1998.
[5] 63 FR 4350
[6] See 66 Fed. Reg. 3217 (Jan 12, 2001). See also, March 1, 2001 USDA Road Management Policy Notice

The “Roadless Rule” protected the last remaining wild places from road building and the associated impacts that roads bring. The “Roads Rule”was developed to deal with the vastly oversized and harmful forest road system that was already constructed. It required the Forest Service "to set a standard that each forest identify the minimum road system required to balance access objectives with ecosystem health goals; and to use a science-based roads analysis to identify the road network needed to serve the public and land administrators".[7] The new “Roads Rule” also required the Forest Service to identify unneeded roads for decommissioning, or other uses, and to give priority to those that pose the greatest risk to public safety or environmental quality. The “Roads Rule’s” intent was to move the forest road system toward a more “sustainable” condition, one that balanced ecological, economic, and social needs. One main failing was its lack of compliance deadline. In fact, the only deadline was the requirement for each forest to complete the “science-based roads analysis” by July 2003, with some exceptions.[8] Most national forests did meet this one deadline, but did so by only analyzing a fraction of their roads—those managed for passenger vehicles that account for less than 20% of the overall system. The other 80% of their road system, the dirt roads or those managed for “high-clearance” vehicles, were ignored.

Figure 2. The photo on the left illustrates a typical “passenger vehicle” maintained road often with paved surface, wider road footprint, safety features such as guardrails and higher maintenance costs. The photo on the right illustrates a typical “high-clearance” vehicle road that is often natural surface, narrow road footprint, less maintenance costs which leads to gullies, ruts and potholes. As of 2018, 83% of nationalforest roads are minimally maintained in the “high-clearance” category.

This narrow review meant that the roads problem wasn’t getting resolved. At the same time, the Forest Service was taking a broader look at the impacts of roads and motor vehicles (i.e. off-highway vehicles (OHV’s) and snowmobiles), leading to the adoption of the Travel Management Rule in 2005. The agency determined that there was a need for a new rule because the types and uses of motorized vehicles had increased, the road system was continuing to deteriorate, and all of this was harming the environment. The Travel Management Rule has three subparts: Subpart A — Administration of the Forest Transportation System; Subpart B - Designation of Roads, Trails and Areas for Motor Vehicle Use; and Subpart C — Use by Over-Snow Vehicles (see Table 1). The agency immediately focused on Subpart B in order to reduce the most harm by restricting off-road vehicles to specific designated roads, trails, and areas.[9] As a result, the agency devoted its time and resources toward addressing poorly managed motorized recreation.

[7] 2001 Roads Rule. 36 CFR Parts 212, 261 and 295.
[8] 66 FR 3235
[9] See 70 Fed. Reg 68264 (Nov. 9, 2005).

Table 1. Overview of the Differences Between Subparts of the Travel Management Rule			
36 C.F.R. §212	**Objective:**	**Requires:**	**Product(s):**
Subpart A; Roads Rule	To achieve a sustainable national forest road system.	Use a science-based analysis to identify the minimum road system and roads for decommissioning	- Travel Analysis Report - Map with roads identified as "likely needed" and "likely unneeded"
Subpart B; Travel Management Rule	To protect forests from unmanaged off-road vehicle use by ending cross-country travel and ensuring the agency minimizes the harmful effects from motorized recreation.	Designating a system of roads, trails, and areas available for off-road vehicle use according to general and specific criteria.	- Motor Vehicle Use Maps that indicate what roads/trails are open for motorized travel
Subpart C; Travel Management Rule	To protect forests from unmanaged over-snow vehicle use in a manner that minimizes their harmful effects.	Designating specific roads, trails, and/or areas for oversnow vehicle use according to the criteria per Subpart B.	- Oversnow vehicle maps designating trails and areas for winter motorized recreation

In 2009, the Forest Service updated its directives pertaining to the "science-based analysis" required under Subpart A, thereby establishing the Travel Analysis Process (TAP) that could support, separately or together, the planning process for both Subparts A and B. Once completed, the resulting Travel Analysis Reports were meant to inform National Environmental Policy Act (NEPA)-level analysis and decisions for the identification of the minimum road system. Yet, upon the release of the new travel analysis process directives, many national forests were already far along in their efforts to designate off-road vehicle use, and either did not produce a Travel Analysis Report or did so only for the purposes of meeting Subpart B requirements. As such, compliance with Subpart A languished.

Then, in 2010, the Forest Service's Washington Office issued a memorandum reaffirming its commitment to identify a minimum road system and unneeded roads as required under Subpart A.[10] The memo explained

[10] See Forest Service Memorandum, November 10, 2010 by Deputy Chief Joel Holtrop (stating, "[b]y completing the applicable sections of Subpart A, the Agency expects to identify and maintain an appropriately sized and environmentally sustainable road system that is responsive to ecological, economic, and social concerns."

that "[b]y completing the applicable sections of Subpart A, the Agency expects to identify and maintain an appropriately sized and environmentally sustainable road system that is responsive to ecological, economic, and social concerns."[11] The memo directed that each forest must complete a travel analysis process, which analyzed the risks, benefits (i.e. access needs), and costs of their road system that incorporated ***all*** system roads. The new deadline was set as the end of fiscal year 2015. The resulting travel analysis reports were to be accompanied by a map and list of roads identifying which are "likely needed" and which are "likely unneeded." Upon concerns by some local governments and proponents of motorized recreation, the Washington Office replaced the 2010 memo with another in 2012 that explained, "...travel analysis does not trigger the NEPA. The completion of the Travel Analysis Process is an important first step towards the development of the future minimum road system (MRS)."[12] The 2012 memo included the triangle diagram (below) describing where the agency viewed roads analysis in relation to NEPA analysis.

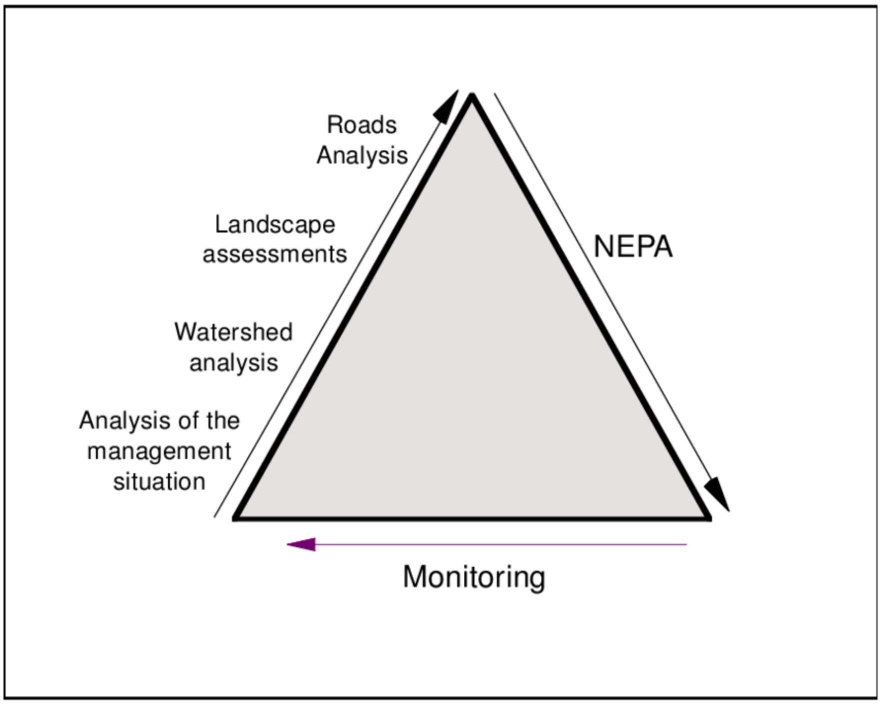

Figure 3. Excerpted from the 2012 Forest Service memo explaining the distinction between the analysis step and minimum road system decisions.

The 2012 memo retained the requirement that each forest complete travel analysis by 2015, which most did. The next step was to use travel analysis recommendations to inform NEPA analyses (the right side of the triangle diagram) and decisions to identify a minimum road system, a process that has yet to occur across most Forest Service lands.

[11] See Forest Service Memorandum, November 10, 2010 by Deputy Chief Joel Holtrop.
[12] See Forest Service Memorandum, March 29, 2012 by Deputy Chief Leslie Weldon, (stating, "[t]he next step in identification of the MRS is to use the travel analysis report to develop proposed actions to identify the MRS. These proposed actions generally should be developed at the scale of a 6th code subwatershed or larger. Proposed actions and alternatives are subject to environmental analysis under NEPA. Travel analysis should be used to inform the environmental analysis.").

Reviews of the Forest Service Travel Analysis Process

The Travel Analysis Process had flaws from the beginning. In an effort to support individual forest autonomy, the Washington Office provided very little direction in how forests should analyze their road systems, how to estimate costs and what criteria to use in determining needed vs. unneeded roads. This led to travel analysis processes that varied widely between regions, with some containing systemic flaws.

In 2016, after repeated examples of problematic processes and reports brought to the attention of the USFS Washington Office (WO) by The Wilderness Society and WildEarth Guardians, the U.S. Department of Transportation John A. Volpe National Transportation Systems Center (Volpe) was contracted to review a random sample of travel analysis reports from each region to provide third-party feedback. In total, Volpe reviewed the travel analysis processes and reports from 38 of the 154 forests. The Volpe Center shared its findings in a draft report shared internally within the Forest Service.[13] The draft report contained several important observations and listed three overarching concerns:

- A lack of clarity regarding the process;
- Failure to follow 36 CFR 212.5(b) direction and Washington Office guidance; and
- Omission of required documents, referenced appendices, or key supporting materials.

Out of numerous critical observations, one top issue was ambiguity in how a given road was rated overall (e.g., high risk, low risk, high benefit, etc.[14]). Volpe found that 14 travel analysis reports, 37% of total reviewed, failed to explain what particular combination of factors led a road to be classified as high risk or high benefit. Some forests used flow charts or prioritized certain factors (e.g., all roads covered by easements or cooperative agreements are considered overall high benefit roads), while others simply broke down the scoring ranges arithmetically (e.g., after adding the scores for all risk factors on each road, those roads with scores in the top 33 percent of possible scores are high risk). The review team even flagged travel analysis reports where no methodology was described or justified at all.

Another top issue was how the results informed recommendations related to the minimum road system. Most forests identified particular risk/benefit categories, such as all high-risk and low-benefit roads, to recommend as "likely not needed" or for specific actions, such as changing the road maintenance level (a lower maintenance level means the road is less costly to maintain). Yet, Volpe found 15 travel analysis reports (39%) did not describe any method for developing recommendations, although a few simply did not explain their rationale for making exceptions to an overall approach.

Further, Subpart A directs that the minimum road system should "reflect long-term funding expectations." Volpe found that forests and regions differed widely in how they analyzed and presented estimates of future funding available for road maintenance. In most cases, forests estimated only an annual basic maintenance cost for the current road system, which omitted costs for the recommended minimum road system or for the backlog of deferred maintenance. The review found few forests' proposed minimum road systems that were actually in alignment with expected budgets. Ten travel analysis reports (26%) either did not include a financial analysis or the numbers were vague with no discussion of how they were derived.

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[13] Volpe Travel Analysis Subpart A Review – Summary of Observations – Draft. U.S. Department of Transportation Volpe Center for the U.S. Forest Service. June 20, 2016.

[14] Road risk referenced how big of an impact the road had on natural resources such as wildlife, fish and water quality. Road benefit referenced how important the road was for recreation, timber, and wildfire management.

The Volpe review demonstrated the poor quality of the travel analysis reports and a need for the entire process to be redone using more consistent guidelines, which has yet to occur. If an entire new process is not feasible forest wide or at a district level, then at a minimum, each national forest should update their minimum road system recommendations during project development. Additionally, updating previous travel analysis reports consistently as part of project-level planning will ensure forest officials incorporate the best available science and changing resource conditions when determining specific road risks and benefits. Ideally, each national forest will fully comply with Subpart A by identifying their minimum road system through NEPA and move forward with implementation on a landscape scale, such as at the district, multi-district, or forest level. Until the Forest Service fully complies with its Subpart A duties, there will be a need to reevaluate and revise travel analysis reports on a consistent basis, and the objectives of the 2001 Roads Rule are left unaddressed.

Lack of Progress Towards Identifying a Minimum Road System

It's important to remember that the overall goals of the Travel Management Rule are to reduce the harm to wildlife, habitat, landscapes, and water from an oversized and deteriorating road system. Establishing a minimum road system is a critical step, which then can more strategically direct restoration efforts. Roads restoration will increase climate resiliency, improve ecological integrity, and decrease habitat fragmentation across the entire forest system, thereby facilitating better connectivity for fish and wildlife. Numerous authors have suggested removing roads is necessary to: 1) restore water quality and aquatic habitats, and 2) improve habitat security and restore terrestrial habitat.[15] However, given declining Forest Service capacity to maintain or treat roads, there is a need for some prioritization. At a landscape scale, certain roads and road segments pose greater risks to terrestrial and aquatic habitat integrity than others. Hence, restoration strategies must focus on identifying and removing, or at least mitigating the higher risk roads. Many forests identified these "high risk roads" in Travel Analysis Reports, but have not yet reduced those risks. Additionally, areas with the highest ecological values, such as being adjacent to a roadless area or dissecting critical wildlife habitat, should also be prioritized for restoration efforts. Yet, few forests are prioritizing road removal or moving towards the sustainable transportation system that was called for over 20 years ago.

Overall, the Forest Service has made limited progress complying with the 2001 Roads Rule, even though most national forests completed some version of a Travel Analysis Report in 2015. As noted in the section above, evaluations of those reports reveal numerous inconsistencies and a systemic failure to identify an affordable road system. Most forests have yet to fully use travel analysis recommendations to identify a minimum road system in NEPA decisions on a broad scale, such as at a forest or district level. Rather, when the agency does include Subpart A compliance in its NEPA decisions, it is often at a project level. Even then, such inclusion is the exception and rarely results in actually identifying a minimum road system that is both ecologically and economically sustainable.

For example, the Payette National Forest's Huckleberry Landscape Restoration Project decision identified a minimum road system that failed to consider how its deferred maintenance backlog would affect the agency's ability to maintain the system after project completion, and failed to disclose the long-term ecological

[15] Gucinski et al. 2000, Hebblewhite et al. 2009. See also: The Environmental Consequences of Forest Roads and Achieving a Sustainable Road System (WildEarth Guardians, 2020).

consequences from its acknowledged lack of maintenance capacity. In addition, all the subwatersheds in the project area are functioning at unacceptable risk for road densities and location, yet the identified minimum road system fails to move these rankings even to the next category of functioning at risk (FR), let alone functioning appropriately (FA). When asked to at least decommission enough roads to improve the rankings for just the Riparian Conservation Areas (RCAs), the Forest Service refused, stating that "*[i]ncluding enough RCA road decommissioning to achieve FR in the Road Density/Location WCI would not address... the Forest Plan emphasis on active management in these subwatersheds.*"[16] Few examples exist that so clearly show the agency's bias for cutting trees over identifying a minimum road system that will provide for the protection of national forest system lands and reflect long-term funding expectations.

As more years pass with the Forest Service failing to identify, let alone implement, an ecologically and economically sustainable forest road system, recommendations in travel analysis reports are becoming more outdated.

The graph below illustrates this lack of progress. Total system miles (blue line) have barely changed since the 2001 Roads Rule. Although there is a slight decrease in open roads and an increase in closed roads, this is likely more indicative of storms washing out roads, forcing closure, rather than thoughtful moves towards a sustainable transportation system.

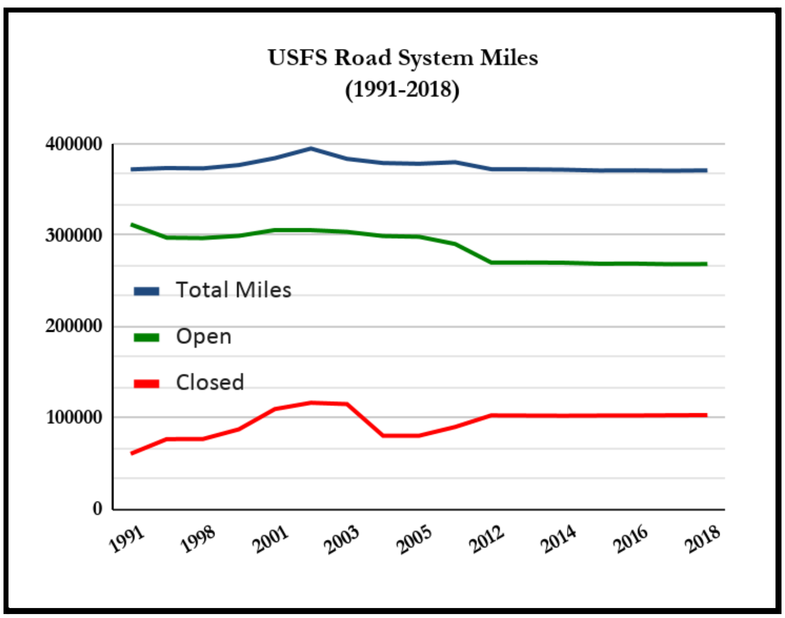

Figure 4. Road system mileage shows only minor changes in the past 30 years. Source: USFS

Notably, Forest Service Region 6 (Pacific Northwest) has shown some commitment toward identifying and implementing a minimum road system. Many forests in the region identify road challenges in their NEPA project purpose/need statements, use information from their travel analysis reports, develop matrices displaying all information for each road and recommendations from travel analysis reports, include detailed maps and photos, and some even identify the minimum road system within the project boundary. The following are example purpose/need statements from projects in the region:

[16] Huckleberry Landscape Restoration Project FEIS Vol 2. Appendix 8, p. 14

- "reduce the density of open road systems in this project area through closure or decommissioning";
- "identify a road system that meets transportation needs while reducing aquatic risk associated with specific roads";
- "sustainably manage the network of roads in the project area"; and
- "identify the minimum road system needed for safe and efficient travel, and for administration, utilization, and protection of National Forest System lands".

Even with the incorporation of roads in most projects in Region 6 and the identification of the minimum road system in some projects, nearly all forests across the U.S. have yet to fully comply with Subpart A requirements, let alone, achieve a sustainable transportation system that is "appropriately sized and environmentally sustainable... that is responsive to ecological, economic, and social concerns".[17] Few remedies exist that can effectively spur the Forest Service to comply with its duties under Subpart A, even within the courts.

Case Law Addressing Compliance with Subpart A

There is limited case law addressing the Forest Service's duty to identify the minimum road system and prioritize roads for decommissioning under Subpart A of the Travel Management Rule. The only Circuit Court decision on point is from the Ninth Circuit Court of Appeals in *Alliance for the Wild Rockies v. U.S. Forest Service*, 907 F.3d 1105 (9th Cir. 2018). There, the Ninth Circuit determined that the Forest Service has discretion to designate a minimum road system that exceeds the number of miles in the minimum road system recommended by the project's travel analysis report.[18] Alliance for the Wild Rockies (Alliance) challenged the Forest Service's approval of the Lost Creek-Boulder Creek Landscape Restoration Project on 80,000 acres of the Payette National Forest in Idaho for violations of the National Forest Management Act (NFMA), National Environmental Policy Act (NEPA) Endangered Species Act (ESA), and Subpart A of the Travel Management Rule (TMR).[19] The District Court for the District of Idaho entered summary judgment for the Forest Service on all claims.[20] On appeal, the Ninth Circuit affirmed in part as to the NEPA and TMR claims, and reversed and remanded in part as to the NFMA claims, dismissing the ESA claim as moot.

Specific to the TMR claim, Alliance alleged that the Forest Service's decision to designate a minimum road system for the project area that exceeded the number of miles in the minimum road system recommended in the Forest Service's travel analysis report was arbitrary and capricious.[21] The Forest Service prepared a travel analysis report for the Lost Creek Project that identified 474 existing miles of roads in the project area, 240 miles of which it recommended for the minimum road system and 68 miles for decommissioning.[22] However, in the final record of decision for the project, the Forest Service designated 401 miles as the minimum road system and identified 68 miles identified for decommissioning.[23] The Ninth Circuit reasoned that the agency's decision did not render the project's minimum road system arbitrary or capricious where the Forest Service

[17] 36 C.F.R. 212.5(b)
[18] 907 F.3d 1105 (9th Cir. 2018) at 1118.
[19] *Id.* at 1109-1112.
[20] *Id.* at 1112.
[21] *Id.* at 1117-18.
[22] *Id.* at 1117-18.
[23] *Id.* at 1118.

fully explained its decision, and considered all of the factors listed under 36 C.F.R. § 212.5.[24] (noting the Final Environmental Impact Statement (FEIS) contained "a robust discussion of maintenance costs . . . and accounts for 'long-term funding expectations'").

The few lower court decisions addressing Subpart A[25] afford the Forest Service considerable discretion in how to identify the minimum road system consistent with the rule. For example, in *Bark v. United States Forest Service*, 393 F. Supp. 3d 1043 (D. Or. 2019), *rev'd and remanded on other grounds*, 958 F.3d 865 (9th Cir. 2020), conservation groups challenged the Forest Service's forest thinning project on Mt. Hood National Forest as violating NEPA, NFMA, and the TMR. The groups claimed the project improperly identified a minimum road system without complying with Subpart A of the TMR.[26] The District Court for the District of Oregon rejected the challenge, holding that the project did not actually identify a minimum road system, and it was not required to do so;[27] (stating, "I find no statutory basis for requiring the Forest Service to identify a minimum road system as part of the CCR Project."). The court explained that minimum road system "proposals may be incorporated into landscape-level restoration projects such as this one," or the Forest Service "may also choose to identify a minimum road system as a stand-alone proposal."[28]

In addition to discretion about how to identify the minimum road system, lower courts have concluded the Forest Service has discretion about when to identify it. In *Center for Sierra Nevada Conservation v. U.S. Forest Service*, 832 F.Supp.2d 1138 (E.D. Cal. 2011), the District Court held the Forest Service has discretion to complete travel management planning under Subpart B of the TMR before identifying a minimum road system under Subpart A. The Court explained, "the Forest Service Manual suggests that the Forest Service may address Subparts A and B in any order."[29]

Regardless of this broad discretion, courts have required the Forest Service to be clear about its actions. In *Idaho Conservation League v. Guzman*, 766 F. Supp. 2d 1056 (D. Idaho 2011), the District Court directed the Forest Service to amend its decision to eliminate any suggestion that the agency made a minimum road system determination. The Court noted, "there is no dispute that the Forest Service could not properly designate a minimum road system, because it did not follow the requisite public notice requirements."[30]

The District Court in *Friends of Bitterroot v. Marten*, No. 9:20-cv-00019-DLC, 2020 WL 5804251 (D. Mont. Sept. 29, 2020), reached a similar result. Conservation groups challenged the Forest Service's designation of a minimum road system for a vegetation management project on the Bitterroot National Forest for violating the TMR, NEPA, and APA by omitting the required analysis and as "substantially different" than what was recommended in the project travel analysis report with explanation.[31] The Court concluded the Forest Service's implementation of a minimum road system lacked the necessary analysis where it addressed only one

[24] *Id.* at 1118.
[25] In *MN Center for Environmental Advocacy v. Forest Service*, 914 F. Supp. 2d 957 (D. Minn. 2012), conservation groups challenged the Superior National Forest's Forest Plan, alleging violations of NFMA, NEPA, ESA, and the Executive Orders and the agency's own regulations. Specifically, the plaintiffs alleged the Forest Service failed to identify the minimum road system. *Id.* at 981 (describing Count VII). Yet because the groups did not brief any argument for that claim, the court deemed the issue abandoned. *Id.* at 981 n.14.
[26] 393 F. Supp. 3d at 1062.
[27] *Id.*
[28] *Id.*
[29] 832 F.Supp.2d 1138 (E.D. Cal. 2011), at 1149-57.
[30] 766 F. Supp. 2d 1056 (D. Idaho 2011), at 1078-79.
[31] *Friends of Bitterroot v. Marten*, No. 9:20-cv-00019-DLC, 2020 WL 5804251 (D. Mont. Sept. 29, 2020) at *10.

of the four factors required under 36 C.F.R. § 212.5(b)(1).[32] However, recognizing that the agency's decision to implement a minimum road system is wholly discretionary, the Court remanded without vacatur and instructed the Forest Service to strike any language in the decision that refers to implementation of a minimum road system.[33]

These are discouraging results from the courts resulting in ongoing delays in identifying the minimum road system, but more importantly, implementation that begins to reverse the harm caused by decades of unfettered road construction.

Recommendations for Achieving a Sustainable Forest Road System

Since the 2001 Roads Rule went into effect, the Forest Service has yet to identify a minimum road system or take action to significantly decrease its massive forest road network that exceeds 370,000 miles and has a deferred maintenance backlog of over $3 billion. USDA National Forest System statistics from Fiscal Years 2012 to 2018 show only a 0.35% decrease in road system miles. Numerous factors demonstrate the need for the agency to correct this situation, not the least of which is the growing climate crisis, a failure to substantially reduce the deferred maintenance backlog, the continued harmful effects to fish, wildlife, and their habitats, and the road washouts/failures that eliminate recreational access for millions of Americans to public lands. Given the agency's failure thus far to rightsize the forest road system, Congress and the new administration must step in and take decisive action not only to ensure identification of a minimum road system for each national forest and grassland, but also to direct that the agency takes measurable actions to reduce road-related ecological impacts as it moves to achieve a more sustainable system. Toward this end, we offer the following recommendations:

- **National Forest Units:**
  - **Projects**

    NEPA Analysis Stage
    - Update travel analysis reports, including reevaluating risks and benefits and incorporating economics as part of the project analysis based on new consistent methods developed at the national level (see below).
    - Use travel analysis reports, with updated information and field verification, to inform proposed actions.
    - Include road-related actions and road decommissioning in every project.
    - Include the need "to identify and implement a minimum road system" as a project purpose and then identify the minimum road system.
    - Include the need "to reduce risks to aquatic resources and wildlife from roads" as a project purpose.
    - Incorporate analysis of transportation vulnerabilities due to climate change and actions for increasing resilience.
    - Identify high priority roads that should be removed to expand a roadless area or connect/improve a wildlife corridor or reduce fragmentation of key habitat.

[32] *Id.* at 12.
[33] *Id.*

- Include unauthorized or other non-system roads/trails/routes in project analysis and incorporate in road/route density calculations.
- Improve understanding of road-related risks/benefits among the public by sharing information, such as photos on road conditions (i.e. driveability), storm-damage, road maintenance costs and budgets, etc.

Project Implementation Stage

- Prioritize timing of road decommissioning and treatments in locations where roads impact water quality, wildlife, and/or habitat.
- Use road decommissioning methods that restore natural ecological conditions, and fully remove road features (i.e. decompacting hardened road surfaces hydrologically disconnecting from streams; native vegetation seeding/planting).
- Hire contractors that are experienced in road treatments and adjust as specific field conditions warrant.
- Perform Best Management Practices (BMP) audits and use field monitoring data to analyze the effectiveness of specific design criteria and practices, making adjustments as necessary. Release monitoring reports and audits annually.
- Monitor decommissioned roads to ensure illegal motorized vehicle incursions have not occurred or caused additional harm.
- Share outcomes and environmental benefits to the public via multiple outreach methods.

- **Land management plans**
  - Include specific components that will ensure the forest achieves an ecologically sustainable road system that also provides for the viability of fish and wildlife species.
  - Include specific components that ensure all system roads are maintained to their objective standard through standards and guidelines.
  - Incorporate ecologically-based road/motorized trail density standards as part of each revised forest plan.
  - Set the identification of the minimum road system as an objective, with annual decommissioning targets to ensure the forest actually implements its identified minimum road system.

- **National Forest Regions**
  - Set regional requirements that forest units include the need "to identify and implement a minimum road system" as a project purpose where the agency has yet to do so.
  - Ensure accountability by requiring annual road decommissioning targets be met by each forest supervisor in the region and is a performance metric reviewed by the Regional Forester.
  - Prioritize existing funding to remove excessive and damaging roads from the system.
  - Incorporate robust outreach and education to increase understanding of the risks, benefits and costs of the road system.

- **USFS Washington Office**
    - Develop updated and consistent methods for the travel analysis process that will ensure the proper assessment and measurement of road-related risks and benefits based on science, and for determining long-term funding expectations. As part of the updated travel analysis process, the methods would direct each forest to consider issues not fully analyzed in previous efforts, specifically climate change vulnerabilities, road/motorized/unauthorized road and trail densities, habitat connectivity, and the increased wildfire risks from the forest road system.
    - Issue a new memorandum establishing a deadline for each national forest to identify unneeded roads and identify the minimum road system for each national forest unit in compliance with Subpart A. The memo would also direct each forest unit to update their Travel Analysis Reports using consistent methods that have been established at the national level.
    - Demand accountability for Subpart A implementation by developing performance metrics that Regional Foresters must achieve.
    - Provide annual reports for the public and Congress on progress towards achieving a sustainable road system, an update on road-related challenges, and an accurate accounting of costs.
    - At all levels, incorporate climate change assessments to drive strategic implementation plans.
    - At all levels, improve coordination between engineering and resource staff to facilitate integrated restoration projects that involve road projects to meet ecological goals.

- **Congress**
    - Reinstate, permanently authorize, and adequately fund the Legacy Roads and Trails program as a budgetary line item that is specifically targeted to reduce impacts to water quality and wildlife from the road system through effective decommissioning of both system and unauthorized roads.
    - Require annual accounting and reporting of Legacy Roads and Trails accomplishments and ongoing needs.
    - Require annual accounting and reporting of the Forest Service's progress in achieving a sustainable road system.

As climate change impacts on national forests increase and intensify, the Forest Service has the ability to make progress on at least one front—reducing the oversized and harmful road system to one that is more sustainable. The tools are already present: various roads analyses, budgetary benefits, an expansive roads database, and an urgent need. With support from Congress and clear administrative guidance, the Forest Service can actually make real progress in achieving a road system that ensures protection of national forest lands and provides sustainable access. There is no more time to waste.

Exhibit 6

WildEarth GUARDIANS
A FORCE FOR NATURE

The Environmental Consequences of Forest Roads and Achieving a Sustainable Road System

March 2020

Table of Contents

Acknowledgements: We thank The Wilderness Society for the report titled, *Transportation Infrastructure and Access on National Forests and Grasslands: A Literature Review. May 2014*. This paper updates and revises the original report adding 59 additional citations, and featuring several new sections. We also thank Adam Switalski, Principal of InRoads Consulting, LLC for the bulk of this report's research and technical writing.

Cover photos credits: Mt. Baker-Snoqualmie National Forest, 2016. WildEarth Guardians.

Introduction

The Forest Service faces many challenges with its vastly oversized, under-maintained, and unaffordable transportation system. With 370,643 miles of system roads and 137,409 miles of system trails (USDA Forest Service 2019), the network extends broadly across every national forest and grassland and through a variety of habitats, ecosystems and terrains. An impressive body of scientific literature addresses the various effects of roads on the physical, biological and cultural environment. Numerous studies demonstrate the harmful environmental consequences to water, fish, wildlife, and ecosystems.

In recent years, the scientific literature has expanded to address the effects of roads on climate change adaptation and conversely the effects of climate change on roads, as well as the multiple benefits of road removal on the physical, biological and cultural environments.

The first section of this paper provides a literature review summarizing the most recent science related to the environmental impacts of forest roads and motorized trails. The second section focuses on climate change effects and strategies to address the growing ecological consequences to forest resources. The third section provides background and specific direction for the Forest Service to provide for an ecologically and economically sustainable road system, including recommendations for future action.

I. Impacts of Transportation Infrastructure and Access to the Ecological Integrity of Terrestrial and Aquatic Ecosystems and Watersheds

It is well understood that transportation infrastructure provides access to national forests and grasslands and also harms aquatic and terrestrial environments at multiple scales. In general, the more roads and motorized trails the greater the impacts. Since its emergence, the field of road ecology and the resulting research has proven the magnitude and breadth of ecological issues related to roads; entire books have been written on the topic (e.g., Forman et al. 2003, van der Ree et al. 2015), and research centers continue to expand their case studies, including the Western Transportation Institute at Montana State University and the Road Ecology Center at the University of California - Davis.[1]

Below, we provide a summary of the current understanding of the impacts of roads and motorized access on terrestrial and aquatic ecosystems, supplementing long-established, peer-reviewed literature reviews on the topic, including Gucinski et al. (2000), Trombulak and Frissell (2000), Coffin (2007), and Robinson et al. (2010). More targeted reviews have been published on the effects of roads on insects (Munoz et al. 2015), vertebrates (da Rosa 2013), and animal abundance (Fahrig and Rytwinski 2009, Benítez-López et al. 2010). Literature reviews on the ecological and social impacts of motorized recreation include Gaines et al. (2003), Davenport and Switalski (2006), Ouren

[1] See http://www.westerntransportationinstitute.org/programs/road-ecology and http://roadecology.ucdavis.edu/

et al. (2007), Switalski and Jones (2012), and, more recently, Switalski (2017). In addition to the physical and environmental impacts of roads, increased visitation has resulted in intentional and unintentional damage to many cultural and historic sites (Spangler and Yentsch 2008, Sampson 2009, Hedquist et al. 2014).

A. Impacts on geomorphology and hydrology

The construction and presence of forest roads can dramatically change the hydrology and geomorphology of a forest system leading to reductions in the quantity and quality of aquatic habitat (Al-Chokhachy et al. 2016). While there are several mechanisms that cause these impacts (Wemple et al. 2001, Figure 1), most fundamentally, compacted roadbeds reduce rainfall infiltration, intercepting and concentrating water, and providing a ready source of sediment for transport (Wemple et al. 2001). In fact, roads contribute more sediment to streams than any other land management activities on Forest Service lands (Gucinski et al. 2000). Surface erosion rates from roads can be up to three orders of magnitude greater than erosion rates from undisturbed forest soils (Endicott 2008).

Erosion and sediment produced from roads occur both chronically and catastrophically. Every time it rains, sediment from the road surface and from cut-and fill-slopes is picked up by rainwater that flows into and on roads (fluvial erosion). The sediment that is entrained in surface flows are often concentrated into road ditches and culverts and directed into streams. The degree of fluvial erosion varies by geology and geography, and increases with increased motorized use (Robichaud et al. 2010). Closed roads produce significantly less sediment than open drivable roads (Sosa Pérez and Macdonald 2017, Foltz et al. 2009).

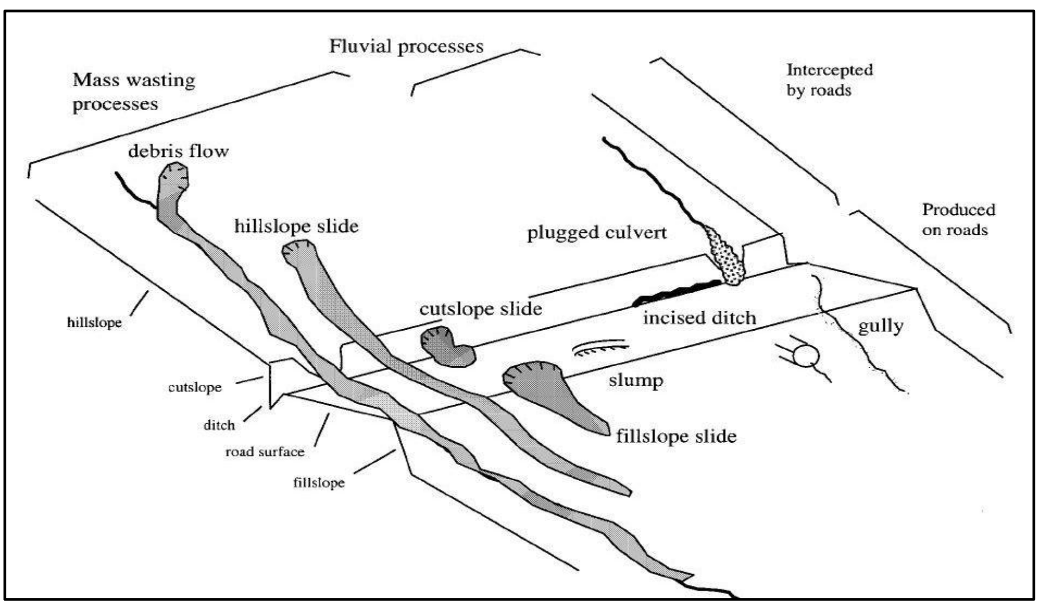

Figure 1: Typology of erosional and depositional features produced by mass-wasting and fluvial processes associated with forest roads (reprinted from Wemple et al. 2001).

Roads also precipitate catastrophic failures of road beds and fills (mass wasting) during large storm events leading to massive slugs of sediment moving into waterways (Gucinski et al. 2000, Endicott 2008). This typically occurs when culverts are undersized and cannot handle the volume of water funneled through them, or they simply become plugged with debris and sediment. The saturated roadbed can fail entirely and result in a landslide, or the blocked stream crossing can erode the entire fill down to the original stream channel.

The erosion of road- and trail-related sediment and its subsequent movement into stream systems affects the geomorphology of the drainage system in a number of ways. It directly alters channel morphology by embedding larger gravels as well as filling pools. It can also have the opposite effect of increasing peak discharges and scouring channels, which can lead to disconnection of the channel and floodplain, and lowered base flows (Gucinski et al. 2000). The width/depth ratio of the stream changes can trigger changes in water temperature, sinuosity and other geomorphic factors important for aquatic species survival (Trombulak and Frissell 2000).

B. Impacts on aquatic habitat and fish

Roads can have dramatic and lasting impacts on fish and aquatic habitat. Increased sedimentation in stream beds has been linked to decreased fry emergence, decreased juvenile densities, loss of winter carrying capacity, increased predation of fish, and reductions in macro-invertebrate populations that are a food source to many fish species (Gucinski et al. 2000, Endicott 2008). Roads close to streams reduce the number of trees available for large wood recruitment, and reduce stream-side shade (Meredith et al. 2014.) On a landscape scale, these effects add up to: changes in the frequency, timing and magnitude of disturbance to aquatic habitat and changes to aquatic habitat structures (e.g., pools, riffles, spawning gravels and in-channel debris), and conditions (food sources, refugia, and water temperature; Gucinski et al. 2000).

River fragmentation

Roads also act as barriers to migration and fragment habitat of aquatic species (Gucinski et al. 2000). Where roads cross streams, road engineers usually place culverts or bridges. Undersized culverts interfere with sediment transport and channel processes such that the road/stream crossing becomes a barrier for fish and aquatic species movement up and down stream (Erikinaro et al. 2017). For instance, a culvert may scour on the downstream side of the crossing, actually forming a waterfall up which fish cannot move. Undersized culverts can infringe upon the channel or floodplain and trap sediment causing the stream to become too shallow and/or warm such that fish will not migrate past the structure. Or, the water can move through the culvert at too high a gradient or velocity to allow fish passage (Endicott 2008).

River fragmentation is problematic for many aquatic species but especially for anadromous species that must migrate upstream to spawn. Well-known native aquatic species affected by roads include salmon such as coho (*Oncorhynchus kisutch*), Chinook (*O. tshawytscha*), and chum (*O. keta*); steelhead

(*O. mykiss*), a variety of trout species including bull trout (*Salvelinus confluentus*) and cutthroat trout (*O. clarki*), as well as other native fish and amphibians (Endicott 2008). The restoration and mitigation of impassable road culverts has been found to restore connectivity and increase available aquatic habitat (Erikinaro et al. 2017), and the quality of aquatic habitat (McCaffery et al. 2007).

C. Impacts on terrestrial habitat and wildlife

Roads and trails impact wildlife through a number of mechanisms including: direct mortality (poaching, hunting/trapping), changes in movement and habitat-use patterns (disturbance/avoidance), as well as indirect impacts including altering adjacent habitat and interference with predator/prey relationships (Coffin 2007, Fahrig and Rytwinski 2009, Robinson et al. 2010, da Rosa and Bager 2013). Some of these impacts result from the road itself, and some result from the uses on and around the roads (access). Ultimately, numerous studies show that roads reduce the abundance, diversity, and distribution of several forest species (Fayrig and Ritwinski 2009, Benítez-López et al. 2010, Munoz et al. 2015).

Abundance and distribution

The extensive research on roads and wildlife establish clear trends of wildlife population declines. Fahrig and Rytwinski (2009) reviewed the empirical literature on the effects of roads and traffic on animal abundance and distribution looking at 79 studies that addressed 131 species. They found that the number of documented negative effects of roads on animal abundance outnumbered the number of positive effects by a factor of 5. Amphibians, reptiles, and most birds tended to show negative effects. Small mammals generally showed either positive effects or no effect, mid-sized mammals showed either negative effects or no effect, and large mammals showed predominantly negative effects. Benítez-López et al. (2010) conducted a meta-analysis on the effects of roads and infrastructure proximity on mammal and bird populations. They found a significant pattern of avoidance and a reduction in bird and mammal populations in the vicinity of infrastructure. Muñoz et al. (2015) found that many insect populations have declined as well.

Direct mortality, disturbance, and habitat modification

Road and motorized trail use affect many different types of species. For example, trapping, poaching, collisions, negative human interactions, disturbance and displacement significantly impact wide ranging carnivores (Gaines et al. 2003, Table 1). Hunted game species such as elk (Cervus canadensis), become more vulnerable from access allowed by roads and motorized trails resulting in a reduction in effective habitat among other impacts (Rowland et al. 2005). Slow-moving migratory animals such as amphibians, and reptiles who use roads to regulate temperature, are also vulnerable (Gucinski et al. 2000, Brehme et al. 2013). Roads and motorized trails also affect ecosystems and habitats because they are major vectors of non-native plant and animal species (Gelbard and Harrison 2003). This can have significant ecological and economic impacts when aggressive invading species overwhelm or significantly alter native species and systems.

Table 1: Road- and recreation trail-associated factors for wide-ranging carnivores (Reprinted from Gaines et al. (2003)[2]

Focal species	Road-associated factors	Motorized trail-associated factors	Nonmotorized trail-associated factors
Grizzly bear	Poaching Collisions Negative human interactions Displacement or avoidance	Poaching Negative human interactions Displacement or avoidance	Poaching Negative human interactions Displacement or avoidance
Lynx	Down log reduction Trapping Collisions Disturbance at a specific site	Disturbance at a specific site Trapping	Disturbance at a specific site
Gray wolf	Trapping Poaching Collisions Negative human interactions Disturbance at a specific site Displacement or avoidance	Trapping Disturbance at a specific site	Trapping Disturbance at a specific site
Wolverine	Down log reduction Trapping Disturbance at a specific site Collisions	Trapping Disturbance at a specific site	Trapping Disturbance at a specific site

Habitat fragmentation

At the landscape scale, roads fragment habitat blocks into smaller patches that may not be able to support interior forest species. Smaller habitat patches result in diminished genetic variability, increased inbreeding, and at times local extinctions (Gucinski et al. 2000; Trombulak and Frissell 2000). For example, a narrow forest road with little traffic was a barrier in Arizona to the Mt. Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*; Chen and Koprowski 2013). Fragmentation intensifies concerns about grizzly bear population viability, especially since roads increase human/bear interactions exacerbating the problem of excessive mortality (Proctor et al, 2012)

Roads also change the composition and structure of ecosystems along buffer zones, called edge-affected zones. The width of edge-affected zones varies by what metric is being discussed; however, researchers have documented road-avoidance zones a kilometer or more away from a road (Robinson et al.2010; Table 2). In heavily roaded landscapes, edge-affected acres can be a significant percentage of total acres. For example, in a landscape where the road density is 3 mi/mi^2 and where the edge-affected zone is estimated to be 500 ft from the center of the road to each side, the edge-affected zone is 56% of the total acreage.

[2] For a list of citations see Gaines et al. (2003).

Table 2: A summary of some documented road-avoidance zones for various species (adapted from Robinson et al. 2010).

Species	Avoidance zone m (ft)	Type of disturbance	Reference
Snakes	650 (2133)	Forestry roads	Bowles (1997)
Salamander	35 (115)	Narrow forestry road, light traffic	Semlitsch (2003)
Woodland birds	150 (492)	Unpaved roads	Ortega and Capen (2002)
Spotted owl	400 (1312)	Forestry roads, light traffic	Wasser et al. (1997)
Marten	<100 (<328)	Any forest opening	Hargis et al. (1999)
Elk	500–1000 (1640-3281)	Logging roads, light traffic	Edge and Marcum (1985)
Grizzly bear	3000 (9840)	Fall	Mattson et al. (1996)
	500 (1640)	Spring and summer	
	1122 (3681)	Open road	Kasworm and Manley (1990)
	665 (2182)	Closed road	
Black bear	274 (899)	Spring, unpaved roads	Kasworm and Manley (1990)
	914 (2999)	Fall, unpaved roads	

Migration disruption

Roads disrupt migration of large ungulates, such as elk, impeding travel at multiple scales, including seasonal home range use and migration to winter range (Buchanan et al. 2014, Prokopenko et al. 2017). For example, a recent study found migrating elk changed their behavior and stopover use on migration routes that were roaded (Paton et al. 2017). The authors suggest this disturbance may lead to decreased foraging, displacement of high-quality habitat, and affect the permeability of the migration route. In addition, roads disrupt grizzly bear movements influencing dispersal away from the maternal home range and ultimately influencing population-level fragmentation." (Proctor et al. 2018).

Oil and gas development (and associated roads) reduced the effectiveness of both mule deer and pronghorn migration corridors in western Wyoming. (Sawyer et al. 2005). Multiple studies found that mule deer increased their rate of travel during migrations, reducing stop over time and their use of important foraging habitats (Sawyer et al. 2012, Lendrum et al. 2012; Ledrum et al. 2013;). A study in Colorado found that female mule deer changed their migration timing which may change alignment with vegetative phenology and potentially result in energetic and demographic costs (Lendrum et al. 2013).

D. Road density thresholds for fish and wildlife[3]

It is well documented that, beyond specific road density thresholds, certain species will be negatively affected, and some risk being extirpated (Robinson et al. 2000, Table 3). Most studies that look into the relationship between road density and wildlife focus on the impacts to large endangered carnivores or hunted game species, although high road densities certainly affect other species. Grizzly bears have been found to have a higher mortality risk as road density increases (Boulanger and Stenhouse 2014). Gray wolves (*Canis lupus*) in the Great Lakes region and elk in Montana and Idaho also face increased mortality risk, and have undergone the most long-term and in-depth analysis. Forman and Hersperger (1996) found that in order to maintain a naturally functioning landscape with sustained populations of large mammals, road density must be below 0.6 km/km² (1.0 mi/mi²).

A number of studies show that higher road densities also impact aquatic habitats and fish (Table 3). Carnefix and Frissell (2009) provide a concise review of studies that correlate cold water fish abundance and road density, and from the cited evidence concluded that:

> 1) no truly "safe" threshold road density exists, but rather negative impacts begin to accrue and be expressed with incursion of the very first road segment; and 2) highly significant impacts (e.g., threat of extirpation of sensitive species) are already apparent at road densities on the order of 0.6 km/km² (1.0 mi/mi²) or less, (Carnefix and Frissell (2009), p. 1).

Cold water salmonids such as threatened bull trout, are particularly sensitive to the impacts of forest roads. The U.S. Fish and Wildlife Service's Final Rule listing bull trout as threatened (USDI Fish and Wildlife Service 1999) addressed road density stating:

> … assessment of the interior Columbia Basin ecosystem revealed that increasing road densities were associated with declines in four non-anadromous salmonid species (bull trout, Yellowstone cutthroat trout, westslope cutthroat trout, and redband trout) within the Columbia River Basin, likely through a variety of factors associated with roads (Quigley & Arbelbide 1997). Bull trout were less likely to use highly roaded basins for spawning and rearing, and if present, were likely to be at lower population levels (Quigley and Arbelbide 1997). Quigley et al. (1996) demonstrated that when average road densities were between 0.4 to 1.1 km/km² (0.7 and 1.7 mi/mi²) on USFS lands, the proportion of subwatersheds supporting "strong" populations of key salmonids dropped substantially. Higher road densities were associated with further declines (USDI Fish and Wildlife Service (1999), p. 58922).

Anderson et al. (2012) showed that watershed conditions tend to be best in areas protected from road construction and development. Using the U.S. Forest Service's Watershed Condition Framework assessment data, they showed that National Forest lands protected under the Wilderness Act tend to have

[3] We intend for the term "road density" to refer to the density of all roads within national forests, including system roads, closed roads, non-system roads, temporary roads and motorized trails, and roads administered by other jurisdictions (private, county, state).

the healthiest watersheds. In support of this conclusion, McCaffery et al. (2005) found that streams in roadless watersheds had less fine sediment and higher quality habitat than roaded watersheds. Miller et al. (2017) showed that in 20 years of monitoring forests managed by the Northwest Forest Plan there were measurable improvements in watershed conditions as a result of road decommissioning, finding "...the decommissioning of roads in riparian areas has multiple benefits, including improving the riparian scores directly and typically the sedimentation scores."

Table 3: A summary of some road-density thresholds and correlations for terrestrial and aquatic species and ecosystems (reprinted from Robinson et al. 2010).

Species (Location)	**Road density (mean, guideline, threshold, correlation)**	**Reference**
Wolf (Minnesota)	0.36 km/km2 (mean road density in primary range); 0.54 km/km^2 (mean road density in peripheral range)	Mech et al. (1988)
Wolf	>0.6 km/km^2 (absent at this density)	Jalkotzy et al. (1997)
Wolf (Northern Great Lakes re- gion)	>0.45 km/km^2 (few packs exist above this threshold); >1.0 km/km^2 (no pack exist above this threshold)	Mladenoff et al. (1995)
Wolf (Wisconsin)	0.63 km/km^2 (increasing due to greater human tolerance	Wydeven et al. (2001)
Wolf, mountain lion (Minne- sota, Wisconsin, Michigan)	0.6 km/km^2 (apparent threshold value for a naturally functioning landscape containing sustained popula- tions)	Thiel (1985); van Dyke et al. (1986); Jensen et al. (1986); Mech et al. (1988); Mech (1989)
Elk (Idaho)	1.9 km/km^2 (density standard for habitat effectiveness)	Woodley 2000 cited in Beazley et al. 2004
Elk (Northern US)	1.24 km/km^2 (habitat effectiveness decline by at least 50%)	Lyon (1983)
Elk, bear, wolverine, lynx, and others	0.63 km/km^2 (reduced habitat security and increased mortality)	Wisdom et al. (2000)
Moose (Ontario)	0.2-0.4 km/km2 (threshold for pronounced response)	Beyer et al. (2013)
Grizzly bear (Montana)	>0.6 km/km^2	Mace et al. (1996); Matt- son et al. (1996)
Black bear (North Carolina)	>1.25 km/km^2 (open roads); >0.5 km/km2 (logging roads); (interference with use of habitat)	Brody and Pelton (1989)
Black bear	0.25 km/km^2 (road density should not exceed)	Jalkotzy et al. (1997)
Bobcat (Wisconsin)	1.5 km/km^2 (density of all road types in home range)	Jalkotzy et al. (1997)
Large mammals	>0.6 km/km^2 (apparent threshold value for a naturally functioning landscape containing sustained popula- tions)	Forman and Hersperger (1996)
Bull trout (Montana)	Inverse relationship of population and road density	Rieman et al. (1997); Baxter et al. (1999)

Fish populations (Medicine Bow National Forest)	(1) Positive correlation of numbers of culverts and stream crossings and amount of fine sediment in stream channels (2) Negative correlation of fish density and numbers of culverts	Eaglin and Hubert (1993) cited in Gucinski et al. (2001)
Macroinvertebrates	Species richness negatively correlated with an index of road density	McGurk and Fong (1995)
Non-anadromous salmonids (Upper Columbia River basin)	(1) Negative correlation likelihood of spawning and rearing and road density (2) Negative correlation of fish density and road density	Lee et al. (1997)

E. Roads and Fires

Wildland forest fire plays an essential role in many forest ecosystems, and with climate change, fire will increasingly shape National Forest lands. Humans have made fire more common on the landscape, and studies have found that forest roads can affect fire regimes and localized fuel regimes. Changes in the timing and location of fire can alter the natural fire regime and has negative, cascading effects in ecological communities. For example, a change in timing and frequency of fire can result in habitat loss and fragmentation, shift forest composition, and affect predator-prey interactions (DellaSalla et al. 2004). Following a fire, exposed bare ground on roads can result in chronic erosion, catastrophic culvert failures, and noxious weed invasion.

Forest roads can increase the occurrence of human-caused fires, whether by accident or arson, and road access has been correlated with the number of fire ignitions (Syphard et al. 2007, Yang et al., 2007, Narayanaraj and Wimberly 2012, Nagy et al. 2018). A recent study found that humans ignited four times as many fires as lightning. This represented 92% of the fires in the eastern United States and 65% of the fire ignitions in the western U.S. (Nagy et al. 2018). Another study that reviewed 1.5 million fire records over 20 years found human-caused fires were responsible for 84% of wildfires and 44% of the total area burned (Balch et al. 2017).

In addition to changes in frequency, human-caused fires change the timing of fire occurring when fuel moisture is significantly higher than lightning-started fires (Nagy et al. 2018.). Forest roads may also limit fire growth acting as a fire break and providing access for suppression (Narayanaraj and Wimberly 2011, Robbinne et al. 2016). The result is a spatial and temporal distribution of fire that differs from historical fire regimes.

Roaded areas create a distinct fire fuels profile which may influence ignition risk and burn severity (Narayanaraj and Wimberly 2013). Forest roads create linear gaps with reduced canopy cover, and increased solar radiation, temperature, and wind speed. Invasive weeds and grasses common along roadsides also create fine fuels that are highly combustible. These edge effects can change microclimates far into the forest (Narayanaraj and Wimberly 2012, Ricotta et al. 2018). While there is little definitive research on roads and burn severity, an increase in the prevalence of lightning-caused fires in roaded areas may be due to roadside edge effects (Arienti et al 2009, Narayanaraj and Wimberly 2012). Furthermore, watersheds that have been heavily roaded have typically received intensive management in the past leaving forests in a condition of high fire vulnerability (Hessburg and Agee 2003).

Roadless areas are remote and secure from many human impacts such as unintentional fire starts or arson. A forest fire is almost twice as likely to occur in a roaded area than a roadless area (USDA Forest Service 2000). In fact, human-ignited wildfire is almost five times more likely to occur in a roaded area than in a roadless area. (USDA Forest Service 2000). Higher road density correlates with an increased probability of human-caused ignitions. (Syphard et al. 2007).

After a forest fire, roads that were previously well vegetated often burn or are bladed for fire suppression access or firebreaks leaving them highly susceptible to erosion and weed invasion. Roads are a source of chronic erosion following a fire, and pulses of hillslope sediment and large woody debris can result in culvert failures (Bisson et al. 2003). Fine sediment is frequently delivered to streams and reduces the quality of aquatic habitat. Noxious weeds are established on many forest roads, and post-fire weed invasion can be facilitated by creating a disturbance, reducing competition, and increasing resource availability (Birdsaw et al. 2012).

II. Climate Change and Transportation Infrastructure

Before the Trump administration took office, the Forest Service recognized the importance of considering and adapting to changing climate conditions. The USDA Strategic Plan for Fiscal Years 2014-2018 set a goal to: "Ensure our national forests and private working lands are conserved, restored, and made more resilient to climate change, while enhancing our water resources." (USDA 2014, p 3). As climate change impacts grow more profound, forest managers must consider the impacts *on* the transportation system as well as *from* the transportation system. In terms of the former, changes in precipitation and hydrologic patterns will strain infrastructure, resulting in damage to streams, fish habitat, and water quality as well as threats to public safety and loss of access. As to the latter, the fragmenting effect of roads on habitat will impede the movement of species which is a fundamental element of adaptation. Through planning, forest managers can proactively address threats to infrastructure, and can actually enhance forest resilience by removing unneeded roads to create larger patches of connected habitat.

A. Climate change, forest roads, and fragmented habitat

It is expected that climate change will be responsible for more extreme weather events, leading to increasing flood severity, more frequent landslides, changing hydrographs, and changes in erosion and sedimentation rates and delivery processes (Schwartz et al. 2014, USDA FS 2018). The Forest

Service Office of Sustainability and Climate has compiled climate change vulnerability assessments for several regions of the Forest Service discussing near-term consequences for managers to consider. (Halofsky et al. 2017, 2018a, 2018b, 2019, with additional vulnerabilities displayed below in Table 4).

> Warmer locations will experience more runoff in winter months and early spring, whereas colder locations will experience more runoff in late spring and early summer. In both cases, future peakflows will be higher and more frequent, (Halofsky et al. 2018b at ii).
>
> The frequency and extent of midwinter flooding are expected to increase. Flood magnitudes are also expected to increase because rain-on-snow-driven peak flows will become more common," (*Id.* at 83).
>
> Roads and other infrastructure that are near or beyond their design life are at considerable risk to damage from flooding and geomorphic disturbance (e.g., debris slides). If road damage increases as expected, it will have a profound impact on access to Federal lands and on repair costs, (*Id.* at viii).

Magnifying these consequences is the fact that roads, culverts and trails in national forests were designed for storms and water flows typical of past decades, and may not be designed for the storms in future decades. Hence, climate driven changes may cause transportation infrastructure to malfunction or fail (USDA Forest Service 2010, ASHTO 2012). The likelihood is higher for facilities in high-risk settings—such as rain-on-snow zones, coastal areas, and landscapes with unstable geology. The following consequences may occur (USDA Forest Service 2010):

- access to national forests will be interrupted temporarily or permanently as roads wash-out due to landslides or blown-out culverts during events of heavier precipitation or flooding;
- public safety will be compromised as roads, trails and bridges become unstable due to landslides, undercut slopes, or erosion of water-logged slopes due to heavy rainfall; and
- infrastructure may be compromised or abandoned along coastal areas or low-lying estuaries when inundated during high tides and coastal storms as sea-levels rise.

Forests fragmented by roads will likely demonstrate less resistance and resilience to stressors, like those associated with climate change (Noss 2001, see also Table 4. below). First, the more a forest is fragmented (and therefore the higher the edge/interior ratio), the more the forest loses its inertia characteristic, and becomes less resilient and resistant to climate change. Second, the more a forest is fragmented, characterized by isolated patches, the more likely the fragmentation will interfere with the ability of species to track shifting climatic conditions over time and space.

> Hence, roads may impede the movement of many species in response to climate change. Closing unnecessary roads and providing wildlife crossings on roads with heavy traffic might mitigate some of these effects (Noss 1993; Clevenger & Waltho 2000), (Noss (2001) p. 584).

Watershed types within national forests may change which will impact hydrology and when high streamflows occur (Halofsky et. al. 2011). A study in Washington's Mt. Baker-Snoqualmie National

Forest (MBSNF) shows that currently 27% of the roads are in watersheds classified as rain-dominated but that will increase to 75% by 2080 - increasing risk of damage to infrastructure (Strauch 2014). By 2040, 300 miles of forest roads in this forest will be located in watersheds that are projected to see a 50% increase in 100-year floods. Landslide risk will be higher during the winter and spring and decline during summer and autumn. These changes reinforce the importance of transportation analysis that incorporates the impacts of climate change.

Earlier snowmelt may open previously snow-closed roaded areas for a greater portion of the year. While this may appear to benefit visitors that wish to access trails and camps early in the spring, this may also put them in harm's way with melting snow-bridges, avalanche chutes and flooding events (Strauch 2015). Wildlife historically protected by snow-closed roads would be more vulnerable.

B. Modifying infrastructure to increase resilience

To prevent or reduce road-triggered landslides and culvert failures, and other associated hazards, forest managers will need to take a series of actions. In December 2012, the USDA Forest Service published a report entitled, *Assessing the Vulnerability of Watersheds to Climate Change* (Furniss et al., 2013) which reinforces that forest managers need to be proactive in reducing erosion potential from roads:

> Road improvements were identified as a key action to improve condition and resilience of watersheds on all the pilot forests. In addition to treatments that reduce erosion, road improvements can reduce the delivery of runoff from road segments to channels, prevent diversion of flow during large events, and restore aquatic habitat connectivity by providing for passage of aquatic organisms. As stated previously, watershed sensitivity is determined by both inherent and management-related factors. Managers have no control over the inherent factors, so to improve resilience, efforts must be directed at anthropogenic influences such as instream flows, roads, rangeland, and vegetation management…. [Watershed Vulnerability Analysis (WVA)] results can also help guide implementation of travel management planning by informing priority setting for decommissioning roads and road reconstruction/maintenance. As with the Ouachita NF example, disconnecting roads from the stream network is a key objective of such work. Similarly, WVA analysis could also help prioritize aquatic organism passage projects at road-stream crossings to allow migration by aquatic residents to suitable habitat as streamflow and temperatures change, (Furniss et al., 2013, p. 22-23).

Other Forest Service reports support road-related actions to increase climate resilience including replacing undersized culverts with larger ones, prioritizing maintenance and upgrades, and restoring roads to a natural state when they are no longer needed and pose erosion hazards (USDA Forest Service 2010, USDA Forest Service 2011a, Furniss et al., 2013, USDA FS 2018, Halofsky et al. 2018a).

The Forest Service has developed several resources to identify and mitigate climate change impacts on forests and infrastructure. The aforementioned climate change vulnerability assessments for each region focus on causes, consequences, and options to address them. For example, Halofsky et al. (2018a) reviews the effects and adaptation options for Region 1 (Northern Region) of the Forest Service, and identifies the increased magnitude of peak streamflows as a primary impact to road infrastructure. Adaptation strategies identified in the report include:

> ...increasing the resilience of stream crossings, culverts, and bridges to higher peakflows and facilitating response to higher peakflows by reducing the road system and disconnecting roads from streams. Tactics include completing geospatial databases of infrastructure (and drainage) components, installing higher capacity culverts, and decommissioning roads or converting them to alternative uses. (Halofsky et al. 2018a)

U.S. Forest Service Transportation Resiliency Guidebook provides a review of the impacts of climate change on Forest Service infrastructure, and a process to assess and address climate change impacts at local and regional levels (USDA FS 2018; Table 4). Included in the guidebook is a step-by-step guide for identifying vulnerabilities and preparedness planning within their transportation network (USDA FS 2018). In addition, the guidebook recommends using the forest plan revision process as "an opportunity to analyze baseline conditions and climate change vulnerabilities and to develop climate resilient strategies for the future." (USDA FS 2018). The Forest Service should use the transportation resilience guidebook to inform forest plan revision analysis and plan components to address climate change in the context of the forest's transportation system.

Table 4. Role of adaptation strategies in reducing climate change impacts of Forest Service lands (reprinted from USDA FS 2018).

	Impacts on Transportation	**Example Strategies to Reduce Impacts**
Heavy Precipitation / Flooding	Flooded roadways interrupting service Damage/destruction of roads and bridges Pavement buckling Erosion comprising soil stability and transportation assets Slope failures Landslides damaging and disrupting routes Plugged or blown out culverts	Retrofit facilities Relocate facilities Upgrade culverts and drainage facilities Build new facilities to climate ready standards Protect existing infrastructure Divest in assets
Wildfires	Additional woody debris that plug culverts Reduced slope stability causing increased landslides Increased heavy vehicle traffic wear and tear on FS roadways	Sustain forest ecology Protect forests from severe fire and wind disturbance
Tree Mortality	Fallen trees disrupt access along transportation routes Increased need for clearing hazard trees along roadways Provide forest fuel for wildfire	Facilitate Forest community adjustments through species transitions

Individual forests have also drafted climate mitigation strategies. The Olympic National Forest in Washington, has developed documents oriented at protecting watershed health and species in the face of climate change, including a 2003 travel management strategy and a report entitled, *Adapting to*

Climate Change in Olympic National Park and National Forest (USDA FS 2011a). The report calls for road decommissioning, relocation of roads away from streams, enlarging culverts as well as replacing culverts with fish-friendly crossings (Table 5). In the travel management strategy, Olympic National Forest recommended that one third of its road system be decommissioned and obliterated. In addition, the plan called for addressing fish migration barriers in a prioritized and strategic way – most of these are associated with roads.

Table 5: Current and expected sensitivities of fish to climate change and associated adaptation strategies and action for fisheries and fish habitat management and relevant to transportation management at Olympic National Forest and Olympic National Park (reprinted from USDA Forest Service 2011a).

Current and expected sensitivities	**Adaptation strategies and actions**
Changes in habitat quantity and quality	Implement habitat restoration projects that focus on re-creating watershed processes and functions and that create diverse, resilient habitat.
Increase in culvert failures, fill-slope failures, stream adjacent road failures, and encroachment from stream-adjacent road segments	Decommission unneeded roads. Remove sidecast, improve drainage, and increase culvert sizing on remaining roads. Relocate stream-adjacent roads.
Greater difficulty disconnecting roads from stream channels	Design more resilient stream crossing structures.
Major changes in quantity and timing of streamflow in transitional watersheds	Make road and culvert designs more conservative in transitional watersheds to accommodate expected changes.
Decrease in area of headwater streams	Continue to correct culvert fish passage barriers. Consider re-prioritizing culvert fish barrier correction projects.
Decrease in habitat quantity and connectivity for species that use headwater streams	Restore habitat in degraded headwater streams that are expected to retain adequate summer streamflow (ONF).

C. Reducing fragmentation to enhance aquatic and terrestrial species adaptation

Reconnecting fragmented forests has been shown to benefit native species (e.g., Damschen et al. 2019). Decommissioning and upgrading roads can reduce fragmentation of both aquatic and terrestrial systems. For example, reducing the amount of road-generated fine sediment deposited on salmonid nests can increase the likelihood of egg survival and spawning success (Switalski et al. 2004, McCaffery et al. 2007). Strategically removing or mitigating barriers such as culverts has been shown to restore aquatic connectivity and expand habitat (Erkinaro et al. 2017). Decommissioning roads in riparian areas may provide further benefits to salmon and other aquatic organisms by permitting reestablishment of streamside vegetation, which provides shade and maintains a cooler, more moderated microclimate over the stream (Battin et al. 2007, Meridith et al. 2014). Coordinating the repair of an aging road system with the mitigation of aquatic organism passage may allow for restoring connectivity while improving infrastructure (Nesson et al. 2018).

One of the most well documented impacts of climate change on wildlife is a shift in the ranges of species (Parmesan 2006). As animals migrate, landscape connectivity will be increasingly important (Holman et al. 2005), and restoring and mitigating migration routes in key wildlife corridors will increase wildlife resiliency. Access management in important elk migration sites would reduce disturbance and improve connectivity (Parton et al. 2017). Similarly, a recent study found grizzly bear population density increased 50 percent following the restriction of motorized recreation (Lamb et al. 2018). Decommissioning roads in key wildlife corridors will also reduce the many road-related stressors. Road decommissioning restores wildlife habitat by providing security and food such as grasses, forbs, and fruiting shrubs (Switalski and Nelson 2011, Tarvainen and Tolvanen 2016).

Forests fragmented by roads and motorized trail networks will likely demonstrate less resistance and resilience to stressors, such as weeds. As a forest is fragmented and there is more edge habitat, Noss (2001) predicts that weedy species with effective dispersal mechanisms will increasingly benefit at the expense of native species. However, decommissioned roads when seeded with native species can reduce the spread of invasive species (Grant et al. 2011), and help restore fragmented forestlands. Off-road vehicles with large knobby tires and large undercarriages are also a key vector for weed spread (e.g., Rooney 2006). Strategically closing and decommissioning motorized routes, especially in roadless areas, will reduce the spread of weeds on forestlands (Gelbard and Harrison 2003).

D. Transportation infrastructure and carbon sequestration

The relationship of road restoration and carbon has only recently been explored. There is the potential for large amounts of carbon (C) to be sequestered by restoring roads to a more natural state. When roads are decompacted during reclamation, vegetation and soils can develop more rapidly and sequester large amounts of carbon. Research on the Clearwater National Forest in Idaho estimated total soil C storage increased 6-fold compared to untreated abandoned roads (Lloyd et al. 2013). Another study concluded that reclaiming 425 km (264 miles) of logging roads over the last 30 years in Redwood National Park in Northern California resulted in net carbon savings of 49,000 Megagrams (54,013 tons) of carbon to date (Madej et al. 2013, Table 5). A further analysis found that recontouring roads had higher soil organic carbon than ripping (decompacting) the roads (Seney and Madej 2015). Finally, a recent study in Colorado found that adding mulch or biochar to decommissioned roads can increase the amount of carbon stored in soil (Ramlow et al. 2018).

Kerekvliet et al. (2008) used Forest Service estimates of the fraction of road miles that are unneeded, and calculated that restoring 126,000 miles of roads (i.e. 30% of the road system) to a natural state would be equivalent to revegetating an area larger than Rhode Island. In addition, they calculate that the net economic benefit of road treatments are always positive and range from US $0.925-1.444 billion.

Table 6. Carbon budget implications in road decommissioning projects (reprinted from Madej et al. 2013).

Road Decommissioning Activities and Processes	Carbon Cost	Carbon Savings
Transportation of staff to restoration sites (fuel emissions)	X	
Use of heavy equipment in excavations (fuel emissions)	X	
Cutting trees along road alignment during hillslope recontouring	X	
Excavation of road fill from stream crossings		X
Removal of road fill from unstable locations		X
Reduces risk of mass movement		X
Post-restoration channel erosion at excavation sites	X	
Natural revegetation following road decompaction		X
Replanting trees		X
Soil development following decompaction		X

E. The importance of Roadless Areas and intact mature forests

Undeveloped natural lands provide numerous ecological benefits. They contribute to biodiversity, enhance ecosystem representation, and facilitate connectivity and provide high quality or undisturbed water, soil and air (Strittholt and Dellasala 2001, DeVelice and Martin 2001, Crist and Wilmer 2002, Loucks et al. 2003, Dellasalla et al. 2011, Anderson et al. 2012, Selva et al. 2015). They can also serve as ecological baselines to help us better understand our impacts to other landscapes, and contribute to landscape resilience in the face of climate change.

Forest Service roadless lands, in particular, are heralded for the conservation values they provide. The benefits are described at length in the preamble of the Roadless Area Conservation Rule (RACR)[4] as well as in the Final Environmental Impact Statement (FEIS) for the RACR[5], and include: high quality or undisturbed soil, water, and air; sources of public drinking water; diversity of plant and animal communities; habitat for threatened, endangered, proposed, candidate, and sensitive species and for those species dependent on large, undisturbed areas of land; primitive, semi-primitive non- motorized, and semi-primitive motorized classes of dispersed recreation; reference landscapes; natural appearing landscapes with high scenic quality; traditional cultural properties and sacred sites; and other locally identified unique characteristics (e.g., include uncommon geological formations, unique wetland complexes, exceptional hunting and fishing opportunities).

The Forest Service, National Park Service, and the U.S. Fish and Wildlife Service recognize that protecting and connecting roadless or lightly roaded areas is an important action agencies can take to

[4] Federal Register, Vol. 66, No. 9. January 12, 2001. Pages 3245-3247.
[5] Final Environmental Impact Statement, Vol. 1, 3–3 to 3–7

enhance climate change adaptation. For example, the *Forest Service National Roadmap for Responding to Climate Change* (USDA Forest Service 2011b) establishes that increasing connectivity and reducing fragmentation are short- and long-term actions the Forest Service should take to facilitate adaptation to climate change. The National Park Service also identifies connectivity as a key factor for climate change adaptation along with establishing "blocks of natural landscapes large enough to be resilient to large-scale disturbances and long-term changes," and other factors. The agency states that: "The success of adaptation strategies will be enhanced by taking a broad approach that identifies connections and barriers across the landscape. Networks of protected areas within a larger mixed landscape can provide the highest level of resilience to climate change."[6] Similarly, the *National Fish, Wildlife and Plants Climate Adaptation Partnership's Adaptation Strategy* (2012) calls for creating an ecologically-connected network of conservation areas.[7]

Crist and Wilmer (2002) looked at the ecological value of roadless lands in the Northern Rockies and found that protection of national forest roadless areas, when added to existing federal conservation lands in the study area, would 1) increase the representation of virtually all land cover types on conservation lands at both the regional and ecosystem scales, some by more than 100%; 2) help protect rare, species-rich, and often-declining vegetation communities; and 3) connect conservation units to create bigger and more cohesive habitat "patches."

Roadless lands also are responsible for higher quality water and watersheds. Anderson et al. (2012) assessed the relationship of watershed condition and land management status and found a strong spatial association between watershed health and protective designations. Dellasalla et al. (2011) found that undeveloped and roadless watersheds are important for supplying downstream users with high-quality drinking water, and developing these watersheds comes at significant costs associated with declining water quality and availability. The authors recommend a light-touch ecological footprint to sustain the many values that derive from roadless areas including healthy watersheds.

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[6] National Park Service. Climate Change Response Program Brief. http://www.nature.nps.gov/climatechange/adaptationplanning.cfm. Also see: National Park Service, 2010. Climate Change Response Strategy. http://www.nature.nps.gov/climatechange/docs/NPS_CCRS.pdf. Objective 6.3 is to "Collaborate to develop cross-jurisdictional conservation plans to protect and restore connectivity and other landscape-scale components of resilience."

[7] See http://www.wildlifeadaptationstrategy.gov/pdf/NFWPCAS-Chapter-3.pdf. Pages 55- 59. The first goal and related strategies are:

Goal 1: Conserve habitat to support healthy fish, wildlife, and plant populations and ecosystem functions in a changing climate.

Strategy 1.1: identify areas for an ecologically-connected network of terrestrial, freshwater, coastal, and marine conservation areas that are likely to be resilient to climate change and to support a broad range of fish, wildlife, and plants under changed conditions.

Strategy 1.2: Secure appropriate conservation status on areas identified in Strategy 1.1 to complete an ecologically-connected network of public and private conservation areas that will be resilient to climate change and support a broad range of species under changed conditions.

Strategy 1.4: Conserve, restore, and as appropriate and practicable, establish new ecological connections among conservation areas to facilitate fish, wildlife, and plant migration, range shifts, and other transitions caused by climate change.

Allowing roadless and other intact forested areas to reach their full ecological potential is an effective and crucial strategy for atmospheric carbon dioxide removal. Moomaw et al (2019) termed this approach as "proforestation" and explained,

> [f]ar from plateauing in terms of carbon sequestration (or added wood) at a relatively young age as was long believed, older forests (e.g., >200 years of age without intervention) contain a variety of habitats, typically continue to sequester additional carbon for many decades or even centuries, and sequester significantly more carbon than younger and managed stands, (Luyssaert et al., 2008; Askins, 2014; McGarvey et al., 2015; Keeton, 2018).

The authors recommend "scaling up" proforestation, which includes both protecting and expanding designations of intact forested areas, as a cost-effective means to increase atmospheric carbon sequestration.

III. Achieving a Sustainable Minimum Road System on National Forest Lands

A. Background

For two decades, the Travel Management Rule, 36 C.F.R. Part 212, has guided Forest Service road management and use by motorized vehicles. It is divided into three parts: Subpart A, the administration of the forest transportation system; Subpart B, designation of roads, trails, and areas for motor vehicle use; and Subpart C, use by over-snow vehicles. *See* 36 C.F.R. Part 212.

Table 7. Travel Management Rule Subparts – Objectives, Requirements & Products

36 C.F.R. §212	Objective:	Requires:	Product(s):
Subpart A; Roads Rule 2001	To achieve a sustainable national forest road system.	Use a science-based analysis to identify the minimum road system and roads for decommissioning	- Travel Analysis Report - Map with roads identified as "likely needed" and "likely unneeded"
Subpart B; Travel Management Rule 2005	To protect forests from unmanaged off-road vehicle use by ending cross-country travel and ensuring the agency minimizes the harmful effects from motorized recreation.	Designating a system of roads, trails and areas available for off-road vehicle use according to general and specific criteria.	- Motor Vehicle Use Maps that indicate what roads/trails are open for motorized travel
Subpart C; Travel Management Rule	To protect forests from unmanaged over-snow vehicle use in a manner that minimizes their harmful effects.	Designating specific roads, trails and/or areas for oversnow vehicle use according to the criteria per	- Oversnow vehicle maps designating trails and areas for winter motorized recreation

		Subpart B.	

This broad-based national rule is needed because at over 370,000 miles, the Forest Service road system is long enough to circle the earth over 14 times and it is over twice the size of the National Highway System.[8] It is also indisputably unsustainable from ecological, economic and management perspectives. The majority of the roads were constructed decades ago when design and management techniques did not meet current standards (Gucinski et al. 2000, Endicott 2008), making them more vulnerable to erosion and decay. Further, current design standards and best management practices have not been updated to address climate change realities. Exacerbating the problem are massive Forest Service road maintenance backlogs that forces the agency to forego actions necessary to ensure proper watershed function, such as preventing sediment pollution and sustaining aquatic organism passages. Nationally, the total deferred maintenance backlog reached $5.5 billion in FY 2019 of which $3.1 billion is associated with roads.[9] As a result, the road network is not only a massive economic liability, it is also actively harming National Forest System lands, waters, fish and wildlife.

Over the past two decades the Forest Service - largely due to the Travel Management Rule - has made some limited efforts to identify and implement a sustainable transportation system. Yet, overall the agency has yet to meet the requirements of Subpart A. The challenge for forest managers is figuring out what is a sustainable road system and how to achieve it – a challenge exacerbated by climate change. It is reasonable to define a sustainable transportation system as one where all the roads and trails are located, constructed, and maintained in a manner that minimizes harmful environmental consequences while providing social benefits and within budget constraints. This could potentially be achieved through the use of effective best management practices. However, the reality is that even the best transportation networks can be problematic simply because they exist and usher in land uses that, without the access, would not occur (Trombulak and Frissell 2000, Carnefix and Frissell 2009, USDA Forest Service 1996), and when they are not maintained to the designed level they result in environmental problems (Endicott 2008; Gucinski et al. 2000). Moreover, what was sustainable yesterday may no longer be sustainable under climate change realities since roads designed to meet older climate criteria may no longer hold up under new scenarios (USDA Forest Service 2010, USDA Forest Service 2011b, AASHTO 2012, Furniss et al., 2013, Schwartz et al. 2014, USDA FS 2018, Halofsky et al. 2018a, 2018b).

Given consistent budget shortfalls and increasing risks from climate change vulnerabilities, it is clear the agency has an urgent need to both identify and implement a minimum road system, one that will ensure the protection of all Forest Service system lands. However, without specific direction from the Forest Service's Washington D.C. office or Congress, it is reasonable to expect the agency will

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[8] USDOT Federal Highway Administration, Office of Highway Policy Information. https://www.fhwa.dot.gov/policyinformation/pubs/hf/pl11028/chapter1.cfm
[9] USDA Forest Service. 2019. FY2020 Budget Justification. p.83.

continue to rely on piecemeal, project-level analyses to identify the minimum road system. Such an approach is inefficient, and insufficient to achieve a sustainable road system forestwide.

Further, where the Forest Service does act to comply with Subpart A, it typically fails to consider shortcoming in its previous travel analysis processes. In fact, an independent review of 38 Travel Analysis Processes and corresponding reports conducted in 2016 by the U.S. Department of Transportation John A. Volpe National Transportation Systems Center found three overarching concerns:

- A lack of clarity regarding the process;
- Failure to follow 36 CFR 212.5(b) direction and Washington Office guidance; and
- Omission of required documents, referenced appendices, or key supporting materials.

Compounding these concerns is the fact that not only do project-level NEPA analyses fail to account for the TAP shortcomings, they also fail to consider real road/motorized densities when identifying the minimum road system. Moreover, these analyses erroneously assume best management practices and project-specific design features will be effective when the Forest Service authorizes actions to achieve a sustainable road system. Finally, if the project-level decision includes actual road decommissioning, the analysis typically fails to consider or specify treatments, resulting in a legacy of ghost-roads persisting on the landscape. The following sections expand on these shortcomings, which the Forest Service must consider in all project-level analyses, and when revising its land and travel management plans.

B. Using Real Road and Motorized Trail Densities to Identify a Minimum Road System

As the Forest Service works to comply with Subpart A, it is crucial that the agency incorporate the true road and motorized trail densities in both its travel analysis process and NEPA-level analyses. Further, the agency must establish standards in land management plan revisions and amendments to ensure each forest achieves an ecologically sustainable minimum road system. Road density analyses should include closed roads, non-system roads, temporary roads, and motorized trails. Typically, the Forest Service calculates road density by looking only at open system road density. From an ecological standpoint, this is a flawed approach since it leaves out the density calculations of a significant percent of roads and motorized trails on the landscape. These additional roads and motorized trails impact fish, wildlife, and water quality, and in some cases, have more of an impact than open system roads. In this section, we provide justification for why a road density analyses should include more than just open road density whenever the Forest Service evaluates the ecological health of an area during NEPA-level analysis or other processes such as for watershed assessments, forest plan revisions or during travel analysis.

Impacts of closed roads

It is crucial to distinguish the density of roads physically present on the landscape, whether closed to vehicle use or not, from "open-road density." An open-road density of 1.5 mi/mi² has been established as a standard in some national forests as protective of some terrestrial wildlife species. However, many areas with an open road density of 1.5 mi/mi² often have more miles of closed roads which are still hydrologically connected and negatively affecting aquatic and wildlife habitat. This higher density occurs because many road "closures" may block vehicle access, but do nothing to mitigate the hydrologic alterations the road causes. The problem is often further compounded by the existence of "ghost" roads that are not captured in agency inventories, but that are nevertheless physically present and causing hydrologic alteration (Pacific Watershed Associates 2005).

Closing a road to public motorized use can mitigate the impacts on water, wildlife, and soils only if proper closure and storage techniques are followed. Flow diversions, sediment runoff, and illegal incursions will continue unabated if the road is not hydrologically stabilized and adequately blocked from motorized traffic. The Forest Service's National Best Management Practices for non-point source pollution recommends the following management techniques for minimizing the aquatic impacts from closed system roads: eliminate flow diversion onto the road surface, reshape the channel and streambanks at the crossing-site to pass expected flows without scouring or ponding, maintain continuation of channel dimensions and longitudinal profile through the crossing site, and remove culverts, fill material, and other structures that present a risk of failure or diversion (USDA Forest Service 2012).

As noted above, many species benefit when roads are closed to motorized use. However, the fact remains that closed system roads are often breached resulting in impacts to fish and wildlife. A significant portion of gates and closure devices are ineffective at preventing motorized use (Griffin 2004, USFWS 2007). For example, in a legal decision from the Utah District Court, *Sierra Club v. USFS*, Case No. 1:09-cv-131 CW (D. Utah March 7, 2012), the court found that, as part of analyzing alternatives in a proposed travel management plan, the Forest Service failed to examine the impact of continued illegal use. In part, the court based its decision on the Forest Service's acknowledgement that illegal motorized use is a significant problem and that the mere presence of roads is likely to result in illegal use.

In addition to the disturbance to wildlife from motorized use, incursions and the accompanying human access can also result in illegal hunting and trapping of animals. The Tongass National Forest refers to this in its EIS to amend the Land and Resources Management Plan. Specifically, the Forest Service notes in the EIS that Alexander Archipelago wolf mortality due to legal and illegal hunting and trapping is related not only to roads open to motorized access, but to all roads, and that *total road densities* of 0.7-1.0 mi/mi² or less may be necessary (USDA Forest Service 2008).

Impacts of unauthorized (non-system) roads

As of 1998, there were approximately 130,000 miles of non-system roads in national forests (USDA Forest Service, 1998). However, the creation of unauthorized roads continues to be a problem as the Forest Service struggles to properly enforce travel management plans protecting areas from motorized travel. No requirements are in place directing the agency to track or inventory unauthorized roads, therefore currently their precise number is unknown. These roads contribute significantly to the environmental impacts of the transportation system on forest resources, just as forest system roads do. Because the purpose of a road density analysis is to measure the impacts of roads at a landscape level, the only way to do this is for the Forest Service to include all roads, including non-system roads, when measuring impacts. An all-inclusive analysis will provide a more accurate representation of the environmental impacts of the road network within the analysis area.

Impacts of temporary roads

Temporary roads are not considered system roads. Most often they are constructed in conjunction with timber sales. Temporary roads have the same types of environmental impacts as system roads, although at times the impacts can be worse if the road persists on the landscape because they are not built to last. It is important to note that although they are termed temporary roads, their impacts are not temporary. According to Forest Service Manual (FSM) 7703.1, the agency is required to "Reestablish vegetative cover on any unnecessary roadway or area disturbed by road construction on National Forest System lands within 10 years after the termination of the activity that required its use and construction."

Regardless of the FSM 10-year direction, temporary roads often remain for much longer because timber sale contracts typically last 3-5 years or more. If the timber purchaser builds a temporary road in the first year of a five-year contract, its intended use may not end until the full project is complete, which can include post-harvest actions such as prescribed burning. Even though the contract often requires the purchaser to close, obliterate and seed the roadbed with native vegetation, this work typically occurs after a few years of treatment activities. The temporary road, therefore, could remain open for 7-8 years or longer before the FSM ten-year clock starts ticking. Therefore, temporary roads can legally remain on the ground for up to 20 years or more, yet they are constructed with fewer environmental safeguards than modern system roads. Exacerbating the problem is the rise of landscape-scale projects that last between 10-20 years. Unless there is explicit direction requiring temporary road removal within a certain time after treatment activities, it is likely these roads could persist for decades.

Impacts of motorized trails

Motorized use on trails has serious harmful effects similar to roads, and it is crucial for the Forest Service to include motorized trails in its density calculations. As we note several times in Section I above, scientific research and agency publications find similar impacts between motorized trails and roads. Off-road vehicle (ORV) use on trails impact multiple resources, resulting in soil compaction and erosion, trampling of vegetation, as well as wildlife habitat loss, disturbance, and direct mortality. Many of these impacts increase on trails not planned or designed for vehicles, as is often the case when the Forest Service designates ORVs on trails built for hiking or equestrian uses. In many instances the agency designates motorized use on unauthorized trails created through illegal use or from a legacy of unmanaged cross-country travel, further exacerbating the related harmful effects. For a full review of the environmental and cultural impacts on forest lands see Switalski and Jones (2012), and for a review of impacts in arid environments see Switalski (2018).

C. Using Best Management Practices to Achieve a Sustainable Road System

Numerous Best Management Practices (BMPs) were developed to help create a more sustainable transportation system and identify restoration opportunities. BMPs provide science-based criteria and direction that land managers follow in making and implementing decisions about human uses and projects that affect natural resources. Several states have developed BMPs for road construction, maintenance, and decommissioning practices (e.g., Logan 2001, Merrill and Cassaday 2003). The report entitled, National Best Management Practices for Water Quality Management on National Forest System Lands, includes specific road BMPs for controlling erosion and sediment delivery into waterbodies and maintaining water quality (USDA FS 2012). These BMPs cover road system planning, design, construction, maintenance, and decommissioning as well as other transportation-related activities.

Forest Service BMPs - Implementation and Effectiveness

While national BMPs have been established, the effectiveness of individual BMPs, and whether they are implemented at all, is in question. Furthermore, design features are increasingly replacing BMPs for project-level mitigation of road-related environmental impacts. These design features are not consistent among projects, but rather adapted from forest plans and state BMPs, rather than national Forest Service guidelines. Design features need to be standardized, and their rate of implementation and effectiveness systematically reviewed.

When considering how effective BMPs are at controlling nonpoint pollution on roads, both the rate of implementation, and their effectiveness should both be considered. The Forest Service tracks the rate of implementation and the relative effectiveness of BMPs from in-house audits. This information is summarized in the *National BMP Monitoring Summary Report* with the most recent data being the fiscal years 2013-2014 (Carlson et al. 2015). The rating categories for implementation are "fully implemented," "mostly implemented," "marginally implemented," "not implemented," and "no BMPs." "No BMPs" represents a failure to consider BMPs in the planning process. More than a hundred evaluations on roads were conducted in FY2014. Of these evaluations, only about one third of the road BMPs were found to be "fully implemented" (Carlson et al. 2015, p. 12).

The monitoring audit also rated the relative effectiveness of the BMP. The rating categories for effectiveness are "effective," "mostly effective," "marginally effective," and "not effective."

"Effective" indicates no adverse impacts to water from project or activities were evident. When treated roads were evaluated for effectiveness, almost half of the road BMPs were scored as either "marginally effective" or "not effective" (Carlson et al. 2015, p. 13). However, BMPs for completed road decommissioning projects showed approximately 60 percent were effective and mostly effective combined, but it was unclear what specific BMPs account for this success (Carlson et al. 2015, p. 35). As explained below, road recontouring that restores natural hillside slopes is a more effective treatment compared to those that leave road features intact.

A recent technical report by the Forest Service entitled, *Effectiveness of Best Management Practices that Have Application to Forest Roads: A Literature Synthesis* summarized research and monitoring on the effectiveness of different BMP treatments for road construction, presence and use (Edwards et al. 2016). They found that while several studies have found some road BMPs are effective at reducing delivery of sediment to streams, the degree of each treatment has not been rigorously evaluated (Edwards et al. 2016). Few road BMPS have been evaluated under a variety of conditions, and much more research is needed to determine the site-specific suitability of different BMPs (Edwards et al. 2016, also see Anderson et al. 2011).

Edwards et al. (2016) cites several reasons for why BMPs may not be as effective as commonly thought. Most watershed-scale studies are short-term and do not account for variation over time, sediment measurements taken at the mouth of a watershed do not account for in-channel sediment storage and lag times, and it is impossible to measure the impact of individual BMPs when taken at the watershed scale. When individual BMPs are examined there is rarely broad-scale testing in different geologic, topographic, physiological, and climatic conditions. Further, Edwards et al. (2016) observes, "The similarity of forest road BMPs used in many different states' forestry BMP manuals and handbooks suggests a degree of confidence validation that may not be justified," because they rely on just a single study. Therefore, BMP effectiveness would require matching the site conditions found in that single study, a factor land managers rarely consider.

Climate change will further put into question the effectiveness of many road BMPs (Edwards et al. 2016). While the impacts of climate will vary from region to region (Furniss et al. 2010), more extreme weather is expected across the country which will increase the frequency of flooding, soil erosion, stream channel erosion, and variability of streamflow (Furniss et al. 2010). BMPs designed to limit erosion and stream sediment for current weather conditions may not be effective in the future. Edwards et al. (2016) states, "More-intense events, more frequent events, and longer duration events that accompany climate change may demonstrate that BMPs perform even more poorly in these situations. Research is urgently needed to identify BMP weaknesses under extreme events so that refinements, modifications, and development of BMPs do not lag behind the need."

The uncertainties about BMP effectiveness as a result of climate change, compounded by the inconsistencies revealed by BMP evaluations, suggest that the Forest Service cannot simply rely on them, or design features/criteria, as a means to mitigate project-level activities. This is especially relevant where the Forest Service relies on the use of BMPs instead of fully analyzing potentially harmful environmental consequences from road design, construction, maintenance or use, in studies and/or programmatic and site-specific NEPA analyses.

D. Effectiveness of Road Decommissioning Treatments

In order to truly achieve a sustainable minimum road system, the Forest Service must effectively remove unneeded roads. According to the Forest Service, the objective of road decommissioning is to "stabilize, restore, and revegetate unneeded roads to a more natural state to protect and enhance NFS lands" (FSM 7734.0). However, rather than actively removing roads, the Forest Service is increasingly relying on abandoning roads to reach decommissioning treatment objectives (Apodaca et al.2018). Simply closing or abandoning roads will lead to continued resource damage. Other treatments such as ripping the roadbed or installing drainage such as waterbars or dips, have limited and often short-term benefits to natural resources (e.g., Luce 1997, Switalski et al. 2004, Nelson et al. 2010). Recontouring roads is the only proven method to attain the intended outcome of road decommissioning.

Several studies have documented the benefits of fully recontouring roads for ecological restoration. Lloyd et al. (2013) found that rooting depths were much deeper in recontoured roads than in abandoned roads in Idaho, and soil organic matter was an order of magnitude higher on recontoured roads than abandoned roads. Further studies show that soil carbon storage is much higher on recontoured roads as well. A study in Northern California found that recontouring roads resulted in higher soil organic carbon than ripping the roads (Seney and Madej 2015). Higher tree growth and wildlife use has also been found on and near recontoured roads than ripped or abandoned roads (Kolka and Smidt 2004, Switalski and Nelson 2011). Switalski and Nelson (2011) found increased use by black bears on recontoured roads than closed or abandoned roads due to increased food availability and increased habitat security. In addition, removing culverts at stream crossings results in restoring aquatic connectivity and expanding habitat (Erkinaro et al. 2017).

Legacy Roads Monitoring Project

Since 2008, the Forest Service Rocky Mountain Research Station has conducted systematic monitoring on the effectiveness of decommissioned roads in reducing hydrologic and geomorphic impacts from the Forest Service road network. One intent of the monitoring project was to gauge the success of the Legacy Roads and Trails Program that Congress established to provide dedicated funding for the treatment and removal of unnecessary forest roads. The monitoring found that recontouring roads and restoring stream crossings results in dramatic declines in road-generated sediment. Storm-proofing treatments lead to fewer benefits, and on control sites (untreated or abandoned roads), high levels of sediment delivery continued, and the risk of culvert failures remained. For example, a study on the Lolo Creek Watershed on the Clearwater National Forest found a 97% reduction in road/stream connectivity following road recontour (Cissel et al. 2011). Using field observations and the Geomorphic Roads Analysis and Inventory Package (GRAIP), they found a reduction of fine sediments from 38.1 tonnes/year to 1.3 tonnes/year along 3.5 miles of road. Furthermore, they found that restoring road/stream crossings eliminated the risk of culverts plugging, stream diversions, and fill lost at culverts (Table 8).

On the other hand, monitoring conducted on the Caribou-Targhee National Forest found only a 59% reduction of fine sediment delivery from a combination of storm proofing (installation of drain dips), ripping, tilling, and outsloping techniques. There was a reduction of 34.9 tons/year to 14.1 ton/year – leaving a significant amount of sediment continuing to be delivered to streams. Additionally, some stream crossing culverts were not treated and the risk of plugging remained leaving 330 m^3 of fill material at risk. While trail conversion and decommissioning treatments reduced slope failure risks, in some cases storage treatments actually increased the risk of failure (Nelson et al. 2010). Additional monitoring studies conducted in Montana, Idaho, Washington, Oregon, and Utah have similar results.[10]

Table 8. Summary of GRAIP road risk predictions for a watershed on the Clearwater National Forest road decommissioning treatment project (reprinted from Cissel et al. 2011).

IMPACT/RISK TYPE	EFFECT OF TREATMENT: INITIAL GRAIP PREDICTION
Road-stream hydrologic connectivity	-97%, -2510 m
Fine Sediment Delivery	-97%, -36.8 tonnes/yr.
Landslide Risk	Reduced to near natural condition
Gully Risk	Reduced from very low to negligible
Stream Crossing Risk -plug potential -fill at risk -diversion potential	 -100% eliminated at 9 sites -100%, 268 m^3 fill removed -100%, eliminated at 3 sites
Drain Point Problems	17 problems removed, 4 new problems

[10] For reports visit https://www.fs.fed.us/GRAIP/LegacyRoadsMonitoringStudies.shtml

The Forest Service recognizes that fundamental to road decommissioning is revegetating the roadbed. FSM 7734 states, "Decommission a road by reestablishing vegetation and, if necessary, initiating restoration of ecological processes interrupted or adversely impacted by the unneeded road." However, roads are inherently difficult to revegetate because of compaction, lack of soil and organic material, low native seedbank, and presence of noxious weeds (Simmers and Galatowitsch 2010, Ramlow et al. 2018). Many recently acquired industrial timberlands (e.g. Legacy Lands) have road systems with limited canopy cover, little woody debris available, and a large weed seedbank. Thus, revegetation is going to be particularly challenging on these lands.

Consistent application of BMPs that direct recontouring roads for decommissioning will be essential to ensure the treatments best achieve improvements in ecological conditions. More than any other treatment, road recontouring ensures complete decompaction of the roadbed, incorporates native soils that were side-cast during construction, and prevents motorized use. This in turn increases plant rooting depths, soil carbon storage, tree growth, and wildlife use. Any earth disturbing activity can create conditions favorable to noxious weeds, so treating weeds before any treatment and ensuring quick revegetation can limit weeds spread. Applying road recontour BMPs that also mitigate risks associated with noxious weed expansion will help prevent their spread

Conclusion

Numerous studies show that roads and motorized trails negatively impact the ecological integrity of terrestrial and aquatic ecosystems and watersheds. There is ample evidence to confirm the harm to wildlife, aquatic species, water quality, and natural processes from forest roads and motorized use. In addition, the evolving science surrounding roads and wildfire demonstrate a direct link between access and human-caused ignitions, and also suggests that land managers must consider how roads affect fire behavior. Minimizing these impacts by reducing road densities could be an effective solution.

An increasing body of literature exists demonstrating that not only is the Forest Service's transportation infrastructure highly vulnerable to climate change, but also that roads exacerbate climate change's harmful effects to other resources. The agency itself has published multiple reports and guidelines for adaptation, yet few forests are fully translating the information into tangible actions. The Forest Service must implement climate change adaptations as soon as possible, including protecting and expanding intact forests as part of a growing effort to promote natural climate change solutions. Opportunities exist to reduce fragmentation, sequester carbon, and expand roadless areas by implementing a minimum road system.

The Forest Service must fulfil its mandate to achieve an ecologically and economically sustainable forest road system by fully complying with the Roads Rule's requirement to identify a minimum road system. Inconsistent policy interpretations, inadequate travel analysis reports and lack of accountability has largely left this goal wholly out of reach. Yet this work remains vitally important, especially in the context of climate change. The Forest Service should reinvigorate its efforts to comply with the rule's requirements. Towards this end, the agency must include current science, particularly related to future climate conditions. All road and motorized trail densities should be included in the analysis. When the agency actually does identify a minimum road system and proposes to remove unneeded roads, it must carefully evaluate the effectiveness of all proposed BMPs and design features, and fully implement the most effective decommissioning treatments to maximize restoring ecological integrity to the area. These actions will ensure the Forest Service finally achieves its goal to establish a truly sustainable forest road system.

Recontoured road, Olympic National Forest - Skokomish Watershed, 2017. By WildEarth Guardians

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Exhibit 7

USDA

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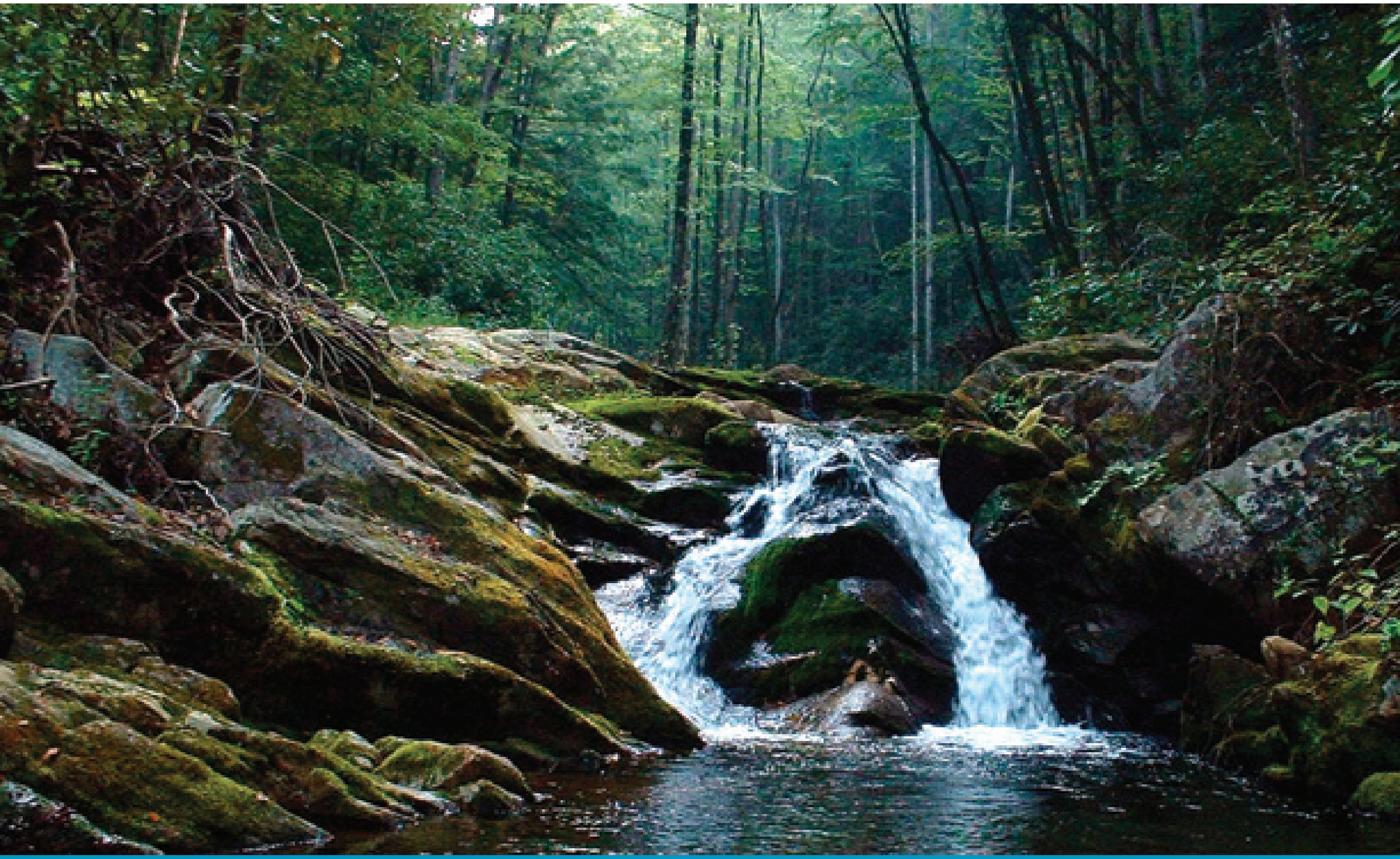
FS-978

July 2011

Watershed Condition Classification Technical Guide



United States
Department of
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FS-978

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Watershed Condition Classification Technical Guide

"Ultimately, our success at the Forest Service will be measured in terms of watershed health on those 193 million acres of national forests and grasslands."

Tom Tidwell
Chief, Forest Service
April 29, 2010

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Cover photo: *Pisgah National Forest by Jack Holcomb.*

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Contents

Introduction

The U.S. Department of Agriculture (USDA) Strategic Plan for fiscal year (FY) 2010–2015 targets the restoration of watershed and forest health as a core management objective of the national forests and grasslands. To achieve this goal, the Forest Service, an agency of USDA, is directed to restore degraded watersheds by strategically focusing investments in watershed improvement projects and conservation practices at landscape and watershed scales.

In a 2006 review of the Forest Service Watershed Program, the Office of Management and Budget (OMB) concluded that the Forest Service lacks a nationally consistent approach to prioritize watersheds for improvement (OMB 2006). The OMB also noted that the current Forest Service direction in the Forest Service Manual (FSM) 2521 for tracking watershed condition class is vague, open to varied interpretation, and insufficient to consistently evaluate watershed condition or track how condition changes over time. To address these issues, the Forest Service formed the National Watershed Condition Team and tasked it with developing a nationally consistent, science-based approach to classify the condition of all National Forest System (NFS) watersheds and to develop outcome-based performance measures for watershed restoration. The team evaluated alternative approaches for classifying watersheds (USDA Forest Service 2007) and developed the watershed condition classification (WCC) system described in this technical guide.

The team designed the WCC system to—

- Classify the condition of all NFS watersheds.
- Be quantitative to the extent feasible.
- Rely on Geographic Information System (GIS) technology.
- Be cost effective.
- Be implementable within existing budgets.
- Include resource areas and activities that have a significant influence on watershed condition.

National forests are required to revise the classification on an annual basis. We will use change in watershed condition class as an outcome-based performance measure of progress toward improving watershed condition on NFS lands. In order to demonstrate improvement in condition class, we need to track activities at the smallest feasible watershed unit, the 6th-level hydrologic unit (typically 10,000 to 40,000 acres in size).

The WCC system is a national forest-based, reconnaissance-level evaluation of watershed condition achievable within existing budgets and staffing levels that can be aggregated for a national assessment of watershed condition. The WCC system offers a systematic, flexible means of classifying watersheds based on a core set of national watershed condition indicators. The system relies on professional judgment exercised by forest interdisciplinary (ID) teams, GIS data, and national databases to the extent they are available, and on written rule sets and criteria for indicators that describe the three watershed condition classes (functioning properly, functioning at risk, and impaired function). The WCC system relies on Washington Office and regional office oversight for flexible and consistent application among national forests. The WCC system is a first approximation of watershed condition, and we will revise and refine it over time. The expectation is that we will improve and refine individual resource indicators and that we will develop databases and map products to assist with future classifications. The WCC information will be incorporated into the watershed condition framework, which will ultimately be employed to establish priorities, evaluate program performance, and communicate watershed restoration successes to interested stakeholders and Congress.

Objectives of This Guide

The watershed condition goal of the Forest Service is "to protect National Forest System watersheds by implementing practices designed to maintain or improve watershed condition, which is the foundation for sustaining ecosystems and the production of renewable natural resources, values, and benefits" (FSM 2520). U.S. Secretary of Agriculture Tom Vilsack reemphasized this policy in his "Vision for the Forest Service" when he stated that achieving restoration of watershed and forest health would be the primary management objective of the Forest Service (USDA 2010). This *Watershed Condition Classification Technical Guide* helps to implement this policy objective by—

1. Establishing a systematic process for determining watershed condition class that all national forests can apply consistently.
2. Improving Forest Service reporting and tracking of watershed condition.

3. Strengthening the effectiveness of the Forest Service to maintain and restore the productivity and resilience of watersheds and their associated aquatic systems on NFS lands.

Defining Watershed Condition

Watershed condition is the state of the physical and biological characteristics and processes within a watershed that affect the hydrologic and soil functions supporting aquatic ecosystems. Watershed condition reflects a range of variability from natural pristine (functioning properly) to degraded (severely altered state or impaired). Watersheds that are functioning properly have terrestrial, riparian, and aquatic ecosystems that capture, store, and release water, sediment, wood, and nutrients within their range of natural variability for these processes. When watersheds are functioning properly, they create and sustain functional terrestrial, riparian, aquatic, and wetland habitats that are capable of supporting diverse populations of native aquatic- and riparian-dependent species. In general, the greater the departure from the natural pristine state, the more impaired the watershed condition is likely to be. Watersheds that are functioning properly are commonly referred to as healthy watersheds.

Watersheds that are functioning properly have five important characteristics (Williams et al. 1997):

1. They provide for high biotic integrity, which includes habitats that support adaptive animal and plant communities that reflect natural processes.
2. They are resilient and recover rapidly from natural and human disturbances.
3. They exhibit a high degree of connectivity longitudinally along the stream, laterally across the floodplain and valley bottom, and vertically between surface and subsurface flows.
4. They provide important ecosystem services, such as high-quality water, the recharge of streams and aquifers, the maintenance of riparian communities, and the moderation of climate variability and change.
5. They maintain long-term soil productivity.

Watershed condition classification is the process of describing watershed condition in terms of discrete categories (or classes) that reflect the level of watershed health or integrity. In our usage, we consider watershed health and integrity are conceptually the same (Regier 1993): watersheds with high integrity are in an unimpaired condition in which ecosystems show little or no influence from human actions (Lackey 2001).

The FSM uses three classes to describe watershed condition (USDA Forest Service 2004, FSM 2521.1).

1. Class 1 watersheds exhibit high geomorphic, hydrologic, and biotic integrity relative to their natural potential condition.
2. Class 2 watersheds exhibit moderate geomorphic, hydrologic, and biotic integrity relative to their natural potential condition.
3. Class 3 watersheds exhibit low geomorphic, hydrologic, and biotic integrity relative to their natural potential condition.

The FSM classification defines watershed condition in terms of "geomorphic, hydrologic and biotic integrity" relative to "potential natural condition." In this context, integrity relates directly to functionality. We define geomorphic functionality or integrity in terms of attributes such as slope stability, soil erosion, channel morphology, and other upslope, riparian, and aquatic habitat characteristics. Hydrologic functionality or integrity relates primarily to flow, sediment, and water-quality attributes. Biological functionality or integrity is defined by the characteristics that influence the diversity and abundance of aquatic species, terrestrial vegetation, and soil productivity. In each case, integrity is evaluated in the context of the natural disturbance regime, geoclimatic setting, and other important factors within the context of a watershed. The definition encompasses both aquatic and terrestrial components because water quality and aquatic habitat are inseparably related to the integrity and, therefore, the functionality of upland and riparian areas within a watershed.

Within this context, the three watershed condition classes are directly related to the degree or level of watershed functionality or integrity:

1. Class 1 = Functioning Properly.
2. Class 2 = Functioning at Risk.
3. Class 3 = Impaired Function.

In this guide, we characterize a watershed in good condition as one that is functioning in a manner similar to natural wildland conditions (Karr and Chu 1999, Lackey 2001). A watershed is considered to be functioning properly if the physical attributes are adequate to maintain or improve biological integrity. This consideration implies that a Class 1 watershed that is functioning properly has minimal undesirable human impact on its natural, physical, or biological processes, and it is resilient and able to recover to the desired condition when disturbed by large natural disturbances or land management activities (Yount and Neimi 1990). By contrast, a Class 3 watershed has impaired function because some physical, hydrological, or biological threshold has been exceeded. Substantial changes to the factors that caused the degraded state are commonly needed to return the watershed to a properly functioning condition.

Defining specific classes for watershed condition is subjective and problematic for several reasons. First, watershed condition is not directly observable (Suter 1993). In nature, no distinct lines separate watersheds that are functioning properly from impaired watersheds, and, therefore, every classification scheme is arbitrary to some extent. Second, watershed condition is a mental construct that has numerous definitions and interpretations in the scientific literature (Lackey 2001). Third, the attributes that reflect the state of a watershed are continually changing because of natural disturbances (e.g., wildfire, landslides, floods, insects, and disease), natural variability of ecological processes (e.g., flows and cycles of energy, nutrients, and water), climate variability and change, and human modifications.

Watershed Condition and Ecological Restoration

The most effective way to approach complex ecological issues is to consider them at the watershed level, where the fundamental connection among all components of the landscape is the network of streams that define the basin (Heller 2004, National Research Council 1999, Newbold 2002, Ogg and Keith 2002, Reid et al. 1996, Sedell et al. 2000, Smith et al. 2005, Williams et al. 1997). Watersheds are also readily recognized by local communities and resonate with much of the public as a logical way to address resource management issues. Watersheds are easily identified on maps and on the ground, and their boundaries do not change much over time (Reid et al. 1996).

Watersheds are integral parts of broader ecosystems, and we can view and evaluate them at a variety of spatial scales. Because watersheds are spatially located landscape features that have been uniformly mapped for the entire United States at multiple scales, they are ideal for tracking watershed improvement accomplishments both in terms of outputs (acres treated on the ground) and outcomes (improvement in watershed condition class). Reporting accomplishments and outcomes by each watershed's unique hydrologic unit code (HUC) avoids double counting. The WCC system analyzes the effect of all activities within a watershed; therefore, the system provides an ideal mechanism for interpreting the cumulative effect over time of a multitude of management actions on hydrologic and soil function. Finally, many hydrologic and aquatic restoration issues can be properly addressed only within the confines of watershed boundaries. Watersheds provide a basis for developing restoration plans and priorities that can treat a multitude of resource problems in a structured, comprehensive manner.

Many terrestrial ecological restoration issues, however, are poorly addressed in a watershed context. Ecological restoration issues dealing with vegetation and wildlife species composition, structure, pattern, and diversity may not affect hydrologic and soil functions and are best evaluated using ecological stratifications such as those depicted in the map, Bailey's Ecoregions and Subregions of the United States, Puerto Rico, and the U.S. Virgin Islands (Bailey 1995). Consequently, we view watershed condition, watershed health, and watershed restoration as a subset of ecological condition, ecological health, and ecological restoration.

In summary, ecological restoration focuses on the composition, structure, pattern, and ecological processes necessary to make terrestrial and aquatic ecosystems sustainable, resilient, and healthy under current and future conditions. This includes watershed condition and health. Watershed condition assessment places specific emphasis on the physical and biological characteristics and processes affecting hydrologic and soil functions that support aquatic ecosystems. Therefore, in this WCC system, primary emphasis is placed on indicators that directly or indirectly affect soil and hydrologic functions and associated riparian and aquatic ecosystems.

Watershed Condition Indicators

The WCC system described in this technical guide uses 12 indicators composed of attributes related to watershed processes. The indicators and their attributes are surrogate variables representing the underlying ecological functions and processes that affect soil and hydrologic function. For most of the indicators, the Forest Service can take direct action, or cause others to take action, which contributes to maintaining or improving watershed condition. This structure provides for a direct linkage between the classification system and management or improvement activities the Forest Service conducts on the ground. Because of this linkage, when a sufficient number of properly designed and implemented restoration and/or management actions occur within a watershed, we can express the outcome as a change in condition class and use the resulting change in condition class for performance accountability purposes. Management activities that affect the watershed condition class are not limited to soil and water improvement activities; they include a broad array of resource program areas: hazardous fuel treatments, invasive species eradication, abandoned mine restoration, riparian area treatments, aquatic organism passage improvement, road maintenance and obliteration, and others. To change a watershed condition class will, in most cases, require changes within a watershed that are significant in their scope and include treatments from multiple resource areas. Sound management or improving management practices can often be as effective as implementing restoration projects and must not be overlooked. To demonstrate improvement in condition class, we will need to track activities at the smallest feasible watershed unit, the 6th-level HUC (typically, 10,000 to 40,000 acres).[1]

The WCC system consists of 12 watershed condition indicators:

1. Water Quality
2. Water Quantity
3. Aquatic Habitat
4. Aquatic Biota
5. Riparian/Wetland Vegetation
6. Roads and Trails
7. Soils
8. Fire Regime or Wildfire
9. Forest Cover
10. Rangeland Vegetation
11. Terrestrial Invasive Species
12. Forest Health

[1] In the context of this classification system, we use the terms "watershed" and "hydrologic unit" synonymously. Hydrologic units, however, are truly only synonymous with the classic watershed definition when their boundaries include all the source areas contributing surface water to a single, defined outlet point. For the intended uses of this reconnaisance-level assessment, this distinction is relatively unimportant.

The Watershed Condition Model

The basic model used in this classification system provides a forestwide, reconnaissance-level evaluation of watershed condition. It offers a systematic, flexible means of classifying and comparing watersheds based on a core set of national watershed condition indicators. The indicators are grouped according to four major **process categories**: (1) aquatic physical, (2) aquatic biological, (3) terrestrial physical, and (4) terrestrial biological (fig.1). These categories represent terrestrial, riparian, and aquatic ecosystem processes or mechanisms by which management actions can affect the condition of watersheds and associated resources.

We will use a simple score card approach to assess watershed condition class. Each of the four process categories is represented by a set of indicators (fig. 2, table 1). Each indicator is evaluated using a defined set of attributes. For example, the Aquatic Physical Processes category contains an indicator for Aquatic Habitat Condition. Aquatic habitat condition is evaluated using three attributes: (1) habitat fragmentation, (2) large woody debris, and (3) channel shape and function. Indicators can have as few as one attribute or as many as four attributes. We designed the classification to be as simple as possible based on the “80/20 Rule,” which states that often 80 percent of effects come from 20 percent of the causes. We also wanted to be responsive to user input obtained during pilot testing on national forests to keep the assessment compatible with the subjective nature of many of the evaluations. We therefore constrained the number of attributes and consequently the amount of data that national forest ID teams will need to deal with during the classification process.

We recognize from a scientific perspective that this watershed conditions model with its many indicators will have problems with autocorrelation. Because of the management need to show linkages between activities on the ground and improvement in watershed condition for performance accountability, however, we chose to include a comprehensive suite of indicators that represents the full scope of Forest Service management activities and program areas. For example, road condition and stream habitat condition may be highly correlated, however, eliminating stream habitat condition as an indicator would then preclude having a feedback mechanism for taking credit for watershed condition improvements derived from stream habitat improvement work. Using a comprehensive set of indicators favors management performance tracking and accountability at the expense of a more scientifically correct classification model.

Figure 1.—*The basic watershed condition model.*

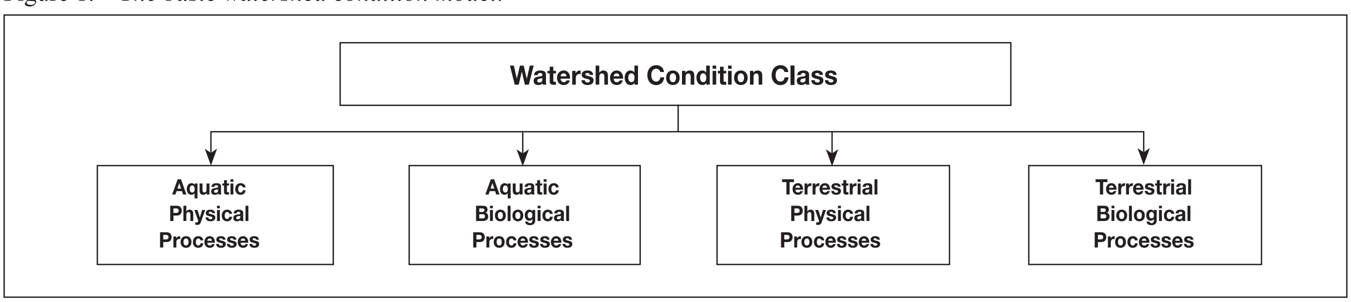

Figure 2.—*Core national watershed condition indicators.*

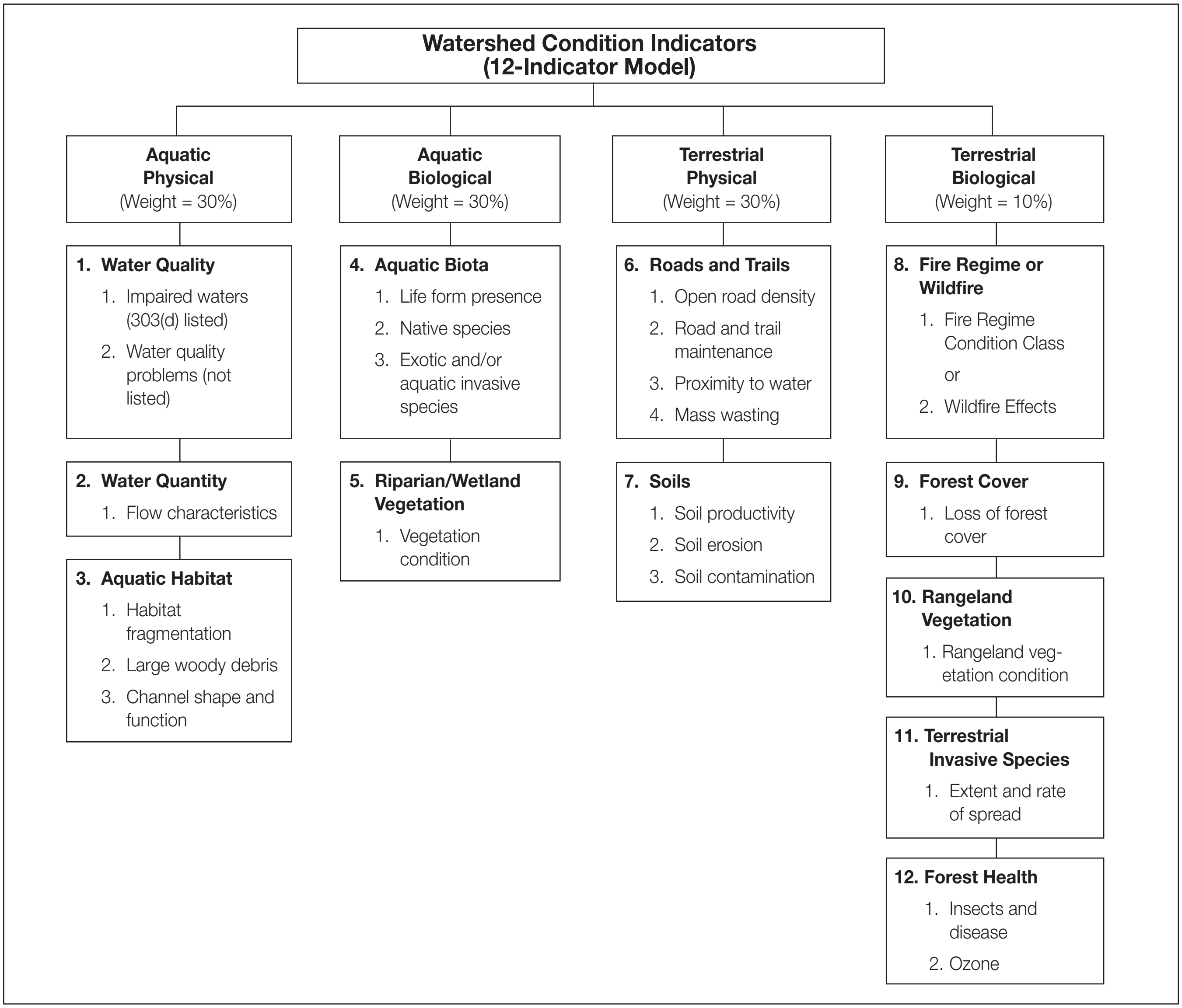

Table 1.—*Description of the 12 national core watershed condition indicators. (See the appendix for the complete rule set.)*

Aquatic Physical Indicators	
1. Water Quality	This indicator addresses the expressed alteration of physical, chemical, and biological components of water quality.
2. Water Quantity	This indicator addresses changes to the natural flow regime with respect to the magnitude, duration, or timing of the natural streamflow hydrograph.
3. Aquatic Habitat	This indicator addresses aquatic habitat condition with respect to habitat fragmentation, large woody debris, and channel shape and function.
Aquatic Biological Indicators	
4. Aquatic Biota	This indicator addresses the distribution, structure, and density of native and introduced aquatic fauna.
5. Riparian/Wetland Vegetation	This indicator addresses the function and condition of riparian vegetation along streams, water bodies, and wetlands.
Terrestrial Physical Indicators	
6. Roads and Trails	This indicator addresses changes to the hydrologic and sediment regimes because of the density, location, distribution, and maintenance of the road and trail network.
7. Soils	This indicator addresses alteration to natural soil condition, including productivity, erosion, and chemical contamination.
Terrestrial Biological Indicators	
8. Fire Regime or Wildfire	This indicator addresses the potential for altered hydrologic and sediment regimes because of departures from historical ranges of variability in vegetation, fuel composition, fire frequency, fire severity, and fire pattern.
9. Forest Cover	This indicator addresses the potential for altered hydrologic and sediment regimes because of the loss of forest cover on forest lands.
10. Rangeland Vegetation	This indicator addresses effects on soil and water because of the vegetative health of rangelands.
11. Terrestrial Invasive Species	This indicator addresses potential effects on soil, vegetation, and water resources because of terrestrial invasive species (including vertebrates, invertebrates, and plants).
12. Forest Health	This indicator addresses forest mortality effects on hydrologic and soil function because of major invasive and native forest insect and disease outbreaks and air pollution.

Types of Indicators

We define indicators as simple quantifiable or qualitatively determined measures of the condition and dynamics of broader, more complex attributes of ecosystem health. We use indicators because complex ecosystem attributes are difficult, inconvenient, or too expensive to measure. Indicators act as surrogates, representing the underlying ecological processes that maintain watershed functionality and condition. The basic watershed condition uses indicators that represent existing, on-the-ground alterations of watershed conditions. We will refine the indicators over time as better data and analysis tools become available.

The indicators include three basic types of attributes:

1. **Numeric attributes** have associated numeric values (e.g., road density <1 mile/mile^2). Quantitative attributes are simple to use but they need to be properly interpreted and appropriate for the geographical setting of the watershed.
2. **Descriptive attributes** are qualitative variables subject to some degree of interpretation by users (e.g., "Native mid to late seral vegetation appropriate to the sites potential dominates the plant communities and is vigorous, healthy, and diverse in age, structure, cover, and composition on more than 80 percent of the riparian and wetland areas in the watershed."). These semiquantitative attributes are typically used when reliable numeric indicators or thresholds are lacking or where quantitative data is either unavailable or too expensive to obtain for entire watersheds.
3. **Map-derived attributes** are produced by teams of experts that synthesize extensive data to create interpreted map products (e.g., Fire Regime Condition Classes). Map products

are generally high quality and objective if applied at the appropriate scale.

We anticipate that map-based and numeric indicators will eventually replace other indicators as better data become available.

Indicator Limitations and the Need for Professional Judgment

Good indicator sets should be comprehensive, accurately reflect watershed functionality, be readily measurable, be repeatable, provide data that we can unambiguously interpret, convey an understanding of how the ecosystem functions, and provide insight into the cause-and-effect relationships between environmental stressors and the response of the ecosystem (Mulder et al. 1999). Indicator sets, however, rarely exhibit all of these characteristics. Our application of indicators in this guide does not provide the level of detail expected from site-specific watershed analysis or assessments (USDA/USDI 1998), nor is it intended as a comprehensive evaluation of ecological conditions. Much like the Dow Jones Index gauges the strength of the stock market, watershed condition indicators rapidly assess the relative health of watersheds at a reconnaissance level. We will need additional detailed assessments to validate conclusions, to identify specific watershed problems, and to arrive at treatment solutions.

As simple surrogates for complex ecological processes, indicators do not necessarily represent cause-and-effect relationships. Indicators are derived from studies that correlate the behavior of indicators with environmental response variables of interest. For example, increasing road density has been correlated with increasing sediment yield in many studies nationwide. However, the true set of environmental conditions that produce sedimentation are complex, unmeasured, or unknown. Numerous other factors including soils, geology, slope, and road condition also influence sediment yield. The result is that road density is not a perfect predictor of the effects on sediment yield. The quality of an indicator ultimately depends on the quality of the research used to support it and its applicability to different environmental settings, but no single indicator is a perfect predictor of an environmental response.

Indicators work best when they are applied within the set of conditions under which they were developed, and the same indicator will have different interpretations in different ecological settings. For example, the naturally low volumes of large woody debris in many streams of the arid Southwest would represent degraded conditions in the forests of western Oregon. Even the map-based indicators such as Fire Regime Condition Class, which have been developed for the entire United States, are subject to local professional validation and interpretation to ensure that they are correctly applied. When used inappropriately, indicators and their attributes can provide misleading or incorrect conclusions. Numeric values should not be thought of as absolutes, but rather as diagnostic tools to promote discussion and understanding of relative watershed condition with respect to the rule set. ***As a result, this process relies on local professional expertise and judgment to interpret the indicators and assess watershed condition.***[2]

Providing for National Consistency and Local Flexibility

Professional judgment is needed to properly interpret the indicators, but a certain level of consistency is needed to compare watersheds at the national level. Achieving consistent evaluation is a challenge when applying professional judgment across diverse ecosystems. To improve consistency, the WCC system uses specific attributes along with quantitative and qualitative rule sets to assess watershed condition. This structured approach, coupled with appropriate regional office oversight is designed to minimize bias among evaluators and promote consistent interpretation of indicators.

Interpreting indicators, however, also requires local flexibility, because only a few simple indicators have numeric ranges of values that we can uniformly apply nationwide. For example, the natural range of water temperatures will have different values in warm water streams compared with high elevation trout streams, but an interpreted threshold specific to each environment indicates impairment. In addition, not all indicators apply in all environmental conditions and geophysical settings. For example, mass movement processes in the mountainous West are virtually nonexistent in the Lake States of the Midwest.

To provide the needed flexibility, the WCC system allows limited adjustment of core indicator attributes based on local data and conditions. To help maintain consistency, regional or national oversight teams need to approve these adjustments.

[2] This process relies on intuitive conclusions and predictions that are dependent on an analyst's training, interpretation of facts, information, and observations and on his or her personal knowledge of the watershed being analyzed. Professional judgment in this context is excercised by a national forest's interdisciplinary team.

The goal of the process is to use the best available information and data to assess watershed condition and to interpret the range of watershed conditions in different physiographic settings in a correct and conceptually similar manner relative to the range of proper and impaired functionality.

Forests may adjust attributes in one of three ways:

1. **Modify the default values of an attribute.** For example, the default ranges in the basic model for road density may be inappropriate for certain physiographic settings. Forests may adjust the range and breaks between good, fair, and poor ratings if they are supported by forest plans or local analysis and data.

2. **Substitute high-quality attribute data where appropriate.** For example, a forest may have extensive Properly Functioning Condition survey data that could be used to rate attributes associated with the Riparian Vegetation Condition indicator. Alternatively, the Alaska Region, may wish to substitute riparian forest age class structure as their indicator of riparian vegetation condition.

3. **Rate an attribute as Not Applicable.** For example, a forest lacking rangelands and grazing lands may exclude rangeland vegetation from their assessment of the terrestrial physical process category. A *Not Applicable (N/A)* rating can also be used for indicators or attributes not relevant within a particular geographical context. Only two indicators (Forest Cover and Rangeland Vegetation) and two attributes (large woody debris and mass wasting) may be rated N/A subject to Regional Oversight Team approval.

Limited attribute adjustments provide the flexibility needed to account for local differences in individual watersheds while maintaining an acceptable level of regional and national consistency. National consistency in scoring is maintained by retaining a consistent set of indicators, averaging attribute scores within each indicator, and weight-averaging indicator scores by process category. National consistency is most important at the process category level because each forest ID team evaluates these fundamental ecosystem process categories in a manner appropriate to their geographic setting.

We anticipate that there will be instances, or locally unique circumstances, where the computed condition rating may not accurately reflect true on-the-ground conditions. In these cases, forests can exercise an "override option" and replace the computed condition rating with the condition class judged to be correct. Typically, the override option would be used to designate severely impaired watersheds. Examples where the override option might be appropriate include situations such as (1) acid streams totally devoid of biological life, (2) water quality impairment because of chemical contamination, or (3) streams that are totally dewatered by diversions. In all of these examples, the upland areas may be in excellent condition but the water body is clearly impaired.

ID teams should use the override option judiciously and rarely. Exercising the override option will require written documentation and approval from the Regional Oversight Team. The National Oversight Team will review use of the override option annually to ensure that it is being applied in an appropriate manner.

Classifying Individual Indicators

Each indicator attribute receives a rating. The ratings are expressions of the "best-fit" descriptor of the attribute for the entire 6th-level watershed being classified. In the absence of established numeric criteria for most of the attributes, the boundaries between the attribute condition ratings were assigned by resource specialists working on the Watershed Condition Advisory Team using professional judgment guided by the conceptual condition descriptions below.

Condition Rating 1 is synonymous with "GOOD" condition. It is the expected indicator value in a watershed with high geomorphic, hydrologic, and biotic integrity relative to natural potential condition. The rating suggests that the watershed is functioning properly with respect to that attribute.

Condition Rating 2 is synonymous with "FAIR" condition. It is the expected indicator value in a watershed with moderate geomorphic, hydrologic, and biotic integrity relative to natural potential condition. The rating suggests that the watershed is functioning at risk with respect to that attribute.

Condition Rating 3 is synonymous with "POOR" condition. It is the expected indicator value in a watershed with low geomorphic, hydrologic, and biotic integrity relative to natural potential condition. The rating suggests that the watershed is impaired or functioning at unacceptable risk with respect to that attribute.

To conceptualize this, the suggested approach is to identify the upper and lower bounds for each indicator attribute to differentiate the desired conditions for that attribute (high integrity or high functionality relative to site potential) compared with the unacceptable or impaired functionality of the attribute in absolute terms. Conceptually, identifying the end points should be the easiest task to accomplish in any rating scheme. The remaining middle designation is then identified by default and may contain a wide range of conditions. Ratings are scaled and evaluated in an absolute sense from functioning properly to impaired function and not relative to a more limited range of attribute conditions that may occur on a particular national forest.

The complete watershed condition rule set for indicators and attributes is contained in the appendix. For each indicator, we provide a brief statement of purpose, the rule set to use to determine the condition rating of each attribute, additional guidance pertaining to rating the indicator attributes, definitions, a brief rationale of how the indicator relates to watershed condition, and references. Careful reading of the "Additional Guidance" section for each indicator is essential for appropriate use of the rule set.

The example below illustrates the process of scoring an individual indicator on Forest Service lands. The example indicator is Roads and Trails Condition. The hypothetical watershed is in the upper Midwest, which has no unstable landforms susceptible to mass wasting. The watershed is heavily roaded, with a road density of 2.5 mi/mi^2. Roads are well maintained but more than 25 percent are within 100 feet of water. The forest ID team decides that mass wasting is not an issue in this watershed and assigned the following ratings to road condition:

Roads and trails attributes	Rating	Explanation
Open road density	3	Poor (impaired function)
Road maintenance	2	Fair (functioning at risk)
Proximity to water	3	Poor (impaired function)
Mass wasting	N/A	N/A (the watershed is not susceptible to mass wasting)
Indicator rating	**2.7**	Poor (impaired function)

The complete classification process for each watershed is described below:

1. For each 6th-level HUC watershed, all attributes for each of the 12 indicators are scored by the forest ID team as 1 (Good—Functioning Properly), 2 (Fair—Functioning at Risk), or 3 (Poor—Impaired Function) using written criteria and rule sets and the best available data and professional judgment.
2. The attribute scores for each indicator are summed and averaged to produce an indicator score.
3. The indicator scores within each ecosystem process category are then averaged to arrive at a process category score.
4. The overall watershed condition score is computed as a weighted[3] average of the four process category scores.
5. The watershed condition scores are tracked to one decimal point and reported as Watershed Condition Classes 1, 2, or 3. Class 1 = scores of 1.0 to 1.6, Class 2 = scores from 1.7 to 2.2, and Class 3 = scores from 2.3 to 3.0.
6. A separate scoring process is conducted for Forest Service and non-Forest Service lands within the watershed. We will report results for Forest Service and non-Forest Service lands and a watershed composite overall watershed condition score (area weighted average of Forest Service and non-Forest Service lands).

We will assign condition ratings to Forest Service ownerships, private lands, and the composite watershed. The composite score rates the whole watershed and includes FS and all other ownerships, which are typically private land. The intent is to differentiate watershed conditions attributable to Forest Service management and problems that the FS can solve from those that are associated with others. We also wish to support the Secretary's call for an "all lands" approach to resource management.

Because we frequently lack data about the condition of non-Forest Service lands, a simpler approach is applied to these ownerships. We will assign non-Forest Service lands a subjective rating on a whole-watershed basis (i.e., we will not score individual indicators and attributes). Non-Forest Service lands will be rated as either THE SAME AS, BETTER THAN, or POORER THAN Forest Service lands in the watershed. If SAME AS is selected, we will assign the non-Forest Service lands the same numeric condition score as Forest Service lands. If non-Forest Service lands are not the same as Forest Service lands, we will designate the non-Forest Service lands as simply Class 1, Class 2, or Class 3 based on the best available knowledge. Forests are encouraged to rate non-Forest Service lands equal to Forest Service lands if the true condition is unknown. Forests may work with partner groups to classify non-Forest Service lands, if they wish.

National forests will complete the classification process using the Watershed Classification and Assessment Tracking Tool (WCATT), a Web-based application developed by the natural resource manager program staff.

[3] We weight process categories to reflect their relative contribution toward watershed condition from a national perspective. The aquatic physical and aquatic biological categories are weighted at 30 percent each because of their direct impact to aquatic systems (endpoint indicators). The terrestrial physical category is weighted at 30 percent because roads are typically one of the highest sources of impact to watershed condition. Terrestrial biological is weighted at 10 percent because these indicators have indirect impact to watershed condition.

Regional and National Oversight

This classification process relies on Washington Office and regional office oversight to provide for flexibility and consistency in application among national forests. The Washington Office technical oversight role will be the primary responsibility of the Watershed, Fish, Wildlife, Air, and Rare Plants program staff, who will be assisted by members of the Watershed Condition Advisory Team because of the interdisciplinary nature of the classification process. Advisory team members will provide technical input, expertise, and advice regarding the rule sets affecting their program areas.

The Washington Office will coordinate an annual meeting to discuss technical classification issues and resolve disputes. This will include, as a minimum, a review of the extent to which regions permitted use of "Not Applicable" and the "Override" options.

National oversight roles and responsibilities include—

1. Managing the national change process for the classification system.
2. Ensuring consistency of classification among the regions.
3. Providing and supporting development of national GIS data products for use in classification.
4. Providing direction and resolving disputes between regions.

Regions will provide the first line of quality control and quality assurance in the classification process. Regions are encouraged to work collectively with their forests to discuss interpretations of the rule-set wording to achieve as much consistency as practicable among forest units. Regions may wish to develop regional additional guidance supplements to this guide that document local application, data sources, and interpretations. The membership of Regional Office Oversight Teams is left to the discretion of the regions.

Regional oversight roles and responsibilities include—

1. Ensuring consistency of classification among the forests in the region.
2. Ensuring that forests use ID teams to perform classifications.
3. Approving use or modification to attribute default value, substituting high-quality attribute data or alternative wording for attributes, and the use of the "Not Applicable" and "Override" options.
4. Coordinating classification with adjoining regions and national forests.
5. Consulting with the Washington Office when significant modifications are approved.

Procedural Guidance

We specifically designed this watershed classification approach as a rapid, coarse filter, office assessment process to be completed by a forest ID team over a 2-week time period using professional judgment relying on existing information, maps, and GIS coverage.

Preparation Checklist

1. Identify the composition and leadership of the forest ID team that will classify watershed condition. Consider having someone from the forest land and resource planning staff as the team leader. The team should include technical specialists with expertise in the 12 condition indicator program areas. Typically, a forest ID team will do the classification, but forests may include district staffs. Specialists with long tenure and familiarity with the forest can prove especially valuable to the team because of the breadth of experience they provide.
2. Designate a technical lead for each of the watershed condition indicators. For example, a hydrologist might lead water-quality and water-quantity assessments.
3. Have each specialist review the rule set and additional guidance for his or her indicator to help him or her understand the types of data and information that are useful to rate the attributes for that indicator.
4. Over a 1-week period, have each specialist assemble the available information in preparation for the classification process. The types of information will vary by discipline and may include forest inventory and monitoring reports, interpreted map products, or assessments done by others.
5. Arrange for support from forest GIS specialists who can provide analysis support (e.g., road density, and road proximity to water analysis) that summarizes data by 6th-level HUCs. Obtain the most current national GIS data

coverage that is relevant to the analysis such as 303(d) impaired streams, Fire Regime Condition Class, and insect and disease maps, as well as local GIS data such as roads and trails, dams and diversions, active and abandoned mines, forest cover, recent large fires, etc.

6. Have each technical specialist develop a preliminary rating for his or her indicator for each 6th-level HUC that can be brought forward to the ID team for discussion.

Classification Process Checklist

1. Allow at least 1 week (5 days) for the ID team to complete the classification process.

2. Convene the ID team and discuss the rule set for classification with the intent of achieving a common understanding. At this time, the team should also discuss and reach agreement on any indicators and/or attributes (forest cover, rangelands, mass wasting, large woody debris) that they may wish to designate as "Not Applicable" to the particular forest, any proposed changes to attribute thresholds (e.g., road density), or substitution of alternative attribute wording for some indicators. Before the actual meeting, discuss and obtain approval from your Regional Oversight Team, if necessary.

3. Determine ratings using an interactive ID team process. Individual specialists may offer their preliminary classification of an indicator rating score, but the team should pool its collective knowledge to arrive at the final rating. The process will go slowly for the first few watersheds as individuals begin to gain a common understanding of the rating approach, and it may take several hours to classify the first watershed. Consider beginning with a watershed known to be in good condition and then rate one known to be in poor condition to help provide perspective on the range of existing conditions. The process will speed up noticeably after several iterations.

4. Use Tom Brown's national watershed risk-rating maps (Brown and Froemke 2010) as the forest's beginning point for classifying watershed condition. The national rating will provide perspective regarding the spatial distribution of watershed condition and illustrate how the local forest ratings fit within the context of national ratings. Remember that Brown and Froemke's work assesses risk and is based on broad-scale 5th-level HUCs using nationally consistent coarse-scale data that are not particularly applicable to forest management activities so they may not match well with your local conditions.

5. Use the Watershed Condition Classification Tool (WCATT) to record ratings and capture notes. Display the WCATT form on a large screen. A second large screen display may be useful to display other relevant GIS data layers.

Annual and Periodic Reassessments

1. Forests will need to update watershed condition classifications each year to track changes in watershed condition class for performance accountability. Concentrate on reassessing those watersheds that are known or suspected to have changed significantly from the previous year, focusing on—
   a. Priority watersheds where improvement activities have been implemented.
   b. Watersheds that have experienced large fires since the previous year.
   c. Watersheds that have experienced extensive natural disturbance. To facilitate annual updates, the WCATT has been designed to roll forward the previous year's classification data into the current year and forests will need to modify only those watersheds that have changed.

2. Conduct a more rigorous classification of all watersheds every 5 years, or sooner if conditions warrant. In all cases, use an ID team to perform annual and periodic reassessments.

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Appendix. Rule Set for Watershed Condition Indicators and Attributes

1. Water Quality Condition

Purpose

This indicator addresses the expressed alteration of physical, biological, or chemical impacts to water quality.

Condition Rating Rule Set

1. Water Quality Condition Indicator	Minimal to no impairment to beneficial uses of the water bodies in the watershed.	Minor impairment to beneficial uses of the water bodies in the watershed.	Significant impairment to beneficial uses of the water bodies in the watershed.
Attributes	**Good (1) Functioning Properly**	**Fair (2) Functioning at Risk**	**Poor (3) Impaired Function**
Impaired waters (303(d) listed)	No State-listed impaired or threatened water bodies.	Less than 10 percent of the stream miles or lake area are listed on the 303(d) or 305(b) lists and are not supporting beneficial uses.	More than 10 percent of the stream miles or lake areas are water quality limited and are not fully supporting beneficial uses as identified by a State water quality agency integrated report (303(d) & 305(b)).
Water quality problems (not listed)	The watershed has minor or no water quality problems. For example, no documented evidence of excessive sediment, nutrients, chemical pollution or other water quality issues above natural or background levels; no consumption advisories or contamination from abandoned or active mines; little or no evidence of acidification, toxicity, or eutrophication because of atmospheric deposition (see “Additional Guidance” related to mines and atmospheric deposition).	The watershed has moderate water quality problems. For example, consumption advisories in localized areas; minor contamination from active or abandoned mines; localized incidence of accelerated sediment, nutrients, chemicals, or infrequent, documented incidents of contamination of public drinking water sources. Moderate evidence of acidification, eutrophication, or toxicity because of atmospheric deposition (see “Additional Guidance” elated to mines and atmospheric deposition).	The watershed has extensive water quality problems. For example, consumption advisories over extended areas; excessive sediment, nutrients, chemicals; extensive contamination from active or abandoned mines; or frequent incidents of contamination of public drinking water sources. Strong evidence of acidification, eutrophication, or toxicity because of atmospheric deposition (see “Additional Guidance” related to mines and atmospheric deposition).

Additional Guidance

1. Water quality should address both surface and ground water.
2. Consider the mainstream systems as indicative of the whole drainage system water quality, (i.e., the composite representative of the condition of all the streams in the watershed).
3. Consider chronic water quality deterioration and short-term effects in light of overall sustained effects to beneficial uses (i.e., both could be irreversible or irretrievable, but are not always so).
4. Consider monitoring and inventory information available from internal and external sources.
5. Because State water quality agency integrated reports (303(d) and 305(b)) are submitted only every 2 years, use the latest and best available information about the status of impaired waters.
6. Atmospheric deposition can affect watersheds by causing acidification (sulfur and nitrogen), eutrophication (nitrogen), or toxicity (mercury). We can use water chemistry or critical loads to classify conditions. A number of sources of water

chemistry data are available (EPA 2006, 2009) and have been compiled into a national database (USDA Forest Service 2009). The most current guidance on using chemistry and critical loads for classification is available at http://www.fs.fed.us/air.

a. For areas where acidification is the major concern, use the following guidance for classification:

   i. Condition Rating 1. All water sample sites from the most sensitive water body in the watershed (or a nearby watershed with similar lithology) show an acid neutralizing capacity (ANC) of 50 microequivalents per liter (ueq/L) or greater.

   ii. Condition Rating 2. One or more water sample sites from the most sensitive water body in the watershed (or a nearby watershed with similar lithology) show an ANC of greater than 20 ueq/L and less than 50 ueq/L.

   iii. Condition Rating 3. One or more water sample sites from the most sensitive water body in the watershed (or a nearby watershed with similar lithology) show an ANC of 20 ueq/L or less.

   iv. Water bodies that are naturally acidic (DOC > 5 mg/L) or low in buffering capacity because of the influence of wetlands or local geology should be assigned Condition Rating 1.

   v. Where ANC data is lacking, consider rating the attribute using national deposition maps and lithology to find similar watersheds where ANC data is available.

b. In areas where eutrophication (nitrogen) is the primary problem, appropriate classification thresholds set by the U.S. Environmental Protection Agency (EPA) (2010) for each region can be found at www.fs.fed.us/air.

c. Where aquatic critical loads for sulfur or nitrogen are available (such as Sullivan et al. 2007), compare current deposition with the critical load and classify as follows:

   i. Condition Rating 1. Sulfur and/or nitrogen deposition is more than 10 percent below the aquatic critical load.

   ii. Condition Rating 2. Deposition is 0–10 percent below the aquatic critical load.

   iii. Condition Rating 3. Deposition is above the aquatic critical load.

d. For rating water quality effects from abandoned and active mines, use the following guidance for classification:

   i. Condition Rating 1. Abandoned and active mines with no associated evidence of water quality contamination.

   ii. Condition Rating 2. Abandoned or active mines that have documented evidence of some adverse effects to surface or groundwater quality.

   iii. Condition Rating 3. Abandoned or active mines that have been determined to be adversely affecting surface or groundwater as a result of water quality sampling.

Definitions

abandoned mines. Facilities, equipment, material, and associated surface disturbance resulting from past mineral exploration or development, for which there exists no current authorization and no evidence of current owner/operator.

acid neutralizing capacity. A measure of a water body's ability to buffer acid compounds, defined as the difference between cations of strong bases and anions of strong acids.

aquatic organism consumption advisories. Advisories issued by the EPA or by State natural resource or other agencies that advise the public to limit or avoid consumption of certain fish, shellfish, mussels, crayfish, or other aquatic organisms because of pollution. These advisories inform the public that high concentrations of chemical contaminants have been found in local fish and aquatic species and include recommendations to limit or avoid consuming certain fish and wildlife species from specific water bodies.

critical load. The amount of deposition of an atmospheric pollutant below which no harmful ecological effects occur. We can calculate critical loads for both acidity and nutrient nitrogen in terrestrial and aquatic systems.

designated beneficial uses. The desirable uses that water quality should support. Beneficial uses include drinking water supply, primary contact recreation (such as swimming), and aquatic life support. Each designated use has a unique set of water quality requirements or criteria that must be met for the use to be supported. A water body may have multiple beneficial uses. Designated beneficial uses are identified by each State water quality management agency.

eutrophication. Increased growth of biota and a rate of productivity that is accelerated over the rate that would have occurred naturally.

impaired or threatened water body. Any water body that is listed according to section 303(d) of the Clean Water Act. The 303(d) list is a comprehensive public record of all impaired or threatened water bodies, regardless of the cause or source of the impairment or threat. A water body is considered impaired when it does not attain the water quality standards needed to support its designated uses. Standards may be violated because of an individual pollutant, multiple pollutants, thermal pollution, or an unknown cause of impairment. A water body is considered threatened if it currently attains water quality standards, but is predicted to violate standards by the time the next 303(d) list is submitted to EPA. This determination is made by individual State water quality management agencies.

lithology. The gross physical character of a rock or rock formation described in terms of its structure, color, mineral composition, grain size, and arrangement of its component parts; all those visible features that in the aggregate impart individuality to a rock formation.

Rationale for Indicator

Nonpoint source pollution, defined as water pollution that comes from many different sources in a watershed, is the leading remaining cause of water quality problems in the United States. Polluted runoff from agriculture, silvicultural activities, and atmospheric deposition are among the leading causes of nonpoint source pollution problems (EPA 2007). Because nonpoint source pollutants are primarily derived from runoff generated from watershed surfaces, watershed condition and water quality are closely linked. The effects of nonpoint source pollutants on specific waters vary and may not always be fully assessed. We do know, however, that these pollutants have harmful effects on drinking water supplies, recreation, fisheries, and wildlife. In a recent report by EPA (2005), 45 percent of the water bodies assessed by State water quality agencies were reported as impaired or not clean enough to support their designated uses, such as fishing and swimming.

Indicator References

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2. Water Quantity Condition

Purpose

This indicator addresses changes to the natural flow regime with respect to the magnitude, duration, or timing of natural streamflow hydrographs.

Condition Rating Rule Set

2. Water Quantity Condition Indicator	Stream hydrographs have no or minor departure from natural conditions.	Stream hydrographs have moderate recognized departures from natural conditions part of the year.	The magnitude, duration, and/or timing of annual extreme flows (low and/or high) significantly depart from the natural hydrograph.
Attributes	**Good (1) Functioning Properly**	**Fair (2) Functioning at Risk**	**Poor (3) Impaired Function**
Flow characteristics	The watershed lacks significant man-made reservoirs, dams, or diversion facilities. The watershed has primarily free-flowing rivers and streams, unmodified lakes, and no or limited ground water withdrawals. Stream hydrographs have no or minor alterations from natural (unaltered by anthropogenic actions) conditions.	The watershed contains dams and diversion facilities that are operated to partially mimic natural hydrographs. A departure from a natural hydrograph occurs during periods other than extreme flows (lows or highs). Peaks and base flows are maintained but changes to the timing, rate of change, and/or duration of mid-range discharges occur.	Dams and diversion facilities are operated so that they fail to mimic natural hydrographs. The magnitude, duration, and/or timing of annual extreme flows (low or high) significantly depart from the natural hydrograph. The timing and the rate of change in flows often do not correlate with expected seasonal changes.

Additional Guidance

1. Compare existing conditions with historic conditions and reference conditions. The natural hydrograph baseline is streamflows unaltered by anthropogenic actions. Emphasis is on the permanent, long-term effects of water diversions and water control features rather than on flow changes caused by vegetation management.

2. Consider both the mainstream and tributaries when evaluating changes to flow hydrology. In most cases, depending on their extent and magnitude, cumulative changes observable in the mainstream stream will reflect flow changes to tributaries.

3. Concentrate evaluation on effects to perennial, mainstream streams rather than headwater tributaries or intermittent flows, except in arid or semiarid regions where intermittent or interrupted flows are important components of the hydrograph.

4. The effect on water quantity condition should be significant enough so that it results in measurable changes to the hydrograph. For example, water yield changes resulting from vegetation management would generally not be included unless the change was extensive and prolonged (e.g., extensive deforestation, urbanization, wildfire, dams, diversions, disease, insects, or other disturbances that significantly and persistently alter runoff).

5. The extent of groundwater pumping would generally need to be developed for large-scale industrial or large municipality use to measurably influence streamflow. In general, household groundwater use for domestic purposes will not have a significant influence on water quantity unless a watershed was developed to such an extent that it was closed to additional well developments by State water resource authorities.

6. Consider the effects of transbasin diversions with respect to both the donor and receiving streams.

Definitions

natural hydrograph. A hydrograph representing the natural seasonal flows of a river without the moderating influence of human-created features (e.g., dams and canals) or management actions.

Rationale for Indicator

Watershed condition has large role to play in the magnitude, frequency, and timing of runoff from a watershed. The quantity and timing of streamflow are critical components of water supply, water quality, and the ecological integrity of river systems (Hill et al. 1991). The effects of human alteration on the natural flow regimes of rivers and ecological processes are now reasonably well understood (Poff et al. 1997). Modifying natural hydrologic processes disrupts the dynamic equilibrium between the movement of water and the movement of sediment that exists in free-flowing rivers (Dunne and Leopold 1978). This disruption alters physical habitat characteristics, including water temperature, oxygen content, water chemistry, and substrate composition, and adversely changes the composition, structure, or function of aquatic, riparian, and wetland ecosystems (Bain et al. 1988). The result is that many rivers no longer support socially valued native species or sustain healthy ecosystems (NRC 1992).

Indicator References

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Poff, N.L.; Allan, J.D.; Bain, M.B., et al. 1997. The natural flow regime: a paradigm for river conservation and restoration. BioScience. 47(11): 769–784.

3. Aquatic Habitat Condition

Purpose

This indicator addresses aquatic habitat condition with respect to habitat fragmentation, large woody debris, and channel shape and function.

Condition Rating Rule Set

3. Aquatic Habitat Condition Indicator	The watershed supports large continuous blocks of high-quality aquatic habitat and high-quality stream channel conditions.	The watershed supports medium to small blocks of contiguous habitat. Some high-quality aquatic habitat is available, but stream channel conditions show signs of being degraded.	The watershed supports small amounts of continuous high-quality aquatic habitat. Most stream channel conditions show evidence of being degraded by disturbance.
Attributes	**Good (1) Functioning Properly**	**Fair (2) Functioning at Risk**	**Poor (3) Impaired Function**
Habitat fragmentation (including aquatic organism passage)	Habitat fragmentation is not a serious concern (more than 95 percent of historic aquatic habitats are still connected).	Aquatic habitat fragmentation is increasing because of temperature, aquatic organism passage blockages, or dewatering (only 25 to 95 percent of the historic aquatic habitats are still connected).	Aquatic habitat fragmentation because of temperature, blockages, or dewatering is a serious concern (less than 25 percent of the historic aquatic habitats still connected).
Large woody debris	In aquatic and riparian systems that evolved with wood near the streams, large woody debris is present and continues to be recruited into the system at near natural rates.	In aquatic and riparian systems that evolved with wood, large woody debris is present but is recruited into the system at less than natural rates because of riparian management activities.	In a system that should contain large wood as an ecosystem component, wood is lacking resulting in poor riparian or aquatic habitat conditions including bank destabilization, inadequate pool formation, and microclimate maintenance.
Channel shape and function	Channel width-to-depth ratios exhibit the range of conditions expected in the absence of human influence. Less than 5 percent of the stream channels show signs of widening. Channels are vertically stable, with isolated locations of aggradation or degradation, which would be expected in near-natural conditions. The distribution of channels with floodplain connectivity is close to that found in reference watersheds of similar size and geology.	Channel width-to-depth and vertical stability are maintained except where riparian vegetation has been disturbed. Between 5 and 25 percent of the stream channel have seen an increase in width-to-depth ratios. Channel degradation and/or aggradation are evident but limited to relatively small sections of the channel network. There is evidence of downcutting to the extent that some stream channels are no longer connected to their floodplain.	More than 25 percent of channels have width-to-depth ratios greater than expected under near-natural conditions. The size and extent of gullied sections of channels are extensive, currently increasing, or have increased recently. Many streambanks show signs of active erosion above that which is expected naturally. Channel degradation and/or aggradation are evident and widespread because of unstable streambeds and banks. Many (more than 50 percent) of the stream channels are disconnected from their floodplain or are braided channels because of increased sediment loads.

Additional Guidance

1. If forest plan aquatic habitat direction exists for habitat fragmentation, large wood, or channel shape and function, use the local thresholds derived from forest plan standards and guidelines to determine the appropriate rating for the attributes.
2. The focus of this evaluations should be on fish bearing channels lower in the watershed that are typically response reaches (<3 percent gradient). Consider the length of these reaches in the watershed, and estimate the length of channel that meets the criteria for the class.
3. Large woody debris. Rate this attribute Not Applicable (N/A) if the aquatic and riparian systems in the watershed

evolved without wood and if the presence of wood is not an important component of the aquatic ecosystem. The use of N/A will likely be limited to western rangeland watersheds.

4. In aquatic habitats lacking aquatic biota and/or permanent habitat (e.g., some Southwest desert streams), evaluate conditions with respect to what you would expected to be present under natural conditions, or absent human-induced impacts.

Definitions

aquatic habitat fragmentation. Habitat fragmentation occurs when a large region of habitat has been degraded or fragmented into a collection of smaller patches of nonconnected habitat. Major causes of aquatic habitat fragmentation are dams, diversions, mines, roads, inadequate culverts, and increased stream temperatures that prevent fish from moving freely throughout an aquatic system.

floodplain connectivity. In channels with existing or historic floodplains, floodplain connectivity refers to the ability of flows greater than bankfull to overflow on to the vegetated floodplain without accelerated impact to streambanks. Floodplain connectivity may be lost through the construction of levees, or through the downcutting of channels because of improper road location and construction, overgrazing, storage dams, or increased flow or sediment. Incised channels lack floodplain connectivity.

response channel reaches. Low gradient (in general, less than 3 percent) transport-limited channels in which significant morphologic adjustment occurs in response to increased sediment supply as defined by Montgomery and Buffington (1993). Response channels generally correspond to Rosgen C, D, E, and F channel types (Rosgen 1996). Response reaches are evaluated because they are the most susceptible to change from disturbance.

Rationale for Indicator

Watersheds in good condition tend to retain most of their natural heterogeneity and complexity such as preserving the lateral, longitudinal, and vertical connections between system components as well as the natural spatial and temporal variability of these components (Naiman et al. 1992). Floodplain connectivity demonstrates maintenance of the vertical component of stream channels and provides for off-channel habitat among other features. Habitat fragmentation evaluates the longitudinal component of healthy systems. Aquatic habitat fragmentation by fish passage blockages, dewatering, or temperature increases, along with simplification from activities including channelization, channel bed sedimentation, woody debris removal, and flow regulation, results in loss of diversity within and among native fish species (Lee et al. 1997). Maintaining heterogeneous and complex aquatic organism habitat at multiple scales is recognized as an important influence on species diversity and ecosystem stability (Sedell et al. 1990).

Indicator References

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4. Aquatic Biota Condition

Purpose

This indicator addresses the distribution, structure, and density of native and introduced aquatic fauna.

Condition Rating Rule Set

4. Aquatic Biota Condition Indicator	All native aquatic communities and life histories appropriate to the site and watershed are present and self-maintaining.	The watershed is a stronghold for one or more native aquatic communities when compared to other sub-basins within the native range. Some life histories may have been lost or range has been reduced within the watershed.	The watershed may support small, wildly scattered populations of native aquatic species. Exotic and/or aquatic invasive species are pervasive.
Attributes	**Good (1) Functioning Properly**	**Fair (2) Functioning at Risk**	**Poor (3) Impaired Function**
Life form presence	More than 90 percent of expected aquatic life forms and communities are present based on the potential natural communities present.	From 70 to 90 percent of expected aquatic life forms and communities are present based on the potential natural communities present.	Less than 70 percent of expected aquatic life forms and communities are present based on the potential natural communities present.
Native species	Most native aquatic species and life histories that would be expected based on potential natural communities are present and self-maintaining. Limited intermixing of native species genetics with outside sources has occurred, which can happen when moving aquatic species from one aquatic habitat to another.	Residual and, at times isolated, native endemic species that would be expected based on potential natural communities may be located in specific aquatic habitats. Some nonnative species may be present but native species are self-sustaining where found.	Exotic and/or aquatic invasive species are present and have mostly replaced native aquatic species. Legacy management effects to habitat from chemicals, sediment or other pollution may limit the knowledge available on endemic native species. Aquatic habitat is disconnected by passage or flow barriers.
Exotic and/or aquatic invasive species	Exotic and/or aquatic invasive species may be present but they have not greatly altered condition of native species (less than 25 percent of the historic aquatic-life-bearing habitats have exotic and/or aquatic invasive species present, spread of exotics and/or aquatic invasive species have been minimal over the past decade).	Exotic and/or aquatic invasive species are generally present and have lowered the health and sustainability of native species (between 25 and 50 percent of the historic native aquatic-life-bearing habitats have exotic and/or aquatic invasive species present and/or there has been an expansion of exotic and/or aquatic invasive species over the past decade).	Exotic and/or aquatic invasive species are present and have greatly lowered the condition of native aquatic species (more than 50 percent of the historic native-fish-bearing streams have exotic and/or aquatic invasive species present and/or there has been an expansion of nonnative exotic and/or aquatic invasive species over the past decade.

Additional Guidance

1. Life form presence. Avoid focus on single species; focus on communities.
2. Exotic and/or aquatic invasive species. The presence of exotic and/or aquatic invasive species or communities is used as an indicator of altered or impaired conditions. Although exotic and/or aquatic invasive species can significantly affect native aquatic faunal integrity, intraspecies interactions are not considered for this assessment. For this assessment, the widespread presence of exotic and/or aquatic invasive species indicates poor conditions. For example, if you note the presence of bluegill in an area that historically supported native rainbow trout, and you find in your records that water temperatures and flow conditions are now favoring bluegill and are not providing suitable habitat conditions for trout, your conclusion is that the habitat is in poor condition and the presence of bluegill is an indicator of this condition.

Definitions

aquatic invasive. Nonnative species that are also considered invasive.

exotic species. Nonnative species that are not considered invasive.

native fauna. Any faunal species native to a watershed.

Rationale for Indicator

Native fish and other native aquatic biota have been adversely affected by land and watershed development, habitat loss, direct human harvest, and increased competition from introduced exotic and/or aquatic invasive species. Introduced species and stocks are major threats to native fishes and aquatic biota by way of predation, competition, introduction of diseases and parasites for which native species lack resistance, environmental modification, inhibition of reproduction, and hybridization (Moyle et al. 1986, Nehlsen et al. 1991). Non-native introductions of species frequently have effects that cascade through entire ecosystems and compromise ecological structure and function in unforeseen ways (Winter and Hughes 1995). Although introductions have increased fishing opportunities, the ecological consequences have been high and the dramatic expansion of nonnative species has left many systems compromised (Angermeier and Karr 1994).

Indicator References

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5. Riparian/Wetland Vegetation Condition

Purpose

This indicator addresses the function and condition of native riparian vegetation along streams, water bodies, and wetlands.

Condition Rating Rule Set

5. Riparian/ Wetland Vegetation Condition Indicator	Native vegetation is functioning properly throughout the stream corridor or along wetlands and water bodies.	Disturbance partially compromises the properly functioning condition of native vegetation attributes in stream corridor areas or along wetlands and water bodies.	A large percent of native vegetation attributes along stream corridors, wetlands, and water bodies is not functioning properly.
Attributes	**Good (1) Functioning Properly**	**Fair (2) Functioning at Risk**	**Poor (3) Impaired Function**
Vegetation condition	Native mid to late seral vegetation appropriate to the site's potential dominates the plant communities and is vigorous, healthy, and diverse in age, structure, cover, and composition on more than 80 percent of the riparian/wetland areas in the watershed. Sufficient reproduction of native species appropriate to the site is occurring to ensure sustainability. Mesic herbaceous plant communities occupy most of their site potential. Vegetation is in a dynamic equilibrium appropriate to the stream or wetland system.	Native vegetation demonstrates a moderate loss of vigor, reproduction, and growth, or it changes in composition, especially in areas most susceptible to human impact. Areas displaying light to moderate impact to structure, reproduction, composition, and cover may occupy 25 to 80 percent of the overall riparian area with only a few areas displaying significant impacts. Up to 25 percent of the species cover or composition occurs from early seral species and/or there exist some localized but relatively small areas where early seral vegetation dominates, but the communities across the watershed are still dominated by mid to late seral vegetation. Xeric herbaceous communities exist where water relationships have been altered but they are relatively small and localized, generally are not continuous across large areas, and do not dominate across the watershed.	Native vegetation is vigorous, healthy, and diverse in age, structure, cover, and composition on less than 25 percent of the riparian/wetland areas in the watershed. Native vegetation demonstrates a noticeable loss of vigor, reproduction, growth, and changes in composition as compared with the site's potential communities throughout areas most susceptible to human impact. In these areas, cover and composition are strongly reflective of early seral species dominance although late- and mid-seral species will be present, especially in pockets. Mesic-dependent herbaceous vegetation is limited in extent with many lower terraces dominated by xeric species most commonly associated with uplands. Reproduction of mid and late seral species is very limited. For much of the area, the water table is disconnected from the riparian area and the vegetation reflects this loss of available soil water.

Additional Guidance

1. Use the following riparian/wetland vegetation attribute questions to help you evaluate the existing condition of riparian/wetland vegetation in the watershed (Prichard et al. 1988). In all cases, evaluate the site relative to the site's potential natural vegetation:

   a. Is there a diverse age-class distribution of native riparian/wetland vegetation (recruitment for maintenance and recovery)?

   b. Is there a diverse composition of native riparian/wetland vegetation (for maintenance and recovery)?

   c. Are native species present that indicate maintenance of riparian/wetland soil moisture characteristics and connectivity between the riparian/wetland vegetation and the water table typical of riparian/wetland systems in the area?

   d. Is streambank native vegetation composed of those plants or plant communities that have root masses capable of withstanding high streamflow events?

   e. Does native riparian/wetland vegetative adequately cover and protect banks and dissipate energy during high flows?

   f. Do native riparian/wetland plants exhibit high vigor?

g. Are native plant communities an adequate source of coarse and/or large woody material (for maintenance and recovery)?

2. If forest plan riparian management direction exists for riparian/wetland vegetation, use the local thresholds derived from forest plan standards and guidelines to determine the appropriate rating for this attribute. For example, riparian timber stand conditions may be appropriate in some ecosystems as a measure of riparian vegetation condition but riparian/wetland herbaceous vegetation conditions are appropriate for other systems.

3. Where the Bureau of Land Management's Proper Functioning Condition assessments have been completed (Prichard et al. 1994), rate the properly functioning condition category as Condition Class 1, the functional at risk category as Condition Class 2, and the nonfunctional category as Condition Class 3 based on the percent of riparian areas in each category.

Definitions

functional at risk (functioning at risk). Riparian/wetland areas that are in functional condition, but one or more existing soil, water, or vegetation attributes makes them susceptible to degradation.

functioning properly. Riparian/wetland health (functioning condition), an important component of watershed condition, refers to the ecological status of vegetation, geomorphic, and hydrologic development, along with the degree of structural integrity exhibited by the riparian/wetland area. Riparian/wetland areas that are functioning properly exist when adequate vegetation, landform, or large woody debris is present to dissipate stream energy associated with high waterflow, thereby reducing erosion and improving water quality; filter sediment, capture bedload, and aid floodplain development; improve flood-water retention and ground-water recharge; develop root masses that stabilize streambanks against cutting action; develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses; and support greater biodiversity.

nonfunctional (impaired). Riparian/wetland areas that clearly are not providing adequate vegetation, landform, or large woody debris to dissipate stream energy associated with high flows, and thus are not reducing erosion, improving water quality, etc.

riparian zone, riparian area, stream corridor. The interface between land and the banks of a stream, river, or other body of water. We use the term riparian in its broadest sense to include areas adjacent to a stream, river, or lake, recognizing that a diverse mixture of different definitions exists across the United States. Plant communities along these water margins are called riparian vegetation and are characterized by hydrophytic plants.

wetlands. Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. In general, wetlands include swamps, marshes, bogs, and similar areas.

Rationale for Indicator

Riparian and wetland areas are the interface between terrestrial and aquatic ecosystems and are an integral part of the watersheds. Consequently, the health of these areas is closely interrelated to the condition of the surrounding watershed (Debano and Schmidt 1989, Hornbeck and Kochenderfer 2000). The health of riparian corridors is dependent on the storage and movement of sediment through the channel system and also on the movement of sediment and water from surrounding hillslopes into the channel system. Human-induced and natural disturbances can alter these processes either indirectly to the watershed or directly to riparian areas themselves by livestock grazing, road construction, mining, irrigation diversion, channel modification, flooding, wildfire, and similar disturbances (Baker et al. 2004, NRC 2002). One good measure of riparian/wetland health is the ecological condition of riparian vegetation relative to reference conditions.

Indicator References

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6. Roads and Trails Condition

Purpose

This indicator addresses changes to the hydrologic and sediment regimes due to the density, location, distribution, and maintenance of the road and trail network.

Condition Rating Rule Set

6. Roads and Trails Condition Indicator	The density and distribution of roads and linear features within the watershed indicate that the hydrologic regime is substantially intact and unaltered.	The density and distribution of roads and linear features within the watershed indicates that there is a moderate probability that the hydrologic regime is substantially altered.	The density and distribution of roads and linear features within the watershed indicates that there is a higher probability that the hydrologic regime (timing, magnitude, duration, and spatial distribution of runoff flows) is substantially altered.
Attributes	**Good (1) Functioning Properly**	**Fair (2) Functioning at Risk**	**Poor (3) Impaired Function**
Open road density	Default road/trail density: less than 1 mi/mi^2, or a locally determined threshold for good conditions supported by forest plans or analysis and data.	Default road/trail density: From 1 to 2.4 mi/mi^2, or a locally determined threshold for fair conditions supported by forest plans or analysis and data.	Default road/trail density: more than 2.4 mi/mi^2, or a locally determined threshold for poor conditions supported by forest plans or analysis and data.
Road and trail maintenance	Best Management Practices (BMPs) for the maintenance of designed drainage features are applied to more than 75 percent of the roads, trails, and water crossings in the watershed.	BMPs for the maintenance of designed drainage features are applied to 50 to 75 percent of the roads, trails, and water crossings in the watershed.	BMPs for the maintenance of designed drainage features are applied to less than 50 percent of the roads, trails, and water crossings in the watershed.
Proximity to water	No more than 10 percent of road/trail length is located within 300 feet of streams and water bodies or hydrologically connected to them.	Between 10 and 25 percent of road/trail length is located within 300 feet of streams and water bodies or hydrologically connected to them.	More than 25 percent of road/trail length is located within 300 feet of streams and water bodies or hydrologically connected to them.
Mass wasting	Very few roads are on unstable landforms or rock types subject to mass wasting with little evidence of active movement or evidence of road damage. There is no danger of large quantities of debris being delivered to the stream channel because of mass wasting.	A few roads are on unstable landforms or rock types subject to mass wasting with moderate evidence of active movement or road damage. There is some danger of large quantities of debris being delivered to the stream channel, although this is not a primary concern in this watershed.	Most roads are on unstable landforms or rock types subject to mass wasting with extensive evidence of active movement or road damage. Mass wasting that could deliver large quantities of debris to the stream channel is a primary concern in this watershed.

Additional Guidance

1. For the purposes of this reconnaissance-level assessment, the term “road” is broadly defined to include roads and all lineal features on the landscape that typically influence watershed processes and conditions in a manner similar to roads. Roads, therefore, include Forest Service system roads (paved or nonpaved) and any temporary roads (skid trails, legacy roads) not closed or decommissioned, including private roads in these categories. Other linear features that might be included based on their prevalence or impact in a local area are motorized (off-road vehicle, all-terrain vehicle) and nonmotorized (recreational) trails and linear features, such as railroads. Properly closed roads should be hydrologically disconnected from the stream network. If roads have a closure order but are still contributing to hydrological damage they should be considered open for the purposes of road density calculations.

2. Open road density. Although default road density guidelines (USFWS 1998) for good, fair, and poor conditions are provided, forests may deviate from the default values based on local analysis and/or forest plan standards and guidelines. For example, existing local or regional planning processes, publications, or other analyses may have established thresholds that are more pertinent to local conditions. The

selected default road density guidelines were derived from U.S. Fish and Wildlife Service guidance that covered a large geographical area of the Western United States.

3. Mass wasting. Mass movement is rated only with respect to the extent and effect it is associated with roads and effects to aquatic resources. Areas that are inherently unstable or at risk from mass movement are not rated.

4. Mass wasting. Geographical areas where mass wasting is not a significant process, may be rated as N/A. Typically, this designation would be applied over a broad geographic area such as an entire national forest. Coordination with the Regional Oversight Team is suggested to ensure consistency among adjacent units.

Definitions

hydrologically connected. Any road segment that, during a high runoff event, has a continuous surface flow path between the road prism and a natural stream channel is a hydrologically connected road segment. The proximity of roads to streams is a surrogate for hydrologic connectivity.

mass wasting. The geomorphic process by which soil, regolith, and rock move downslope under the force of gravity. Mass wasting may also be known as slope movement or mass movement. It encompasses a broad range of gravity-driven rock, soil, or sediment movements, including weathering processes. Types of mass wasting include creep, slides, flows, topples, and falls, and they are differentiated by how the soil, regolith, or rock moves downslope as a whole.

unstable landforms, geologic types, and landslide prone areas. Areas determined unstable by individual national forests using exiting soil resource inventories, terrestrial ecological unit inventories, geologic inventories, or maps.

Rationale for Indicator

Roads affect watershed condition because more sediment is contributed to streams from roads and road construction than any other land management activity. Roads directly alter natural sediment and hydrologic regimes by changing streamflow patterns and amounts, sediment loading, transport, deposition, channel morphology and stability, and water quality and riparian conditions within a watershed (Copstead et al. 1997, Dunne and Leopold 1978, Gibbons and Salo 1973). Road maintenance can also increase sediment routing to streams by creating areas prone to surface runoff, altering slope stability in cut-and-fill areas, removing vegetation, and altering drainage patterns (Burroughs and King 1989, Luce and Black 2001, Megahan 1978, Reid and Dunne 1984). Road density is known to play a dominant role in human-induced augmentation of sediment supply by erosion and mass wasting in upland forested landscapes in the Pacific Northwest (Cederholm et al. 1981, Furniss et al. 1991), and it is reasonable to assume that similar relationships exist elsewhere. Road-related mass soil movements can continue for decades after roads have been constructed, and long-term slope failures frequently occur after road construction and timber harvest (Megahan and Bohn 1989).

Indicator References

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7. Soils Condition

Purpose

This indicator addresses alteration to natural soil condition, including productivity, erosion, and chemical contamination.

Condition Rating Rule Set

7. Soils Condition Indicator	Minor or no alteration to reference soil condition, including erosion, productivity, and chemical characteristics is evident.	Moderate amount of alteration to reference soil condition is evident. Overall soil disturbance is characterized as moderate.	Significant alteration to reference soil condition is evident. Overall soil disturbance is characterized as extensive.
Attributes	**Good (1) Functioning Properly**	**Fair (2) Functioning at Risk**	**Poor (3) Impaired Function**
Soil productivity	Soil nutrient and hydrologic cycling processes are functioning at near site-potential levels, and the ability of the soil to maintain resource values and sustain outputs is high in the majority of the watershed.	Soil nutrient and hydrologic cycling processes are impaired and the ability of the soil to maintain resource values and sustain outputs is compromised in 5 to 25 percent of the watershed.	Soil nutrient and hydrologic cycling processes are impaired and the ability of the soil to maintain resource values and sustain outputs is compromised in more than 25 percent of the watershed.
Soil erosion	Evidence of accelerated surface erosion is generally absent over the majority of the watershed.	Evidence of accelerated surface erosion occurs over less than 10 percent of the watershed, or rills and gullies are present but are generally small, disconnected, poorly defined, and not connected into any pattern.	Evidence of accelerated surface erosion occurs over more than 10 percent of the watershed, or rills and gullies are actively expanding, well-defined, continuous, and connected in a definite pattern.
Soil contamination	No substantial areas of soil contamination in the watershed exist. When atmospheric deposition is a source of contamination, sulfur and/or nitrogen deposition is more than 10 percent below the terrestrial critical load.	Limited areas of soil contamination may be present, but they do not have a substantial effect on overall soil quality. When atmospheric deposition is a source of contamination, sulfur and/or nitrogen deposition is 0 to 10 percent below the terrestrial critical load.	Extensive areas of soil contamination may be present. When atmospheric deposition is a source of contamination, sulfur and/or nitrogen deposition is above the terrestrial critical load.

Additional Guidance

1. If forest or regional direction exists for soil quality or soil management, these local thresholds may be used to determine the appropriate rating for soil attributes.
2. Soil nutrient and hydrologic cycling processes are evaluated using available relevant soil properties such as compaction, porosity, infiltration, bulk density, organic matter, soil cover, microbial activity, or other appropriate indicators.
3. Soil erosion should not double count road-related erosion effects that are considered in the roads and trails condition indicator.
4. Atmospheric deposition. Compare current deposition with either site-specific terrestrial critical loads for acidity and/or nutrient nitrogen (Geiser et al. 2010, Pardo et al. in review), or with the best available critical loads calculated for similar sites in the region. Where acidification is the primary concern and site-specific critical loads are absent, use the risk assessment map of exceedence of critical loads (based on McNulty et al. 2007) to classify the watershed. Current information (including directions to Geographic Information System (GIS) coverage) for site-specific, regional, and national scale critical loads is available at http://www.fs.fed.us/air.

Definitions

critical load. The amount of deposition of an atmospheric pollutant below which no harmful ecological effects occur. We can calculate critical loads for both acidity and nutrient nitrogen in terrestrial and aquatic systems.

reference soil condition. The condition of the soil with which functional capacity is compared. Using indicators, soil quality is usually assessed by comparing a management system with a reference condition. The reference condition may be represented with (1) baseline measurements taken previously at the same location; (2) established and achievable indicator values such as salinity levels related to salt tolerance of crops; or (3) measurements from the same or similar soil under the reference state or inherent or attainable conditions (Tugel et al. 2008).

soil condition. A description of soil physical, chemical and biological properties that affect soil ecosystem services, including productivity, hydrologic function, stability, and resilience.

Rationale for Indicator

Determining natural soil condition includes evaluating erosion, nutrients, productivity, and the physical, chemical, and biological characteristics of the soil (USDA Forest Service 2009). Soil condition is related to watershed condition because of significant water supply benefits associated with developing forest soils that promote infiltration and high-quality water. Forest soils, with litter layers, high organic content, and large macropore fraction, promote rapid infiltration and minimize erosive overland flow (Ice 2009). In other ecosystems, soil supplies air, water, nutrients, and mechanical support for the sustenance of plants. It also receives and processes rainfall and controls how much of that rainfall becomes surface runoff, how much is stored for slow, sustained delivery to stream channels, and how much is stored and used for soil processes (Neary et al. 2005). Management activities, such as intensive grazing, logging, recreational activity, and other disturbances, can lead to reduced soil structure, soil compaction, and damage to or loss of vegetative cover. These activities contribute to increased surface runoff resulting in soil erosion, loss of nutrients, and a decrease in soil productivity (Meehan and Platts 1978). The soil contamination attribute addresses various sources of contaminants, including abandoned mines, illegal dumping, drug labs, spills, atmospheric deposition, and others. For atmospheric sources, the critical load standard addresses the impact of air pollution (sulfur and nitrogen) deposition on forest soils. Sulfur and/or nitrogen deposition estimates above the critical load for soil indicate the potential for significant harmful effects to the forest ecosystem through the accelerated loss of base cations, a decrease in soil pH, an increased risk of biologically toxic levels of aluminum released from the soils, or nitrogen in excess of and detrimental to biological demand.

Indicator References

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8. Fire Regime or Wildfire Condition

Purpose

This indicator addresses the potential for altered hydrologic and sediment regimes because of departures from historical ranges of variability in vegetation, fuel composition, fire frequency, fire severity, and fire pattern.

Condition Rating Rule Set

8. Fire Regime or Wildfire Condition Indicator	Low likelihood of losing defining ecosystem components because of the presence or absence of fire.	Moderate likelihood of losing defining ecosystem components because of the presence or absence of fire.	High likelihood of losing defining ecosystem components because of the presence or absence of fire.
Attributes	**Good (1) Functioning Properly**	**Fair (2) Functioning at Risk**	**Poor (3) Impaired Function**
Fire Regime Condition Class	Fire Regime Condition Class (FRCC) 1—A predominate percentage of the watershed is within the natural (historical) range of variability (“reference fire regime”) of vegetation characteristics; fuel composition; fire frequency, severity, and pattern; and other associated disturbances. The vegetative species and cover types are well adapted to the fire regime and offer good protection to soil and water resources.	FRCC 2—A predominate percentage of the watershed has a moderate departure from the reference fire regime of vegetation characteristics; fuel composition; fire frequency, severity, and pattern; and other associated disturbances. The vegetative species and cover types are somewhat affected by the abnormal fire regime and this results in less protection to soil and water resources when fire occurs.	FRCC 3—A predominate percentage of the watershed has a high departure from the reference fire regime of vegetation characteristics; fuel composition; fire frequency, severity, and pattern; and other associated disturbances. The vegetative species and cover types are affected by the fire regime and this results in periods of fuel accumulation with infrequent intense fires with high severity that are more likely to lead to vegetation mortality, loss of soil organic matter, and poor protection to soil and water resources.
Attributes	**Good (1) Functioning Properly**	**Fair (2) Functioning at Risk**	**Poor (3) Impaired Function**
Wildfire Effects	Following a significant wildfire, effects are such that soil and ground cover conditions in the burned area are expected to recover within 1 to 2 years to levels that provide watershed protection appropriate for the location and ecotype.	Following a significant wildfire, soil and ground cover conditions are causing some post-fire runoff and erosion concerns but are not sufficient to jeopardize long-term watershed condition integrity. This condition may persist for 2 to 5 years after a wildfire.	Following a significant wildfire, soil and ground cover conditions are causing considerable post-fire runoff, erosion, and flooding threats to watershed condition integrity lasting for more than 5 years.

Additional Guidance

1. The Fire Regime or Wildfire Condition Indicator is unique in that it is an either/or proposition in which either Fire Regime Condition or Wildfire Effects is rated. In most cases, we will rate the Fire Regime attribute. Following a significant wildfire, however, the Wildfire Effects attribute is rated and the Fire Regime attribute is rated N/A. This is the only indicator that operates in this either/or manner.

2. Wildfire Effects. We will rate watersheds experiencing a significant wildfire (one that effectively changes the FRCC using the Wildfire Effects attribute until the watershed fully recovers from any adverse wildfire effects (i.e., recovers from a rating of 2 or 3), and during this time we will rate the FRCC attribute as N/A. Forests should switch to the Wildfire Effects attribute if more than 50 percent of the watershed is affected by a significant wildfire. If less than 50 percent of the watershed is affected by a significant wildfire, switching to this attribute may still be appropriate and should be determined by the forest on a case-by-case basis. In the wake of a significant wildfire, only the Wildfire Effects attribute correctly characterizes the state of the watershed with respect to watershed condition. For example, following a severe wildfire, a watershed previously in

FRCC3 (Poor) reverts to FRCC1 (Good) because it has been returned to its natural reference condition and the Wildfire Effects attribute will now be rated as 3 (Poor) due to post-fire conditions. Averaging the two attributes will result in an incorrect characterization of watershed condition. To avoid this, we will rate watershed condition based on the Wildfire Effects attribute during the entire watershed recovery period.

3. Fire Regime Condition Class. In watersheds that clearly have more than one FRCC, use the formula below to determine the Category.

   Methodology:

   a. For each 6th-level hydrologic unit code (HUC) watershed, determine the percentage of the total watershed area within each of the Fire Regime Condition Classes (FRCC1, FRCC2, and FRCC3). Use GIS overlays if possible.

   b. FRCC1 is assigned a category score of 1, FRCC2 is assigned a category score of 2, and FRCC3 is assigned a category score of 3.

   c. Calculate the weighted average fire regime condition class ($FRCC_{wtavg}$) using the formula below:

$$FRCC_{wtavg} = \frac{(FRCC1 * 1) + (FRCC2 * 2) + (FRCC3 * 3)}{FRCC1 + FRCC2 + FRCC3}$$

   where:

   FRCC1 = acres of watershed within Fire Regime Condition Class 1,

   FRCC2 = acres of watershed within Fire Regime Condition Class 2,

   FRCC3 = acres of watershed within Fire Regime Condition Class 3.

   Categorize fire regime condition using the following calculated weighted average FRCC ranges:

   Category 1—1.0 to 1.66.

   Category 2—1.67 to 2.33.

   Category 3—2.33 to 3.0.

4. Fire Regime Condition Class. Although the use of national FRCC map products is encouraged, forests may refine FRCC as appropriate to fit their local situations.

   a. Example 1. Forests in the Southern Region may wish to use the Fire Frequency-Severity Condition Class and omit the Succession Class Condition Class in their determination of Watershed Condition ratings since this seems more appropriate for these ecosystems.

   b. Example 2. Forests in the Southwest may wish to use Integrated Forest Resource Management System (INFORMS) data instead of the national Landscape Fire and Resource Management Planning Tools (LANDFIRE) data since it provides a better estimate of local conditions.

   Document and coordinate modifications with your Regional Oversight Team.

Definitions

Fire Regime Condition Class (FRCC). Fire regime condition classes measure the degree of departure from reference conditions, possibly resulting in changes to key ecosystem components, such as vegetation characteristics (species composition, structural stage, stand age, canopy closure, and mosaic pattern); fuel composition; fire frequency, severity, and pattern; and other associated disturbances, such as insect and disease mortality, grazing, and drought. Possible causes of this departure include (but are not limited to) fire suppression, timber harvesting, livestock grazing, introduction and establishment of exotic plant species, and introduced insects and disease. FRCC is strictly a measure of ecological trends.

The three fire regime condition classes are categorized using the following criteria: FRCC1 represents ecosystems with low (less than 33 percent) departure and that are still within the estimated historical range of variability during a specifically defined reference period; FRCC2 indicates ecosystems with moderate (33 to 66 percent) departure; and FRCC 3 indicates ecosystems with high (more than 66 percent) departure from reference conditions. As described below, departure is based on a central tendency (or mean) metric and represents a composite estimate of the reference condition vegetation characteristics; fuel composition; fire frequency, severity, and pattern; and other associated natural disturbances. Low departure includes a range of plus or minus 33 percent deviation from the central tendency.

Characteristic vegetation and fuel conditions are considered to be those that occurred within the natural fire regime, such as those found in areas categorized as FRCC1 (low departure). Uncharacteristic conditions are considered to be those that did not occur within the natural regime, such as areas that are often categorized as FRCC2 and FRCC3 (moderate to high departure). These uncharacteristic conditions include, but are not limited to the following: invasive species (weeds and insects), diseases, “high graded” forest composition and structure (in which, for example, large, fire-tolerant trees have been removed and small fire-intolerant trees have been left within a frequent surface fire regime), or overgrazing by domestic livestock that adversely effects native grasslands or promotes unnatural levels of soil erosion (Hann et al. 2004, 2008).

watershed recovery period. The period of time, in years, that is required for the burned area to develop vegetation and infiltration conditions sufficient to reduce runoff and erosion potential to essentially predisturbance conditions. This is a best estimate of natural regeneration, soil stabilization, and hydrophobicity reduction, supplemented by any treatments prescribed (USDA Forest Service 2009).

Rationale for Indicator

To a large extent, watershed condition is controlled by the composition and density of vegetative cover and the amount of bare soil resulting from anthropogenic or natural disturbances that affect the watershed (Neary et al. 2005). Fire primarily alters vegetation and soil properties, changing hydrologic and geomorphic processes. In general, the effects of fire are increased soil water and overland flow that result in accelerated erosion by a variety of surface and mass movement processes. The magnitude of the effects on an ecosystem depends to a large degree on the frequency and intensity of fire and the sensitivity of the ecosystem to disturbance (Swanson 1981). Fire regime and geomorphic sensitivity may be used to characterize and contrast the geomorphic consequences of fire in different ecosystems. For example, frequent, intense fire in highly erosive landscapes, such as steep-land chaparral in southern California, is an extremely important component of some geomorphic systems. The effects of fire are progressively less significant in ecosystems in which fire is less frequent and/or less intense. FRCC, which is a measure of vegetation departure from reference condition, effectively evaluates potential vegetation change effects to watershed condition. Wildfires have the potential to exert a tremendous influence on the hydrologic conditions of watersheds in many forest ecosystems depending on the fire’s severity, duration, and frequency. Wildfire is the single forest disturbance that has the greatest potential to change watershed condition (DeBano et al. 1998). An extensive, high-severity wildfire can destroy the vegetation and litter layer in a watershed and detrimentally alter physical properties of the soil, including infiltration and percolation capacities. These cumulative fire effects can change the watershed condition from good to poor, resulting in unacceptable increases to overland flow, erosion, and soil loss (Neary et al. 2005).

Indicator References

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9. Forest Cover Condition

Purpose

This indicator addresses the potential for altered hydrologic and sediment regimes because of the loss of forest cover on forest lands.

Condition Rating Rule Set

9. Forest Cover Condition Indicator	The amount of National Forest System (NFS) forest land in the watershed that is not supporting forest cover is minor.	The amount of NFS forest land in the watershed that is not supporting forest cover is moderate.	The amount of NFS forest land in the watershed that is not supporting forest cover is high.
Attributes	**Good (1) Functioning Properly**	**Fair (2) Functioning at Risk**	**Poor (3) Impaired Function**
Loss of forest cover	Less than 5 percent of NFS land in the watershed contains cut-over, denuded, or deforested forest land where appropriate forest cover should be reestablished or restored to achieve the desired conditions or other applicable forest plan direction for NFS lands.	Between 5 and 15 percent of NFS land in the watershed contains cut-over, denuded, or deforested forest land where appropriate forest cover should be reestablished or restored to achieve the desired conditions or other applicable forest plan direction for NFS lands.	More than 15 percent of NFS land in the watershed contains cut-over, denuded, or deforested forest land where appropriate forest cover should be reestablished or restored to achieve the desired conditions or other applicable forest plan direction for NFS lands.

Additional Guidance

1. This indicator focuses on the presence or absence of forest cover (lands being managed as natural or seminatural forest ecosystems) on NFS lands in consideration of National Forest Management Act (NFMA) requirements. Because non-NFS lands do not have this Federal legal standard for forest cover, those private and other ownerships are not included in rating the watershed for this indicator.

2. This indicator may be rated N/A if forest cover (as precisely defined below) is absent in the watershed. If forest cover is rated N/A, rangeland condition must be rated. In effect, we characterize a watershed as having forest cover, rangelands, or both. In many watersheds, we will rate both indicators. Note that lands that meet the forest land definition will also normally have a rangeland component to the understory. This is especially true in those forest lands where the tree cover is relatively sparse (normally less than 60 percent canopy cover), with the amount of rangeland vegetation increasing as tree canopy cover decreases. In these instances, both indicators shall be evaluated and rated.

3. We will produce the most accurate and rapid assessment if the Forest Service Activity Tracking System (FACTS) database reflects current conditions regarding loss of forest cover and planned or subsequent reforestation activities. Use sources such as Rapid Assessment of Vegetation Condition After Wildfire to update FACTS until field exams can be conducted. Apply FACTS business rules.

4. Methodology:

   a. Calculate percent for each 6th-level HUC watershed using the formula below:

   $$\frac{A_D}{A_T}(100)$$

   where:

   A_D = area (in acres) of NFS forest land within the watershed that is not providing forest cover. NFS forest land must meet all three of the following criteria:

   i. is being managed as forest land (a land-use determination defined by the land and resources management plan).

   ii. has been cut over, denuded, or lost forest cover from any human or natural disturbance.

   iii. where forest cover has not yet been reestablished. See the definition of “forest cover” below.

   A_T = total area (in acres) of NFS forest land within the watershed. Obtain from best source such as NRM-Natural Resource Information Systems (NRIS), legacy databases, other assessments, remote sensing, or GIS sources.

b. Using the percentage determined from step a, categorize each watershed's forest cover condition into either Category 1, 2, or 3.

Definitions

forest cover. Areas where trees provide 10 percent or greater canopy cover and are part of the dominant (uppermost) vegetation layer, including areas that have been planted to produce woody crops. For the purposes of watershed condition assessment, lands that do not yet provide 10 percent tree canopy cover will be considered as meeting the definition of forest cover if the areas have been certified and recorded in FACTS as having been regenerated to appropriate forest cover (whether through natural or artificial regeneration) as specified in the land and resources management plan. "Appropriate forest cover" may be defined in one or more of the following forest plan components (desired conditions, standards, guidelines, management area prescriptions and allocation map, map of lands suitable for timber production, or other direction). The following FACTS codes are applicable (these are used to generate the Reforestation Needs Report): Harvest Codes 4101, 4102, 4110-17, 4131-34, 4143, 4147, 4150-52, 4160, 4162, 4175-77, 4183, and 4194; Causal Agent: 4250, 4260, 4265, 4270, 4280, and 4290.

forest land. Land is at least 10 percent occupied by forest trees, or it previously had such tree cover, is and not currently developed for nonforest use. Lands developed for nonforest use include areas for crops, improved pasture, residential, or administrative areas, improved roads of any width, and adjoining road clearing and power-line clearing of any width (FSM 1905). Note: Designated wilderness, roadless areas, and unproductive forest land that meet the above definition are classified as forest land.

Rationale for Indicator

This is a foundational indicator of whether forest ecosystems are being sustained or lost over time ("Maintain forests as forests"). The ability of forests to regulate water flows and maintain quality supplies is affected by the condition of the forest and the occurrence of disturbances that change the structure, composition, and pattern of forest vegetation. Forest cover is a primary terrestrial ecosystem component that is important to watershed condition. Trees provide many water- and soil-related ecosystem services such as intercepting precipitation and protecting soil, regulating snowmelt, and stabilizing steep slopes. Extensive loss of forest cover because of severe wildfires, widespread insect and disease epidemics, timber harvest, weather events, and long-term drought affect runoff, erosion, sediment supply, bank stability, large woody debris retention, and stream temperature relationships (MacDonald et al. 1991, Meehan 1991, Reid 1993). Many of the effects from these and similar disturbances decrease after the initial disturbance but may remain above natural levels for many years (Platts and Megahan 1975). Carefully designed and executed management actions can both restore vegetative cover and improve watershed condition.

Section 4 (Reforestation) of the Forest and Rangeland Renewable Resources Planning Act of 1974, as amended by NFMA (National Forest Management Act of 1976) (16 U.S.C. 1601(d)(1)), establishes the policy of Congress that all forested lands in the NFS be maintained in appropriate forest cover with species of trees, degree of stocking, rate of growth, and conditions of stand designed to secure the maximum benefits of multiple-use sustained yield management in accordance with land management plans.

Regarding private lands, note that some States (such as California) have forest regulations requiring reestablishment or maintenance of forest cover after timber harvest.

Indicator References

MacDonald, L.H.; Smart, A.; Wissmar, R.C. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. EPA/910/9-91-001. Seattle, WA: U.S. Environmental Protection Agency, Region 10. 166 p.

Meehan, W.R., ed. 1991. Influences of forest and rangeland management on salmonid fishes and their habitat. Special Publication 19. Bethesda, MD: American Fisheries Society.

Platts, W.S.; Megahan, W.F. 1975. Time trends in riverbed sediment composition in salmon and steelhead spawning areas. In: Proceedings, 40th American wildlife and natural resources conference: 229–239.

Reid, L.M. 1993. Research and cumulative watershed effects. Gen. Tech. Rep. PSW-GTR-141. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 118 p.

U.S. Government. 1974. Forest and Rangeland Renewable Resources Planning Act of 1974, as amended by the National Forest Management Act of 1976 (16 United States Code 1600-1614, 472a).

10. Rangeland Vegetation Condition

Purpose

This indicator addresses impacts to soil and water relative to the vegetative health of rangelands.

Condition Rating Rule Set

10. Rangeland Vegetation Condition Indicator	Rangelands reflect native or desired nonnative plant composition and cover at near-natural levels as defined by the site potential.	Rangelands reflect native or desired nonnative plant composition and cover with slight to moderate deviation compared to natural levels as defined by the site potential.	Rangelands reflect native or desired nonnative plant composition and cover are greatly reduced or unacceptably altered compared to natural levels as defined by the site potential.
Attributes	**Good (1) Functioning Properly**	**Fair (2) Functioning at Risk**	**Poor (3) Impaired Function**
Rangeland vegetation condition	Vegetation contributes to soil condition, nutrient cycling, and hydrologic regimes at near-natural levels; functional/structural groups, number of species, plant mortality and decadence closely match that expected for the site average annual plant production equals or exceeds 70 percent of production potential; litter amount is approximately what is expected for the site potential and weather; the reproductive capacity of native or naturalized perennial plants to produce seeds or vegetative tillers is sustainable over the long term; and introduced plant species are being managed to facilitate long-term replacement by site-adapted native species.	Functional/structural groups and number of species are slightly to moderately reduced; some dead and/or decadent plants are present above what would be expected for the site; average annual plant production is 40 to 69 percent of production potential; litter amount is moderately less than would be expected relative to site potential and weather; the reproductive capacity of perennial native or naturalized plants to produce seeds or vegetative tillers is somewhat reduced but is still sustainable over the long term; and, introduced plant species are being managed to facilitate long-term replacement by site-adapted native species or to ensure adequate ground cover to protect the soil.	Functional/structural groups and number of species are moderately to greatly reduced or altered relative to site potential; dead and/or decadent plants are significantly more common than would be expected for the site; average annual plant production is less than 40 percent of production potential; litter is largely absent or is sparse and disconnected relative to site potential and weather; the reproductive capacity of native or naturalized perennial plants to produce seeds or vegetative tillers (native or seeded) is severely reduced relative to site potentials; and introduced plant species are dominant and are not effective in protecting the site and soil.

Additional Guidance

1. Rangelands are rated relative to biotic integrity. Use guidance and definitions found in the publication, "Interpreting Indicators of Rangeland Health" (Pellant et al. 2005), to assist with this evaluation. Because of the close interrelationship between soils, hydrology, and vegetation condition, rangeland ecologists, hydrologists, and soil scientists are encouraged to work together to make this evaluation. Rangeland soil/ and site stability and hydrologic function are rated in the Soils Condition indicator. Invasive species are rated in the Terrestrial Invasive Species Condition Indicator.

2. If forest plan rangeland direction exists for ecological condition (functional structural groups, plant mortality and decadence, annual production, litter amounts, reproductive capacity, or similar attributes), use the local thresholds derived from forest plan standards and guidelines to determine the appropriate rating.

3. This indicator may be rated N/A if rangelands (as defined below) are absent in the watershed. If rangeland is rated N/A, forest cover condition must be rated. In effect, we characterize a watershed as having forest cover, rangelands, or both. In many watersheds, we will rate both indicators. If rangelands are not present, we may decide to exclude them on an individual watershed basis, but in many cases the decision will apply to an entire national forest. Coordination with the Regional Oversight Team is recommended.

Definitions

biotic integrity (integrity of the biotic community). Capacity of a site to support characteristic functional and structural communities in the context of normal variability, to resist loss of this function and structure because of a disturbance, and to recover following such disturbance (Pellant et al. 2005).

functioning at risk. Rangelands that have a reversible loss in productive capability and increased vulnerability to irreversible degradation based upon an evaluation of current conditions of the soil and ecological processes (National Research Council 1994).

functioning properly. Rangelands that are functioning properly relative to the ecological site description and/or ecological reference area given the normal range of variability associated with the site and climate.

impaired. Rangelands on which degradation has resulted in the loss of ecological processes that function properly and the capacity to provide values and commodities to a degree that external inputs are required to restore the health of the land (National Research Council 1994).

rangeland. Land on which the indigenous vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs, or shrubs and is managed as a natural ecosystem. If plants are introduced, they are managed similarly. Rangelands include natural grasslands, savannas, shrub lands, many deserts, tundra, alpine communities, marshes, and wet meadows (Society of Range Management 1999). (Pellant et al. 2005) include oak and pinyon-juniper woodlands in this definition). In this assessment, we will rate the condition of marshes under the Riparian/Wetland Vegetation indicator.

Rationale for Indicator

Rangeland health is a function of (1) soil/site stability—the capacity of the site to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water; (2) hydrologic function—the capacity of the site to capture, store, and safely release water from rainfall, runoff, and snowmelt and to recover following disturbance; and (3) the integrity of the biotic community—the capacity of the site to support ecological processes within the normal range of variability expected for the site and to recover after a disturbance (Pellant et al. 2005). Improper management can decrease ground cover and reduce species diversity, composition and/or cover. Improper management can result in diminished watershed functionality through soil compaction, which may increase overland flow and lead to incised channels and bank erosion (Bohn and Buckhouse 1986, Kaufman and Kreuger 1984, Platts 1991). Conversely, proper management can lessen adverse effects (Clary and Webster 1989). In summary, rangeland vegetative communities that are functioning properly provide for conditions that sustain soil stability, hydrologic function, and biotic diversity.

Indicator References

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Clary, W.P.; Webster, B.F. 1989. Managing grazing of riparian areas in the Intermountain Region. Gen. Tech. Rep. INT-263. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 11 p.

Johnson, K.L. 1992. Management for water quality on rangeland through best management practices: the Idaho approach. In: Watershed management: balancing sustainability and environmental change. New York: Springer-Verlag: 415–441.

Kaufmann, J.B.; Kreuger, W.C. 1984. Livestock impacts on riparian ecosystems and streamside management implications: a review. Journal of Range Management. 37: 430–438.

National Research Council. 1994. Rangeland health: new methods to classify, inventory, and monitor rangelands. Washington, DC: National Academy Press, National Research Council. 180 p.

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11. Terrestrial Invasive Species Condition

Purpose

This indicator addresses potential impacts to soil, vegetation, and water resources due to terrestrial invasive species (including vertebrates, invertebrates, and plants).

Condition Rating Rule Set

11. Terrestrial Invasive Species Condition Indicator	Few or no populations of terrestrial invasive species infest the watershed that could necessitate removal treatments that would affect soil and water resources.	Populations of terrestrial invasive species are established within the watersheds and/or the rate of expansion and/or potential for impact on watershed resources is moderate.	Terrestrial invasive species populations infest significant portions of the watershed, are expanding their range, and there is documentation of widespread impacts to watershed resources.
Attributes	**Good (1) Functioning Properly**	**Fair (2) Functioning at Risk**	**Poor (3) Impaired Function**
Extent and rate of spread	Few (less than 10 percent) or no populations of terrestrial invasive species infest the watershed that could necessitate removal treatments to protect, soil, native vegetation, or other water resources. Those that occur are small in extent and scattered in nature. The rate of spread and/or potential for impact on watershed resources is minimal or unlikely. Management intervention may be necessary to prevent increased risk of spread or invasion. Integrated management treatments may temporarily negatively affect soil, native vegetation, and other water resources, but the scale and scope would be minor.	Populations of terrestrial invasive species are established within (10 to 25 percent) the watershed and/or the rate of spread and/or potential for impact on soil, vegetation, or other water resources is moderate. Integrated treatments affect 10 to 25 percent of the watershed and must be ongoing just to keep the invasive species in check. Management intervention will be required to prevent increased level of risk.	Populations of terrestrial invasive species infest significant portions (more than 25 percent) of the watershed, may be expanding their range, and widespread impacts to soil, native vegetation, or other water resources have been documented. Treatments for containment affect more than 25 percent of the watershed, and management adjustments and/or treatments need to be ongoing just to keep the invasive species in check. Management intervention is necessary to alleviate significant resource damage and increased degradation of watershed condition.

Additional Guidance

1. This indictor applies only to terrestrial vertebrates, invertebrates, and plants that may have an adverse effect on soil and water resources. Aquatic invasive species are considered under Aquatic Biota Condition. Invasive insects and pathogens (including native forest insect pests and diseases) are covered under the Forest Health indicator.

2. Infestation extent. Infestation extent is usually evaluated with risk assessments and other inventory and evaluation procedures at either the species level, site level, or project level. For example, the extent of the terrestrial invasive species infestation on an individual species-level may indicate that the watershed condition rating is “good,” but when viewed within the context of all the documented terrestrial invasive species infesting the entire watershed, the overall condition rating may be considered “poor.”

3. Integrated management treatments against terrestrial invasive species may temporarily negatively affect soil, native vegetation, and other watershed resources, requiring a restoration component to the project plan.

Definitions

native species. With respect to a particular ecosystem, a species that historically occurred in that ecosystem.

terrestrial invasive species. A terrestrial invasive species (including vertebrates, invertebrates, pathogens, and plants) is a species not native to the ecosystem location under consideration, and its introduction causes or is likely to cause economic or environmental harm, or harm to human health. The lack of natural ecological controls (which typically kept these exotic species regulated in their native home) allows these exotic species to significantly harm the areas they invade. Terrestrial invasive species refers to harmful exotic species that are found or occur on the land surface rather than in aquatic environments. Many exotic plant and animal species occupy terrestrial habitats, but they are not necessarily harmful and typically cause little to no economic or environmental damage, and do not out-compete or displace native plants or animals.

Rationale for Indicator

When they produce significant changes in ecological processes, invasive species may cause environmental harm to watershed conditions, sometimes across broad geographical areas, which results in conditions that native animal and plant communities cannot tolerate. Some invasive species can significantly alter effective ground cover, erosion rates, and nutrient cycling; change the frequency and intensity of wildfires; or alter the hydrology of rivers, streams, lakes, and wetlands (Mack et al. 2000). For example, for cheatgrass the link to soil and hydrologic processes is through a chain of logic that recognizes that while cheatgrass may seasonally provide adequate cover for watershed protection, because it is an annual that it leaves little to no vegetative soil protection in dry years to provide soil protection. Consequently, its overall ability to protect the soil is minimal (and is well outside of the native site potential). Also, since disturbance of the soil is the main reason cheatgrass spreads, it is closely associated with an undesirable condition from a soil and water perspective. Cheatgrass in the Great Basin region has been shown to decrease the interval between the occurrences of wildfires from once every 70 to 100 years to every 3 to 5 years because it forms dense stands of fine fuel annually. This decrease in interval between wildfires causes more severe soil erosion and dramatically alters desirable native plant communities (Knapp 1996; Pimentel et al. 2000). Similarly, tamarisk (salt cedar) [Tamarix spp.] in the Southwest disrupts the structure and stability of North American native riparian plant communities by out-competing and replacing native plant species, increasing soil salinity, monopolizing limited sources of moisture, and increasing the frequency, intensity, and effect of fires and floods. Tamarisk has taken over large sections of riparian ecosystems in the Western United States that were once home to native cottonwoods and willows (Christensen 1962; Stromberg 1998). In addition, infestations of terrestrial invasive vertebrate species such as wild (feral) pigs cause widespread soil erosion, harbor infectious diseases, damage native vegetation, and aggressively prey upon native vertebrate and invertebrate wildlife (USDA-APHIS 1999).

Indicator References

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Knapp, P.A. 1996. Cheatgrass (*Bromus tectorum* L.) dominance in the Great Basin Desert: history, persistence, and influences to human activities. Global Environmental Change. 6(1): 37–52.

Mack, R.; Simberloff, D.W.M.; Lonsdale, H., et al. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications. 10: 689–710.

Pimentel, D.; Lach, L.; Zuniga, R.; Morrison, D. 2000. Environmental and economic costs of nonindigenous species in the United States. Bioscience. 50(1): 53–65.

Stromberg, J.C. 1998. Functional equivalency of saltcedar (*Tamarix chinensis*) and Fremont cottonwood (*Populus fremontii*) along a free-flowing river. Wetlands. 18: 675–686.

U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS). 1999. Wild pigs: hidden danger for farmers and hunters. Agricultural Information Bulletin. 620: 3–7.

12. Forest Health Condition

Purpose

This indicator addresses forest mortality impacts to hydrologic and soil function due to major invasive and native forest pest, insect, and disease outbreaks and air pollution.

Condition Rating Rule Set

12. Forest Health Condition Indicator	A small amount of the forested land in the watershed is anticipated to experience or is experiencing tree mortality from insects and disease and from air pollution.	A moderate amount of the forested land in the watershed is anticipated to or is experiencing tree mortality from insects and disease and from air pollution.	A large amount of the forested land in the watershed is anticipated to or is experiencing tree mortality from insects and disease and from air pollution.
Attributes	**Good (1) Functioning Properly**	**Fair (2) Functioning at Risk**	**Poor (3) Impaired Function**
Insects and disease	Less than 20 percent of the forested land in the watershed is at imminent risk of abnormally high levels of tree mortality (a level of 25 percent in a stand is deemed to represent an uncommon, rather extraordinarily high amount of mortality) because of insects and disease.	Between 20 and 40 percent of the forested land in the watershed is at imminent risk of abnormally high levels of tree mortality (a level of 25 percent is deemed to represent an uncommon, rather extraordinarily high amount of mortality) because of insects and disease.	More than 40 percent of the forested land in the watershed is at imminent risk of abnormally high levels of tree mortality (a level of 25 percent is deemed to represent an uncommon, rather extraordinarily high amount of mortality) because of insects and disease.
Ozone	Ozone causes a decrease in biomass growth in fewer than 20 percent of the years evaluated.	Ozone causes a decrease in biomass growth in 20 to 40 percent of the years evaluated.	Ozone causes a decrease in biomass growth in more than 40 percent of the years evaluated, and/or the watershed is within an area exceeding the National Ambient Air Quality Standards for ground-level ozone.

Additional Guidance

1. Insects and disease. Once outbreaks occur, we can do very little to halt or slow the spread, thus in this condition classification, we treat the presence of imminent outbreaks as if the undesirable condition already exists.

2. Insects and disease. Forests will use the 2006 National Insect and Disease Risk Map (NIDRM) (Krist et al. 2007) as a beginning point for evaluating potential future conditions. Areas at risk on NIDRM represent locations at which current stand or ecological conditions indicate that potential exists for insect and disease activity in the near term (i.e., next 15 years) if remediation is not undertaken. NIDRM is an integration of 188 individual risk models constructed within a common framework that is adaptable to regional variations in current and future forest health. The 2006 risk assessment introduced a consistent, repeatable, transparent process from which spatial and temporal risk assessments were at various scales. Primary contributors to the risk of mortality included mountain pine beetle, oak decline on red oaks, southern pine beetle, root diseases, gypsy moth, pine engraver beetle, fir engraver beetle, Douglas-fir beetle, spruce beetle, hardwood decline, and western pine beetle. The threshold for mapping risk is the following: the expectation that, without remediation, 25 percent or more of the standing live basal area on trees greater than 1 inch in diameter will die over the next 15 years because of insects and diseases. Krist et al. (2007) mapped watersheds most at risk at the 4th-level HUC (see fig. 11) showing the percentage of forested lands at risk. The lowest risk category (0–20 percent) is assigned as Condition Rating 1, the 20 to 40 percent category is assigned as Condition Rating 2, and more than 40 percent is assigned as Condition Rating 3. These breakpoints are consistent with recent investigations of watershed impacts following mountain pine beetle outbreak in Fraser Experimental Forest in Colorado (Rhoades et al. 2008).

3. Insects and disease. Finer scale maps at the 6th-level HUCs are available from the Forest Health Technology Enterprise Team (FHTET) in Fort Collins, CO.

4. Insect and disease detection surveys. Aerial sketch mapping is the primary data-collection method for this annual dataset. Observers code polygon data with damage agent, damage type, and a range of other possible attributes including host, severity, and approximate dead trees per acre. Data describing the condition within the polygon can be continuous or discontinuous and serves mostly as a snapshot in time of current and past activity. These data are subjective in nature, but may add valuable information for watershed assessment, particularly in areas where large mortality or defoliation events have occurred. Information about Forest Service Insect and Disease Detection Surveys are available from http://www.fs.fed.us/foresthealth/technology/adsm.shtml. Contact the local Forest Health Specialist for assistance with assessment of current insect or disease outbreaks.

5. Ozone. Assessments should use data from a nearby ambient ozone monitor or the national GIS coverage based on the ozone monitoring network. The attribute rating is determined by the percentage of years during which modeling shows that biomass growth is reduced by 10 percent or more. Contact the local Air Specialist or Forest Health Specialist for assistance with this analysis.

6. Ozone. Any years where the soil moisture is low (i.e., during a drought), the watershed(s) should be classified as "Good" because it is unlikely the ozone exposures contributed to any biomass reductions.

7. Ozone. The forests are encouraged to obtain ozone bioindicator data from the national Forest Health Monitoring program or by conducting field surveys if a watershed is consistently being rated as poor. The presence of ozone symptoms on ozone-sensitive species indicates a physiological response to the chronic or acute ozone exposure.

Rationale for Indicator

Healthy forests are an important component of watershed health. Two primary influences on forest health are insects and disease, and air pollution. Insects and disease along with fire are important regulators of forest change. Insects and disease can negatively affect resource values and ecosystem functions including reducing the ability of forest canopies to intercept snow and prevent excessive runoff. Recent increases in insect outbreaks have created a resurgence of interest in their effects on water quantity, water quality, and increased fire risks. Relatively few studies have examined the hydrologic response of forests to insects and disease, especially at long-term scales or in large watersheds (WSTB 2008). Although we still have much to understand, we can extrapolate the effects of insects and disease on watershed condition from general principles derived from studies of timber harvest and fire (MacDonald and Stednick 2003). Investigations of a recent outbreak of mountain pine beetle (*Dendroctonus ponderosae*) in Fraser Experimental Forest in Colorado indicate that spring and fall nitrate concentrations were 30 percent higher during 6 years following onset of bark beetle activity than preoutbreak concentrations (Rhoades et al. 2009). Air pollution effects are addressed by the effect of ground-level ozone on forest vegetation. Ozone can cause reductions in photosynthesis, which can decrease the amount of root growth, tree height, and crown width, which makes the weakened trees more susceptible to insect attacks (Lefohn 1992, Lefohn and Runeckles 1987).

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MANAGEMENT OF OLD GROWTH IN THE U.S. NORTHERN ROCKY MOUNTAINS
Debasing the concept and subverting science to plunder national forests

by Jeff Juel
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October 21, 2021

Friends of the Clearwater is a 501(c)(3) nonprofit dedicated to protecting and advocating for the wildlife and wildlands of the Clearwater Basin of North Central Idaho. These wildlands comprise the Wild Clearwater Country, and include federal public lands bordered on the north and south by the St. Joe and Salmon rivers, and bordered on the east and west by Montana and Oregon. Our mission includes educating the public about the issues these wildlands face, monitoring government management activities, and holding agencies accountable when their actions violate environmental laws or otherwise threaten ecological integrity or species.

This report was funded by a donation from the Clif Bar Family Foundation and by our generous membership. We sincerely thank you.

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EXECUTIVE SUMMARY

Old growth originates from complex and interconnected forest ecosystems developing over timescales much longer than a human lifespan. The idea is nurtured by the human capacity for appreciation of nature and by scientific discoveries of the important role old growth plays for sustaining biological diversity. This report touches on old growth's contributions to these recreational, spiritual, ecological and scientific values, and critically examines the management policies and practices of the U.S. Forest Service for national forests of the U.S. northern Rocky Mountains bioregion.

Challenges in defining old growth arise from divergent perspectives, which vary depending upon the values of the beholder. It is undisputed that old-growth forests are structurally complex, feature large, old trees and associated characteristics that develop over relatively long intervals of time, feature large snags and down dead wood, and exhibit variations in forest canopy including small openings caused by various agents of tree mortality. Old growth is structurally distinct from earlier successional stages.

The complex character of old growth makes it fascinating to the general public. Its biological diversity attracts scientific inquiry. Some species have co-evolved with, and depend on, specific conditions in old-growth forests.

The highest quality water is produced by older, intact forests, and several attributes of old-growth forests are important to maintain healthy native fish populations.

Science also recognizes that forests of mature and old trees continue to store disproportionally massive amounts of carbon, helping to moderate the effects of climate change.

The Chief of the Forest Service issued a 1989 policy statement that "recognizes the many significant values associated with old growth forests, such as biological diversity, wildlife and fisheries habitat, recreation, aesthetics, soil productivity, water quality, and industrial raw material. Old growth on the National Forests will be managed to provide the foregoing values for present and future generations." The Chief's statement was partly to address to the controversy surrounding the logging of spotted owl habitat in federally owned Pacific Northwest old-growth forests. This also came shortly after the first long-term land management plans for national forests had been written, as directed by the National Forest Management Act (NFMA). Congress's passage of NFMA itself was largely in response to earlier controversies surrounding clearcutting of national forest lands. By the time these "forest plans" were formulated, logging had already eliminated almost all old growth from private lands, and left the extent of old growth in national forests in the lower 48 states much depleted and highly fragmented.

The relative scarcity of old growth and its recognized importance for wildlife elevated its status as a metric for diversity for planning purposes, following from NFMA's mandate to "provide for diversity of plant and animal communities." And early forest plans recognized the inherent incompatibility of logging and old growth, prohibiting commercial exploitation in those old-growth stands identified for conservation.

Because of the relative novelty of old growth as a scientific concept, forest plans circa late-1980s—many of which remain in effect—reflected a wide variety of management approaches. The prevailing silvicultural view of old growth (i.e., "a decadent stand of trees" and "… an undesirable goal for timber management"), with its strong timber bias, seemed to be waning. Almost all forest plans prioritized protection of much of the remaining old growth. And as directed by NFMA, old-growth "management indicator species" (MIS) were designated under these forest plans. The objective of MIS designation is to keep track of their population trends, which provides feedback on the adequacy of forest plan protections for their habitat, thus insuring viable populations would persist across each national forest.

Generally, forest plans have required a minimum percentage of the forest be maintained in old-growth condition (ten percent at the very most), with old growth well-distributed to reflect biological needs of MIS and other species. However forest planners cited no biological basis to support the adequacy of their respective plan's minimum requirements. And while analyzing timber sale proposals, the agency ignores publicly presented scientific information suggesting their minimums are likely well below historic norms.

Another scientifically questionable aspect of the Forest Service's old-growth policies is an almost exclusive focus on existing old-growth stands, while ignoring the wider geographic and longer temporal contexts within which old-growth stands develop. Even old growth—generally requiring a minimum of 150 years to develop and often existing for centuries more—doesn't last forever, so planning for future old growth is necessary for its persistence on the landscape.

Old-growth stands are only one element of dynamic landscapes. Natural processes including fire, insect activity, disease, wind, regeneration of new seedlings, and nutrient allocations among individual trees interact to maintain a variety of conditions across the landscape. Old-growth components vary spatially and temporally, and only some of this ever-shifting landscape mosaic would exist as old growth at any given time.

Since it's not certain where old growth will occur decades or centuries in the future, maintaining old growth at any semblance of its historic abundance requires allowing natural processes operate across large landscapes. This conflicts with the Forest Service's prevailing prioritization of resource extraction on most national forest land.

Several lawsuits succeeded in halting Forest Service timber sales projected to destroy habitat for old-growth associated species, because the Forest Service could not prove it was preserving forest plan minimums and therefore meeting population viability requirements. The agency lacked comprehensive forestwide old-growth inventories, and had gathered practically no MIS population trend monitoring data.

Because agency budgets prioritize timber production goals above conservation, the Forest Service has responded to lawsuits by changing the rules. This has played out in several ways, primarily by removing quantitative minimum old-growth standards in the process of amending or revising forest plans, which hampers the public from holding the agency accountable. Other changes have included weakening the definition of old growth or altogether erasing the term from forest plans. And in 2012, the agency updated its planning regulations, significantly diminishing the overall role of science in planning and removing the mandate for assuring viability of species.

Paralleling this disturbing trend of devaluing old growth is a Forest Service's culture of controlling nature, emerging in the early 1990s as "ecosystem management." The Forest Service promotes vague, unmeasurable goals such as "improving forest health" and "increasing resilience and resistance to wildfire and insect pests" under this manipulate-and-control management. Such terminology has become ubiquitous in timber sale environmental analysis documents, agency public relations statements, and industry campaigns attempting to conceal the fact that its management bears much resemblance to the unsustainable logging of the past.

This culture also postures that management can engineer better forests than those growing naturally. Such posturing has facilitated—and fully rendered the Forest Service vulnerable to—industry capture. Under a politically inspired misinformation campaign, logging proponents demonize forests as "unhealthy," and as "hazardous fuels" posing risks of "catastrophic fire" to justify management "prescriptions." The fear incited by raising the specter of imminent destruction distracts from and prevents sober evaluation of the science that indicates logging is destructive, and itself increases fire risk.

According to the Forest Service worldview, management even facilitates or accelerates development of old growth. Yet there is little scientific support for—and much expert opinion opposing—the hypothesis that active management can develop or maintain old growth over time.

The Forest Service implicitly or explicitly denies that the natural processes that created and maintained old-growth landscapes over countless millennia can continue to do so without constant and repetitive management intervention. As a product of centuries of natural ecological processes, old growth is an anathema to the Forest Service worldview that asserts lack of intensive management equates to an unhealthy forest.

For old growth to persist, it's not enough to prohibit logging of all existing old growth. Natural processes must be the "managers" for long intervals over large landscapes to be the cradles for future old growth. And there needs to be much tighter constraint on national forests management policies. Old-growth values must be reordered so the wood products that consume forests take a back seat to spiritual, ecological, recreational and scientific values.

Currently, the only detailed initiative that would adequately change management priorities over large landscapes in the northern U.S. Rocky Mountains is a bill in Congress—the Northern Rockies Ecosystem Protection Act (NREPA). NREPA would protect the remaining roadless areas on federal lands in this bioregion as Wilderness, and importantly for old-growth landscapes it would provides a template for preserving biological connecting corridors and restoring damaged landscapes by designating wildland restoration and recovery areas on federal lands.

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MANAGEMENT OF OLD GROWTH IN THE U.S. NORTHERN ROCKY MOUNTAINS
Debasing the concept and subverting science to plunder national forests

By Jeff Juel

I. INTRODUCTION

I submit that an old-growth forest has worth in itself, worth beyond human uses. It is a manifestation of the "fierce, green fire" (Leopold, 1949) of life growing across the face of the earth. Saving old-growth forests for their own sakes, for their intrinsic value as ancient communities of life, represents a novel moral achievement that goes beyond even the most sophisticated human self-interest.

—Kathleen Dean Moore

The conception of old growth originates with complex and interconnected forest ecosystems that develop over timescales much longer than a human lifespan. The idea is nurtured by the human capacity for wonder, fascination, and appreciation of nature, tempered by the awareness of old growth's dwindling presence in an over-developed and exploited natural world.

This report examines the policies of the U.S. Forest Service, an agency tasked with sustaining the values of our national forests into perpetuity. The geographic area of interest is national forests of the U.S. northern Rocky Mountains bioregion, which encompasses large portions of Montana and Idaho, part of Wyoming, and some eastern portions of Oregon and Washington.

First, an overview of some scientific perspectives on old growth is presented. Old growth is then viewed through the lens of humanity's urgent existential crisis—climate change. The bulk of this report examines the management of old growth on national forests of the northern Rocky Mountains bioregion, from the 1980s until present. In conclusion, recommendations for policy changes are discussed.

II. OLD GROWTH AS AN ECOLOGICAL CONCEPT

Old growth …by combining sacred groves with ecological rationality …is a refuge for both the human spirit and a diversity of species threatened by the advance of commercialized landscapes.

—Robert G. Lee

As Lee suggests, spiritual sentiment and rational evaluation are two sides of the same human coin. Since expressions of the former are best left to the more literary and philosophical, and because conservation within our 21st century context demands a strong basis of objectivity, this report leans mostly upon scientific perspectives to advocate for this thing called "old growth."

Defining old growth in objective terms has proven to be no simple matter, however. Hunter (1989) noted, "there is a great deal of confusion over just what constitutes an old-growth stand because there is no generally accepted or universally applicable definition of old-growth."

A. Biological diversity associated with old growth

Scientists recognize the wide diversity of living and nonliving features as a defining character of old growth. Franklin and Spies, 1991 note the "later stages in forest development that are often compositionally and always structurally distinct from earlier successional stages." They describe the complexity and diversity that are defining traits:

> Structurally, old-growth stands are characterized by a wide within-stand range of tree sizes and spacing and include trees that are large for the particular species and site combination. Decadence is often evident in larger and older trees. Multiple canopy layers are generally present. Total organic matter accumulations are high relative to other developmental stages. Functionally, old-growth forests are characterized by slow growth of the dominant trees and stable biomass accumulations that are constant over long periods.

Countless scientific studies have explored the exceptional role old growth plays in providing essential habitat for wildlife species. Marcot, et al., 1991 recognize that old-growth habitat includes components serving many life functions:

> Old growth provides optimal habitat for some management indicator species, including spotted owl, pileated woodpecker, and marten, and for many other species of plants, fish, amphibians, reptiles, birds, and small mammals. It also provides thermal and hiding cover for ungulates, especially in winter. …Some wildlife species may have co-evolved with, and depend on, specific amounts and conditions of old-growth forests. Specific kinds, sizes, and patterns of old-growth environments are, therefore, keys to the long-term survival of these species. (Internal cites omitted.)

Similarly, Warren (1990) states:

> The greater vertical and horizontal diversity found within an old-growth stand allows for niche specialization by wildlife. Although the individual wildlife species occurring may not

> be unique to old-growth stands, the assemblage of wildlife species and the complexity of interactions between them are different than in earlier successional stages.

The 1987 Forest Plan for the Kootenai National Forest (USDA Forest Service, 1987a) states, "With respect to wildlife (old growth) represents a distinct successional stage that is an important component of wildlife habitat" and also:

> Richness in habitat translates into richness in wildlife. Roughly 58 wildlife species on the Kootenai (about 20 percent of the total) find optimum breeding or feeding conditions in the "old" successional stage, while other species select old growth stands to meet specific needs (e.g., thermal cover). Of this total, five species are believed to have a strong preference for old growth and may even be dependent upon it for their long-term survival (see Appendix I[1]).

Hammond, 2020 states:

> The highest quality water, provided in adequate and manageable quantities throughout an annual cycle is produced by old/old-growth forests. The multi-layered, large canopies, canopy gaps, and accumulations of decayed fallen trees provide for effective, natural water management that benefits forest ecosystems and aquatic ecosystems, and provides for human needs and safety. In short, old-growth forests are Nature's water storage and filtration system.

Likewise, Reeves and Bisson, 2009 note, "many attributes of old-growth forests are important for maintaining healthy fish populations…"

Beyond the numerous species commonly referred to as "wildlife", old growth uniquely exhibits diversity of other life forms (*Id*.):

> Wildlife richness is only a part of the story. Floral species richness is also high, particularly for arboreal lichens, saprophytes, and various forms of fungus and rots. Old growth stands are genetic reservoirs for some of these species, the value of which has probably yet to be determined.

From their literature review, Tomao et al. (2020) conclude, "Old-growth forests are recognized as an important reserve of fungal diversity for several fungal functional guilds. Indeed, a very large number of ectomycorrhizal species can be hosted in old growth stands (Richard et al., 2004; Zhang et al., 2017)." They note:

> • Fungal diversity is positively related with canopy cover, basal area and tree species diversity.
> • Diversity of deadwood size and decomposition stage is positively related to richness of wood-inhabiting fungi.

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[1] The Kootenai National Forest's Forest Plan Appendix I wildlife species list is found in Appendix A of this report.

B. Old-growth ecosystems and old-growth landscapes

As discussed later in this report, Forest Service management policies have focused mainly on identifying, designating, inventorying and managing at the level of the old-growth "stand"[2] or patches consisting of multiple contiguous stands. Kaufmann et al. 2007 identify limitations of this approach: "The term 'stand' may be more useful for management purposes than for describing the ecology of forests." This report advocates for a more holistic idea of old growth—what Kaufmann et al. 2007 call "old-growth forests or landscapes" which:

> …contain sufficient numbers of patches and stands of old growth to be reasonably representative of the forest type in historical times. However, portions of the landscape may be in various stages of development (even temporary openings or patches of very young trees) to provide future old-growth patches in the landscape. Landscapes vary in size, but are generally considered to be at least as large as major natural disturbances, such as fire.

Accordingly, this report examines diversity beyond the stand level, as well as across longer scales in time. Franklin and Spies, 1991 recommend such a perspective:

> Our failure to study old-growth forests as ecosystems is increasingly serious in considerations of old-growth issues. Without adequate basic knowledge of the ecosystem, we risk losing track of its totality in our preoccupation with individual attributes or species. Definitional approaches to old growth based on attributes… predispose us to such myopia. The values and services represented by old-growth ecosystems will be placed at ever greater risk if we perpetuate our current ignorance about these ecosystems. It will also increase doubts about our ability to manage for either old-growth ecosystems or individual attributes (for example, species and structures) associated with old growth. We must increase ecosystem understanding and management emphasis on holistic perspectives as we plan for replacement of old-growth forests.

Green et al., 1992 (Old-Growth Forest Types of the Northern Region), while largely focusing on stand-level old-growth criteria, also acknowledges the need to look beyond:

> (A) stand's **landscape position** may be as important, or more important than any stand old growth attribute. …Stands are elements in **dynamic landscape**. We need to have representatives of the full range of natural variation, and **manage the landscape mosaic as a whole** in order to maintain a healthy and diverse systems. (Emphases added.)

Similarly, Hamilton, 1993 (Characteristics of Old-Growth Forests in the Intermountain Region) incorporates definitions of Landscape Ecology, Ecological Process and Ecosystem in describing old-growth definitions for the Intermountain Region.

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[2] Warren (1990) explains, "Timber stands are delineated on the basis of predominant overstory species, tree sizes, and tree density. Contiguous old-growth habitat may be composed of more than one stand."

C. Disturbance processes intrinsic to old growth ecosystems

Natural disturbance processes are inherent to forest ecosystems in the northern Rocky Mountains. The "Generic Definition and Description of Old Growth Forests" (USDA Forest Service, 1989b) notes, "Sporadic, low to moderate severity **disturbances are an integral part of the internal dynamics of many old growth ecosystems**. Canopy openings resulting from the death of overstory trees often give rise to patches of small trees, shrubs, and herbs in the understory." (Emphasis added.)

Hamilton, 1993 acknowledges that natural tree mortality is important for creating the very conditions that help define old growth:

> Tree deaths resulting in standing dead and down woody materials, plus some living trees with broken tops or rotting boles contribute to decadence, a necessary attribute of Old-growth. Decadent conditions in old-growth result in important snags, logs, and rotting trees that provide potential habitat for several species of birds and small mammals. Decadent conditions also indicate suitable habitat for certain plants which are not easily seen such as saprophytes and lichens which are not readily inventoried.

Franklin et al. 1987, state: "Tree death also demonstrates some principles of ecological processes: the importance of defining the spatial and temporal context of a study, the importance of stochastic processes, the fact that most ecological processes are driven by multiple mechanisms and that the relative importance of these mechanisms changes in time and space, and the importance of species' and ecosystems' natural histories."

Bollenbacher and Hahn, 2008 recognize that "(old-growth) stands, as well as various other forest conditions, have been influenced by landscape-level processes, such as fire (low-, mixed-, and high-severity), insect outbreaks, and disease. These processes result in a mosaic pattern of forest conditions across the landscape."

III. OLD GROWTH AND CLIMATE CHANGE

At least in terms of the modern climate crisis, perhaps the greatest benefit of old-growth forests is their ability to retain carbon.

— Marina Richie, *The Secret Power of Old Growth*

There is growing scientific concern over the imminent effects of climate change on the earth's ecosystems, as well as their implications for human civilization. The Intergovernmental Panel on Climate Change 2018 report states that if greenhouse gas emissions continue at the 2018 rate, the atmosphere will warm up by as much as 2.7 degrees Fahrenheit (1.5 degrees Celsius) above preindustrial levels by 2040, inundating coastlines and intensifying droughts, poverty, and strife. More recently, a 2021 report from the same panel amplifies the urgency to act.

A. Carbon sequestration and old-growth forests

Science recognizes the critical role forests, particularly old growth, play in sequestering carbon and thus moderating the effects of climate change. The vital role forests play as stores of sequestered carbon is recognized by Achat et al., 2015: "Compared with other terrestrial ecosystems, forests store some of the largest quantities of carbon per surface area of land." More specific to old growth, Mildrexler et al., 2020 state, "Large-diameter trees store disproportionally massive amounts of carbon and are a major driver of carbon cycle dynamics in forests worldwide." In a global perspective, "Given the urgency of keeping additional carbon out of the atmosphere and continuing carbon accumulation from the atmosphere to protect the climate system, it would be prudent to continue protecting ecosystems with large trees for their carbon stores, and also for their co-benefits of habitat for biodiversity, resilience to drought and fire, and microclimate buffering under future climate extremes." (*Id.*) Also, Lutz et al., 2018 (co-authored by dozens of scientists) "recommend managing forests for conservation of existing large-diameter trees or those that can soon reach large diameters as a simple way to conserve and potentially enhance ecosystem services" including carbon sequestration.

Thomas DeLuca, former Dean of the University of Montana's W.A. Franke College of Forestry & Conservation, discusses research that shows "if the objective of management is carbon storage, old-growth forests are better left standing." (DeLuca, 2009.) "Old growth, rather than being thought of as stagnant with respect to carbon fixation, can sequester atmospheric carbon dioxide long past the achievement of old-growth conditions." (*Id.*)

McKinley et al. 2011 state:

> [I]f the starting point is a mature forest with large carbon stocks (Cooper 1983, Harmon et al. 1990), then harvesting this forest and converting it to a young forest will reduce carbon stocks and result in a net increase in atmospheric [CO^2] for some time (Fig. 8B; Harmon and Marks 2002). Even if the mature forest is converted to a very productive young forest, it could take several harvest intervals to equal the amount of carbon that was stored in the mature forest, even with 100% utilization efficiency, biomass for energy and substitution (Harmon et al. 1990; Fig. 8A).

Even in cases where logging does not regenerate a stand, carbon emissions can be significant. A literature review by Law & Harmon (2011) concludes:

> Thinning forests to reduce potential carbon losses due to wildfire is in direct conflict with carbon sequestration goals, and, if implemented, would result in a net emission of CO_2 to the atmosphere because the amount of carbon removed to change fire behavior is often far larger than that saved by changing fire behavior, and more area has to be harvested than will ultimately burn over the period of effectiveness of the thinning treatment.

Such conclusions are confirmed in multiple studies such as Campbell et al., 2011, Mitchell et al., 2009, and Reinhardt and Holsinger, 2010.

B. Old-growth stands buffer climate change effects

The microclimatic effects in old-growth stands become of increasing importance as average forest temperatures rise. Frey et al., 2016 find: "Vegetation characteristics associated with older forest stands appeared to confer a strong, thermally insulating effect. Older forests with tall canopies, high biomass, and vertical complexity provided cooler microclimates compared with simplified stands. This resulted in differences as large as 2.5°C between plantation sites and old-growth sites, a temperature range equivalent to predicted global temperature increases over the next 50 years." They hypothesize older, more complex forests may help to "buffer organisms from the impacts of regional warming and/or slow the rate at which organisms must adapt to a changing climate…" Additionally, forest canopies can buffer climate extremes and promote microclimates that in turn provide refugia for species in the understory. (Davis et al. 2019b.)

C. Climate change affects old growth

Acute effects of higher annual temperatures include increased extent, frequency, and severity of wildfire. Similarly, warmer temperatures can foster outbreaks of tree-killing insects, whose populations were more balanced under historic climates. These effects potentially accelerate natural disturbance processes occurring within old growth, creating unknown impacts on its persistence.

As climate conditions change in particular areas, shifts in forest composition are likely. Funk et al., 2014 believe suitable conditions for four common tree species in this bioregion (Douglas-fir, ponderosa pine, lodgepole pine, and Engelmann spruce) could dramatically contract.

IV. OLD GROWTH AND U.S. FOREST SERVICE MANAGEMENT

Foresters trained in the twentieth century …were committed to bringing order to the forest and replacing the messiness of "decadent" older forests with manageable, fast-growing plantations of uniform trees. …The messiness of natural forests was to be ordered by forest regulation. Manipulation of both time and space was fundamental to bringing order to forests. Considerations of time involved measuring how much trees of a given species grow each year and calculating volume accumulation to predict harvestable age. Space was derived from time by calculating how much area of a forest should be harvested and regenerated each year to set a harvest level that would ensure a constant supply of wood.

-Robert G. Lee

Beginning in the 1980s, long-term land management plans for the national forests were written by the U.S. Forest Service, as required under the National Forest Management Act (NFMA). The passage of NFMA was largely in response to the increasing public controversies surrounding overexploitation and clearcutting of national forest lands.

Also in the 1980s, the concern over rare wildlife species brought increased public scrutiny to federal management of old-growth forests. Litigation from environmental groups and the listing of species under the Endangered Species Act (ESA) spurred changes in management of old-growth forests. Already old growth had been logged to a small fraction of what existed prior to EuroAmerican settlement, leading to the need "to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved." (Endangered Species Act of 1973.)

The highest profile controversy over old-growth forests arose in the federal forests of the Pacific Northwest, with its iconic ancient forests of giant trees such as redwood, Douglas-fir, western hemlock, Sitka spruce, and western redcedar. Increasingly, economic exploitation of the timber resource conflicted with other social values prizing natural forests, and the habitat values native forests provided for species such as the northern spotted owl. In granting an injunction against logging, U.S. District Court Judge William Dwyer called out "a deliberate and systematic refusal … by higher authorities in the executive branch of government … to comply with the laws protecting wildlife."

At that time, the first generation of land management plans ("forest plans") reflected changing public values and to the growing scarcity of old-growth forests. For the first time, explicit protections for some old growth on national forests were adopted.

A. The Forest Service and "Old Growth Values"

In 1989, in the midst of the controversy, Forest Service Chief Dale Robertson issued a "Position Statement on National Forest Old Growth Values" (Chief's Position Statement; USDA Forest Service, 1989a). The Chief's Position Statement began, "The Forest Service recognizes the many significant values associated with old growth forests, such as biological diversity, wildlife and fisheries habitat, recreation, aesthetics, soil productivity, water quality, and industrial raw material. Old growth on the National Forests will be managed to provide the foregoing values for present and future generations. …Where goals for providing old growth values are not compatible with timber harvesting, lands will be classified as unsuitable for timber production."

In the Chief's Position Statement the Forest Service recognized old growth holds a wide range of values beyond timber, and admitted that the agency's timber program fundamentally conflicts with those values. It also included measures national forest managers were to take to reflect this range of old growth values. The direction included:

- Old growth definitions are to be developed by forest type or type groups for use in determining the extent and distribution of old growth forests.

- Old growth values shall be considered in designing the dispersion of old growth. This may range from a network of old growth stands for wildlife habitat to designated areas for public visitation. In general, areas to be managed for old growth values are to be distributed over individual National Forests with attention given to minimizing the fragmentation of old growth into small isolated areas.

- Regions with support from Research shall continue to develop forest type old growth definitions, conduct old growth inventories, develop and implement silvicultural practices to maintain or establish desired old growth values, and explore the concept of ecosystem

> management on a landscape basis. Where appropriate, land management decisions are to maintain future options so the results from the foregoing efforts can be applied in subsequent decisions. Accordingly, field units are to be innovative in planning and carrying out their activities in managing old growth forests for their many significant values.

Green et al., 1992 and Hamilton, 1993 were prepared by the Northern and Intermountain Regions, respectively, in response the that first point. Green et al., 1992 states "…old growth is valuable for a whole host of resource reasons such as habitat for certain animal and plants, for aesthetics, for spiritual reasons, for environmental protection, for research purposes, for production of unique resources such as very large trees." And Hamilton, 1993 states, "Values for such items as wildlife, recreation, biological diversity, and juxtaposition of old-growth stands with other forest conditions need to be considered in relation to Forest land management planning objectives."

Spies, 2009 notes some **scientific values** of old growth:

> (i) providing controls for measuring the effects of human activities; (ii) shifting our focus to relatively long timeframes to help us understand how and why forests change; (iii) helping us identify the unique contributions of all forest stages to biological diversity and ecological processes; and (iv) opening our eyes to the importance of structural complexity in providing habitat for organisms and the foundation for ecological processes.

B. Management policies of northern Rocky Mountains bioregion national forests

By the late 1980s, most national forests in the U.S. northern Rocky Mountains bioregion had finalized their original forest plans. This section examines some of the ways those plans evaluated old growth.

<u>1. Definitions of old growth in forest plans</u>

Because of the relative novelty of old growth as a scientific concept, forest plans reflected a wide variety of old-growth definitions.

Some forest plans include measurable criteria, e.g., the Nez Perce National Forest (1987):

> Old-growth stand refers to a stand of timber that, generally, meets the following criteria:
> 1. At least 15 trees per acre ≥ 21 inches diameter at breast height (DBH). Providing trees of this size in the lodgepole pine and sub-alpine fir stands may not be possible.
> 2. Two or more canopy layers.
> 3. At least .5 snags per acre ≥ 21 inches DBH and at least 40 feet tall.
> 4. Signs of rot and decadence present.
> 5. Overstory canopy closure of 10-40 percent; understory canopy closure of at least 40 percent; total canopy closure at least 70 percent.
> 6. Logs on the ground.

Other forest plans described old growth with less specific terminology, e.g., the Kootenai National Forest (USDA Forest Service, 1987g):

> Several authors have described old growth conditions (Juday, 1978; McClelland, 1977; McClelland et al., 1979; Thomas, 1979) with certain features appearing to be universal. These features include: 1) large diameter trees (often exceeding 20" dbh) with a relatively dense, often multilayered canopy, 2) the presence of large standing dead or dying trees, 3) down dead trees 4) stand decadence associated with the presence of various fungi and heartrots, 5) an average age often in excess of 200 years, and 6) a basal area ranging from 150-400 square feet per acre. Some of the individual features listed above may occur in other successional stages, but old growth stands are unique in integrating all of these features in a complex and diverse whole.
>
> … Old growth stands are representative of a variety of characteristics and it is not possible to define them with a "minimum number" for any one characteristic.

Other forest plan terminology reflected a bias toward the timber value, e.g., the Salmon National Forest (1988):

> Old Growth - A stand of trees that is past full maturity and showing decadence; the last stage in forest succession.
> Old Growth Habitat - Habitat for certain wildlife that is characterized by overmature coniferous forest stands with large snags and decaying logs.
> Overmature Timber - Trees that have attained full development, particularly in height, and are declining in vigor, health, and soundness.

And from the forest plan for the Lolo National Forest (1986): "Old-growth Timber: Individual trees or stands of trees that in general are past their maximum rate in terms of the physiological processes expressed as height, diameter and volume growth."

Yanishevsky (1987), likely the earliest comprehensive critique of old growth considerations in forest plans of the Northern Region, warned "at best, planners are managing for marginally viable populations of old-growth species." Yanishevsky (1987) states:

> With the warning that old age alone is not a sufficient criterion for old growth, researcher Dr. Riley McClelland from the University of Montana has stated that if a single age must be chosen, it at least ought to be set realistically at 200 years. At 200 years, larch/Douglas-fir forests …are just *beginning* to show many of the values associated with old growth habitat. Moreover, there are distinctly valuable ecological characteristics in much older stands. Stands with these older components are also needed to preserve natural diversity.
>
> We found that no forest in Region One used an acceptable minimum of 200 years for estimating current amounts of old growth. Minimum ages range from 100 years …to 160 years… Most forests used a minimum age of only 120 years.

> Setting an unrealistically early age for old growth grossly overestimates the amount of old growth, present and planned, in Region One forests. Using even a realistic age as the *only* criterion has limitations. On-the-ground evaluation of ecological characteristics is essential.

2. Regional old-growth definitions

Not long after forest plans were finalized in the northern Rocky Mountains bioregion the Chief's Position Statement (USDA Forest Service, 1989a) issued a policy directing regional offices to set more consistent old-growth definitions and adopted a "Draft Action Plan" for a Forest Service Old Growth Task Group (USDA Forest Service, 1989c). The number one item for the Task Group was to "Develop a generic definition of ecological old growth. It will identify characteristics for which **measurable criteria** would be established in more specific **definitions for forest types, habitat types, or plant associations**; and would help guide the design of **new inventories** that will include the **measurement of old growth attributes**." (Emphases added.) Green et al., 1992 ("Old-Growth Forest Types of the Northern Region") and Hamilton, 1993 ("Characteristics of Old-Growth Forests in the Intermountain Region") were a direct result of those regional efforts.

Green et al., 1992 admits: "Although old growth ecosystems may be distinguished functionally as well as structurally, this definition is restricted primarily to stand-level structural features which are readily measured in forest inventory." Also, "These old growth minimum criteria, associated characteristics, and descriptions were developed to apply to individual stands." (Id.)

Franklin and Spies, 1991 explain a rationale for writing definitions mainly emphasizing structural considerations within **old-growth stands**:

> Obviously, a series of ecological attributes must be considered because of the many relevant compositional, functional, and structural features. For practical reasons, however, a working definition—one for everyday use in gathering stand data—emphasizes structural and compositional rather than the conceptually important functional features that are difficult to measure.

What followed was a focus on stand-level attributes, measurable from this "practical" perspective. Green et al., 1992 and Hamilton, 1993 set screening criteria for old-growth stands, both establishing a minimum number per acre of old and large trees, varying by "forest type" and geographic area. In other words, the minimum number per acre of trees of sufficient age and diameter vary by forest type and geographic area. For example, for the "Northern Idaho Zone" (Green et al., 1992), in stands meet screening criteria for old growth for one habitat type there must be a minimum of eight trees per acre at least 150 years old and over 21 inches diameter at breast height (DBH), with Douglas-fir, ponderosa pine, or western larch being the tree species counted. For stands in another habitat type, the corresponding numbers are ten trees, 120 years old and 13" DBH of lodgepole pine. And for a third, requirements are ten trees, 120 years old, and 25" DBH of western redcedar, respectively.

This variability was later explained by Hammond, 2020:

> (O)ld-growth attributes will look different in areas of different site productivity and climate, and are influenced by the type, frequency, and distribution of natural disturbance regimes. In other words, the attributes of old-growth forests are manifested in a range of tree ages, sizes, shapes, and distribution, along with accompanying non-tree vegetation. These different old-growth composition and structures in turn shape different habitat types in different old-growth areas. …Old-growth forests that develop in landscapes where stand replacing natural disturbances are infrequent, or do not occur tend to be characterized by larger older trees than old-growth forests found in landscapes where stand replacing disturbances are common.

Green et al., 1992 includes "associated characteristics (such as number of snags, down woody material, dead tops and decay, and diameter variation)" which were to be evaluated but not treated as minimum old-growth criteria. Hamilton, 1993 includes similar discretionary considerations.

In sum, the effect of Regional definitions was intended mostly to clarify how the national forests are to identify **old-growth stands**. They did not mandate Forest Service managers to embrace wider old-growth values nor recognize old-growth landscapes or old-growth ecosystems. They mostly fine-tuned the process whereby structural criteria were used to identify old-growth stands.

The Regional definitions were not developed under the planning process governed by NFMA regulations. Appendix B examines the relationship between the Northern Region's Green et al., 1992 and forest planning.

Yanishevsky, 1994 expressed concerns regarding the Green et al., 1992 definitions for old growth: "Quality of old growth was not addressed during the definition process. The Committee did not take into account the legacy of logging that has already destroyed much of the best old growth. This approach skewed the characteristics that describe old-growth forests toward poorer remaining examples."

3. The necessity of setting aside old growth from logging

Most of the 1980s-era forest plans for northern Rocky Mountains national forests included requirements for maintaining minimum forestwide amounts of old growth, minimum amounts over smaller geographic areas such as watersheds, or both (*e.g., see* Juel, 2003 for standards in national forests of the Northern Region). Also, some forest plans include requirements to identify areas of forest nearly meeting or approximating minimum old-growth criteria, to be applied where forest plan minimums for smaller geographic areas are not being met. Forest plan requirements to identify these stands—referred to, variously as "recruitment", "step-down" or "replacement" old growth—respond to habitat distribution requirements found in the National Forest Management Act (NFMA) implementing regulations.

Those forest plans implicitly or explicitly distinguished between old growth that was not to be logged (in order to manage within minimum standards) vs. old growth in excess of minimum requirements, which could be logged. For example, the Final Environmental Impact Statement for the Kootenai National Forest's original 1987 forest plan noted, "The suitable timber base will be smaller as a result of the removal from timber harvest of additional acres for old-growth timber management for wildlife diversity…" (USDA Forest Service, 1987h) Also, it noted the forest plan "…designated 126,000 acres of old-growth timber as unsuitable timberland. These stands were high volume-per-acre stands which, when removed, reduced the inventory and the resulting inventory per acre." (*Id*.) That Forest Plan defined "unsuitable timber land" in part as: "not selected for timber production …due to: (1) the multiple-use objectives for the alternative preclude timber production, (2) other management objectives for the alternative limit timber production activities to the point where management requirements set forth in 36 CFR 219.27 cannot be met…" (USDA Forest Service, 1987g.)

This "unsuitable timber land" included a forest plan designated Management Area for old growth. Outside that Management Area, the plan allowed logging of old growth as long as minimums within the old growth analysis areas were being met.

The 1988 Forest Plan for the Salmon National Forest allows "no harvest in identified and mapped old growth stands" in one management area within the suitable timber base. The FEIS for the forest plan also recognizes the incompatibility of old growth with timber management:

> The old growth component of habitat diversity is probably the most sensitive component of Forest management activities. **Old growth is essentially a decadent stand of trees, and old growth management is an undesirable goal for timber management. When timber rotation ages are less than the length of time needed to produce old growth, a conflict results**. A downward trend of old growth on suitable acres will occur under all alternatives. Consequently, 10 percent of the suitable acres have been removed from the timber base, by specie type, to ensure maintenance of habitat for minimum viable populations of old growth obligate species. (Emphasis added.)

Also, recall that the Chief's Position Statement directed, "Where goals for providing old growth values are not compatible with timber harvesting, lands will be classified as unsuitable for timber production." (USDA Forest Service, 1989a.)

4. Stand size criteria

Aside from the features to be assessed within stands, managers considered spatial dimensions of the patches of old growth. Such considerations are often based upon habitat needs of species associated with old growth. For example, the Forest Service's Warren (1990) notes, "Of 48 old-growth-associated species occurring in the Northern Region, about 60 percent are thought to require stands larger than 80 acres (Harger 1978)" and "Wilcove et al. (1986) estimated that habitat islands should exceed 250 acres to provide for birds inhabiting forest interior."

Appendix 17 of the 1987 forest plan for the Kootenai National Forest (USDA Forest Service 1987a) exemplifies the relationship of species habitat needs and old growth:

> A unit of 1000 acres would probably meet the needs of all old growth related species (Munther, et al., 1978) but does not represent a realistic size unit in conjunction with most other forest management activities. On the other hand, units of 50-100 acres are the

> smallest acceptable size in view of the nesting needs of pileated woodpeckers, a primary cavity excavator and an old growth related species (McClelland, 1979). However, managing for a minimum size of 50 acres will preclude the existence of species which have larger territory requirements. In fact, Munther, et al. (1978), report that units of 80 acres will meet the needs of only about 79 percent of the old growth dependent species (see Figure 1). Therefore, while units of a minimum of 50 acres may be acceptable in some circumstances, <u>50 acres should be the exception rather than the rule</u>. Efforts should be made to provide old growth habitat in blocks of 100 acres or larger. …Isolated blocks of old growth which are less than 50 acres and surrounded by young stands contribute very little to the long-term maintenance of most old growth dependent species.

Kootenai National Forest biologist Johnson, 1999 acknowledges, "Patch size also plays a role in habitat suitability. Small patches of old growth may not be usable, depending on surrounding forest conditions." The implication is that modeled population potential for old-growth associated species could be underestimated to an unknown extent because modeling may not quantify the lesser habitat value of smaller patches.

One of the old-growth standards in the Idaho Panhandle National Forests' original Forest Plan (USDA Forest Service, 1987c) was derived from scientific recommendations found in its Appendix 27 (USDA Forest Service, 1987d), in consideration of the habitat needs of the pileated woodpecker, a forest plan management indicator species. That standard read:

> One or more old-growth stands per old-growth unit should be 300 acres or larger. Preference should be given to a contiguous stand; however, the stand may be subdivided into stands of 100 acres or larger if the stands are within one mile. The remaining old-growth management stands should be at least 25 acres in size. Preferred size is 80 plus acres.

Similarly, the 1988 Forest Plan for the Colville National Forest contained standards for specific old-growth management indicator species, which set minimum stand sizes along with spatial configuration and structural considerations for the pine marten, pileated woodpecker, and northern three-toed woodpecker. (USDA Forest Service, 1988a.)

Finally, although the Regional definitions recommended larger stand sizes, they did not mandate minimums nor even a consideration of their biological rationale.

<u>5. Forestwide minimum percentages of old growth</u>

As mentioned above, 1980s forest plans for the Northern Rocky Mountains usually included requirements for maintaining minimum forestwide amounts or minimum amounts within smaller geographic areas. At most these minimums were 10%. The Forest Service assumed that maintaining forest plan minimums would accomplish the task of meeting NFMA requirements for species population viability, as discussed below, all the while the national forests were being managed for high rates of timber production. Yet no scientifically adequate rationale is presented to support the forest plan minimum requirements.

One might assume these minimums resemble estimates of historic amounts in this bioregion prior to EuroAmerican exploitation, so that maintaining such amounts would prevent wildlife populations from vanishing from any national forest, or require listing under the ESA. But such estimates are not reliable, because so much forest had been logged long before adoption of old-growth definitions. This is explained in a Forest Service response to a comment about lack of data on presettlement amounts of old growth (USDA Forest Service, 2019c):

> Regarding the historic range of variability of old growth in the analysis area, **there is no way to accurately determine how much of the Forest may have met the Green definitions of old growth (Green et al., 1992**). To determine whether a forest stand meets those definitions, it requires detailed information on how many trees per acre exist in the stand over a certain diameter and age, the total stand density, the forest type and lastly, the habitat type group that the stand occupies. **No historical information exists that can provide that level of detail.** Therefore, a numeric desired condition or an HRV estimate for old growth is not included in this analysis. (Emphases added.)

Similarly, the Northern Region's Bollenbacher and Hahn, 2008g state, "actual estimates for the amount of OG are constrained by the limited field inventory data collected before the 1930s, and inconsistent—or absent—OG definitions."

Following his research, Lesica (1996) suggested reliance on 10% as minimum old-growth standard could result in extirpation of some species. He estimated that 20-50% of low and many mid-elevation forests were in old-growth condition prior to European settlement.

Further, analysis by the Kootenai National Forest's Gautreaux (1999) indicates 22% old growth is near the bottom of "reference conditions" on that national forest. Gautreaux, 1999 estimates include:

- (R)esearch in Idaho (Lesica 1995) of stands in Fire Group 4, estimated that over 37% of the dry Douglas-fir type was in an old growth structural stage (>200 years) prior to European settlement, approximately the mid 1800's.

- Based on research of Fire Group 6 in northwest Montana (Lesica 1995) it was estimated that 34% of the moist Douglas-fir type was in an old growth structural stage (>200 yrs.) prior to European settlement, approximately the mid 1800's.

- Based on fire history research in Fire Group 11 for northern Idaho and western Montana (Lesica, 1995) it was estimated that an average of 26% of the grand fir, cedar, and hemlock cover types were in an old growth structural stage prior to European settlement.

- (F)ire history research in Fire Group 9 for northern Idaho and western Montana (Lesica, 1995) estimated that 19-37% of the moist lower subalpine cover types were in an old growth structural stage (trees > 200 yrs.) prior to European settlement. While this estimate is lower than suggested by Losensky's research, it is a useful representation of average conditions that may be fairly typical for the Kootenai. Lesica's estimate of historic vegetative conditions is also closer to the findings in the ICBEMP assessment that estimated 20-30% levels for historic distributions of mature and late seral forest in moist forests.

- Lesica found an estimated 18% of the cool lodgepole pine sites was in an old growth structural stage (>200 years) prior to European settlement, approximately the mid 1800's. … This same research in Fire Group 8 in drier, lower subalpine types of Montana had over 25% of the stands in an old growth structural stage during the same historical period.

Deciding how much old growth should be preserved on any given landscape and thus included in forest plan direction is partially a question of values—specifically, those beyond timber ("biological diversity, wildlife and fisheries habitat, recreation, aesthetics, soil productivity, water quality") as per the Chief's Position Statement. Thomas et al., 1988 emphasized values pertaining to wildlife and diversity from a context of laws and regulations. In recognizing that meaningful implementation of regulatory requirements must include a simultaneous awareness of the limits of scientific knowledge, they advocate **for preserving all that remains**:

> The lack of quantitative information about functional attributes of old growth and habitat associations of potentially dependent plants and animals and the rapidly declining old-growth resource indicates that purposely conservative management plans should be developed and adopted. Our knowledge and understanding of old-growth communities is not adequate to support management of remaining old growth on criteria that provide *minimum* habitat areas to sustain *minimum* viable populations of one or several species. The potential consequences and the distinct probability of being wrong are too great to make such strategies defensible in the ecological sense.
>
> …The answer to— "How much?"—must be predicated on the relatively small amount of unevenly distributed remaining old growth and the current, inconclusive scientific knowledge of old-growth ecosystems. Therefore, the best probability of success is to preserve all remaining old growth and, if possible, produce more.

V. OLD GROWTH AND THE REGULATORY SETTING

Fish and wildlife habitat shall be managed to maintain viable populations of existing native and desired non-native vertebrate species in the planning area. For planning purposes, a viable population shall be regarded as one which has the estimated numbers and distribution of reproductive individuals to insure its continued existence is well distributed in the planning area. In order to insure that viable populations will be maintained, habitat must be provided to support, at least, a minimum number of reproductive individuals and that habitat must be well distributed so that those individuals can interact with others in the planning area.

— National Forest Management Act planning regulations, 1982

A. Viability as a Forest Service methodology for conserving diversity

The National Forest Management Act (NFMA) requires the Forest Service to "provide for diversity of plant and animal communities based on the suitability and capability of the specific land area in order to meet overall multiple-use objectives…" In complying with this diversity mandate, the 1982 NFMA regulations included the viability requirement stated above. Thus, those regulations required forest plans to acknowledge the strong association between many wildlife species and their reliance on a set of habitat conditions forest plans later defined as old growth—habitat which had already been heavily depleted.

The 1982 NFMA regulations also required: "(C)ertain vertebrate and/or invertebrate species present in the area shall be identified and selected as management indicator species and the reasons for their selection will be stated." The rationale was, "These species shall be selected because their population changes are believed to indicate the effects of management activities." (*Id*.) Juel, 2003 includes a list of management indicator species adopted by the original forest plans of Northern Region national forests.

Viability claims under NFMA were the basis of the original successful litigation efforts concerning the northern spotted owl in the federal forestlands of the Pacific Northwest.

The 1987 Forest Plan for the Clearwater National Forest states that old growth "is vital to the perpetuation of old-growth dependent species of wildlife." (USDA Forest Service, 1987f.) In other words—vital for maintaining viability.

Similarly Appendix 27 of the 1987 Forest Plan for the Idaho Panhandle National Forests (USDA Forest Service, 1987d) states, "Drastic reduction in quantity of old growth not only reduces diversity, but it also makes old-growth dependent wildlife vulnerable to significantly reduced populations, extirpation, or even extinction."

And as stated in Green et al., 1992: "Old growth dependent and associated species are provided for by supplying the full range of the diversity of late seral and climax forest community types that make up habitat for these species."

Another provision of the 1982 NFMA regulations required: "Population trends of the management indicator species will be monitored and relationships to habitat changes determined." Thus, the regulations created a feedback mechanism for managers to check if management actions implemented under the forest plan were harming wildlife populations to the extent that forest plan standards needed strengthening to maintain viable populations.

The Committee of Scientists (1999) believe it is vital to "monitor those species whose status allows inference to the status of other species, are indicative of the soundness of key ecological processes, or provide insights to the integrity of the overall ecosystem."

The idea that population trends of management indicator species (MIS) could serve as a proxy for ensuring viability of all wildlife enjoys much scientific support (Committee of Scientists, 1999). It assumes that persistence of MIS populations within the context of managed landscapes would be a reasonable feedback mechanism, given that monitoring populations of all old-growth associated species is impractical.

However, management incentives to actually monitor population trends of MIS pale in comparison to those for exploiting resources in their habitat. Congress bears much of the responsibility for this situation, consistently failing to appropriate sufficient funds for fully implementing forest plan monitoring programs. In evaluating forest plans, Yanishevsky, 1994 noted, “In many cases monitoring is reliant on inadequate funding. This makes even the best intentions meaningless.” At best, the Forest Service has gathered spotty data on population trends of management indicator species in this bioregion.

Committee of Scientists member and Nobel Laureate Roger A. Sedjo, (1999) explains his perspective on the problem:

> The major problem is that there are essentially two independent planning processes occurring simultaneously: one involving the creation of individual forest plans and a second that involves congressionally authorized appropriations for the Forest Service. Congressional funding for the Forest Service is on the basis of programs, rather than plans, which bear little or no relation to the forest plans generated by the planning process. There is little evidence that forest plans have been seriously considered in recent years when the budget is being formulated. Also, the total budget appropriated by the Congress is typically less than what is required to finance forest plans. Furthermore, the Forest Service is limited in its ability to reallocate funds within the budget to activities not specifically designated. Thus, the budget process commonly provides fewer resources than anticipated by the forest plan and often also negates the “balance” across activities that have carefully been crafted into forest plans. Balance is a requisite part of any meaningful plan. Finally, as noted by the GAO Report (1997), fundamental problems abound in the implementation of the planning process as an effective decision making instrument. Plans without corresponding budgets cannot be implemented. Thus forest plans are poorly and weakly implemented at best. Major reforms need to be implemented to coordinate and unify the budget process.

B. Shortcutting scientific assurance of wildlife viability

Lacking robust population trend data on management indicator species, which is the science-based substitute, or proxy, for ensuring wildlife viability under NFMA, managers chose to substitute more simplistic, less scientifically robust measures of viability. Estimating the remaining amount of old-growth habitat has been used as a secondary proxy for the population trend proxy. The 1988 Forest Plan for the Colville National Forest (USDA Forest Service, 1988a) included a commitment and intent to “Inventory … old growth forests…” and use the “old growth inventory” as a suggested method of meeting Forest Plan wildlife monitoring requirement[3]. This assumes that maintaining enough old growth to meet forest plan/forestwide minimums would adequately substitute for MIS population trend data, for the purpose of assuring viable wildlife populations. There is a lack of scientific support for this proxy-on-proxy approach. Schultz, 2010 criticizes wildlife analyses based primarily upon habitat availability, because habitat alone is insufficient for understanding the status of populations. (See also Noon et al., 2003; Committee of Scientists, 1999.) The use of the proxy-on-proxy approach glosses over many nuances of the habitat needs of native species. It also places too much faith in forest

[3] At the time the Colville forest plan was replaced upon revision in 2019, the Forest Service had not come close to completing the forestwide old-growth inventory promised in the original Plan. *See* West, 2011.

plan minimums—having been adopted without scientific validation, as discussed above. The "Complex ecological relationships, involving many wildlife species and other organisms, …evolved within old-growth forests" (Thomas, et al., 1988) are essentially ignored in substituting minimum habitat requirements for population trend monitoring.

A simplistic habitat proxy ignores that spatial distribution and connectivity of wildlife habitat across a national forest affects population persistence. It omits spatial and temporal considerations across old-growth landscapes. It also ignores the diversity of "old-growth types" dispersed across the different forest types found in a given national forest—a major outcome of the Regional definition process. Additionally, this proxy-on-proxy ignores many of the human artifacts of management that degrade habitat quality and thus profoundly affect wildlife populations. These include edge effects and habitat fragmentation (Hargis et al., 1999; Harris, 1984; Lehmkuhl et al., 1991; Moriarty et al., 2011; Potvin et al., 2000; USDA Forest Service, 2004a; Warren, 1990; Webb and Boyce 2009; Yanishevsky, 1987). The habitat proxy also ignores many indirect impacts of roads—such factors as noise disturbance (Heinemeyer and Jones, 1994), population pressures on old growth associated wildlife due to facilitation of trapper access (Carroll, et al., 2000; Heinemeyer and Jones, 1994; Jones (undated); Wisdom et al., 2000; Witmer et al., 1998), and loss the of dead tree component from public firewood cutting (Warren, 1990; USDA Forest Service, 2004a).

On occasion, federal courts have allowed the Forest Service to rely on the habitat proxy as evidence of maintaining population viability. Yet Forest Service managers have still struggled to meet forestwide minimums. In the 1990s and early 2000s, at least four national forests in this bioregion—Clearwater, Boise, Kootenai, and Idaho Panhandle—could not satisfy federal courts in this regard.

At times the Forest Service uses questionable methodology to claim it meets a forest plan minimum forestwide old growth requirement. The Nez Perce National Forest Plan requires the Forest Service to "Inventory, Survey and Delineate" old-growth habitat by 1990. (USDA Forest Service, 1987e.) Over thirty years post-deadline, the Forest Service still cannot produce a reliable forestwide old-growth inventory for the Nez Perce National Forest. In the case of this national forest, the Forest Service relies upon Forest Inventory and Analysis (FIA) data to claim it is meeting its forestwide 10% minimum. From a recent environmental impact statement[4]: "The most recent Forest Inventory and Analysis (FIA) data (Bush et al. 2010) indicate that ...approximately 13.6 percent of the Nez Perce National Forest meets the Forest Plan definition of old growth… . Based on this information, the Nez Perce National Forest is above the Forest Plan minimum standard of 10 percent old growth forest-wide."

But this FIA methodology faces insurmountable barriers to calculating old growth at the landscape level. For one, it does not verify the size of old-growth stands in consideration of wildlife habitat needs. In discussing such methodology, a Northern Region report (Bollenbacher, et al., 2009) states, "All northern Idaho plots utilized a primary sample unit (PSU) composed of four fixed radius plots with trees 5 – 20.9 inches tallied on a 1/24th acre plot and trees 21.0 inches DBH and larger tallied on a ¼ acre plot." And the Forest Service's Czaplewski, 2004 states, "Each FIA sample location is currently a cluster of field sub-plots that collectively cover

[4] Hungry Ridge Restoration Project Final Environmental Impact Statement, November 2019

an area that is nominally one acre in size and FIA measures a probability sub-sample of trees at each sub-plot within this cluster."

Sample design for FIA plots is semi-systematic; a sample taken randomly within a systematically placed grid. As stated above, at most each plot samples a maximum of one acre—far smaller than an old-growth stand—and so resulting estimates cannot determine the capability to meet biological needs of the associated wildlife.

Moreover, the location of plots is confidential, and for good reason. Managers are not allowed to know the location of FIA plots, to prevent selective management at plot locations which could skew the FIA data. As a result, conclusions such as the forestwide old-growth percentage claimed by the Nez Perce National Forest cannot be verified by independent investigators. This thwarts independent peer review—a hallmark of the scientific method.

FIA statistics have no correspondence to forest plan minimum old-growth stand sizes, nor to the spatial habitat needs of wildlife species. No mapping of existing old growth is possible using FIA data because the specific location of old-growth stands is not derived from FIA data. Therefore, there can be no scientific study to determine correlation of FIA estimates with estimates based on actual, publicly available data gathered in the forest using forest plan or other old-growth definitions.

The Forest Service does not use the FIA in all analyses on all national forests in the study bioregion. But the use of even a robust, reliable database or other inventory must be supportable by scientific validation, which means results can be replicated. To this author's knowledge, such research does not exist.

C. Removing the viability requirement altogether

For any regulatory structure to be effective, accountability to and empowerment of the public must be built into the equation. Flournoy et al., 2005 discuss how this has played out regarding viability:

> The …requirement that the Forest Service obtain data sufficient to analyze population trends of indicator species and their relationship to habitat changes caused by management activities in the National Forests has been a benchmark against which the public has been able to track the agency's performance. Numerous lawsuits brought by parties tracking Forest Service compliance with that requirement have resulted in judicial invalidation of harmful site-specific projects.

Following those litigation successes, the all-too predictable response of the federal government ultimately led to viability requirements being weakened to the extent that they are virtually unenforceable and/or nonexistent. In commenting on an earlier version of a replacement for the 1982 NFMA Regulations, Flournoy et al., 2005 identify this shift in power as reducing the role of science:

> Given that the Forest Service has freed itself from such scientific constraints as the need to: …ensure species viability through monitoring population data; and …monitor progress toward anything but self-established and broadly stated objectives, it is apparent that the 2004 forest planning rule significantly diminishes the overall role of science in planning.

After multiple attempts, when the NFMA Regulations were finally replaced in 2012 the new 36 CFR § 219.9 at (b)(1) made assurance of viability altogether discretionary. And at (b)(2) the discretion was further watered into merely suggesting "plan components, including standards or guidelines, to maintain or restore ecological conditions within the plan area to *contribute to* maintaining a viable population of the species within its range." (Emphasis added.)

VI. THE FINAL DEVOLUTION OF MANAGEMENT: TARGETING OLD GROWTH FOR LOGGING

(I)t is built into the agency culture that they must always find a way to log trees and that, in turn, feeds back on the science that is cited or requested by the agency. There is a complete lack of objectivity and independence.

—DellaSala and Baker, 2020

Prioritizing non-timber old-growth values constrains exploitation of old growth for timber, and to an extent even hinders the logging of potential future old growth. Since preserving old growth is the antithesis of management and is therefore a natural enemy to the Forest Service—as the old saying goes—truth is the first casualty of war.

A. National Forests and politics

The legacy of overcutting public forests resulted in litigation that reduced public land logging in the 1990s and early 2000s. But the Forest Service, a bureaucracy of the administrative branch of government, is very much a political animal. So in attempting to pacify growing public distaste for logging of national forests while appeasing political pressure and financial interests, managers have concocted layers of rationale attributing ecological benefits to logging.

Steel, 2009 notes "special interests and symbolic politics, a powerful combination that has proven its worth in muddying the waters of public knowledge and stopping intelligent progress in the thoughtful management" of old growth.

In order to muddy the waters, the Forest Service purposefully conflates tree farming techniques—known to grow wood more quickly for harvest on tree farms—with ecological benefits. Ecological damage is justified with a promise of healthier trees—a classic case of missing the forest for the trees. Terminology such as "improving forest health" and "increasing resilience and resistance to wildfire and insect pests" are ubiquitous in timber sale environmental analyses and in public relations campaigns by land management agencies and industry representatives. Yet the results bear much resemblance to the unsustainable logging of the past[5], with no scientifically proven ecological benefits for forests, including old growth.

[5] See, e.g. "The Clearcut Kings: The US Forest Service Northern Region and its obsession with

Under this politically inspired misinformation campaign, logging proponents demonize "unhealthy" forests to justify management "prescriptions." One finds such language in every timber sale NEPA document[6] prepared by the Forest Service.

One campaign tool is fire. The fear incited by raising the specter of imminent destruction to property and forests distracts from a sober evaluation of any science that might question the application of logging as the solution. Kerr, 2009 notes the "timber industry …exploiting the public's unbounded ignorance of wildfire. The public loves old trees, scenic forests, healthy watersheds, and roadless areas. The public does not love burned forests. Yet."

The federal government, in its "Smokey Bear" role (*Id*.) helps facilitate this charade, with administrative policies such as the 2002 Healthy Forest Initiative (HFI) "to improve regulatory processes to ensure more timely decisions, greater efficiency, and better results in reducing the risk of catastrophic wildland fires." This led to Congress passing the 2003 Healthy Forest Restoration Act (HFRA) to:

> …conduct hazardous fuel reduction projects (fuel projects) on specified types of Federal lands, including on certain lands that contain threatened and endangered species habitat. Directs the Secretary concerned to fully maintain, or contribute toward the restoration of, the structure and composition of old growth stands according to the pre-fire suppression old growth conditions characteristic of the forest type, taking into account the contribution of the stand to landscape fire adaptation and watershed health, and retaining the large trees contributing to old growth structure.

An explicit goal of these programs is to reduce occurrences and severity of wildland fire. This disregards the fact that the ecosystems of this bioregion evolved with fire at all severities. It also ignores the fact that many wildlife and other organisms actually depend upon fire to create their favored habitat conditions. (Hutto 1995, 2006, 2008, Hutto et al. 2016, Saab and Dudley 1998). Even high-severity fire is ecologically important. (Bond et al. 2012.) Snag forest habitat "is one of the most ecologically important and biodiverse forest habitat types in western U.S. conifer forests (Lindenmayer and Franklin 2002, Noss et al. 2006, Hutto 2008)." (Hanson 2010.)

Tingley et al., 2016 note the diversity of habitats following a fire is related to the diversity of burn severities: "…within the decade following fire, different burn severities represent unique habitats whose bird communities show differentiation over time… Snags are also critical resources for many bird species after fire. Increasing densities of many bird species after fire—primarily wood excavators, aerial insectivores, and secondary cavity nesters—can be directly tied to snag densities…"

In claiming to avert so-called catastrophes, both the HFI and HFRA shortcut the public review and environmental assessment processes required by NEPA and other laws. And what of the old

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supersized clearcuts" (Bilodeau and Juel, 2021), which documents an increase in size and extent of clearcuts in recent years.

[6] The National Environmental Policy Act (NEPA)—requires the Forest Service to analyze the environmental impacts of timber sales in the context of public involvement.

growth the HFRA mentions? The Forest Service focuses on the clause, "contribute toward the restoration of, the structure and composition of old growth stands **according to the pre-fire suppression old growth conditions characteristic of the forest type**…" (Emphasis added.) The emphasis on re-creating historical conditions is not limited to old-growth forests. Old growth is merely a subset of the larger target of exploitation—forests. But before discussing how a distortion of science has been used to promote logging all across forest ecosystems, this report examines how seeking so-called "healthy forests" thwarts the natural processes that create habitat for old-growth associated wildlife. Likewise, vilification of "unhealthy forests" demonizes old growth itself.

B. Disqualifying old growth

Proponents of the tree farming, manipulate-and-control management paradigm portray natural agents of tree mortality as a sign of ecological dysfunction. In old-growth stands, mortality of large trees may disqualify them from old-growth status because the number of live, old trees may decline below a set minimum. In many cases the Forest Service subsequently conducts aggressive "salvage" timber sales in such stands.

Several natural events potentially disqualify old growth from minimum criteria. A fire may be the agent of tree mortality. It could be native insects or fungi. A windstorm could blow down some of the large, old live trees. It doesn't matter if the event is natural and fully expected of old-growth ecosystems; and it is irrelevant if the rest of the structural components of this "former" old-growth stand continue to provide habitat diversity and therefore serve old-growth associated wildlife species. When a stand no longer meets the minimum numerical criteria, often no other forest plan protection remains to constrain logging. (E.g., USDA Forest Service 2017e, USDA Forest Service, 2016b, USDA Forest Service, 1999a).

Large trees die and are transformed into snags pocked with nesting or denning cavities. They eventually topple to form structures providing cover from predators. They finally become incorporated into forest soil—providing water-holding capacity and soil nutrients as they rot, potentially sequestering carbon for centuries. Such events are natural and expected of old-growth forests—and in fact vital for the cycle of life. But when these events cause a stand to fall below minimum live tree requirements, forest plan old growth protections are removed.

C. Biased diagnoses and false cures

Fire, insects, and tree diseases are vital natural processes comprising the ecosystems within which old growth develops. They create essential and vital habitat conditions for wildlife. Yet today, forestry practiced on national forests is promoted as minimizing the effects of fire, insects and tree diseases. In other words, it is thinly veiled tree farming.

The Forest Service brazenly asserts that national forests across the western U.S. are greatly suffering from exclusion of fire, to justify "treatments" necessary to "restore" forests. Such claims are made in the absence of representative data on historic forest conditions, as discussed in the next section.

Further, since enlightened fire suppression policies are not possible when the Forest Service stokes the terror of fire, the agency's manipulate-and-control paradigm must forever dominate. Odion and DellaSala, 2011 describe this situation as untenable: "…fire suppression continues unabated, creating a self-reinforcing relationship with fuel treatments which are done in the name of fire suppression. Self-reinforcing relationships create runaway processes and federal funding to stop wildfires now amounts to billions of tax dollars each year." Such a management paradigm implicitly or explicitly denies the fact that forest ecosystems have evolved under highly varying climate conditions and disturbances over the millennia and therefore can be expected to exhibit a wide range of conditions and evolutionary recovery mechanisms which truly embody the notion of "resilience."

Insects are also scapegoated as a scourge to forests. Again, this is ecologically absurd. Black, 2005 states:

> Insects, including those that feed on and sometimes kill trees, are integral components of healthy forest ecosystems. They help decompose and recycle nutrients, build soils, maintain genetic diversity within tree species, generate snags and down logs that wildlife and fish rely on, and provide food for birds and small mammals. (Id.)

And Rhoades et al. (2012), state, "…researchers are …finding that beetles may impart a characteristic critically lacking in many pine forests today: structural complexity and species diversity."

In playing the fire card, the Forest Service often claims that trees killed by fire or disease would lead to more severe fires. However DellaSala (undated) summarizes results from dozens of recent field studies from multiple regions and forest types on effects of mountain pine beetle tree kill on fire severity. He states, "There is now substantial field-based evidence showing that beetle outbreaks do not contribute to severe fires nor do outbreak areas burn more severely when a fire does occur." Congressional testimony by Kulakowski (2013) agrees, and also identifies weather and climate as much more relevant to increased fire severity. Hart et al. (2015) found that "that the observed effect of (mountain pine beetle) infestation on the area burned in years of extreme fire appears negligible at broad spatial extents."

D. The myth of ubiquitous low-severity wildland fire

Another Forest Service false premise specific to old growth in the Northern Rockies is that, prior to the advent of logging and fire suppression in the twentieth century, most old growth was maintained under a low severity fire regime. This notion was nurtured at least as early as in the development of the Northern Region's old-growth definitions—Green et al., 1992: "In reviewing historic data it has recently been determined that the bulk of the presettlement upland old growth in the northern Rockies was in the lower elevation, ground-fire maintained ponderosa pine/western larch/Douglas-fir types (Losensky 1992)." When this Losensky cite ("Personal communication. Jack Losensky, Ecologist, Lolo National Forest, Missoula, MT") was requested under FOIA, the Forest Service replied that it had no record of it. (Marten, 2020.)

Green et al., 1992, also states:

> Many of the oldest stands of old growth are dominated by seral tree species that are maintained as dominants and protected from crown fire, by repeated underburns that reduce ladder fuels and competition from more tolerant tree species. These relationships are **well documented by Arno and others (1985), Arno (1980), Fisher and Clayton (1983), and Fisher and Bradley (1987)**. (Emphasis added.)

Yet none of the references cited in Green et al. 1992 specify the geographic extent of the alleged short fire-interval forests in the Northern Rockies. At best, the Forest Service relies upon anecdotal information. There is no credible science supporting the agency's portrayal of most forest conditions in this bioregion being maintained in an orderly, relatively open-canopy status by low severity fire. The basis of rigorous science is data, which the Forest Service lacks.

This lack of scientific certainty is discussed by scientists such as Baker, 2017 who notes the limitations of tree-ring and fire scar studies. Baker observes biases that result in significant underestimates of average between-fire intervals on landscapes in western U.S. dry forests[7]:

> Past reconstructions of low-severity fire in dry forests, using tree-rings, focused on long records of dated fire years in small plots, and most were not intended to accurately estimate key rate parameters of low-severity fire needed to restore and manage low-severity fire across large landscapes. These small-plot reconstructions have known inaccuracies and biases if inappropriately used for this purpose.

Baker, 2017 found that only about 14% of historical dry forests in the western U.S. had average between-fire intervals of less than 25 years. This 14% was "concentrated in Arizona and New Mexico (and) were scattered across parts of all other states."

Also, Northern Region scientists Bollenbacher and Hahn, 2008g acknowledge, "Estimating the historical extent of old forests is also constrained by incomplete fire scar data and imprecise fire histories from the pre-settlement era (Baker and Ehle 2003)."

Baker and Ehle, 2003 state:

> For most of the ponderosa pine forests of the western United States there are no data at all that would allow a determination of whether crown fires or mixed-severity fires were present or absent before EuroAmerican settlement, or have increased or decreased.
>
> … No one, in any study anywhere in the West, has yet estimated how frequent crown- or mixed-severity fires were in ponderosa pine forests, how large these fires may have been, or what the fire rotation for these fires might have been prior to EuroAmerican settlement. … It may be difficult or impossible to determine whether large, high-severity fires did or did not occur in ponderosa pine landscapes prior to EuroAmerican settlement.

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[7] "Dry forests in the western USA cover 25.5 million ha and include dry pine forests, dominated by ponderosa pine (Pinus ponderosa) or other dry pines, and dry mixed-conifer forests that also have firs (Abies concolor, A. grandis, Pseudotsuga menziesii) and other trees." (Baker, 2017.)

Lesmeister et al., 2019 assert, "The extent of these (low-severity) forest types was often overrepresented in historical records due to the ease of traveling through them and the opportunities for pleasing photographs (Van Pelt 2008). In truth, these open, parklike forest conditions do not represent many forests in western North America (Odion et al. 2014)."

Forests of the intermountain west, including ponderosa pine forests, have burned at various severities historically, and high-severity fire is a natural part of this mix (Pierce et al. 2004, Baker et al. 2006, Hessburg et al. 2007).

Overestimating the amount of forest maintained naturally by low severity fire is another aspect of the agency cover story, told to support "treatments" of allegedly unhealthy northern Rocky Mountain forests using wide-scale "thinning" and prescribed burning. Lacking scientific, time-tested validation, the agency still blusters it is "increasing resiliency" and "restoring" forests from the damage its previous heavy-handed management has inflicted—using essentially the same heavy-handed management techniques.

In contrasting to the agency's exaggerations of the geographic extent of landscapes experiencing mostly frequent, low severity fire are Forest Service statements in recently revised forest plans acknowledging that mixed-severity fire regimes dominate the northern Rocky Mountains (*see* e.g., Nez Perce-Clearwater National Forests Draft EIS, Kootenai National Forest Final EIS, Flathead National Forest Final EIS, Colville National Forest Final EIS).

E. Fire refugia and post-disturbance legacies

Certainly, in the fire prone ecosystems of the northern Rockies, wildland fire presents challenges for managers, given that these landscapes have already been logged to well below historic levels of old growth. Also, old growth definitions existing at the time of the Chief's Position Statement were heavily influenced by the notion of old growth based on iconic Pacific Northwest forests, where intervals between severe, stand replacing fires are commonly hundreds of years. Yet despite acknowledging a dynamic landscape caused by the prevalence of fire in the Northern Rocky Mountains bioregion, the Forest Service has no management strategy providing spatially and quantitatively explicit measures to assure old growth will remain well distributed across landscapes over time. And if climate change increases the prevalence of severe wildfire as some climate projections suggest, old growth will be placed even more at risk.

Many areas of forests in this bioregion have longer fire return intervals, allowing forests to develop old-growth character. However, in landscapes where fire intervals may be shorter, "fire refugia" is a term referring to more isolated locations disturbed less frequently or less severely by wildfire than the surrounding landscape matrix. (Krawchuk et al., 2016; Camp et al., 1997; Meddens et al., 2018.)

Fire refugia are more likely than their surroundings to exhibit old-growth habitat characteristics. Camp et al. 1997 say "Before Euro-American settlement, late-successional species and compositions were found within fire refugia-stands that burned less frequently than the surrounding matrix …by virtue of topographic position, soil type, or a combination of environmental conditions and vegetation attributes." The latter "include areas adjacent to stream confluences, on perched water tables, and within valley bottoms and headwalls, especially at higher elevations (higher total precipitation) and on northerly aspects (more terrain shading, less insolation and thus reduced evapotranspiration)."

Ecologically, fire refugia "provide habitat for individuals or populations in which they can survive fire, in which they can persist in the postfire environment, and from which they can disperse into the higher-severity landscape." (Meddens et al. 2018.) The Forest Service has no management strategy that recognizes—let alone conserves—fire refugia. This is a problem during wildfire suppression operations, when burnouts might even target these locations (*Id.,* also *see* Zimmer, 2018).

Lesmeister, et al., 2019 explain why dense, late-successional forest tended to burn with high severity less frequently:

> The microclimate and forest structure likely played a key role in lower fire severity in nesting/roosting habitat compared to other forest types. As succession progresses and canopy cover of shade-tolerant tree species increases, forests eventually gain old-growth characteristics and become less likely to burn because of **higher relative humidity in soil and air, less heating of the forest floor due to shade, lower temperatures, lower wind speeds, and more compact litter layers** (Countryman 1955, Chen et al. 1996, Kitzberger et al. 2012, Frey et al. 2016, Spies et al. 2018). In addition, as the herbaceous and shrub layer is reduced by shading from lower to mid-layer canopy trees, **the connection between surface fuels and the canopy declines**, despite possible increases in canopy layering (Halofsky et al. 2011, Odion et al. 2014). (Emphases added.)

Finally, even where fire severity is such that vegetation is highly altered, patches of older, fire-resistant trees and even larger dead wood remain, providing many of the habitat features sought by old-growth associated wildlife. The Colville Forest Plan Final Environmental Impact Statement defines "biological legacy" as "Organisms, organic matter, and biologically created patterns that persist from the pre-disturbance ecosystem and influence recovery processes in the post-disturbance ecosystem." The Nez Perce-Clearwater National Forest's draft revised forest plan recognizes "live legacy trees and snags" as important as habitat and "are primarily the largest." Still, at best only a fraction of such biological legacies are specifically required for retention during logging operations, allowing continued depletion in managed landscapes.

F. Old growth logging promoted in revised forest plans

Forest plans recently revised or proposed for revision in the northern Rocky Mountain bioregion promote a worldview wherein extensive management actions are necessary to restore and maintain forest ecosystems, including old growth. Scientific information is lacking in support of such assumptions. Wales, et al. 2007 modeled various potential outcomes of fire and fuel management scenarios on the structure of forested habitats in northeast Oregon, and projected that the natural disturbance scenario resulted in the highest amounts of all types of medium and large tree forests combined, and best emulated the Natural Range of Variability for medium and large tree forests by potential vegetation type after several decades.

Next, this section explores examples of forest plan revisions or amendments using false premises and pseudoscience to devolve from conservation oriented approaches to those emphasizing logging. And in every case, following plan changes the Forest Service omitted minimum forestwide old-growth standards.

1. Boise National Forest

Following extensive wildfires on the Boise National Forest, in the early 2000s the outcome of litigation dramatically reduced logging because the Forest Service could no longer meet forest plan minimum old-growth requirements. So the Forest Service sought to sidestep its failed viability proxy by amending it out of the forest plan. This started with changing the term itself—from old growth to "old forest." The Forest Service[8] justified this change:

> Because old forest characteristics have been aggregated into **two basic categories**, it is generally easier to identify, monitor, and compare the characteristics of these old forest types with desired vegetative conditions than it is with "old growth." …Definitions of old growth generally vary by forest type, depending on the disturbance regimes that may be present. Also, within a given forest type, considerable variability can exist across the type's geographical range for specific ecological attributes that characterize late seral and climax stages of development. **This variability among and within multiple (often 10-20) forest types makes old growth characteristics difficult to identify, monitor, and compare to desired vegetative conditions**. (Emphases added.)

In other words, since the Forest Service found it difficult to conserve the diversity of old-growth types while conducting timber sales, the agency chose to remove old growth from the forest plan so it could no longer be held legally accountable for not preserving this diversity.

Boise National Forest managers further explain, "old forest habitat …includes old growth, but is also broader to **include the mid-seral, fire maintained systems**."[9] Yet their previous Hamilton, 1993 old-growth definitions already included such forest types. Furthermore, the "old forest" definition lacks minimum age criteria for the large trees, as found in Hamilton, 1993. This is, ecologically speaking, a critical omission because much of what defines old growth takes much longer to develop that typical timber harvest rotation periods.

Also, substituting "old forest" obscures the fact that forestwide levels of old growth had been reduced below original forest plan minimums because of extensive logging and wildfire. With "old forest habitat" being much more common than old growth, the agency need no longer consider the scarcity of the remaining old growth.

Furthermore, even managing for a minimum of "old forest" is sidestepped, because the agency further devolves from using measurable parameters to instead pursue nebulous "Desired Conditions." In defining that term, the Boise's 2010 forest plan amendment stated, "Also called Desired Future Condition, a portrayal of the land, resource, or social and economic conditions

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[8] Passage is from the Final Environmental Impact Statement of Boise National Forest's 2010 Wildlife Conservation Strategy forest plan amendment.

[9] *Id*., emphasis added

that are expected in 50-100 years if management goals and objectives are achieved. A vision of the long-term conditions of the land." So instead of doing its duty to conserve biological diversity, the agency resorts to making promises to "achieve" vaguely stated goals at some point in the distant future.

Furthermore, this ecologically empty "desired conditions" approach has become disturbingly ubiquitous in forest planning, as seen in the 2012 revision of the NFMA implementing regulations.

2. Colville National Forest

As noted above, the original 1988 Forest Plan for the Colville National Forest stated a commitment and intent to "Inventory … old growth forests…" and to use said old growth inventory as a method of meeting Forest Plan wildlife monitoring requirements. (USDA Forest Service, 1988a.) In 2019, the Colville National Forest's revised forest plan was approved, and the words "old growth" were completely omitted—even though the associated Final EIS acknowledged[10] that "Old Growth Dependent Species Habitat …provide(s) essential habitat for wildlife species that require late and old forest habitat components (e.g., structure such as large and old trees, large snags, and downed wood) and contribute to the maintenance of diversity of wildlife habitats and plant communities." In place of old growth, here the Forest Service also uses the term "old forest" in the revised forest plan; and in further obfuscation uses the terms, "late forest" and "late successional forest" without defining either one.

So under the revised Colville forest plan's Orwellian scheme, "…timber harvest would be used as a management tool in the late forest structure MA to maintain and improve resiliency of the late and old forest habitat components (e.g., structure such as large and old trees, large snags, and downed wood)." In other words, logging is explicitly marketed as benefitting old growth and associated wildlife.

Yet the long-term development and persistence of old growth, with its characteristic complexity, proves its inherent natural resiliency and therefore precludes the need for active management. DeLuca, 2009 states, "Old growth forests, having survived the fires, droughts, and insect and disease outbreaks of the past, have shown themselves to be resilient elements of the forest ecosystem. The diversity of species and tree sizes in old-growth forests makes them inherently resistant to dramatic change." The provisions placed into forest plans that allow logging of old growth to increase resilience or resistance are not based in science. Rather, they are loopholes for allowing management (logging) of the entire Forest—old growth included.

3. Kootenai and Idaho Panhandle National Forests

Unlike the original 1987 forest plans of these national forests—which featured old growth forestwide minimum standards of 10%—the 2015 revised forest plans include no minimums. Instead, the newer plans sanction logging in old growth, using the Green et al., 1992 stand-level criteria as minimum retention requirements when logging within stands of old growth. Both

[10] In the Final Environmental Impact Statement for Colville National Forest's 2019 Revised Forest Plan.

revised plans[11] include the following standard: "Within old growth stands, timber harvest or other vegetation management activities shall not be authorized if the activities would likely modify the characteristics of the stand to the extent that the stand would no longer meet the (Green et al.) definition of old growth…"

Under such a management regime, where the Forest Service is less and less willing to abstain from logging old-growth, the best quality old-growth habitat is highly attractive to agency managers seeking to achieve timber targets. The following is an example of what happens under a regime encouraging active management within old growth, using Green et al., 1992 old-growth definitions as minimum qualifying criteria.

Green et al., 1992 recognizes a fairly common "old growth type" in the North Idaho Zone where one often finds large, old Douglas-fir, grand fir, western larch, western white pine, Engelmann spruce, subalpine fir, and western hemlock trees on cool, moist environments. (*Id*.) Such old growth is relatively dense: "There are an average of 27 trees per acre 21 inches DBH or more. The range of means across forests and forest types is from 12 to 53." (*Id*.)

However, Green et al., 1992 sets the "minimum number" of trees per acre 21 inches DBH at only ten. (*Id.*). Which means, under the above Idaho Panhandle Forest Plan standard, the "average" stand could experience logging 17 of its 27 largest, oldest trees and still qualify as old growth.

So why does Green et al., 1992 specify such a small minimum number of large, old trees—so far below the recognized average, and even less than the bottom limit of the recognized range? The answer lies in how those authors intended the criteria to be used: "The number of trees over a given age and size (diameter at breast height) were used as **minimum screening criteria** for old growth. …The **minimum screening criteria** can be used to identify stands that **may meet** the old growth type descriptions. " (*Id*., emphases added.) Green et al., 1992 further explain:

> The minimum criteria in the "tables of old growth type characteristics" are meant to be used as a screening device to select stands that maybe suitable for management as old growth, and the associated characteristics are meant to be used as a guideline to evaluate initially selected stands. They are also meant to serve as a common set of terms for old growth inventories. Most stands that meet minimum criteria will be suitable old growth, but there will also be some stands that meet minimum criteria that will not be suitable old growth, and some old growth may be overlooked**. Do not accept or reject a stand as old growth based on the numbers alone; use the numbers as a guide.**

(*Id.*, emphasis in the original.) So the abuse of the Green et al., 1992 minimum large tree screening criteria results in logging of large, old trees from old growth. And even if the existing stand in the above example possesses only the bare minimum large, old trees, managers could still log smaller and/or younger trees in the old-growth stand without disqualifying it, because numbers of such trees are not a part of the minimum criteria.

[11] *See* Idaho Panhandle National Forest revised forest plan and Kootenai National Forest revised forest plan.

Likewise, the Green et al. 1992 minimum total basal area was set well below the recognized range, again presumably for its utilization as a screening device. For the same old growth type discussed above, the "average basal area is 210 ft^2 per acre. The range is 160 to 270 ft^2". Yet the minimum is either 80 or 120 ft^2 depending upon type sub-categorization.[12] Basal area is a measure of stand density, or the square footage of an acre that is occupied by tree stems. So logging a stand with a basal area of 270 ft^2 (upper end of range) down to 80 ft^2 ("minimum") could result in the loss of medium diameter trees—another enticement for managers with timber priorities to log within old-growth stands.

In the above examples, the artificially reduced abundance of younger, smaller trees has unknown but dubious implications for the stand's potential development and habitat quality, since it is deviating from a natural trajectory.

Collateral damage of this forest plan-sanctioned logging in old growth includes the loss or reduction of old-growth habitat components. Green et al., 1992 recognize "Associated characteristics (such as number of snags, down woody material, dead tops and decay, and diameter variation)…". These "associated characteristics" are not included as minimum screening criteria, but represent the very diversity defining old growth in its truest meaning. These associated characteristics are typically and inevitably reduced during logging activities, which would squeeze the diversity out of old growth and the old-growth ecosystem.

4. Nez Perce-Clearwater National Forests

As of this writing, the original forest plans for these two national forests are undergoing revision for the administratively combined unit. Here, the Forest Service concocts yet another scientifically-challenged rationale for logging old growth. The draft forest plan advances the notion that some old growth is "non-desired" and may be "converted to a desired old growth type to meet desired conditions…" The draft Environmental Impact Statement vaguely identifies "Douglas fir, grand fir, western larch, Engelmann spruce/subalpine fir, western hemlock, western white pine, and ponderosa pine forest types on cool, moist environments" as undesirable. Notably, no definition of these "types" is provided. And if the agency determines the conversion of these "types" cannot be engineered—which is likely because there is no science to support such a notion—then the plan would promote "regeneration" (clearcutting) of such old growth.

G. Creating old growth?

Fully embedded within the Forest Service's perspective on old growth is an assumption that management can facilitate or accelerate development of fully functioning old growth. There is simply no science supporting the position that vegetation manipulation can help to maintain old growth over time, or foster development of non-old growth into old growth. As stated by Thomas et al., 1988:

> The ecological complexity of old growth makes it unlikely that forest managers can create functional old growth through silvicultural manipulations of younger-aged, second-growth

[12] With the issuance of the Green et al. 1992 (**errata correction 2007**) the Forest Service emphasizes and clarifies that stand basal area is one of the "minimum criteria."

> forests. Certainly, such knowledge does not now exist. …If silviculture is used to expedite this process, it should be done with the understanding that such action is experimental, and **results lie many decades or centuries in the future**. Accordingly, management options that include retention of existing old growth must be given priority. (Emphasis added.)

Pfister et al., 2000 agrees that the outcome of legitimate experimentation to help create old growth can only be known far into the future:

> (T)here is the question of the appropriateness of management manipulation of old-growth stands… Opinions of well-qualified experts vary in this regard. As long term results from active management lie in the future—likely quite far in the future—considering such manipulation as appropriate and relatively certain to yield anticipated results is an informed guess at best and, therefore, encompasses some unknown level of risk. In other words, producing "old-growth" habitat through active management is an untested hypothesis.

Hunter, 1989 quotes from writing by the Society of American Foresters:

> With present knowledge, it is not possible to create old-growth stands or markedly hasten the process by which nature creates them. Certain attributes, such as species composition and structural elements, could perhaps be developed or enhanced through silviculture, but we are not aware of any successful attempts. Old growth is a complex ecosystem, and lack of information makes the risk of failure high. In view of the time required, errors could be very costly. At least until substantial research can be completed, the best way to manage for old growth is to conserve an adequate supply of present stands and leave them alone.

Speaking to the hubris exhibited by forest managers, Franklin and Spies, 1991 ask, "How can we presume to maintain or re-create what we do not understand?"

The Forest Service implicitly or explicitly denies that the natural processes that created and maintained our old-growth landscapes over countless millennia can continue to do so without management intervention. The 2018 revised forest plan for the Flathead National Forest is exemplary of the manipulate-and-control management paradigm:

> Forest plan direction for old-growth forest supports the enhancement of the successional process towards old growth that could be achieved in some stands through management activities.
>
> Vegetation management within old-growth forest (see glossary) shall be limited to actions that
>
> - maintain or promote old-growth forest characteristics and ecosystem processes;
> - increase resistance and resilience of old-growth forest to disturbances or stressors that may have negative impacts on old-growth characteristics (such as severe drought, high-severity fire, epidemic bark beetle infestations);
>
> … treatment prescriptions that would promote the development of old-growth forest in the future should be considered.

Thus it is unsurprising the Flathead National Forest's revised forest plan claims its general forestwide logging direction promotes the development of old growth:

> …many of the desired conditions for vegetation characteristics (e.g., forest composition and size classes), and the standards and guidelines developed to achieve those desired conditions, also contribute to the long-term development of old-growth forest.

Therefore, much skepticism is justified concerning the Flathead National Forest's proposed Mid-Swan Landscape Restoration and Wildland Urban Interface Project, wherein the agency blusters that up to 35,000 acres of clearcuts could "contribute to the long-term development of old-growth forest."

There has been little research, if any, by the Forest Service to validate the old growth active management paradigm. Independent researchers investigated the ecological effects of forest restoration treatments on several old-growth forest stands in the Flathead National Forest. Hutto, et al., 2014 found:

> Relative abundances of only a few bird species changed significantly as a result of restoration treatments, and these changes were characterized largely by **declines in the abundances of a few species associated with more mesic, dense-forest conditions, and not by increases in the abundances of species associated with more xeric, old-growth reference stand conditions.** (Emphasis added.)

In its zeal to promote the benefits of its active management (logging and burning) of old growth, the Forest Service downplays and ignores the damage it causes.

VII. CONCLUSIONS AND RECOMMENDATIONS

If no management practices are performed for a long time, stands may gradually evolve into so-called "old-growth forests". In the absence of anthropogenic disturbances, forests may slowly recover the natural disturbance dynamics (forest fires and windstorms, parasite outbreaks, fungal decay, gap creation due to insects) and develop those stand structural features (large living trees, large amount of deadwood, canopy gaps of various size, coexistence of senescent, mature and initial stages) typical of primary forests...

—Tomao et al. (2020)

If the worldview prevails where old-growth on national forests is valued more for timber than for other values such as "habitat for certain animal and plants, for aesthetics, for spiritual reasons, for environmental protection, for research purposes, for production of unique resources such as very large trees" (Green et al., 1992)—old growth simply will not persist in our shared landscapes. The natural processes that create and maintain old growth, operating necessarily over large landscapes, will continue to be hijacked and thwarted by Forest Service management policies, and old growth will dwindle into small, isolated remnants. The continuing assault on science, weakening of regulatory protections, and rapidly changing climate do not bode well for our old-growth landscapes and values.

On the other hand, if non-timber values are to hold any sway, management policies of government agencies including the U.S. Forest Service need a drastic overhaul before it's too late. Mildrexler et al. (2020) sum up the benefits of prioritizing these non-timber values:

> Given the urgency of keeping additional carbon out of the atmosphere and continuing carbon accumulation from the atmosphere to protect the climate system, it would be prudent to continue protecting ecosystems with large trees for their carbon stores, and also for their co-benefits of habitat for biodiversity, resilience to drought and fire, and microclimate buffering under future climate extremes.

As, Keith, et al., 2009 recognize, "Conserving forests with large stocks of biomass from deforestation and degradation avoids significant carbon emissions to the atmosphere."

The urgency to act on the climate crisis is reason enough to change society's relationship to forests from exploitation to preservation. If our elected officials and the managers they appoint were to strongly lead in objective consideration of what scientists are telling us about the critical role forests play in sequestering carbon and mitigating the effects of climate change, we would also enjoy the other benefits of conserving old growth. However, the emphasis of these conclusions and recommendations is based upon more traditional forest ecology, to help empower those effecting policy changes over their more local or regional landscapes.

A. Recovering old-growth landscapes

In order for old growth to persist on the landscape and return to an extent and condition resembling its past splendor, clearly forest managers are not able to actively create it, as discussed above. Nor can management necessarily choose the specific locations for stands of old growth to develop. This is because ecologically, the dynamics of **old-growth landscapes** operate at very broad scales—both geographically and temporally. From Kaufmann et al. (2007):

> The arrangement of patches—the landscape mosaic—is not constant over time. Rather, natural processes, such as fire, insect activity, disease, wind, regeneration of new seedlings, and competition among individual trees, interact to maintain a variety of conditions across the landscape. Just as the components of patches, stands, and landscapes vary spatially, so do the characteristics of ecological processes vary with time. A wind event may be as brief as a moment or as long as hours or days, fire an hour or a day or months, drought a season or a year or more, regeneration a year or decades or a century or more, and reaching an old-growth condition a matter of centuries. Under the influence of climate and fire, the patches in the mosaic changed with time, and in a fully functioning ecosystem, the old-growth forest landscape was maintained even though the locations and proportions of various patch types varied. And through all the changes of fire-adapted forests, fire remained a primary factor that, with some regularity, shaped the spatial arrangement of patches and stands in the landscape.

Franklin and Spies, 1991 state, "Old-growth forest is a biological or ecological concept that presumes ecosystems systematically change as they persist over long periods. An ecosystem has, in effect, a series of linked life stages …which vary in composition, function, and structure. Such progressions can take a very long time in forests because the dominant organisms, trees, typically live very long."

In a 1983 document that was later adopted into the 1987 Forest Plan for the Idaho Panhandle National Forests (USDA Forest Service 1987d), biologist Danielle Jerry recognized the spatial and temporal "shifting mosaic" created by natural disturbance processes:

> Episotic high and low mortality caused by fire, disease and insects are balanced by primary production. Borman and Likens (1979) describe this condition as a "shifting-mosaic steady state." Over a large area the average condition (steady state) of the vegetation is a forest dominated by old-growth trees. Within the gross boundaries of the old-growth forest are found patches representing every successional stage. The location of these patches of seral vegetation shift over time, for as one stand passes from pole to mature to old-growth trees, another stand may be eliminated by an insect attack. Thus, within the gross boundaries of an old-growth ecosystem a mosaic of varying age class stands constantly shift internal boundaries. Traditional ideas about climax vegetation are not really appropriate, for seral species and a heterogeneous age class are important elements in this "shifting mosaic steady state."

Noon, 2009 describes the multiple scales of this "shifting mosaic" and its importance for biological diversity:

> The distribution of different-aged, small-scale patches embedded within the larger old-growth forest patch is an important source of habitat diversity. Thus, old growth conservation requires management at both landscape and local scales. At the landscape scale, the extent of forest management must be sufficiently broad to accommodate the shifting mosaic of forest age classes generated by large-scale disturbances. At the local scale, individual old-growth reserves must be sufficiently large to incorporate most small-scale disturbance events that promote fine-grained habitat diversity.

Harris (1984) states, "biotic diversity will be maintained on public forest lands only if conservation planning is integrated with development planning; and site-specific protection areas must be designed so they function as an integrated landscape system." Harris, 1984 also states:

> Because of our lack of knowledge about intricate old-growth ecosystem relations (see Franklin et al. 1981), and the notion that oceanic islands never achieve the same level of richness as continental shelf islands, a major commitment must be made to set aside representative old-growth ecosystems. This is further justified because of the lack of sufficient acreage in the 100- to 200-year age class to serve as replacement islands in the immediate future. …(A) way to moderate both the demands for and the stresses placed upon the old-growth ecosystem, and to enhance each island's effective area is to surround each with a long-rotation management area.

And Marcot, et al., 1991 recommend integrating the biological needs of old-growth associated wildlife species across large landscapes to better inform management policies.

Although there are few specifics insofar as designs to restore and maintain old-growth over large landscapes, the following are general recommendations from scientists and other experts.

Yanishevsky, (1987) stated, "It is important to have areas set aside for old growth to curtail timber harvesting, reduce habitat fragmentation or insularization, and ensure the long-term retention of quality old-growth habitat." Also:

> Management schemes based on island biogeographic theories may help reduce impacts of adjacent management on old growth. These schemes (1) dedicate an existing core of old growth with no timber harvesting, (2) surround the core with a long rotation management island (thereby increasing the habitat effectiveness by providing adjacent mature stands), and (3) provide timbered corridors connecting the old growth management areas. (*Id*.)

Foster et al., 1996 state:

> The maintenance of many natural ecosystems requires the protection not only of current old-growth areas, but also of naturally disturbed forests that represent future old-growth. To ensure the continued presence of old growth, these areas must be maintained **within a landscape that is adequate in size to allow for the continuing mosaic of disturbance and for the dispersal of organisms and processes among patches**. (Emphasis added.)

Harrison and Voller, 1998 assert "connectivity should be maintained at the landscape level." They adopt a definition of landscape connectivity as "the degree to which the landscape facilitates or impedes movement among resource patches." Also:

> Connectivity objectives should be set for each landscape unit. …Connectivity objectives need to account for all habitat disturbances within the landscape unit. The objectives must consider the duration and extent to which different disturbances will alienate habitats. … In all cases, the objectives must acknowledge that **the mechanisms used to maintain connectivity will be required for decades or centuries**.
>
> Corridor is another term commonly used to refer to a tool for maintaining connectivity. …(T)he successful functioning of a corridor or linkage should be judged in terms of the connectivity among subpopulations and the maintenance of potential metapopulation processes. (Emphasis added; internal citations omitted.)

Noon, 2009 believes "issues of landscape connectivity, measured in terms of the likelihood of successful movement between patches of old-growth forest, become critical to sustaining wildlife over the long term. …Therefore, the matrix in which old-growth reserves are embedded must be managed so as to maintain connectivity among reserves."

Harris, 1984 discusses connectivity and effective interior habitat of old-growth patches:

> Three factors that determine the effective size of an old-growth habitat island are (1) actual size; (2) distance from a similar old-growth island; and (3) degree of habitat difference of the intervening matrix. …(I)n order to achieve the same effective island size a stand of old-growth habitat that is surrounded by clearcut and regeneration stands should be perhaps ten times as large as an old-growth habitat island surrounded by a buffer zone of mature timber.

Thomas et al., 1988 states:

> … Management plans for providing old growth must be based on existing stands because replacement stands cannot be produced by silvicultural practices; they must come from stands that are allowed to develop naturally into old growth.

Warren (1990) states:

> In devising a conservation strategy, Forman and Godron (1981:738) emphasize the importance of recognizing that "no patch stands alone", but is influenced by surrounding patches. Harris (1984) recommended surrounding old-growth habitat islands with a long-rotation management area, and interconnecting these with riparian corridors and other linkages. Similarly, Noss and Harris (1986) suggest that a regional landscape level be used, wherein high-quality nodes, such as an old-growth patch, be integrated with interconnected "multiple use modules" where management activities are scheduled to maintain the integrity of the nodes.
>
> …Natural disturbance regimes such as fire often occur on a spatial scale larger than a landscape patch (Urban et al. 1987). Providing for well-distributed habitat patches with interconnections between habitat patches thus are necessary to maintain species diversity of the long term.
>
> …A complex, multi-storied structure and a mosaic of both early and late successional stages often are important attributes (Bormann and Likens 1979).

Green et al., 1992 recognize, "Stands are elements in **dynamic landscape**. We need to have representatives of the full range of natural variation, and **manage the landscape mosaic as a whole** in order to maintain a healthy and diverse systems." (Emphases added.)

Spies, 2009 describes the important perspective of old growth existing in the whole forest ecosystem:

> Old forests are inextricably intertwined in space and time in a continuum of forest development, just as young, mature, and mixed-age forests are. Focusing on only one part of the continuum is like trying to understand light by examining only one color or wavelength, or like trying to understand a river by looking only at the deep, quiet pools and ignoring the rapids.

Marcot, et al., 1991 bring wildlife into this discussion:

> Landscape attributes affecting the perpetuation of old-growth dependent and associated wildlife include the spatial distribution of old growth; the size of stands; the presence of habitat corridors between old-growth or old-forest stands; proximity to other stands of various successional stages and especially for well-developed mature-forest stages and species with different seasonal uses of habitats; and the susceptibility of the old-growth habitat to catastrophic loss (such as wildfire, insects, disease, wind and ice storms, and volcanic eruptions.
>
> Stand size, in combination with its landscape context (the condition, activities, or both on the adjacent landscape that affect the stand) …can have a major effect on their use by wildlife. …If such stands are separated by unsuitable habitat or disruptive activities, however, the remaining old-growth stands become smaller in effective (interior) size, more fragmented, and possibly not suitable for occupancy or for successful reproduction.

DeLuca, 2009 discusses considerations for recruitment of future old growth:

> A fundamental question that must be addressed is: What developing stands should be priorities for recruitment as old growth stands? What are the dominant characteristics of the stand and the surrounding landscapes that should be considered when identifying sites for old growth recruitment? The following is a simple list of possible attributes that could be considered when identifying priority candidates for old growth recruitment:
>
> 1) Stands should have importance or relevance to the surrounding landscape from a connectivity perspective (largest intact units of naturally functioning forests, species migration potential, and proximity to important (e.g. T&E) habitat).
> 2) Stands should exhibit characteristics of natural forest succession for that forest type and physiography (e.g. multi-aged, understory species diversity, occurrence of fire as appropriate, presence of snags and coarse woody debris)
> 3) Stands should be capable of achieving old growth characteristics without a great degree of human effort or intervention
>
> Fundamental to the notion of maintaining and recruiting old growth forests is the role of natural disturbances on the landscape. Landslides, wildfire, microbursts, etc… will occur and will help shape the landscape. If these processes cause the mortality of a majority of the standing timber, then the question must be asked: Is a dead forest an old growth forest? Clearly there would be a lack of mature trees, but disturbance is a given and is an important part of the natural forest succession pattern.

DeLuca, 2009 believes "Wildlife inhabitation of these stands should also be considered an important index of success in recruitment of old growth condition."

B. Initiatives for protecting old-growth landscapes

The implication is clear: for old growth and its intrinsic values to exist, natural processes must be the main agents of disturbance and change over large landscapes and for long intervals of time. This means active management must be constrained more than it currently is. Major policy changes and reordering of priorities for national forests must be undertaken for old growth to persist.

1. Endangered Species Act

Listings of species under the Endangered Species Act (ESA) have achieved habitat protection over large landscapes, depending upon the ranges of the species protected. Implementing mechanisms under the ESA that restrain or reduce exploitation of ecosystems include creating Recovery Plans and designating Critical Habitat. See this Defenders of Wildlife website for more details on the ESA. Less directly, ESA requirements for consultation with federal agencies such as the U.S. Fish and Wildlife Service (USFWS) result in review of Forest Service management projects that potentially improve outcomes for listed species' habitat, one project at a time. However attempts to attain listing of species are met by USFWS resistance, which can result in rare species not being listed or long delays when they are (e.g., Bechtold, 1999 regarding the bull trout). And subsequent to listing, designation of Critical Habitat and creation of Recovery Plans are likewise vulnerable to political meddling and bureaucratic opposition.

Unlike the northern spotted owl in the Pacific Northwest, listing efforts for old-growth associated wildlife in the Northern Rocky Mountains bioregion have been mostly unsuccessful. The Canada lynx, listed in the 1990s, relies upon old-growth conditions for some of its life functions, but its largely higher-elevation habitat doesn't sufficiently overlap with the forests most targeted by logging, so lynx listing has not resulted in adequate landscape-level protections for old growth.

Wildlife advocates have petitioned the USFWS to list other old-growth associated species, with no success so far. These include petitions for the northern goshawk and fisher—old-growth management indicator species in some forest plans and species of conservation concern across much of this report's landscape of interest. Eventual success in listing such species would open the door for science-based habitat protections not found in current forest plans or other Forest Service direction.

2. Habitat protections under forest plans

Forest Planning under NFMA is a potential opportunity to preserve old-growth ecosystems over large landscapes. The best example is the Northwest Forest Plan (NWFP), which revised existing land management plans following the controversial management of old-growth forests on federal lands in the range of the northern spotted owl. Success of the NWFP has been a mixed bag. It "protected remaining old-growth forests from clearcutting and enabled growth and development of vegetation conditions to support threatened species" (Spies, et al. 2019). And yet, "populations of northern spotted owl and Washington populations of marbled murrelet, along with other bird species associated with older forests, have continued to decline" (*Id*.). Others are even less complimentary of the NWFP's ecological outcomes. According to a web page by Oregon Wild:

> The Northwest Forest Plan was a compromise that did not go far enough to protect the region's remaining old-growth forests, sensitive wildlife species, or, arguably, a sustainable economy. The Plan allows logging and road building in ecologically critical areas, across

all land use allocations. The Northwest Forest Plan did not fully protect mature and old-growth forests, roadless areas, municipal watersheds, and complex young forests that are recovering from fire. The Plan is also too dependent on under-funded, but necessary, restoration and monitoring efforts. And the Plan expects an unattainable amount of timber production from public land.

Although most of the forest plans in the Northern Rocky Mountains bioregion have been revised in recent years, or are undergoing revision, none improved protection of old growth as did the NWFP. The Flathead National Forest Amendment 21 to its original 1986 forest plan is the only significant forest plan amendment in this bioregion with a central focus on old growth, and it came in response to litigation. Conservationist groups Swan View Coalition and Friends of the Wild Swan submitted an alternative for consideration in the Amendment 21 Final Environmental Impact Statement (USDA Forest Service, 1998). That alternative proposed designating all existing old growth as management indicator species (MIS) habitat blocks and making them off-limits to commercial logging, and managing all younger forests as recruitment old growth with logging subject to strict requirements[13] until the amount of old-growth forest recovers to above the median of the historic range of variability. (*Id.*) It also proposed designating some old-growth recruitment as MIS blocks and providing robust linkage corridors between all MIS blocks based upon the biological needs of the MIS. (*Id.*) The Forest Service ignored the nuances and portrayed the conservationist's alternative as banning all logging, and unsurprisingly did not select it.

As discussed above in this report, more recent plans are written to allow managers wide discretion to authorize logging just about anywhere, including within old growth. Only in cases where other laws prohibit commercial exploitation, such as with the Wilderness Act, is old growth safe from logging on these national forests. Even Inventoried Roadless Areas, supposedly protected by the Roadless Area Conservation Rule and the Idaho Roadless Rule, are subject to heavy logging (Friends of the Clearwater, 2020a).

An avenue for installing into forest plans the notion of how old-growth ecosystems and landscapes actually work involves widening the interpretation of "desired conditions." Forest Plans revised in recent years include this component, which the 2012 regulations define as: "a description of specific social, economic, and/or ecological characteristics of the plan area, or a portion of the plan area, toward which management of the land and resources should be directed. Desired conditions must be described in terms that are specific enough to allow progress toward their achievement to be determined, but do not include completion dates."

The Forest Service's current interpretation of desired conditions result in management actions striving "toward"—at some vague future time—the attainment of forest conditions conforming to static descriptions, rather than integrating the dynamic nature of ecosystems into management as discussed above in the subsection, **Recovering old-growth landscapes**. For example, the revised Forest Plan for the Kootenai National Forest includes this Desired Condition for old growth:

[13] "(O)n a very limited and experimental basis, and efforts to change the structure or composition of these forests would be paired with control plots and subject to a scientifically valid and peer-reviewed monitoring program of sufficiently long duration to assess the effectiveness of the treatments in moving the forest toward old growth forest MIS habitat." (USDA Forest Service, 1998).

> The amount of old growth increases at the forestwide scale. At the finer scale of the biophysical setting, old growth amounts increase for the Warm/Dry and Warm/Moist settings while staying close to the current level for the Subalpine setting. Relative to other tree species, there is a greater increase in old growth stands that contain substantial amounts (i.e., 30% or more of the total species composition) of one or more of the following tree species: ponderosa pine, western larch, western white pine, and whitebark pine. Old growth stands are more resistant and resilient to disturbances and stressors such as wildfires, droughts, insects and disease, and potential climate change effects. The size of old growth stands (or patches of multiple contiguous old growth stands) increase and they are well-distributed across the five Geographic Areas on the Forest.

How "old growth increases at the forestwide scale" is not explained. The statement merely describes a trend, with no target numbers specified nor any specific date of achievement. This is typical of current forest plans' interpretation of "desired conditions." However, an abundance of scientific opinion indicates that fully functioning natural processes should be the desired "conditions"—or better yet, **dynamics**. The key phrases are emphasized in the following cites.

McClelland (undated) critiques Forest Service management that "concentrates on the products of ecosystem processes rather than the processes themselves. It does not address the most critical issue—long-term perpetuation of diverse forest habitats, a mosaic pattern which includes stands of old-growth... **The processes that produce suitable habitat must be retained or reinstated by managers**."

Hessburg and Agee, 2003 also emphasize the primacy of natural processes for management purposes:

> Ecosystem management planning must acknowledge **the central importance of natural processes and pattern–process interactions**, the dynamic nature of ecological systems (Attiwill, 1994), the inevitability of uncertainty and variability (Lertzman and Fall, 1998) and cumulative effects (Committee of Scientists, 1999; Dunne et al., 2001).

From Sallabanks et al., 2001:

> Given the dynamic nature of ecological communities in Eastside (interior) forests and woodlands, particularly regarding potential effects of fire, **perhaps the very concept of defining "desired future conditions" for planning could be replaced with a concept of describing "desired future dynamics."**

Noss, 2001: "If the thoughtfully identified critical components and **processes of an ecosystem are sustained**, there is a high probability that the ecosystem as a whole is sustained."

Hutto, 1995: "Efforts to meet legal mandates to maintain biodiversity should, therefore, be directed toward **maintaining processes like fire**, which create the variety of vegetative cover types upon which the great variety of wildlife species depend.

Noss and Cooperrider (1994):

> **Considering process is fundamental to biodiversity conservation because process determines pattern**. Six interrelated categories of ecological processes that biologists and managers must understand in order to effectively conserve biodiversity are (1) energy flows, (2) nutrient cycles, (3) hydrologic cycles, (4) disturbance regimes, (5) equilibrium processes, and (6) feedback effects.

The Environmental Protection Agency (1999):

> (E)cological processes such as natural disturbance, hydrology, nutrient cycling, biotic interactions, population dynamics, and evolution determine the species composition, habitat structure, and ecological health of every site and landscape. **Only through the conservation of ecological processes** will it be possible to (1) represent all native ecosystems within the landscape and (2) maintain complete, unfragmented environmental gradients among ecosystems.

Forest Service researcher Everett (1994) states:

> To prevent loss of future options we need to simultaneously **reestablish ecosystem processes and disturbance effects that create and maintain desired sustainable ecosystems**, while conserving genetic, species, community, and landscape diversity and long-term site productivity.
>
> …We must address **restoration of ecosystem processes and disturbance effects** that create sustainable forests before we can speak to the restoration of stressed sites; otherwise, we will forever treat the symptom and not the problem.

3. Legislation

A legislative effort to preserve large landscapes in the northern U.S. Rocky Mountains is the Northern Rockies Ecosystem Protection Act (NREPA). NREPA has been introduced and re-introduced into Congress repeatedly since the early 1990s. Unfortunately Congress has yet to make a serious attempt to pass the bill. NREPA would designate the remaining roadless areas on federal lands in this bioregion as Wilderness. Importantly for old-growth landscapes, between the core roadless areas NREPA proposes to restore integrity of habitats for the purpose of providing connectivity, within twenty-eight "biological connecting corridors …essential for wildlife and plant migration and genetic interchange" totaling roughly 2,358,000 acres. Within these corridors:

> The practice of even-aged silvicultural management and timber harvesting is prohibited within the special corridor management areas. … ensure that road densities within the biological connecting corridor approach, as nearly as possible, zero miles of road per square mile of land area. Such road density shall not exceed 0.25 miles per square mile…

Furthermore NREPA designates nine "Wildland Restoration And Recovery Areas" covering approximately 1,023,000 acres:

> …managed so as to restore their native vegetative cover and reduce or eliminate invasive non-native species, facilitate native species diversity to the extent possible with climate change, stabilize slopes and soils to prevent or reduce further erosion, recontour slopes to their original contours, remove barriers to natural fish spawning runs, and generally restore such lands in their entirety to a natural roadless and wild condition.

With government agencies and elected officials firmly opposed to protecting old-growth landscapes, it falls upon citizens who appreciate old growth for non-timber values to take the lead. In the words of Margaret Mead, "Never doubt that a small group of thoughtful, committed citizens can change the world; indeed, it's the only thing that ever has."

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APPENDIX A

Wildlife species in U.S. Northern Rockies bioregion associated with old-growth habitat

I. Forest Plan old-growth associated wildlife species list, 1987 Kootenai National Forest

The species listed below find optimum habitat in the "old" successional stage. They may also utilize the "mature" stage if adequate sizes and numbers of snags/down logs, or large live trees are present.

B= breeding F=feeding

Species	Habitat Need	Species	Habitat Need
Dusky flycatcher	F	+ Common flicker	B,F
Hammond's flycatcher	B,F	Black-backed three-toed woodpecker	B,F
Olive-sided flycatcher	B	Northern three-toed woodpecker	B
Black-capped chickadee	B	Downy woodpecker	B,F
Boreal chickadee	B	Hairy woodpecker	B,F
Chestnut-backed chickadee	B	Lewis' woodpecker	B
Bald eagle	B	Williamson's sapsucker	B,F
Goshawk	B	Yellow-bellied sapsucker	B,F
Osprey	B	+ Varied thrush	B,F
Great blue heron	B	Hermit thrush	B,F
Rocky mountain wolf	B	Common raven	B
Marten	B,F	Kestrel	B
Northern flying squirrel	B	+ Clark's nutcracker	B,F
+ Red squirrel	B	Evening grosbeak	B
Hoary bat	B	Pygmy owl	B,F
Long-eared myotis	B	Saw whet owl	B,F
Little brown myotis	B	Screech owl	B
Silver-haired bat	B	Pygmy nuthatch	B,F
Pacific giant salamander	B	+ Red-breasted nuthatch	B,F
Van Dyke's salamander	B,F	White-breasted nuthatch	B,F
Pacific treefrog	B,F	Tree swallow	B
Spotted frog	B	Violet green swallow	B
Tailed frog	B	Vaux's swift	B,F
Common merganser	B	Golden-crowned kinglet	B
Hooded merganser	B	Winter wren	B,F
Wood duck	B		
Dipper	B		
Western bluebird	B		

In addition, the five species listed below are believed to have an especially strong preference or possibly a dependence on the old successional stage:

Barred owl
Great grey owl
* Pileated woodpecker
Boreal redback vole
* Brown creeper

* = old growth indicator species
\+ = indicators of other types of habitat (riparian tree, for example)

II. List of wildlife in the USFS Northern Region associated with old-growth habitats (Bollenbacher and Hahn, 2008)

Birds	
Northern goshawk	*Accipiter gentilis*
Great gray owl	*Strix nebulosa*
Flammulated owl	*Otus flammeolus*
Northern Pygmy owl	*Glaucidium gnoma*
Saw-whet owl	*Aegolius acadicus*
Boreal owl	*Aegolius funereus*
Barred owl	*Strix varia*
Vaux's swift	*Chaetura vauxi*
White-headed woodpecker	*Picoides albolarvatus*
Pileated woodpecker	*Dryocopus pileatus*
Three-toed woodpecker	*Picoides dorsalis*
Black-backed woodpecker	*Picoides arcticus*
Red-naped sapsucker	*Sphyrapicus nuchalis*
Williamson's sapsucker	*Sphyrapicus thyroideus*
White-breasted nuthatch	*Sitta carolinensis*
Red-breasted nuthatch	*Sitta canadensis*
Pygmy nuthatch	*Sitta pygmaea*
Brown creeper	*Certhia americana*
Hermit thrush	*Catharus guttatus*
Varied thrush	*Ixoreus naevius*
Townsend's warbler	*Dendroica townsendi*
Mammals	
Silver-haired bat	*Lasionycteris noctivagans*
Long-eared bat	*Myotis evotis*
Long-legged myotis	*Myotis volans*
California myotis	*Myotis californicus*
Fisher	*Martes pennanti*[14]
Marten	*Martes americana*
Lynx	*Lynx canadensis*
Wolverine	*Gulo gulo*
Woodland caribou	*Rangifer tarandus*
Boreal red-backed vole	*Clethrionomys gapperi*
Northern flying squirrel	*Galucomys sabrinus*

[14] Based upon recent genetic studies scientists have placed the fisher in a monotypic genus, classifying it as *Pekani pennanti*.

APPENDIX B

Old-Growth definitions: Forest Plan or Regional?

The Regional definitions (Green et al., 1992 and Hamilton 1993) were not developed under the planning process governed by NFMA regulations. Appendix D of Green et al., 1992 explains that its creation was part of a wider 1990 Regional Action Plan—of which step 8 would invoke the forest planning process:

ACTION PLAN: **The Regional Old Growth Committee has revised the action plan (5/90) to accomplish the Chief a objectives and continue the old growth strategy for the Region.**

	ACTION	DATE	RESPONSIBILITY RO/Forest
1.	Initiate analysis to develop definitions Form zone OG Teams for Eastside forests, Western Montana forests, and northern idaho forests	1/90	Hann/Zone OG ID Teams
2.	Initiate public involvement	3/90	Forests
3.	Evaluate inventory procedures	3/90	Hann/Naumann/Deden
4.	Complete draft definitions & descriptions	7/90	Hann/Zone OG ID Teams
5.	Correlate definitions between zones	7/90	Hann/Zone Representatives
6.	Coordinate definitions with adjacent Regions	8/90	Naumann
7.	Initiate development of old growth management strategies (Deferred for SES analysis)	8/90	Subcommittee (Naumann will coordinate)
8.	Develop guidelines for integrating definitions, inventories, and management strategies into the Forest Plan process (Deferred for SES analysis)	9/90	Prather/Forest Planners
9.	Field work to fill data gaps for definitions	7-10/90	Forest Inventory
10.	Write a chapter on old growth for the Effects Analysis Handbook (Deferred for SES analysis	8-10/90	Subcommittee (Prather/Hann will coordinate)
11.	Analyze data for old growth definitions	10/90 - 4/91	Hann/Zone OG ID Teams
12.	Identify values for each old growth type (Deferred for SES analysis)	8/90 – 4/91	Subcommittee (Davis will coordinate)
13.	Correlate definitions between zones	5/91	Hann/Zone Reps
14.	Coordinate definitions with adjacent Regions	6/91	Naumann
15.	Complete summary report on old growth	9/30/91	Naumann-OG Committee Zone OG Committees

However, Action Plan step 8 ("Develop guidelines for integrating definitions, inventories, and management strategies into the Forest Plan process") was cryptically "Deferred for SES[15] analysis" as were steps 7, 10 and 12. Green et al., 1992 states, also cryptically, "These definitions will be used in the implementation of Forest Plans. Where there are conflicts with existing plan requirements, differences will be worked out on a case by case basis." That has played out as the utilization of Green et al., 1992 at the **project** analysis level, ranging from citing it as best available science to proposing "site-specific" forest plan amendments for substituting Green et al., 1992 in place of existing forest plan old-growth definitions.

[15] "SES" refers to a "current Regional effort of Sustaining Ecological Systems" (Green et al., 1992) of which that document was clearly a part of, since it is headed, "NORTHERN REGION USDA FOREST SERVICE APRIL 1992 R-1 SES 4/92."

Exhibit 9

Forest Service
U.S. DEPARTMENT OF AGRICULTURE

April 2023 | FS-1215a

Mature and Old-Growth Forests: Definition, Identification, and Initial Inventory on Lands Managed by the Forest Service and Bureau of Land Management

Fulfillment of Executive Order 14072, Section 2(b)

Old-growth ponderosa pine forest stand on the Fremont-Winema National Forest in Oregon. USDA Forest Service Photo.

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Contents

Figures

Tables

Executive Summary

Lands managed by the U.S. Department of Agriculture, Forest Service and U.S. Department of the Interior, Bureau of Land Management (BLM) contain more than 178 million acres of forest and provide a variety of ecological, social, Tribal, and economic values. Among these values are those provided by older forests, sometimes referred to as old-growth and mature forests. Neither of these terms, however, has been consistently defined, nor has their national extent on Forest Service or BLM lands been inventoried by these agencies previously.

This report is national in scale and presents initial estimates of old-growth and mature forests across all Forest Service and BLM lands. This report contains the first national inventory of old-growth and mature forests focused specifically on Forest Service and BLM lands and demonstrates that both old-growth and mature forests are generally widely distributed geographically and across land use allocations.

The definitions of old-growth and mature forests are presented in two forms. Narrative frameworks are descriptive, general definitions of old-growth and mature forests that can be used consistently across geographic scales and forest types. Working definitions provide detailed quantitative criteria, using measureable structural characteristics, that were applied to specific regions and forest types in this national-scale inventory.

Forest Service and BLM lands combined contain 32.7 +/- 0.4 million acres[1] of old-growth and 80.1 +/- 0.5 million acres of mature forest. Old-growth forest represents 18 percent and mature forest another 45 percent of all forested land managed by the two agencies. This initial national-scale inventory was conducted by applying the old-growth and mature working definitions to Forest Inventory and Analysis field plot data.

Like all the Nation's forests, old-growth and mature forests are threatened by climate change and associated stressors. The initial inventory and definitions for old-growth and mature forests are part of an overarching climate-informed strategy to enhance carbon sequestration and address climate-related impacts, including insects, disease, wildfire risk, and drought. Initial inventory results will be used to assess threats to these forests, which will allow consideration of appropriate climate-informed forest management, as required by subsequent sections of Executive Order 14072.

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[1] Sampling error at 68 percent confidence level.

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Introduction

Executive Order 14072 (also known as "Strengthening the Nation's Forests, Communities, and Local Economies") instructed the Department of the Interior, Bureau of Land Management (BLM) and U.S. Department of Agriculture (USDA), Forest Service to define and inventory old-growth and mature forest for lands managed by the agencies. The old-growth and mature definition, identification criteria, and resulting initial inventory reported here meet this direction and identify these forests in a consistent way at a national scale.

Executive Order 14072 is about fostering resilience in our forests in an era of rapidly changing climate. Likewise, it's about the critical role our forests play in slowing the pace of climate change and conserving biodiversity; it's about how forests help local communities thrive through recreation and forest management activities, including the sustainable forest products sector, and in enabling subsistence and cultural uses. The Executive order calls particular attention to the importance of old-growth and mature forests on Federal lands for the many benefits they provide, as well as their role in contributing to nature-based climate solutions by storing large amounts of carbon. These forests are also at risk from climate-related stressors and disturbances, potentially requiring climate-informed interventions to reduce these risks.

Federal public lands support a substantial amount of forest: lands managed by the BLM and the Forest Service have more than 178 million acres that meet the Forest Inventory and Analysis[2] (FIA) forest land definition: currently or recently having at least 10 percent canopy cover and at least 1 acre in size (Burrill et al. 2021). Old-growth and mature forests look dramatically different from coast-to-coast, State by State, and locally. For instance, old-growth sequoias in California can be thousands of years old and upwards of 250 feet tall with a 30-foot or greater trunk diameter, while an old-growth stand of dwarf pitch pine in New Jersey may include trees that are hundreds of years old, roughly 14 feet tall and only several inches in diameter. These differences underscore the complexity of defining old-growth and mature forest and the need for a set of definitions.

Tribes, stakeholders, and the public hold many different values for old-growth and mature forests. There are also key ecological processes and characteristics associated with different forests. Creating a framework that accounts for these diverse values and perspectives is challenging (Pesklevits 2011, Wirth et al. 2009). Additionally, the ecological literature contains definitions of mature forest only for a few forest types, and a universal definition of either old-growth or mature forests is difficult to create (Wirth et al. 2009). Tree age, size, and carbon storage capacity differ dramatically across old-growth and mature forest types depending on species, local ecosystems, site conditions, and more. Despite these challenges, a common understanding of which forests are old-growth or mature, and the extent of these forests on lands

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[2] The Forest Inventory and Analysis Program of the USDA Forest Service provides the information needed to assess America's forests (https://www.fia.fs.usda.gov/).

managed by the BLM and Forest Service, is the foundation for assessing the status, condition, and restoration needs to mitigate the effects of climate change.

Section 2(b) of Executive Order 14072 specifically addresses old-growth and mature forest definitions and inventory:

> **The Secretary of the Interior, with respect to public lands managed by the Bureau of Land Management, and the Secretary of Agriculture, with respect to National Forest System lands, shall, within 1 year of the date of this order, define, identify, and complete an inventory of old-growth and mature forests on Federal lands, accounting for regional and ecological variations, as appropriate, and shall make such inventory publicly available.**

The old-growth and mature definitions, identification criteria, and resulting initial inventory reported here meet this requirement and identify, at a national scale, the geographic extent and distribution of these forests. The initial inventory will then be used to assess threats to these forests, which will allow consideration of appropriate climate-informed forest management, as required by subsequent sections of the Executive order.

The Executive order discusses "mature and old-growth" forests, with mature coming before old-growth. However, this document discusses old-growth forests before mature forests, because people have long recognized unique old-growth values, and more definitions and local-scale inventories existed for old-growth forests prior to the Executive order. Mature forests have not previously been ecologically defined in a consistent way at a national scale, and in this effort, they are explicitly linked to corresponding old-growth definitions. Therefore, despite the mature forest stage occurring prior to the old-growth stage in terms of forest stand development, it makes sense to first introduce the reader to definitions for old-growth.

Results

Narrative Frameworks and Working Definitions

Despite the complex and multifaceted nature of old-growth and mature forests, the Forest Service and BLM are tasked with creating clear narratives and working definitions. It is expected that a continual adaptive management process will refine old-growth and mature forest definitions over time.

Narrative frameworks establish common definitions for old-growth and mature forests that can be used across forest types. They provide a consistent national framework that has stability and longevity, even as working definitions in specific forest types are refined over time.

Working definitions apply quantitative measurement criteria to structural characteristics and fit under the umbrella of the narrative frameworks, reflecting the diversity of forest development in unique forest types. Old-growth and mature working definitions for over 200 regional vegetation types can be viewed in appendix 1 and appendix 2.

Old-Growth Forest Narrative Framework

Old-growth forests are dynamic systems distinguished by old trees and related structural attributes. Old growth encompasses the later stages of stand development that typically differ from earlier stages in a variety of characteristics, which may include tree size, accumulations of large dead woody material, number of canopy layers, species composition, and ecosystem function (USDA Forest Service 1989).

In addition to their ecological attributes, old-growth forests are distinguished by their ecosystem services and social, cultural, and economic values. Old-growth forests have place-based meanings tied to cultural identity and heritage; local economies and ways of life; traditional and subsistence uses; aesthetic, spiritual, and recreational experiences; and Tribal and Indigenous histories, cultures, and practices. Dialogue with stakeholders and Tribal Nations and integration of local and Indigenous Knowledge[3] with evolving scientific understanding are critical in identifying and stewarding old-growth forests.

Mature Forest Narrative Framework

Mature forests are delineated ecologically as the stage of forest development immediately before old growth. Mature forests exhibit structural characteristics that are lacking in earlier stages of forest development and may contain some but not all the structural attributes in old-growth forests. The mature stage of stand development generally begins when a forest stand moves beyond self-thinning, starts to diversify in height and structure, and/or the understory begins to reinitiate. Structural characteristics that mark the transition from an immature to mature forest are unique to each forest type; they may include but are not limited to abundance of large trees, large tree stem diameter, stem diameter diversity, horizontal canopy openings or patchiness, aboveground biomass accumulation, stand height, presence of standing and/or downed boles, vertical canopy layers, or a combination of these attributes.

Mature forests vary widely in character with age, geographic location, climate, site productivity, relative sense of awe, characteristic disturbance regime, and the values people attribute to or receive from them. Dialogue with stakeholders and Tribal Nations and integration of local and Indigenous Knowledge with evolving scientific understanding are critical in effectively managing mature forests.

Working Definitions

The team developed working definitions (quantitative measurement criteria reflecting structural characteristics) that fit within the umbrella of the narrative frameworks. It is expected that a continual adaptive management process integrating new science, local conversations, and social processes will refine mature forest definitions over time, just as old-growth forest definitions have evolved over the past three decades. Working definitions have been applied to FIA data at national scale for the purpose of this initial national-level inventory. Further refinement may be necessary to apply working definitions at local scales due to diverse ecology, forest types, site

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[3] Indigenous Knowledge is a body of observations, oral and written knowledge, innovations, practices, and beliefs developed by Tribes and Indigenous Peoples through interaction and experience with the environment.

characteristics, and varied management contexts. Full old-growth and mature working definitions for over 200 unique forest vegetation types within each Forest Service region (hereafter, regional vegetation types) can be viewed in appendix 1 and appendix 2, respectively.

Old-growth and Mature Forest Initial Inventory Estimates

Old-growth and mature forests combined cover the majority of forest lands managed by the Forest Service and BLM forest lands. Between 30 and 40 percent of Forest Service and BLM forested areas are younger forest (forests not mature or old growth). Both old-growth and mature forests are distributed across land use allocations, with similar proportions in Congressionally designated areas as in other land use allocations (Table 1).

Table 1.—National total area (acres) of mature and old-growth forest land[a] on Forest Service and BLM lands, shown by Congressionally designated land use allocations. "Other" category includes all remaining land use allocations.

Agency & Land Use Allocation	Younger Forest *acres*	Younger Forest *SE%[b]*	Old Growth *acres*	Old Growth *SE%[b]*	Mature *acres*	Mature *SE%[b]*	Total Forest Land *acres*
Forest Service	**52,505,613**	**1**	**24,400,019**	**1**	**67,413,361**	**1**	**144,318,993**
Wilderness[c]	9,937,704	2	4,194,748	3	9,335,433	2	23,467,885
Inventoried Roadless Area	12,094,84	2	9,116,931	2	16,076,595	2	37,288,373
National Monument	243,552	15	88,470	26	212,917	15	544,938
Other	30,229,50	1	10,999,871	2	41,788,417	1	83,017,797
BLM	**13,212,751**	**2**	**8,258,370**	**3**	**12,698,776**	**2**	**34,169,897**
Wilderness	589,153	10	494,901	11	495,233	11	1,579,287
Wilderness Study Area	1,111,718	7	1,231,592	7	982,506	8	3,325,816
National Conservation Lands[c]	575,959	10	837,732	8	727,802	9	2,141,492
Other	10,935,92	2	5,694,145	4	10,493,235	3	27,123,302
Total BLM & Forest Service	**65,718,364**	**1**	**32,658,390**	**1**	**80,112,137**	**1**	**178,488,890**

[a] Forest land includes areas meeting the FIA forest land definition, https://www.fia.fs.usda.gov/. Sample area excludes 3.4 million acres of forested land managed by the Forest Service and 27.5 million acres of potentially forested land managed by the BLM in Alaska; permanent field plot monumentation is prohibited in Alaska. Forest Service wilderness areas and Interior Alaska have not yet been inventoried by FIA but are in progress for inclusion in future inventories.

[b] SE% is percent sampling error. Estimate plus and minus one sampling error gives a 68 percent confidence interval.

[c] Forest Service Wilderness includes both Wilderness and Wilderness Study Areas. National Conservation Lands include National Monument, National Conservation Area, and other similar designations, collectively referred to as NM/NCAs.

Although the iconic image of old-growth forest tends to be of moist forests that grow in highly productive coastal areas, extensive areas of old-growth forest occur in pinyon-juniper and other lower productivity forest types. Table 2 shows nationwide old-growth and mature area estimates for FIA forest type groups; the most extensive area of both old-growth and mature forests occurs in pinyon-juniper forests, followed by fir/spruce/mountain hemlock and Douglas-fir. Pinyon-juniper forest occurs on over 32 million acres of lands managed by the Forest Service and BLM, with over 9 million and 14 million acres of old-growth and mature forest, respectively. Pinyon-juniper forests cover diverse biophysical settings across the Western United States, with 10 distinct old-growth working definitions for this forest type group (appendix 1).

Table 2. Area (acres) of mature and old-growth forest land[a] by FIA forest type group, shown in alphabetical order. Combined total acres are shown for Forest Service and BLM forested lands.

FIA Forest Type Group	Younger Forest *acres*	Younger Forest *SE%[b]*	Old Growth *acres*	Old Growth *SE%[b]*	Mature *acres*	Mature *SE%[b]*	Total Forest Land *acres*
Alder/maple group	**261,505**	**10**	**29,974**	**29**	**105,242**	**19**	**396,720**
Aspen/birch group	**3,231,745**	**4**	**1,770,840**	**7**	**3,391,596**	**4**	**8,394,181**
California mixed conifer group	**1,207,106**	**7**	**952,582**	**8**	**2,998,424**	**4**	**5,158,112**
Douglas-fir group	**8,527,544**	**2**	**3,603,743**	**3**	**9,832,292**	**2**	**21,963,579**
Elm/ash/cottonwood group	**307,231**	**11**	**56,007**	**30**	**342,658**	**9**	**705,896**
Exotic softwoods group	**2,766**	**78**	**0**	**0**	**461**	**99**	**3,227**
Fir/spruce/mountain hemlock group	**7,891,108**	**2**	**7,291,903**	**3**	**13,248,240**	**2**	**28,431,252**
Hemlock/Sitka spruce group	**1,074,185**	**6**	**3,798,888**	**3**	**1,138,310**	**6**	**6,011,383**
Loblolly/shortleaf pine group	**1,393,124**	**5**	**38,211**	**32**	**2,042,821**	**3**	**3,474,155**
Lodgepole pine group	**3,633,316**	**3**	**1,147,142**	**7**	**6,520,603**	**3**	**11,301,062**
Longleaf/slash pine group	**532,953**	**7**	**138,918**	**15**	**529,552**	**7**	**1,201,424**
Maple/beech/birch group	**435,222**	**7**	**43,591**	**29**	**2,903,074**	**2**	**3,381,888**
Oak/gum/cypress group	**198,062**	**11**	**10,959**	**47**	**338,377**	**9**	**547,399**
Oak/hickory group	**1,795,135**	**4**	**890,287**	**6**	**6,040,503**	**2**	**8,725,925**
Oak/pine group	**605,030**	**7**	**94,621**	**18**	**1,279,550**	**5**	**1,979,201**
Other eastern softwoods group	**46,519**	**28**	**0**	**0**	**15,630**	**56**	**62,149**
Other hardwoods group	**504,810**	**9**	**33,623**	**35**	**183,747**	**15**	**722,180**
Other western softwoods group	**2,768,472**	**4**	**543,706**	**10**	**1,758,217**	**5**	**5,070,396**
Pinyon/juniper group	**8,155,699**	**3**	**9,123,484**	**2**	**14,863,446**	**2**	**32,142,628**
Ponderosa pine group	**4,632,836**	**3**	**1,388,256**	**5**	**6,450,428**	**2**	**12,471,520**
Redwood group	**0**	**0**	**9,876**	**75**	**11,819**	**65**	**21,695**
Spruce/fir group	**1,092,310**	**9**	**755,900**	**17**	**2,052,148**	**9**	**3,900,358**

FIA Forest Type Group	Younger Forest *acres*	Younger Forest *SE%[b]*	Old Growth *acres*	Old Growth *SE%[b]*	Mature *acres*	Mature *SE%[b]*	Total Forest Land *acres*
Tanoak/laurel group	**578,117**	**8**	**133,529**	**18**	**210,910**	**16**	**922,556**
Tropical hardwoods group	**12,131**	**61**	**5,628**	**105**	**0**	**0**	**17,759**
Western larch group	**809,060**	**8**	**152,832**	**17**	**207,384**	**12**	**1,169,276**
Western oak group	**2,315,411**	**4**	**17,197**	**56**	**872,005**	**8**	**3,204,613**
Western white pine group	**69,982**	**28**	**20,403**	**48**	**81,530**	**25**	**171,915**
White/red/jack pine group	**766,072**	**6**	**60,707**	**20**	**572,568**	**7**	**1,399,347**
Woodland hardwoods group	**4,198,427**	**4**	**545,584**	**10**	**2,120,600**	**5**	**6,864,611**
Nonstocked[c]	**8,672,486**	**2**	**0**	**0**	**0**	**0**	**8,672,486**
Total	**65,718,364**	**1**	**32,658,390**	**1**	**80,112,137**	**1**	**178,488,890**

[a] Forest land includes areas meeting the FIA forest land definition, https://www.fia.fs.usda.gov/. Sample area excludes 3.4 million acres of forested Forest Service land and 27.5 million acres of potentially forested BLM land in Alaska; permanent field plot monumentation is prohibited in Alaska. Forest Service wilderness areas and interior Alaska have not yet been inventoried by FIA but are in progress for inclusion in future inventories.

[b] SE% is percent sampling error. Estimate plus and minus one sampling error gives a 68 percent confidence interval.

[c] Nonstocked forest land is land that currently has less than 10 percent stocking but formerly met the definition of forest land. Forest conditions meeting this definition have few, if any, trees sampled.

Background

Old-Growth and Mature Forest Definition Chronology

Early attempts at defining old-growth forests date back to the 1940s, when the term old growth was used to differentiate slower growing, older forests from faster growing, younger forests. The idea was largely based on the diameter at breast height of the largest live trees. Discussions around what constitutes old growth expanded in the 1970s with a growing environmental movement (Wirth et al. 2009). By the late 1980s, the conversation around old-growth forest characteristics had developed sufficiently for adoption of a generic, forest-structure based definition to guide the Forest Service regions: "Old-growth forests are ecosystems distinguished by old trees and related structural attributes. Old growth encompasses the later stages of stand development that typically differ from younger stages in a variety of characteristics that may include tree size, accumulations of large dead woody material, number of canopy layers, species composition and ecosystem function" (USDA Forest Service 1989). The BLM also developed a similar broad description at that time but did not further refine definitions for local conditions in most States. Under the umbrella of this definition, the Forest Service developed more localized working definitions for old-growth forest, as did the BLM in western Oregon. These definitions have undergone review and revision in each of the Forest Service's nine regions, some more than others, over the past three decades and are expected to continue to do so. These definitions are considered dynamic, not static, and thus are subject to refinement as new information is incorporated (working definitions).

Current agency old-growth forest definitions are based on the unique biophysical characteristics within regions of the United States corresponding with agency management units (such as Forest Service regions). The definitions recognize that tree species, climate, soil productivity, and disturbance history all influence the development of old-growth forests. Therefore, regional definitions account for the vast variation in old-growth forest character that occurs across North America, and these definitions are specific to vegetation types because even within a specific geographic area, no one definition represents the diversity of old-growth ecosystems.

It is important to note that in many Forest Service regions, old-growth forest definitions have been used and improved upon for more than 30 years in the development of land management plans (LMPs). Each national forest and BLM district has a LMP governing its activities. The appropriate set of old-growth forest definitions has been used in developing the plan components for many LMPs.

Today, the discussion of older forests has expanded to include the stage of forest development preceding old growth, called mature forest. Concerns associated with a range of environmental threats led to a broader view of forest management that includes all stages of development (such as Swanson et al. 2012 and White House 2022). Although national definitions and initial inventory for mature forests are included in this report, further scientific development and refinement to better capture local diversity of geographic location, climate, site productivity, and characteristic disturbance regime is expected to improve mature definitions. As such, like old-growth definitions, mature forest definitions are considered working definitions.

Although the term "mature forest" as outlined in Executive Order 14072 is a relatively new concept for the Forest Service and BLM, many LMPs incorporate it in different terms when assessing forest successional, seral, or structural classes and natural range of variation. For example, the term late successional, used interchangeably with mature, is discussed and monitored in the Northwest Forest Plan (Davis et al. 2022). Applicable LMP direction constitutes current management direction for old-growth and mature forest. This definition and initial inventory effort does not change existing LMP management direction.

Old-Growth and Mature Forests Executive Actions and Legislation

Other congressional and Executive actions preceded Executive Order 14072 that signaled a desire for agencies to manage for resilient older forests. Notably, the 2021 Bipartisan Infrastructure Law (BIL; Infrastructure Investment and Jobs Act 2021) led the way in placing significant emphasis on establishing resilient landscapes, including large trees and old-growth stands, considering future climate conditions. BIL invested $5.5 billion over 5 years to tackle the Forest Service's most pressing issues, including the increased risk of wildland fire, ecosystem restoration, and the conservation of old-growth forests. Section 40803, Wildfire Risk Reduction, in the BIL directed Federal agencies to "maximize the retention of large trees, as appropriate for the forest type, to the extent that the trees promote fire-resilient stands" and prioritize projects based on several items, including projects "that fully maintain or contribute toward the restoration of the structure and composition of old growth stands consistent with the characteristics of that forest type, taking into account the contribution of the old growth stand to landscape fire adaption and watershed health."

Executive Order 14072, section 2b, signed on April 22, 2022, directed the Forest Service and BLM to develop mature and old-growth definitions and inventory on Federal lands by April 22, 2023. More broadly, the Executive order aims to accelerate reforestation, develop recommendations for community-led economic development opportunities, and develop policies to institutionalize these actions. It further promotes the continued health and resilience of our Nation's forests (including old-growth and mature forests) by retaining and enhancing carbon storage, conserving biodiversity, mitigating wildfire risks, enhancing climate resilience, enabling subsistence and cultural uses, providing outdoor recreational opportunities, and promoting sustainable local economic development.

Once the definitions and inventory are established, section 2c then calls on the Forest Service and BLM to:

- Coordinate conservation and wildfire risk reduction activities, including consideration of climate-informed stewardship of mature and old-growth forests, with other executive departments and agencies, States, Tribal Nations, and any private landowners who volunteer to participate;
- Analyze the threats to mature and old-growth forests on Federal lands, including from wildfires and climate change; and

- Develop policies, with robust opportunity for public comment, to institutionalize climate-informed management and conservation strategies that address threats to mature and old-growth forests on Federal lands.

Finally, on June 23, 2022, Department of Agriculture Secretary Tom Vilsack released the Secretary’s Memorandum on Climate Resilience and Carbon Stewardship of America's National Forests and Grasslands (Secretary’s Memorandum 1077-004). Emphasizing Executive Order 14072, the Secretary’s memo directs the Forest Service to undertake specific and time-bound actions so that data-informed policies, strategies, and actions are in place to provide for increased carbon stewardship and climate resilience on our national forests and grasslands.

Tribal, Stakeholder, and Public Perspective Considerations

Tribal and Public Engagement To Inform Agency Efforts

Recognizing the many values people hold related to old-growth and mature forests, the Forest Service and BLM created several opportunities to gather input from Tribes, the public, stakeholders, and agency employees. The Forest Service Office of Tribal Relations held a Tribal forum in the summer of 2022, during which Forest Service and BLM representatives shared information about the joint effort to define, identify, and inventory old-growth and mature forests on Federal land; discussed potential Tribal implications; and requested input on the definition and inventory process. The Forest Service also opened a Tribal consultation on December 23, 2022, to provide Tribal leaders with opportunities to inform subsequent phases of this effort, including the development of policy related to old-growth and mature forests. To gather public and stakeholder input, the U.S. Departments of Agriculture and the Interior jointly published a request for information (RFI) in a July 15, 2022, Federal Register notice seeking comments on the old-growth and mature forest definition and inventory process (87 FR 42493). In addition, both Departments held several virtual information sessions in the summer of 2022 that were targeted for stakeholders from industry, government, science, and conservation groups, as well as forest users, the general public, and agency employees. Additional engagement sessions were held in early 2023 to provide a progress update and request further feedback on the definition and inventory process.

In total, roughly 2,000 people attended the virtual engagement sessions, and the RFI public comment period resulted in over 4,000 comment letters, with 927 letters providing unique perspectives. In addition to public input, Forest Service and BLM employees submitted 118 unique letters. The project team coded all comments and identified the following 13 themes:

- Opposition to a single definition or framework to serve the needs for any future policy work;
- Suggest incorporating ecological integrity into the definition framework;
- Suggest 80 years old as a reasonable criterion for defining mature forests;
- Opposition to a definition that facilitates or promotes resource exploitation;
- Concern about the management implications of a definition and associated inventory;
- Suggest using existing definitions found in forest plans and resource management plans;
- Suggest measurable criteria at appropriate scales;

- Concern about the ability and accuracy associated with inventorying mature and old-growth forests;
- Concern with definition and inventory consistency with existing Federal statutes and mandates;
- Concern with using tree age as a definition for mature and old-growth forests;
- Concern regarding specific criteria for mature and old-growth forests;
- Concern that Tribal perspectives, Indigenous Knowledge, and social aspects (such as spirituality, sense of place, and recreation) are included in any definition; and
- Concern that definition and inventory not affect private lands.

The stakeholder, public, and Tribal input received through the RFI, engagement sessions, and Tribal forum informed decisions made by the project team and significantly shaped the definition and inventory of mature and old-growth forests in this effort.

Social, Economic, and Cultural Aspects of Older Forests

Input received through public comment, stakeholder engagement, and Tribal participation drew substantial attention to the diversity and depth of human relationships with older forests. These sentiments are reflected in the narrative frameworks developed to describe mature and old-growth forests in terms that will be durable working definitions of these ecosystems as they evolve over time, even when localized. Although the working definitions used in the current national-level inventory rely on measurable ecological characteristics, the narrative frameworks leave opportunities to integrate social, cultural, and economic values; a variety of ecosystem services; local and Indigenous Knowledge; and place-based meanings into the ways land managers define, identify, and steward old-growth and mature forests into the future.

Multiple conceptual frameworks developed to understand and communicate about human values and meanings might be applied to the management of older forests. For example, the concept of ecosystem services highlights the many ways that human life and well-being are tied to natural systems, from climate regulation and nutrient cycling to food provision and spiritual connection. Additional frameworks distinguish between the “use values” and “nonuse values” people hold for forests. While the concept of use values captures the importance of the forest resources humans actually use, such as timber, nontimber forest products, recreation, or tourism, nonuse values capture the value people attach to the mere existence of forests or the ability of future generations to experience them. The role of place attachment or identity, meaning “the symbolic importance of a place as a repository for emotions and relationships that give meaning and purpose to life” may also be particularly relevant in our understanding of how people relate to and value old-growth forests (Williams and Vaske 2003). Another important way of understanding and effectively managing old-growth forests is through traditional ecological knowledge, or Indigenous Knowledge, which Tribes and Indigenous communities have practiced for millennia (Hoagland 2017). The narrative frameworks included in this report prompt land managers to revisit their understanding of mature and old-growth forests as processes are refined for integrating these social, cultural, and economic perspectives into the policy and practice of forest management.

Definition Development

An old-growth and mature definition development team met in Washington, DC, in October 2022 to evaluate mature and old-growth forest definition options based on a combination of existing definitions and comments received. Nine major old-growth forest and seven mature definition approaches were evaluated; those shown in bold were recommended for further evaluation and potential collaborator coproduction, with the expectation that elements of the other approaches would be incorporated where possible.

Old-Growth Forest Definition Approaches:

1. **Current Forest Service region-by-region structural definitions;**
2. **Forest development/forest dynamics;**
3. **Remotely sensed forest structural diversity;**
4. **National criteria and inventory for mature forest, local definition, and inventory of old-growth forest;**
5. Desired condition framework for restoration based on disturbance dynamics;
6. Ecological and spiritual value framework—determine proxy ecological characteristics to reflect social and cultural values;
7. Wildlife habitat approach;
8. Carbon storage focus approach; and
9. 2012 Forest Service Planning Rule approach.

Mature Forest Definition Approaches:

1. **Structural complexity**
2. **Functional growth dynamics**
3. Multicohort
4. Dominant species lifespan histogram
5. Stage of maturity
6. Reproduction
7. Proportion of old-growth criteria met

The approaches brought forward were those most responsive to comment, but also potentially achievable within the timelines prescribed by Executive Order 14072.

A 15-member definition and inventory technical team (hereafter, team) formed in late fall under a charter that focused work on the definition and inventory efforts. The team consisted of scientists representing USDA Forest Service's National Forest System and Research and Development Deputy areas, including the FIA program, as well as the U.S. Department of the Interior's Bureau of Land Management and United States Geological Survey. The team's focus was to develop definitions and conduct initial inventory with a high level of ecological rigor while also considering the 4-month timeline required by the Executive order. The following principles guided development of old-growth and mature forests definitions and initial inventory on Federal land:

- Scientifically sound
- Objective and simple
- Metrics compatible across a spectrum of stand conditions
- Compatible with FIA plot data for all stand conditions
- Applicable across spatial scales and Federal jurisdictions
- Consider public input gathered through engagement sessions and formal request for information
- Operational to meet the April 22, 2023, Executive Order 14072 deadline

The structural characteristics approach was ultimately chosen for the old-growth and mature forest inventory; it refers to measurable structural characteristics such as tree size and the presence or distribution of snags. The structural approach was chosen because it is consistent with Forest Service old-growth definitions developed over three decades, it is well documented in scientific literature, and it is readily interpretable by resource managers across scales. Elements of many approaches are indirectly included in the structural approach or are highly correlated with old forest structures. For example, the narrative framework explicitly identifies Tribal and social values in addition to ecological components as important for identifying old growth. The structural approach also applies unique criteria to define mature and old-growth forest within regional vegetation types that capture different disturbance regimes and productivity levels.

Old-Growth Definition Development

As previously described, the agencies decided in late fall to apply existing structural old-growth definitions as currently maintained by each Forest Service region (Beardsley and Warbington 1996; Boughton 1992a, 1992b; Davis et al. 2022; Gaines 1997; Green 1992; Hamilton 1993; Mehl 1992; Tyrell 1998; USDA Forest Service 1993, 2019). While each Forest Service region's definitions were first developed in the early 1990s in response to then Forest Service Chief Dale Robertson's 1989 letter, many have been refined over the past three decades. Forest Service regions vary in their use and refinement of old-growth definitions. Many definitions have been incorporated into Forest Service LMPs and therefore benefit from some public review. Public comments from many external and internal sources recommended using existing definitions. Retaining existing definitions for old growth allows for consistency with existing LMPs and uses structural characteristics that have been vetted for use by resource managers at multiple scales and using standard field protocols such as common stand exam.

Detailed methods for how regional old-growth definitions were applied to the FIA data for the initial national old-growth inventory are being outlined in Pelz et al. (in preparation). The team worked with Forest Service regional staff to determine how to apply regional definition criteria to FIA field plot data for this initial national-scale inventory. All of the regional old-growth definitions employ structural characteristics and include an attribute that captures abundance of large trees (minimum live trees per acre of a minimum size and/or minimum basal area of live trees). Many of the regional definitions also set a minimum stand age or tree age, and some definitions include standing snags or downed wood. Each region recognizes important ecological variation by defining unique old-growth criteria for vegetation types. Tables listing the old-growth definitions applied to FIA data by region can be found in appendix 1.

While the old forest estimation effort that began prior to Executive Order 14072 originally included only lands managed by the Forest Service, regional definitions for old growth have been applied to lands managed by the BLM for the initial inventory directed by the Executive order. This decision was made because most BLM units do not have specific old-growth definitions. Definitions were applied to each FIA plot on lands managed by the BLM based on the geographic footprint of the Forest Service region that each BLM field plot falls within. For example, the BLM California State Office contains FIA plots falling within the Forest Service's Southwestern, Intermountain, and Pacific Southwest Regions.

Mature Forest Definition Development

The concept of ecologically mature forest has been extensively discussed in terms of ecological processes but not objectively defined in terms of explicit forest attributes in the scientific literature. While some examples for mature forest definitions exist (Davis et al. 2022, Franklin et al. 2002, Pabst et al 2005), they are mainly limited to the Pacific Northwest. Silvicultural practice often refers to economic maturity using the culmination of mean annual increment (CMAI), defined as the age at which merchantable tree volume reaches a peak or plateau in most even-aged stands. Many LMPs for individual national forests contain tables that refer to stand age of CMAI for specific forest types and site productivity classes; these may be used to calculate maximum sustained yield as required by the 1976 National Forest Management Act. While CMAI has practical application for production forestry, it is not easily applied to forest types that are not managed for timber production or to uneven aged management for conservation and restoration goals applied on Federal lands. Therefore, the team interpreted the Executive order direction to inventory mature forest ecologically rather than economically.

While ecological maturity is not well defined for the myriad of forest types across the United States, several well-known models of forest stand development frame this concept. Franklin et al. (2002) decribe seven stages of stand development for Douglas-fir forests, including a maturation stage and three distinct phases within old growth. Oliver and Larson (1996) and Bormann and Likens (1979) present well-cited models that describe four stages of forest stand development after severe disturbance: stand initiation, stem exclusion, understory reinitiation, and old growth. This four stage model was generally developed for productive forest types subject to infrequent yet high-severity fire. However, without more nuanced models for site-limited and frequent disturbance forest types that could be applied nationwide, the team chose to apply the four stage model to identify the mature forest stage (Figure 1).

In applying this model for the purpose of these definitions and initial inventory, the term mature forest is defined as the entire stage of stand development from understory reinitiation to onset of old growth.

Given the 4-month timeline to develop detailed mature forest definitions and conduct an initial inventory, the team completed a rapid inquiry and relied on several basic assumptions when creating initial definitions. These mature definitions are considered working definitions, and further refinement is expected to improve them over time, as old-growth definitions have evolved over the past three decades.

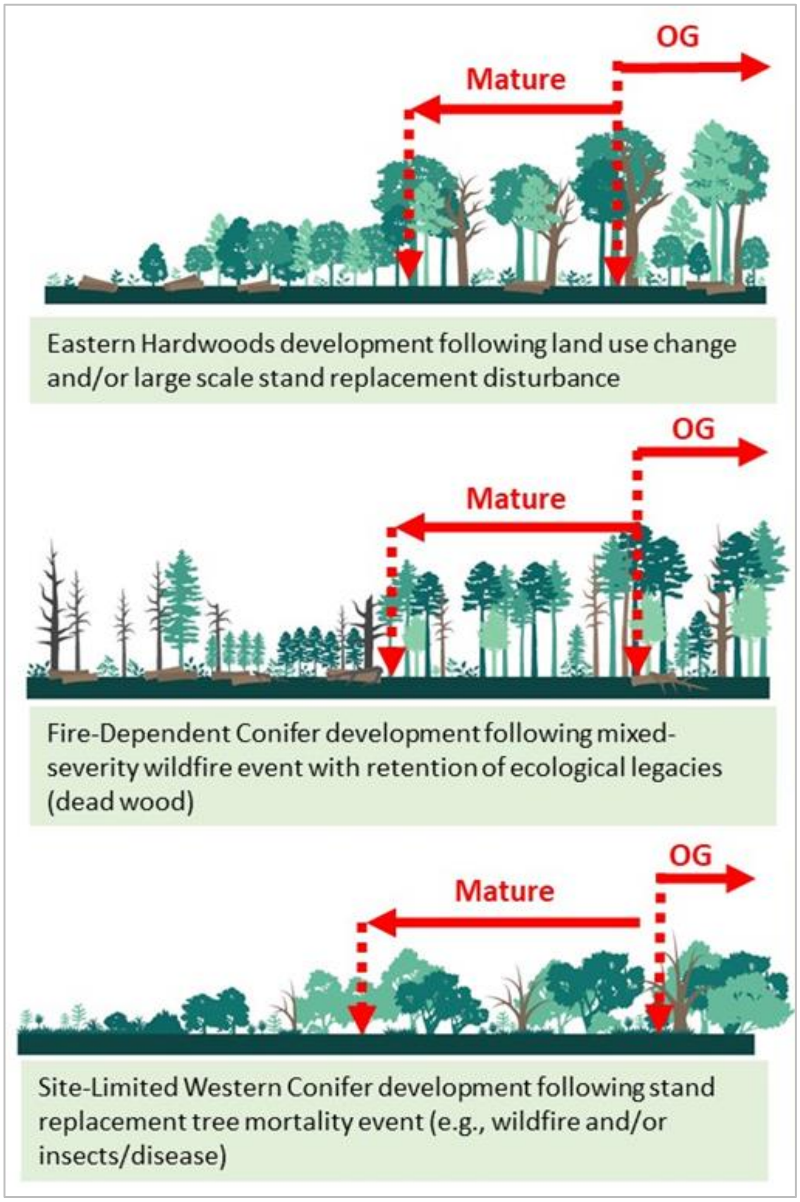

Figure 1.—Four-stage forest development model for several ecosystem archetype examples. Adapted from Woodall et al (in preparation).

Pesklevits et al. (2011) and Gray et al. (in preparation) describe many of the difficulties and inherent contradictions that scientists have faced when attempting to define and inventory old-growth and mature forests. The team encountered similar challenges when developing definitions that would provide a robust and repeatable initial national-scale inventory while also capturing enough variation in forest type, disturbance regime, and productivity level to be relevant at regional scales. Using the principles outlined above, the team explored several options for how structural characteristics could be applied to define mature forests. Key concepts the team considered included how different forest productivity levels and disturbance regimes could be accounted for, which structural characteristics were most indicative of the onset of ecological maturity in different forest types (for example canopy gaps, diameter diversity, or height diversity to indicate understory reinitiation, or an inflection point in height growth). The team also considered whether the structural indicators used in old-growth definitions would be indicative of the mature stage.

FIGSS Method for Mature Forest Definitions

The Forest Inventory Growth Stage System (FIGSS) (Woodall et al., in preparation) uses the FIA condition records from individual FIA plots (hereafter, FIA records) classified as old growth based on Forest Service regional old-growth definitions to inform inverse modeling of the prior mature growth stage's structural thresholds (see Figure 1). FIGSS identifies unique structural indicators (

Table 3) for 80 regional vegetation types based on their correlation with stand age. Of more than 200 regional vegetation types used in old-growth definitions, types with fewer than 10 old-growth FIA records were grouped to allow modeling of structural indicators. This affected 2.9 percent of the 49,153 FIA records used in the analysis. For each regional vegetation type, all FIA records classified as old growth are used to estimate the 25th percentile of each indicator. This estimate is then “walked down” to approximate the onset of maturity (such as structural conditions) via the use of carbon accumulation curves (Barnett et al. 2023) and maximum physiological ages as part of a composite index as the lower threshold of old-growth forest characteristics.

Carbon accumulation curves (Barnett et al. 2023) and maximum physiological ages (MAXMORT; Loehle 1988; Supplementary Table S3) are used to estimate the proportion of time from maturity to mortality for each vegetation type. This proportion is used as the “walkdown factor” from the lower threshold of old growth to the onset of mature characteristics for each structural indicator (for example inverse modeling paradigm). Each structural indicator also receives a correlation weighted composite index to determine its relative weight in classification as mature (Figure 2). Resulting working definitions for mature forest are shown in appendix 2.

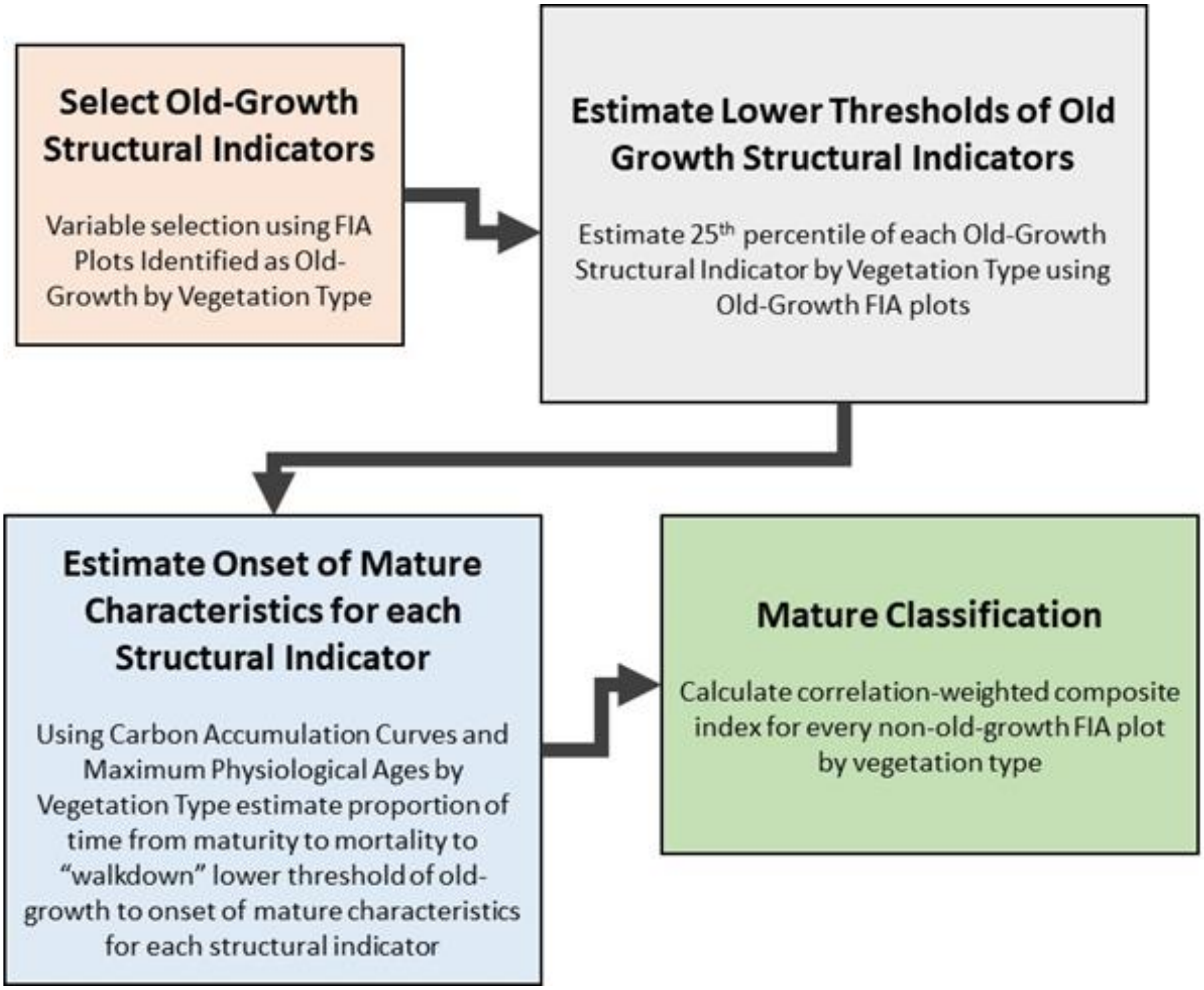

Figure 2.—Fundamental components of the FIGSS approach (Woodall et al. in preparation) include selecting old-growth structural indicators that are used to identify the lower thresholds of old-growth attributes, then using a walkdown factor to identify the onset of mature forest conditions. The definitions are then applied non-old-growth plots to classify mature forest.

Table 3.—Structural indicator variables used in mature forest definitions. Structural indicators were selected from 36 potential FIA attributes based on their ecological relevance to forest stand development, scalability from old-growth to mature developmental stages for identifying classification thresholds, minimal multicollinearity between indicators, and ability to measure indicators in the field at various scales.

Variable	Description	Ecological Significance	Calculation from Field Data
tpadom	Density of dominant or codominant live trees ≥1-inch DBH	Abundance of large trees in the upper layers of the canopy serve to indicate the stage of stand development	Sum of live trees per acre, where diameter ≥1 inches and crown class code (CCLCD) is 1,2, or 3.
badom	Total basal area of dominant or codominant live trees ≥1-inch DBH (ft^2/ac)	Indicates the site occupancy of the dominant, large trees in a stand	Sum of basal area for live dominant trees (crown class code 1,2, or 3) from the FIA tree table. BA= tpa_unadj*3.141593*(dia/24)*2
QMDdom	Quadratic mean diameter of all dominant and codominant trees (in)	The average size of trees that dominate the canopy is highly correlated with stand development as dominant trees in the stand continue to add diameter growth as they age	QMD_DOM = √((BA_DOM / (TPA_DOM* 0.005454)))
ddiscore	Diameter diversity index. DDI is a measure of the structural diversity of a forest stand, based on tree densities in different DBH classes.	The variation in tree size in a stand is an indicator of cohorts developing over time and differentiation of tree sizes in the canopy	Calculate the 4 TPA classes: Class_0 = 2–9.8 inches DBH Class_1 = 9.9–19.7 inches DBH Class_2 = 19.8–39.4 inches DBH Class_3 = 39.5+ inches DBH Calculate index values from TPA classes, then calculate DDI from index values. https://lemma.forestry.oregonstate.edu/data/structure-maps
HTquart	Mean height of tallest 25% of trees (TPA-weighted) (ft)	Height development in a stand indicates stage of stand development	Calculated from HT for all live trees from the FIA tree table, weighted by tpa_unadj.
HTsd	Standard deviation of height of all trees (TPA-weighted) (ft)	The variation in tree height in a stand is an indicator of extended periods of stand development and differentiation of tree sizes in the canopy	Calculated from HT for all live trees from the FIA tree table, weighted by tpa_unadj.
snagbatot	Total basal area of standing dead trees (ft^2/ac)	Dead wood resources can indicate stand development processes such as self-thinning and/or disturbance related tree mortality	Sum of basal area for all standing dead trees from the FIA tree table. BA= tpa_unadj*3.141593*(dia/24)*2

BA = basal area; DBH = diameter at breast height; HT = height; QMD = quadratic mean diameter; TPA = trees per acre

The mature forest working definitions developed using FIGSS (appendix 2) were applied to all non-old-growth FIA records to classify each as mature forest or not. When an FIA record's composite index was greater than 0.5 it was classified as mature. All analyses were conducted in R (R Core Team 2022) using base-R. Detailed information about the FIGSS approach, assumptions, and limitations will be described in Woodall et al. (in preparation).

Estimation

The initial inventory relies on the FIA field plot network, which is the primary source for information about the extent, condition, status, and trends of forest resources across the United States (Oswalt et al. 2019). The FIA program applies a nationally consistent sampling protocol using a systematic design covering all ownerships across the United States with a national sample intensity of approximately one plot per 6,000 acres (Bechtold and Patterson 2005). All data used in the intital inventory are available in the public FIA database (https://apps.fs.usda.gov/fia/datamart/datamart.html), with the exception of several geospatial layers (Table 4). Estimates used data from the most recent FIA cycle for each State as of December 2022 (see appendix 3; Burrill et al. 2021). It is important to note that any inventory represents a snapshot in time and presents the existing condition at the date of the field data collection. Initial inventory results provide information about the status of old-growth and mature forests; they do not present any information about their sustainability, climate-informed management, or desired conditions for any given forst type or location.

Each Forest Service and BLM FIA record was assigned a singular classification of old-growth, mature, or younger forest. All FIA records with nonstocked FIA forest type were assigned to the younger forest class as those conditions do not meet the definitions of old growth or mature presented in this document. All reported forest area estimates were computed using the standard FIA estimation procedure (Bechtold and Patterson 2005). Note that sampling error should be considered alongside estimates; some vegetation types or firesheds that contain small amounts of forested lands managed by the Forest Service or BLM have large sampling errors.

Table 4. Geospatial layers used to attribute FIA plots for inventory reporting. FIA spatial data services staff completed spatial overlay to overlay exact plot locations while maintaining plot location confidentiality.

Attribute	Geospatial Data Source
Fireshed	https://www.fs.usda.gov/research/rmrs/projects/firesheds Firesheds in Alaska were included based on a draft layer developed by the Rocky Mountain Research Station team and used with permission.
BLM Administrative Unit	https://gbp-blm-egis.hub.arcgis.com/datasets/blm-national-administrative-unit-boundary-polygons-and-office-points-national-geospatial-data-asset-ngda-1
BLM Wilderness	https://gbp-blm-egis.hub.arcgis.com/maps/blm-natl-nlcs-wilderness-areas-polygons

Attribute	Geospatial Data Source
BLM Wilderness Study Area	https://gbp-blm-egis.hub.arcgis.com/maps/blm-natl-nlcs-wilderness-study-areas-polygons
BLM National Conservation Areas	https://gbp-blm-egis.hub.arcgis.com/maps/blm-natl-nlcs-national-monuments-national-conservation-areas-polygons
USDA Forest Service Wilderness	USDA Forest Service FSGeodata Clearinghouse - Download National Datasets National Wilderness Areas
USDA Forest Service National Monument and Wilderness Study Areas	USDA Forest Service FSGeodata Clearinghouse - Download National Datasets National Forest Lands with Nationally Designated Management or Use Limitations
USDA Forest Service Inventoried Roadless Area	USDA Forest Service FSGeodata Clearinghouse - Download National Datasets Roadless Areas: 2001 Roadless Rule

Discussion

Context and Relation to Other Estimates

This report contains the first national inventory of old-growth and mature forests focused specifically on lands managed by the Forest Service and BLM. It demonstrates that old-growth and mature forests are generally widely distributed geographically and across land use allocations, with old-growth covering 18 percent and mature forest covering 45 percent of forested lands managed by the Forest Service and BLM. The structural approach presented here is consistent with the way the Forest Service administrative regions have been defining and communicating old-growth forest for the past 30 years, and it is easily applied across spatial scales, which is desirable in coordinating actions within land management agencies.

The Federal initial inventory results differ substantially from those reported by two studies published while Federal definitions were being developed (DellaSala et al. 2022, Barnett et al. 2023). Part of this difference is scale: other publications report estimates of old-growth and mature forest across all ownerships in the 48 contiguous States, including estimates for lands managed by the Forest Service and BLM. By contrast, the Federal estimate of old-growth and mature forest includes inventoried portions of Alaska, which contains large amounts of BLM and Forest Service-managed land. Those differences aside, the Federal estimate is larger than DellaSala et al. (2022) and Barnett et al. (2023) when compared at equivalent scale (lands in the contiguous United States managed by the BLM and Forest Service) and combining both old-growth and mature forest: more than 104 million acres as compared to 53 million acres and 59 million acres respectively. This outcome is not surprising given the differing goals and methodologies of the three inventories. It is worth noting that the ratios of mature to old growth estimated by Barnett et al. (2023) and this report (Woodall et al. in preparation) are virtually identical (ratio = 2.4).

Disparities among various estimates also arise based on the datasets used and classification of forest types. The Federal approach applies existing definitions based on structural characteristics for old-growth forest types to FIA data. Barnett et al. (2023) also used FIA data but classified old-growth and mature forest based on the pattern of biomass accumulation. DellaSala et al. (2022) developed their classification based on remotely sensed data, emphasizing tall, high-biomass, and closed-canopy forests. The Federal approach stratifies forest into 200 regional vegetation types; the finer resolution of forest types results in an inventory accommodating greater variation in the expression of old-growth and mature forest characteristics, especially in low productivity types.

Appropriate Use of Data

This initial inventory report is national in scale and presents estimates of old-growth and mature forests across all lands managed by the Forest Service and BLM. In preparing this report, published scientific literature was reviewed and scientists were consulted to understand the current work in this area and to get technical assistance in providing what was needed to respond to Executive Order 14072. Some cited references (e.g., "in preparation" notations) have not yet undergone scientific peer review and are therefore subject to change. Applicable Forest Service and BLM land management plan direction constitutes current management direction for old-growth and mature forests on individual management units. This definition and initial inventory effort does not change existing LMP management direction. It is expected that a continual adaptive management process integrating new science, local conversations, and social processes will refine old-growth and mature forest working definitions over time.

Although there is interest in a high-resolution spatial representation of old-growth and mature forest, this was not achievable with a rapid, national-scale inventory based solely on FIA field plot data. The national FIA sample was designed to provide national- and regional-scale estimates that can be used to inform resource management questions (Oswalt et al. 2019). Application of FIA estimates for small areas (with few sample plots) can result in substantial uncertainty as indicated by large sampling error. Some of the FIA forest type groups (redwood, exotic softwoods, and tropical hardwoods) presented in this report contain only small amounts of forested Federal land and should be used with caution.

The importance of spatial scaling in ecology and land management is well recognized (e.g., Schneider 2001, Turner et al. 1993, and Wiens 1989). Application of the national inventory results at fine spatial extents is not appropriate.

Applying working definitions to field reconnaissance of individual stands: Foundational descriptions of old-growth forest in general technical reports may discuss supplementary indicators not included in appendix 1. Some Forest Service regions have operationalized additional indicators to describe old-growth quality of individual stands (such as Green et al. 1992, errata 2011).

Direct application of the working definitions in appendix 1 and appendix 2 should be preceded by evaluation of the indicators and thresholds which were selected to apply to FIA data at national scale. Appropriateness of structural indicators and thresholds for mature forest had not been tested for regional vegetation types at local levels.

It is expected that a continual adaptive management process integrating new science, local conversations, and social processes will refine old-growth and mature forest working definitions over time.

The remeasurement cycle for FIA plots is 10 years in the Western United States and 5–7 years in the Eastern United States. These estimates are based on the most recent available data measured; appendix 3 provides the ranges in dates for each State. Growth of trees as well as disturbances such as fires, harvest, and insects may have affected the trees on an FIA plot after measurement and the subsequent changes are not reflected in these estimates. For example, wildfire impacts in California since 2020 are not captured in these estimates. It is important to consider that any sample of current forest condition reflects existing vegetation rather than historical or potential vegetation structure and composition.

Assumptions and Limitations

Any inventory of old-growth forest is based on a definition of old growth that represents human values; old growth is a social, cultural, and ecological concept (e.g., Wirth et al. 2009). While old-growth and mature forests are difficult to classify, there is value in defining and identifying older forests that have unique qualities and management needs. Some limitations of the data and methods are outlined here to provide a framework for improvement in future inventories.

Stages of Stand Development

The four-stage stand development model (stand initiation, stem exclusion, understory reinitiation, and old growth) assumes mature forest upper and lower thresholds are based on the typical progression of forests on productive sites (for example, not limited by soil moisture, nutrients, or depth) after a severe disturbance. Not all stands follow four development stages in smooth progression. For example, stands affected by frequent low- to moderate-severity disturbance (such as frequent fires or insect and disease outbreaks) may contain individual trees or clumps of trees that cycle between intermediate stages for centuries (standing dead trees and/or old living trees of low abundance). While these stands generally follow the four stages of development, progressing from seedling to old growth, the period spent in each stage varies and setbacks to earlier stages may occur due to site limitations (moisture, substrate, or climate) or intermediate disturbances, making the stand origin or endpoint difficult to determine (e.g., Franklin et al. 2007, Palik et al. 2020).

FIA Limitations for Old-Growth and Mature Inventory

FIA is a national- and regional-level strategic inventory that provides unbiased estimates of forest attributes over large areas by sampling forests systematically (approximately one plot per 6,000 acres). While the FIA design effectively samples variation in forest composition and structure regionally, rare vegetation types are captured less precisely. Classification error decreases with increasing plot size and increasing density of the attribute being estimated (Azuma and Monleon 2011). Classification errors of old-growth or mature forest for this national-scale inventory have not been tested. Furthermore, our use of FIA stand age is imperfect; stand age is straight-forward for young, even-aged forests; for older stands with multiple cohorts or uneven-aged stands, stand age may not correspond to the time since the last major disturbance (Stevens et al. 2016). Old-growth and mature forests are known to contain trees of varying ages.

Refinements and Opportunities for Future Research

Old-growth and mature forests defined here are grounded in a narrative framework based on measurable structural characteristics, with the acknowledgement that old-growth and mature forests also have cultural, Indigenous, functional, historic, carbon capture and storage, economic, wildlife, and recreational values. Understanding how older forests are valued and viewed by different stakeholders is an essential part of developing conservation strategies that are both equitable and durable. Because these values and the ecological elements differ, local dialogue will be required to improve the inventory over time.

Forest Service regional old-growth working definitions may be updated in the future during planning processes. Mature forest working definitions are also expected to be refined. Woodall et al. (in preparation) identify refinements for the FIGSS mature model, including enhanced sampling strategies for rare conditions, review of structural indicators, and analysis of thresholds used to identify old-growth and mature forests. FIGSS, which is currently based on structural attributes, has potential to assess old-growth and mature forest systems using alternative approaches such as carbon, Indigenous Knowledge, wildlife habitat, or risk profiles.

The addition of remotely sensed data and modeling is expected to improve the spatial resolution of old-growth and mature forest inventory and provide a faster data update cycle that will be useful in long-term monitoring. The FIA BIGMAP project is one example of a model that uses FIA plot data combined with other information, including satellite imagery, ecological ordination, spatial modeling, and powerful computing to calculate finely scaled maps of forest attributes (Bell et al. 2022). Emerging datasets and techniques such as lidar (Jarron et al. 2020, Dubayah et al. 2020), synthetic aperture radar (SAR) (Adeli et al. 2021), and fusion of lidar and SAR (e.g., Silva et al. 2021) could enhance the spatial resolution of current estimates. Work to incorporate remotely sensed data is ongoing, but further quality assurance is required prior to incorporating it into the inventory. As processes are refined it is likely that a hybrid approach using field plots combined with remotely sensed data will improve the spatial resolution and temporal relevance of old-growth and mature estimates.

Next Steps

This initial inventory represents the current condition of forests managed by the Forest Service and BLM at the time of the most recent FIA measurement; it does not provide any information on resilience or climate response of these forests. Some old-growth and mature forests may be ecologically resilient while others may be at risk of catastrophic loss. The team plans to apply working definitions for old-growth and mature forest to prior FIA data, which will inform how these forests have changed over the past 10–20 years. In addition, the team will explore how old-growth and mature forests are distributed in additional land use allocations that are currently grouped into the "other" category.

Forests are dynamic systems that will change over time. Both congressional (BIL) and Executive directives mandate the Forest Service and BLM identify sustainable 21st century forest conditions. Indeed, Executive Order 14072 section 2c and USDA Secretarial Memo 1077-004 provide some clarity on next steps following the initial classification presented here. Next steps identified in the Executive order and Secretarial memo include:

- Identify threats to old-growth and mature forests on Federal lands from wildfires, insects and disease, drought, invasive species, and other 21st century stressors.
- Develop strategies to recruit, sustain, and restore old-growth and mature forests that are at risk from acute and chronic disturbances, often amplified by climate change.
- Advance policy-level guidance to address climate-informed management of old-growth and mature forests on Federal lands.
- Further develop guidance on how old-growth and mature forests can be managed to conserve biodiversity, provide recreational opportunities, promote and sustain local economic development, and enable subsistence and cultural uses.
- Provide new guidelines for carbon stewardship while also addressing the multiple objectives stated above.

Strategies to recruit, sustain, and restore old-growth and mature forests that are at risk, as called for in Executive Order 14072 section 2c, will need to support conditions that facilitate the sustainability of older forests. The fire exclusion era allowed some forests to develop fuels and stocking levels that put them at risk for catastrophic loss from high-intensity wildfire, severe insect epidemics, and unnatural shifts in forest species composition. Wildfire risk reduction strategies in identified firesheds can be compatible with restoring and conserving these at-risk forests.

Finally, it should be recognized that many of the old-growth forests of today developed under different climate and disturbance regimes. Executive Order 14072 calls for the Forest Service and BLM to recruit, sustain, and restore old-growth and mature forests, albeit more adapted to 21st century conditions. That will require climate-informed management and potentially novel treatments, embracing different perspectives and redoubling efforts to work with partners and stakeholders. Inherent in this approach are both adaptive management and scenario planning methods of continued learning by collecting and analyzing well-designed monitoring data (including from remote sensing), considering alternative future conditions, and sharing those results with managers, policy makers, and many stakeholders.

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Appendix 1: Old-Growth Working Definitions

Existing old-growth definitions for each Forest Service region were applied to FIA data for the national-scale inventory using the criteria listed below. These criteria constitute working definitions as used in this report.

Northern Region (Region 1)

Northern Region minimum criteria for old growth from “Old-Growth Forest Types of the Northern Region” (Green et al. 1992, errata 2011) were applied to FIA data for the national inventory. For a given old-growth forest type and habitat type group, in each of three geographic areas, there must be a minimum number of live trees per acre meeting age and diameter at breast height (DBH) thresholds, and a minimum basal area (square feet per acre of live trees greater than or equal to 5-inches DBH) in order to be considered old growth (tables 5–7). Further details on Northern Region old growth definitions, including how forest types and habitat type groups are determined, are available in Green et al. (1992, errata 2011). Old growth associated characteristics, such as variation in diameters, decay measures (dead/broken tops or bole decay), canopy layers, and standing and downed dead wood, which are additional attributes not required as minimum criteria, were not included in the national inventory. The presence and quality of these associated characteristics depends on forest type, biophysical setting, and disturbance regime(s).

Table 5.—Northern Region old-growth forest types and minimum criteria thresholds for old-growth status for the Northern Idaho Zone

Old-growth forest type	Habitat type group	Large tree age (years)	Large tree density (trees ac^{-1}) and DBH (in)	Basal area (ft^2 ac^{-1})
1 - Ponderosa pine (PP), Douglas-fir (DF), Western larch (L)	A, B	150	8 ≥ 21”	40
2- Lodgepole pine (LP)	B, C, D, E, G, H, I, J, K	120	10 ≥ 13”	60
3 - Pacific yew (Y)	C, C1, G1	150	3 ≥ 21”	80
4A - DF, Grand fir (GF), L, Engelmann spruce/subalpine fir (SAF), Western white pine (WP), PP	C, C1, D, E	150	10 ≥ 21”	80
4B - DF, GF, L, Western hemlock (WH), WP, PP	F, G, G1, H, I	150	10 ≥ 21”	120/80[a]
5 – SAF, Mountain hemlock/alpine larch/subalpine fir (MAF)	F, G, G1, H, I	150	10 ≥ 17”	80
6 – Whitebark pine (WBP)	I, J, K	150	5 ≥ 13”	60/40[b]
7 – Western redcedar (C)	F, G, G1	150	10 ≥ 25”[c]	120

Old-growth forest type	Habitat type group	Large tree age (years)	Large tree density (trees ac^{-1}) and DBH (in)	Basal area (ft^2 ac^{-1})
8 – DF, L, SAF, MAF, WP	J	150	10 ≥ 17”	60
9 – SAF, MAF	K	150	5 ≥ 13”	40

[a] In old growth type 4B, 120 ft^2 ac^{-1} basal area applies to habitat type groups F, G, and G1; 80 applies to habitat type groups H and I.

[b] In old growth type 6, 60 ft^2 of basal area applies to habitat type groups I and J, and 40 ft^2 applies to habitat type group K.

[c] In old growth type 7, the 25” minimum DBH only applies to cedar trees; old trees of other species are evaluated with a minimum DBH appropriate for that species on these habitat types (21” for DF, GF, L, WH, WP, PP; and 17” for SAF, MAF).

Table 6.—Northern Region old-growth forest types and minimum criteria thresholds for old-growth status for the Western Montana Zone

Old-growth forest type	Habitat type group	Large tree age (years)	Large tree density (trees ac^{-1}) and DBH (in)	Basal area (ft^2 ac^{-1})
1 - Ponderosa pine (PP), Douglas-fir (DF), Western larch (L), Grand fir (GF), Lodgepole pine (LP)	A, B	170	8 ≥ 21”	60
2 - DF, L, PP, Engelmann spruce/subalpine fir (SAF), GF	C	170	8 ≥ 21”	80
3 - LP	C, D, E, F, G, H	140	10 ≥ 13”	60/70/80[a]
4 -SAF, DF, GF, Western redcedar (C), L, Mountain hemlock/subalpine fir (MAF), PP, Western white pine (WP), Western hemlock (WH), combinations of alpine larch/whitebark pine/limber pine (WSL)	D, E, F	180	10 ≥ 21”	80
5 - SAF, DF, GF, L, MAF, PP, WP, WSL	G, H	180	10 ≥ 17”	70/80[b]
6 - SAF, WSL, DF, L	I	180	10 ≥ 13”	60
7 - LP	I	140	30 ≥ 9”	70
8 - SAF, WSL	J	180	20 ≥ 13”	80

[a] In old growth type 3, 60 ft^2 applies to habitat type group E for LP; 70 ft^2 of basal area applies to habitat type group C for LP and habitat type group H for ES, AF, WBP; 80 ft^2 of basal area applies to all others.

[b] In old growth type 5, 70 ft^2 applies to habitat type group H for SAF; 80 ft^2 of basal area applies to all others.

Table 7. Northern Region old-growth forest types and minimum criteria thresholds for old-growth status for the Eastern Montana Zone

Old-growth forest type	Habitat type group	Large tree age (years)	Large tree density (trees ac^{-1}) and DBH (in)	Basal area (ft^2 ac^{-1})
1 – Douglas-fir (DF)	A	200	4 ≥ 17”	60
2 – DF	B, C, D, E, F, H	200	5 ≥ 19”	60
3 – DF	G	180	10 ≥ 17”	80
4 – Ponderosa pine (PP)	A, B, C, K	180	4 ≥ 17”	40
5 – Limber Pine (PF)	A, B	120	6 ≥ 9”	50
6 – Lodgepole pine (LP)	A, B, C, D, E, F, G, H, I	150	12 ≥ 10”	50
7 – Engelmann spruce/subalpine fir (SAF)	C	160	12 ≥ 17”	80
8 – SAF	D, E	160	7 ≥ 17”	80
9 – SAF	F, G, H, I	160	10 ≥ 13”	60
10 – SAF	J	135	8 ≥ 13”	40
11 – Whitebark pine (WBP)	D, E, F, G, H, I	150	11 ≥ 13”	60
12 – WBP	J	135	7 ≥ 13”	40

Rocky Mountain Region (Region 2)

The Rocky Mountain Region provided current definitions for old growth based on Mehl (1992). These definitions, with limited modification based on current individual land management plans, were used as the foundation for the region’s old-growth criteria. Stands had to have a certain number of trees per acre over a threshold size and estimated age, a certain number of trees with cull or broken or dead tops, and a certain number of dead trees more than 10 inches diameter to qualify as old growth (Table 8). In Nebraska and South Dakota, the minimum tree age was applied instead as a minimum stand age because tree ages are not available in these states.

Table 8. Region 2 forest types with old-growth definitions, their corresponding FIA forest type groups, and mimumum thresholds

Forest type	FIA forest type groups	Large tree age	Large tree diameter (inches)	No. of large trees per acre	No. of trees with cull or broken/dead top, per acre	# Dead trees per Acre
Ponderosa pine	220	200	16	10	1	2
Mixed conifer	200	200	16	10	1	2
Spruce/fir	120, 260	200	16	10	1	2
Aspen	900	200	14	10	1	0
Lodgepole pine	280	150	10	10	1	2
Pinyon-juniper	180	200	12	30	1	1
White pine	360	200	12	10	0	0
Gambel oak	970	80	4	30	0	0
Cottonwood	700	100	14	20	0	0

Southwestern Region (Region 3)

The Southwestern Region developed old-growth definitions based on analysis done to support plan revision (USDA Forest Service 2019, Weisz and Vandendriesche 2013) (Table 9). This region classifies vegetation with “ecological response units” (ERUs) and uses FIA habitat types to assign stands to an ERU (Table 10). Most forest types (ERUs) are defined as old growth if they had a Zeide’s stand density index (SDI) (Zeide 1983) value that was above a certain percentage, when compared to the maximum SDI. Three types (bristlecone pine, juniper grass, and semi-desert grassland) used a minimum quadratic mean diameter (QMD) of trees ≥10 in DBH criteria.

Table 9.—Southwestern Region ecological response units and their old-growth minimum criteria.

Ecological response unit	Minimum % SDI from trees ≥18" diameter	Minimum QMD of trees ≥10” diameter
Spruce-Fir Forest	n/a	18
Mixed Conifer w/ Aspen	n/a	18
Bristlecone Pine	n/a	18
Mixed Conifer -- Frequent Fire	56	n/a
Ponderosa Pine Forest	57	n/a

Ecological response unit	Minimum % SDI from trees ≥18" diameter	Minimum QMD of trees ≥10” diameter
Ponderosa Pine -- Evergreen Oak	26	n/a
PJ Evergreen Shrub	n/a	18
PJ Woodland (persistent)	n/a	18
PJ Sagebrush	n/a	18
PJ Deciduous Shrub	n/a	18
PJ Grass	29	n/a
Juniper Grass	36	n/a
Madrean Pinyon-Oak	20	n/a
Madrean Encinal Woodland	20	n/a
Gambel Oak Shrubland	n/a	18
Semi-Desert Grassland	36	n/a
Ponderosa Pine/Willow	57	n/a
Arizona Walnut	n/a	18
Rio Grande Cottonwood/Shrub	n/a	18
Narrowleaf Cottonwood - Spruce, Narrowleaf Cottonwood/Shrub	n/a	18
Upper Montane Conifer/Willow	n/a	18

Table 10. Ecological response units (ERUs) and the corresponding habitat type codes on Southwestern Region FIA plots

Ecological response unit	Habitat type codes
Spruce-Fir Forest	415, 435, 604, 1100, 3060, 3080, 3090, 3110, 3111, 3112, 3200, 3201, 3202, 3203, 3231, 3240, 3300, 3301, 3310, 3320, 3350, 3370, 3999, 4060, 4061, 4062, 4151, 4152, 4300, 4310, 4320, 4330, 4340, 4350, 4351, 4360, 4999, 26005, 240300
Mixed Conifer w/ Aspen	1010, 1011, 1012, 1020, 1030, 1070, 1080, 1081, 1110, 1111, 1120, 1150, 1160, 1231, 1999, 6010, 6060, 6070, 6071, 6080, 6130, 12320, 12333
Bristlecone Pine	238040, 238310
Mixed Conifer -- Frequent Fire	1021, 1022, 1040, 1041, 1042, 1050, 1051, 1052, 1053, 1054, 1060, 1090, 1140, 1141, 1203, 1213, 1239, 1241, 6090, 11130, 12140, 12141, 12142, 12143, 12330, 12331, 12332, 12340, 12341, 12350, 12360, 12361, 12362, 12380, 12420, 12430, 12999, 238300

Ecological response unit	Habitat type codes
Ponderosa Pine Forest	11030, 11031, 11032, 11033, 11035, 11090, 11091, 11092, 11093, 11210, 11211, 11212, 11213, 11214, 11215, 11216, 11320, 11330, 11340, 11341, 11350, 11380, 11390, 11391, 11392, 11400, 11460, 11500, 11999
Ponderosa Pine -- Evergreen Oak	11034, 11220, 11360, 11361, 11370, 11410, 11411, 11420, 11430, 11440, 32010, 32030, 32999, 33010, 33020, 33030
PJ Evergreen Shrub	3102, 204400, 230030, 230040, 230041, 230042, 230999, 231010, 232070, 233010, 233030, 233040, 233041, 233042, 233050
PJ Woodland (persistent)	202500, 202500, 204320, 204330, 204500, 232020, 232330, 233330
PJ Sagebrush	20406, 20410, 20411, 20431, 23204, 204021, 204022, 204023, 204024, 204300, 204350, 204370, 204999, 231020, 232030, 232999, 233020, 233021, 233022, 233999, 9000042
PJ Deciduous Shrub	20404, 204050, 204321, 2040303
PJ Grass	20406, 20410, 20411, 20431, 23204, 204021, 204022, 204023, 204024, 204300, 204350, 204370, 204999, 231020, 232030, 232999, 233020, 233021, 233022, 233999, 9000042
Juniper Grass	20140, 201010, 201011, 201020, 201040, 201331, 201332, 201333, 201340, 201350, 201400, 201410, 201999, 202320, 202321, 202330, 202331, 202999, 231021, 231030, 231040, 231050, 231999, 9000043
Madrean Pinyon-Oak	3101, 204360, 232050, 232060, 630010, 630030, 630040, 630043, 630050, 2040301, 2040302
Madrean Encinal Woodland	31999, 610010, 610020, 620010, 620020, 620021, 620030, 620999, 630020, 630041, 630042, 632999, 650010, 650999
Gambel Oak Shrubland	640999
Semi-Desert Grassland	201420, 201430, 210999
Ponderosa Pine/Willow	11470
Arizona Walnut	1130, 620040
Rio Grande Cottonwood / Shrub	104
Narrowleaf Cottonwood - Spruce, Narrowleaf Cottonwood/Shrub	103
Upper Montane Conifer/Willow	3

Intermountain Region (Region 4)

Hamilton (1993) defines old-growth forest characteristics and sets regional old-growth definitions, along with the 2007 memo from Regional Forester Troyer clarifying that only age, size, and density should be used to determine old growth status (Table 11). For a given forest type, as defined by composition, geography, and productivity, stands must meet the minimum number of trees per hectare over a threshold size and estimated age to be considered old growth.

Table 11.—Intermountain Region old-growth types and minimum criteria. Vegetation crosswalk code was used to determine which Intermountain Region old-growth type a given FIA observation was assigned to. Code uses variables in the FIA public database (Burrill et al. 2021) and abbreviations for FIA table names (c = condition table; p = plot table; t = tree table).

Old-growth type	Minimum large tree age	Minimum large tree diameter (inches)	Minimum large trees per acre	Vegetation crosswalk code
Engelmann Spruce-Subalpine Fir-Warm-UT	220	20	25	(p.statecd not in(16) and ((c.fortypcd in(265,261)) or (c.fortypcd = 266 and c.physclcd > 20) or (c.fortypcd = 266 and t.spcd not in(113,101,72))))
Engelmann Spruce-Subalpine Fir-Warm-ID	220	24	25	(p.statecd = 16 and ((c.fortypcd in(265,261)) or (c.fortypcd = 266 and c.physclcd > 20) or (c.fortypcd = 266 and t.spcd not in(113,101,72))))
Engelmann Spruce-Subalpine Fir-Cold	150	15	15	((c.fortypcd = 266 and c.physclcd < 20) or (c.fortypcd = 266 and t.spcd in(113,101,72)) or (c.fortypcd = 268 and c.siteclcd < 7))
Engelmann Spruce-Subalpine Fir-Alpine	150	12	10	(c.fortypcd = 268 and c.siteclcd = 7)
Whitebark Pine	250	18	15	(c.fortypcd = 367)
Bristlecone Pine	300	10	5	(c.fortypcd = 365)
Douglas-Fir-High	200	24	15	(c.fortypcd = 201 and c.siteclcd < 6)
Douglas-Fir-Low	200	18	10	(c.fortypcd = 201 and c.siteclcd >= 6)
Grand Fir	200	24	15	(c.fortypcd = 267)
Blue Spruce	250	16	10	(c.fortypcd = 269)
Conifer Mixed Forests-Low	256	29	11	(c.fortypcd in(371, 262) and c.physclcd < 20)

Old-growth type	Minimum large tree age	Minimum large tree diameter (inches)	Minimum large trees per acre	Vegetation crosswalk code
Conifer Mixed Forests-Productive	188	39	10	(c.fortypcd in(371, 262) and c.physclcd > 20)
Aspen-Dry	100	12	10	(c.fortypcd = 901 and c.physclcd < 20)
Aspen-Mesic	100	12	20	(c.fortypcd = 901 and c.physclcd > 20)
Lodgepole Pine	140	11	25	(c.fortypcd = 281)
Limber Pine-Lower	250	16	10	(c.fortypcd = 366 and c.siteclcd > 6)
Limber Pine-Montane	500	16	10	(c.fortypcd = 366 and c.siteclcd <= 6)
Ponderosa Pine-N-Seral	200	24	10	(c.fortypcd in(220,221,222,225) and c.adforcd in(402,412,413,414) and c.siteclcd > 5)
Ponderosa Pine-N-Climax	200	24	5	(c.fortypcd in(220,221,222,225) and c.adforcd in(402,412,413,414) and c.siteclcd <= 5)
Ponderosa Pine-RM-Seral	200	20	14	(c.fortypcd in(220,221,222,225) and c.adforcd not in(402,412,413,414) and c.siteclcd > 5)
Ponderosa Pine-RM-Climax	200	16	7	(c.fortypcd in(220,221,222,225) and c.adforcd not in(402,412,413,414) and c.siteclcd <= 5)
Pinyon-Juniper-NW-Low	200	12	12	(c.fortypcd in(182,184,185) and (c.adforcd in(402,403,412,413,414,415,417,420) or (c.adforcd in(418,419) and p.ECOSUBCD in('M331Dn', 'M331Do', 'M331Dv', 'M331Di'))) and c.physclcd < 20)
Pinyon-Juniper-NW-High	250	18	30	(c.fortypcd in(182,184,185) and (c.adforcd in(402,403,412,413,414,415,417,420) or (c.adforcd in(418,419) and p.ECOSUBCD in('M331Dn', 'M331Do', 'M331Dv', 'M331Di'))) and c.physclcd > 20)

Old-growth type	Minimum large tree age	Minimum large tree diameter (inches)	Minimum large trees per acre	Vegetation crosswalk code
Pinyon-Juniper-SE-Low	150	9	12	(c.fortypcd in(182,184,185) and (c.adforcd in(401,407,408,410) or (c.adforcd in(418,419) and p.ECOSUBCD not in('M331Dn', 'M331Do', 'M331Dv', 'M331Di'))) and c.physclcd < 20)
Pinyon-Juniper-SE-High	200	12	30	(c.fortypcd in(182,184,185) and (c.adforcd in(401,407,408,410) or (c.adforcd in(418,419) and p.ECOSUBCD not in('M331Dn', 'M331Do', 'M331Dv', 'M331Di'))) and c.physclcd > 20)

Pacific Southwest Region (Region 5)

The Pacific Southwest Region developed a series of white papers defining old-growth forest; the criteria were compiled in a table in Beardsley and Warbington (1996). These were modified by regional staff to reflect current knowledge and reduce the number of productivity classes (Table 12). Vegetation types based on dominant tree species were grouped by productivity class based on Dunning's site index, with index <45 assigned to "low," otherwise "high." Old-growth criteria consisted of a minimum stand age and a minimum density of large diameter live trees. Defined vegetation types were crosswalked to FIA forest types; oak and pinyon-juniper forest types did not have applicable old-growth criteria and therefore had no potential to be classified as old growth. Criteria for some Region 5 forest types were distinguished by ecoregion code (ECOSUBCD in the FIA database). Because most applications of stand age are based on the oldest trees in a stand and not the average age of the overstory trees, this report uses either the age of the oldest increment-cored tree in the condition or the FIA stand age to determine whether age criterion was met. Conditions that met the minimum density of large trees and the age criteria were classified as old growth.

Table 12.—Pacific Southwest Region old-growth types, FIA forest type codes, and minimum criteria

Region 5 vegetation type name	FIA forest type code	Site	Minimum diameter (inches)	Minimum trees per acre	Minimum stand age
Coast Redwood	341	All	40	15	
Conifer Mixed Forests	371, 226, 361	Productive	39	6	188
Conifer Mixed Forests	371, 226, 361	Low	29	5	256
White Fir (NWFP area)	261	Productive	30	5	160
White Fir (NWFP area)	261	Low	25	23	303

Region 5 vegetation type name	FIA forest type code	Site	Minimum diameter (inches)	Minimum trees per acre	Minimum stand age
White Fir (not NWFP)	261	Productive	39	6	143
White Fir (not NWFP)	261	Low	29	8	239
Pacific Douglas-fir	201,202	Productive	40	12	180
Pacific Douglas-fir	201,202	Low	30	18	260
Douglas-fir/Tanoak/Madrone	941	Productive	30	10	180
Douglas-fir/Tanoak/Madrone	941	Low	30	8	300
Mixed Subalpine (Western White Pine Association)	241, 342, 365, 366, 367	Productive	30	9	150
Mixed Subalpine (Western White Pine Association)	241, 342, 365, 366, 367	Low	30	10	200
Mixed Subalpine (Mountain Hemlock Association)	270	Productive	30	12	150
Mixed Subalpine (Mountain Hemlock Association)	270	Low	30	6	200
Mixed Subalpine (Western Juniper Association)	369	All	30	5	200
Mixed Subalpine (Quaking Aspen Association)	901	Productive	18 aspen/30 conifer	5	80
Mixed Subalpine (Quaking Aspen Association)	901	Low	18 aspen/30 conifer	1	80
Red Fir	262	Productive	30	8	150
Red Fir	262	Low	36	5	200
Jeffrey Pine	225	Productive	30	3	150
Jeffrey Pine	225	Low	30	1	200
Lodgepole Pine	281	Productive	36	7	150
Lodgepole Pine	281	Low	36	4	200
Interior Ponderosa Pine[1]	221	Productive	21	19	150
Interior Ponderosa Pine[1]	221	Low	21	16	200
Pacific Ponderosa Pine[a]	221	All	30	9	125

[a] Ponderosa Pine is considered Interior Productive in ECOSUBCD= M261G*, 342B*, M261Ea, M261Eb, M261Ec, M261Ei, M261Ej, M261D* but not M261Di,M; Interior Low in ECOSUBCD=M261G*, 342B*, M261Ea, M261Eb, M261Ec, M261Ei, M261Ej, M261D* but not M261Di,M, otherwise Pacific.

Pacific Northwest Region (Region 6)

Parts of the Pacific Southwest Region are managed under the Northwest Forest Plan (NWFP). In the NWFP areas, an old-growth structure index score for stand age 200 (OGSI 200) identified old growth (Davis et al. 2022) (Table 13). For remaining lands in the Pacific Northwest Region (eastern Oregon and Washington), the 1993 "interim definitions" were used (https://ecoshare.info/2009/12/16/r6-old-growth-interim-definitions/) (Table 14).

For both sets of criteria, tree and understory species on FIA plots were classified to plant association zone (PAZ) by regional ecology staff and matched to the old-growth criteria.

Table 13.—Pacific Northwest Region, Northwest Forest Plan area old-growth forest types and minimum threshold for old-growth status, OGSI 200

Plant association zone	Large tree diameter (in)[a]	Large tree density (trees ac^{-1})	Snag diameter (in)[a]	Snag density (trees ac^{-1})	Cover of downed wood ≥9.8-in DBH	Diameter diversity index[b]
Grand fir/white fir	29.5	6	19.7	4	2	yes
Juniper	19.7	6	n/a	n/a	n/a	n/a
Mountain hemlock	29.5	4	19.7	5	2	yes
Oak woodland	19.7	6	n/a	n/a	n/a	n/a
Ponderosa pine	29.5	4	n/a	n/a	n/a	n/a
Port Orford cedar	29.5	5	19.7	6	1	yes
Redwood	39.4	8	39.4	1	3	yes
Shasta red fir	29.5	10	19.7	4	1	yes
Silver fir	29.5	9	19.7	8	4	yes
Sitka spruce	39.4	7	39.4	5	6	yes
Subalpine	19.7	6	19.7	1	2	yes
Tanoak	39.4	5	39.4	2	2	yes
Western hemlock	39.4	4	39.4	3	4	yes
Douglas-fir	29.5	3	19.7	1	1	yes

Plant association zone	Large tree diameter (in)[a]	Large tree density (trees ac^{-1})	Snag diameter (in)[a]	Snag density (trees ac^{-1})	Cover of downed wood ≥9.8-in DBH	Diameter diversity index[b]
Lodgepole pine	9.8	60	n/a	n/a	n/a	n/a
Jeffrey pine/knobcone pine	29.5	5	n/a	n/a	n/a	n/a

[a] Conifers only, except in Oak woodland

[b] Score is based on trees per acre of trees 2–9.8, 9.9–19.7, 19.8–39.4, and >39.4 inches

Old Growth Structure Index (OGSI) is the sum of scores of four elements. The density required to exceed the OGSI200 score based on that attribute alone is shown. However, no stand can meet OGSI200 without at least 10 percent live tree cover and QMD >=50% of the minimum live diameter. For frequent-fire or sparse PAZ types, live trees were the only attribute used to calculate OGSI.

Table 14.—Pacific Northwest Region old-growth criteria outside the Northwest Forest Plan area

Forest plant association zones	Site[a]	Large tree diameter (in)	Large tree density (trees ac^{-1})	Age[b]	Regional geography[c]
White/Grand fir	H	21	15	150	Central Oregon
White/Grand fir	L-M	21	10	150	Central Oregon
White/Grand fir	H	21	20	150	Blue Mountains
White/Grand fir	L-M	21	10	150	Blue Mountains
Douglas-fir (interior)	ALL	21	8	150	Eastside
Lodgepole pine	ALL	12	60	120	Central and southeast Oregon
Pacific silver fir	5	22	9	260	Westside
Pacific silver fir	6	22	1	360	Westside
Pacific silver fir	2&3	26	6	180	Westside
Pacific silver fir	4	25	7	200	Westside
Ponderosa pine	M-H	21	13	150	Eastside
Ponderosa pine (very late decadent)	M-H	31	3	200	Eastside
Ponderosa pine	L	21	10	150	Eastside
Ponderosa pine (very late decadent)	L	31	2	200	Eastside
Subalpine fir	H	21	10	150	Eastside

Forest plant association zones	Site[a]	Large tree diameter (in)	Large tree density (trees ac^{-1})	Age[b]	Regional geography[c]
Subalpine fir	L	13	10	150	Eastside
Western hemlock	1	42	8	200	Westside
Western hemlock	2	35	8	200	Westside
Western hemlock	3	31	8	200	Westside
Western hemlock	4&5	21	8	200	Westside

[a] FIA site classes 1+2 were assigned to "high," 3+4 to "medium," and >4 to low.

[b] The density of live trees greater than the minimum DBH was calculated, and the presence of any increment-cored trees greater than the minimum age. Any condition with more than the minimum density of large trees and at least one old tree was classified as old growth. In the absence of cored trees, stand ages were used.

[c] Central Oregon was defined as being in the east Cascades ecoregion (M242C) and not in Hood River or Wasco Counties, with the remaining areas assigned to the Blues and eastern Washington grouping.

Southern Region (Region 8)

Definitions for characteristics of old growth in the Southern Region are listed by old-growth community type in Gaines et al. (1997), necessitating a crosswalk from FIA forest types to old-growth community types. To be considered old growth, each stand had to meet or exceed minimum values of live basal area (ft^2 ac^{-1}; of trees ≥5 in DBH), stand age, dead trees density, and have ≥6 trees per acre that met a minimum diameter for a given old-growth community type (Table 15). FIA forest types were often matched to more than one old-growth community type (Table 16); if the thresholds were met for any of the stand's potential old-growth community types, the stand was considered old growth. Forests in Puerto Rico were considered old growth if in a wilderness area. Forest types dominated by commonly planted pine species were only considered old growth if they met the appropriate thresholds and were located in a county where the species is known to be native; information will be available in Pelz et al. (in preparation).

Table 15. Region 8 old-growth community types and minimum criteria.

Region 8 old-growth code	Region 8 old-growth type	Stand age	Stand basal area (ft^2 ac^{-1})	Large tree diameter (inches)	Dead trees per acre
1	Northern hardwood forest	100	40	14	13
2	Conifer-northern hardwood forest	140	40	20	6
5	Mixed mesophytic and western mesophytic forest	140	40	30	4
6	Coastal plain upland mesic hardwood forest	120	40	24	4
10	Hardwood wetland forest	120	40	20	0

Region 8 old-growth code	Region 8 old-growth type	Stand age	Stand basal area (ft^2 ac^{-1})	Large tree diameter (inches)	Dead trees per acre
13	River floodplain hardwood forest	100	40	16	0
14	Cypress-tupelo swamp forest	120	40	8	3
21	Dry-mesic oak forest	130	40	20	26
22	Dry and xeric oak forest, woodland, and savanna	90	10	8	10
24	Xeric pine and pine-oak forest and woodland	100	20	10	6
25	Dry and dry-mesic oak-pine forest	120	40	19	15
26	Upland longleaf and south Florida slash pine forest, woodland, and savanna	80	10	16	0
27	Seasonally wet oak-hardwood woodland	100	40	20	0
28	Eastern riverfront forest	100	40	25	6
29	Southern wet pine forest, woodland, and savanna	80	10	9	0
31	Montane and allied spruce and spruce-fir forest	120	40	20	14

Table 16.—FIA forest type codes cross-walked to Southern Region old-growth community types. Each FIA observation was classified as old growth if it met criteria for any matched old-growth community type.

FIA forest type code(s)	Region 8 old-growth community type code(s) matched to forest type
104, 105, 123, 124	2
129	31
141	26, 29
142, 166, 407	29
161	25
162, 163, 404, 405, 409	24, 25
165, 167	24
400	2, 24, 25, 26, 29
401	2

FIA forest type code(s)	Region 8 old-growth community type code(s) matched to forest type
403	26
406	25
500	5, 13, 21, 22, 24, 27
501	22
502, 515, 519	21, 22
504	21, 27
505	21
506, 511, 516	5
508	13
510	21, 22, 24
514	22, 24
517, 800, 801, 805	1, 5
520	27
600	6, 10, 13, 22, 27, 28
601, 602, 605, 706	13
607, 609	14
608, 809	10
700	10, 28
702, 703, 704	28
705	13, 28
708	10, 13
709	28
902	312
962	1, 5, 6, 10, 13, 21, 22, 27, 28

Eastern Region (Region 9)

Characteristics of old-growth forests derived from extensive field surveys by major vegetation types (Tyrell et al. 1998) were used as the primary basis for old-growth definitions in the Eastern

Region. These field surveys of sites deemed by regional botanists and ecologists to be old growth were conducted decades ago in a nonsystematic manner using vegetation types that differ from FIA forest types. As such, upon consultation with contemporary regional staff, the Tyrell et al. (1998) vegetation types were classified into the old-growth types (10 types, including an "other" category) deemed most appropriate and aligned with specific FIA forest types. To be considered old growth, FIA plot measurements had to meet thresholds for stand age (100–160 years) and density (5–20 trees ac^{-1}) of large trees at least 12- to 20-in DBH (Table 17).

Table 17.—Eastern Region old-growth community types, corresponding FIA forest types, and large tree diameter and density and stand age minima

Old-growth Type	FIA Forest Type Code	Tree Diameter (inches)	Trees per acre	Stand Age
Beech maple basswood	805	16	10	141
Northern hardwood	520, 801, 802, 809	16	10	141
Dry oak	162, 163, 165, 167, 182, 184, 404, 405, 501, 502, 506, 507, 509, 510, 513, 515	16	20	101
Mesic northern oak	503, 504, 505, 511, 512, 516	20	5	161
Wetland hardwood	701, 702, 703, 704, 705, 706, 707, 708, 709	18	10	121
Conifer northern hardwood	104, 105, 401	16	10	141
Northern pine	101, 102, 103	12	20	101
Montane spruce	121, 123, 124, 128, 129	15	10	141
Sub-boreal spruce/fir	122, 125	12	10	141
Other	All others	14	10	101

Alaska Region (Region 10)

The Alaska Region used old-growth forest definitions from Boughton et al. (1992a, 1992b) as the basis for their old-growth criteria. The team developed a crosswalk from the described old-growth types to available data on FIA plots using forest type, elevation, slope, the Pacific Northwest Research Station (PNW) topographic code, and understory vegetation composition. FIA plot records were identified as old growth if they met either minimum density of large live trees, minimum density of large dead trees, minimum stand age, or minimum-aged tree (Table 18). Original definitions required meeting all four criteria. Relaxing the definition to classify FIA site as old growth when any of four criteria were met agreed more closely with the independent map-based classification of old growth used by the Alaska Region. The current FIA sample of coastal Alaska does not include designated and candidate wilderness areas due to restricted access, so these areas are not included in the inventory.

Table 18.—Alaska Region old-growth forest types and minimum threshold for old-growth status

National forest	Forest type name	FIA forest type code	Series	Age	Large tree diameter (in)	Large tree density (trees ac^{-1})	Snag diameter (in)	Snag density (trees ac^{-1})
Chugach	Sitka Spruce - Alluvial	305	n/a	150	16	24	16	3
Chugach	Sitka Spruce - Other	305	n/a	200	13	21	13	4
Chugach	Western Hemlock - well Drained	301	n/a	150	14	28	14	3
Chugach	Western Hemlock - poorly drained	301	n/a	170	10	61	10	16
Chugach	Mountain Hemlock - Hi-elevation	270	n/a	150	10	24	10	5
Chugach	Mountain Hemlock -low elevation	270	n/a	170	7	58	7	5
Chugach	White Spruce	122	n/a	150	7	37	7	22
Chugach	Black Spruce	125	n/a	200	5	150	5	10
Chugach	Aspen	901	n/a	80	5	73	5	6
Tongass	Sitka Spruce - Alluvial	n/a	PISI	260	27	6	27	2
Tongass	Sitka Spruce - Other	n/a	PISI	160	23	7	23	1
Tongass	Western Hemlock - well Drained	n/a	TSHE	150	19	21	19	2
Tongass	Western Hemlock - poorly drained	n/a	TSHE	180	15	17	15	3
Tongass	Western Hemlock/western redcedar - well Drained	n/a	THPL	170	21	16	21	5
Tongass	Western Hemlock/western redcedar - poorly drained	n/a	THPL	150	19	15	19	3
Tongass	Western hemlock/Alaska yellow cedar	n/a	CHNO	150	15	26	15	3
Tongass	Mixed conifer	n/a	MIXC	170	11	12	11	4
Tongass	Mountain hemlock	n/a	TSME	160	13	12	13	2

National forest	Forest type name	FIA forest type code	Series	Age	Large tree diameter (in)	Large tree density (trees ac^{-1})	Snag diameter (in)	Snag density (trees ac^{-1})
Tongass	Shore pine	n/a	PICO	170	9	18	9	2

Appendix 2: Mature Forest Working Definitions

Mature working definitions as applied to FIA data for the national inventory for each mature vegetation class (Table 19). Mature vegetation classes were developed from old-growth regional vegetation types; old-growth regional vegetation types were merged into mature vegetation classes based on similar forest types when fewer than 10 old-growth plots were classified. Structural indicator variables (indicators) used in mature forest definitions are defined in

Table 3 of the main text.

Table 19.—Working definitions for mature forest as applied to FIA data for the national old-growth and mature forest inventory. Definitions were applied to each FIA plot record based on the Forest Service region and mature vegetation class.

Mature vegetation class	Walkdown	Indicators	Correlation	Threshold	Weight	Old-growth regional vegetation types
Region 1 Douglas fir	0.86	ddiscore	0.41	32.6	0.34	R1 Douglas fir; R1 Douglas-fir group; R1 Douglas-Fir-High
		badom	0.39	82.5	0.33	
		QMDdom	0.39	10.3	0.33	
Region 1 Fir/spruce/ mountain hemlock group	0.8	ddiscore	0.52	24	0.44	R1 Engelmann Spruce-Subalpine Fir-Warm-ID; R1 Spruce/Fir (Fir/spruce/mountain hemlock group); R1 Fir/spruce/mountain hemlock group; R1 Western white pine group; R1 Grand Fir
		HTsd	0.35	49.6	0.3	
		HTquart	0.31	39.2	0.26	
Region 1 Hardwoods (FIA aspen/birch group[a])	0.8	ddiscore	0.61	23.9	0.31	R1 Alder/maple group; R1 Elm/ash/cottonwood group; R1 Aspen; R1 Gambel Oak; R1 Aspen/birch group; R1 Oak/hickory group; R1 Cottonwood; R1 Woodland hardwoods group
		badom	0.56	62	0.28	
		HTquart	0.52	38.4	0.26	
		HTsd	0.29	28	0.15	
Region 1 Hemlock/Sitka spruce group	0.86	ddiscore	0.64	45	0.38	R1 Hemlock/Sitka spruce group
		HTsd	0.48	74.4	0.28	
		HTquart	0.35	69.2	0.21	
		tpadom	-0.22	70	0.13	
Region 1 Lodgepole Pine	0.49	HTquart	0.58	25	0.28	R1 Lodgepole Pine; R1 Lodgepole pine group
		ddiscore	0.54	14.6	0.26	
		badom	0.53	43.6	0.26	
		HTsd	0.39	24	0.19	
Region 1 Pinyon Juniper - Western Softwoods	0.8	ddiscore	0.61	24	0.3	R1 Other Western Softwoods; R1 Other western softwoods group; R1 Pinyon/juniper group; R1 Pinyon-Juniper
		HTquart	0.52	28.6	0.25	
		QMDdom	0.5	7	0.25	
		HTsd	0.41	29.4	0.2	
	0.83	ddiscore	0.55	31.5	0.36	

Mature vegetation class	Walkdown	Indicators	Correlation	Threshold	Weight	Old-growth regional vegetation types
Region 1 Ponderosa Pine		QMDdom	0.53	13	0.34	R1 Ponderosa Pine; R1 Ponderosa pine group; R1 Ponderosa Pine-RM-Climax
		HTsd	0.46	40.7	0.3	
Region 1 Western larch group	0.93	QMDdom	0.65	15.8	0.31	R1 Western larch group
		ddiscore	0.65	53	0.31	
		HTsd	0.43	80.9	0.21	
		tpadom	-0.34	69	0.16	
Region 2 Aspen/Cottonwood/Oaks	0.62	HTquart	0.67	32.9	0.31	R2 Aspen; R2 Cottonwood; R2 Oak/hickory group; R2 Other hardwoods group
		ddiscore	0.59	18.6	0.27	
		badom	0.56	55.1	0.26	
		HTsd	0.33	25.3	0.15	
Region 2 Douglas fir	0.86	ddiscore	0.48	29.2	0.3	R2 Douglas fir
		badom	0.33	65.8	0.21	
		HTquart	0.28	40.6	0.18	
		QMDdom	0.27	9.3	0.17	
		snagbatot	0.24	21.3	0.15	
Region 2 Gambel Oak	0.8	badom	0.32	25.3	0.3	R2 Gambel Oak
		ddiscore	0.26	8	0.25	
		HTquart	0.25	10.4	0.24	
		QMDdom	0.22	2.9	0.21	
Region 2 Lodgepole Pine	0.49	QMDdom	0.6	3.7	0.46	R2 Lodgepole Pine
		badom	0.5	33.8	0.38	
		HTsd	0.21	17.5	0.16	
Region 2 Other Western Softwoods	0.8	ddiscore	0.69	24	0.32	R2 Other Western Softwoods; R2 Other eastern softwoods group
		QMDdom	0.61	6.5	0.29	
		HTquart	0.51	28.2	0.24	
		HTsd	0.33	21.6	0.15	
	0.8	ddiscore	0.51	33.5	0.55	R2 Pinyon-Juniper

Mature vegetation class	Walkdown	Indicators	Correlation	Threshold	Weight	Old-growth regional vegetation types
Region 2 Pinyon-Juniper		QMDdom	0.42	8.6	0.45	
Region 2 Ponderosa Pine (FIA Ponderosa Pine Group[a])	0.83	QMDdom	0.42	11.8	0.33	R2 Ponderosa Pine
		ddiscore	0.35	31.6	0.28	
		HTsd	0.27	39	0.21	
		badom	0.23	67.3	0.18	
Region 2 Spruce/Fir	0.79	ddiscore	0.57	28.8	0.31	R2 Spruce/Fir (Fir/spruce/mountain hemlock group); R2 Spruce/Fir (Spruce/fir group)
		badom	0.51	87.2	0.27	
		HTquart	0.45	43.5	0.24	
		HTsd	0.33	44.6	0.18	
Region 3 Hardwoods (FIA Woodland Hardwoods Group[a])	0.77	QMDdom	0.64	3.5	0.34	R3 Arizona Walnut; R3 Rio Grande Cottonwood/Shrub; R3 Gambel Oak Shrubland; R3 Sycamore - Fremont Cottonwood; R3 Narrowleaf Cottonwood - Spruce, Narrowleaf Cottonwood/Shrub; R3 Upper Montane Conifer/Willow; R3 Woodland hardwoods group; R3 Other
		ddiscore	0.63	7.7	0.34	
		HTquart	0.37	10.8	0.2	
		tpadom	-0.22	69.5	0.12	
Region 3 Juniper Grass	0.8	QMDdom	0.59	10.7	0.3	R3 Juniper Grass
		HTquart	0.53	11.2	0.27	
		ddiscore	0.53	19	0.27	
		HTsd	0.34	4	0.17	
Region 3 Madrean Encinal Woodland	0.8	QMDdom	0.6	8.8	0.36	R3 Madrean Encinal Woodland
		HTquart	0.49	15.2	0.3	
		ddiscore	0.3	16.8	0.18	
		tpadom	-0.26	56.4	0.16	
Region 3 Madrean Pinyon-Oak	0.8	QMDdom	0.49	8.3	0.32	R3 Madrean Pinyon-Oak
		HTquart	0.43	14.4	0.28	
		ddiscore	0.35	23.8	0.23	
		HTsd	0.24	10.4	0.16	

Mature vegetation class	Walkdown	Indicators	Correlation	Threshold	Weight	Old-growth regional vegetation types
Region 3 Mixed Conifer -- Frequent Fire	0.82	ddiscore	0.61	21.4	0.41	R3 Mixed Conifer -- Frequent Fire
		QMDdom	0.56	13.3	0.38	
		HTsd	0.32	44.7	0.21	
Region 3 Mixed Conifer w/ Aspen	0.76	ddiscore	0.73	34.6	0.39	R3 Mixed Conifer w/ Aspen; R3 Bristlecone Pine
		HTsd	0.45	41.2	0.24	
		HTquart	0.4	36.3	0.22	
		snagbatot	-0.28	15	0.15	
Region 3 PJ Grass - Sagebrush	0.8	ddiscore	0.6	19.6	0.29	R3 PJ Grass; R3 PJ Sagebrush; R3 Semi-Desert Grassland
		QMDdom	0.55	9.5	0.26	
		HTquart	0.54	12.8	0.26	
		HTsd	0.39	6.4	0.19	
Region 3 PJ Shrub - Woodland	0.78	ddiscore	0.51	20.2	0.46	R3 Pinyon/juniper group; R3 PJ Woodland (persistent); R3 PJ Deciduous Shrub; R3 PJ Evergreen Shrub
		QMDdom	0.38	9.2	0.34	
		HTquart	0.23	13.3	0.21	
Region 3 Ponderosa Pine	0.81	ddiscore	0.46	24.3	0.45	R3 Ponderosa Pine Forest
		badom	0.29	40	0.28	
		QMDdom	0.28	13.5	0.27	
Region 3 Ponderosa Pine - Mixed	0.81	ddiscore	0.63	32.4	0.5	R3 Ponderosa Pine -- Evergreen Oak; R3 Ponderosa Pine/Willow
		QMDdom	0.41	9	0.32	
		HTsd	0.23	24.1	0.18	
Region 3 Spruce - Fir	0.75	ddiscore	0.57	32.4	0.24	R3 Douglas-fir group; R3 Spruce-Fir Forest
		HTsd	0.51	51.8	0.22	
		QMDdom	0.44	11.4	0.19	
		HTquart	0.44	43.5	0.19	
		badom	0.41	57.4	0.17	
Region 4 Aspen-Dry	0.51	badom	0.67	22.6	0.33	R4 Aspen-Dry
		ddiscore	0.62	12	0.3	

Mature vegetation class	Walkdown	Indicators	Correlation	Threshold	Weight	Old-growth regional vegetation types
		HTquart	0.53	16.8	0.26	
		HTsd	0.22	14.7	0.11	
Region 4 Aspen-Mesic	0.51	HTquart	0.68	29.1	0.39	R4 Aspen-Mesic
		ddiscore	0.65	15.3	0.37	
		HTsd	0.41	16.3	0.24	
Region 4 Bristlecone/Limber/Whitebark Pines	0.8	QMDdom	0.62	9.8	0.39	R4 Bristlecone Pine; R4 Limber Pine-Lower; R4 Limber Pine-Montane; R4 Whitebark Pine
		badom	0.54	77.2	0.34	
		HTquart	0.43	26.4	0.27	
Region 4 Douglas fir	0.82	ddiscore	0.41	33	0.43	R4 Douglas-Fir-High; R4 Douglas-Fir-Low; R4 Fir/spruce/mountain hemlock group; R4 Grand Fir; R4 Western larch group; R4 Conifer Mixed Forests-Productive
		QMDdom	0.32	11.1	0.34	
		HTquart	0.22	40.2	0.23	
Region 4 Elm/ash/cottonwood (FIA Elm/Ash/ Cottonwood Group[a])	0.74	badom	0.46	47.5	0.42	R4 Elm/ash/cottonwood group
		ddiscore	0.43	19.1	0.39	
		HTsd	0.2	15.5	0.18	
Region 4 Engelmann spruce	0.8	ddiscore	0.55	29.8	0.32	R4 Engelmann Spruce-Subalpine Fir-Warm-ID; R4 Engelmann Spruce-Subalpine Fir-Warm-UT; R4 Engelmann Spruce-Subalpine Fir-Alpine; R4 Blue Spruce; R4 Engelmann Spruce-Subalpine Fir-Cold; R4 Conifer Mixed Forests-Low
		QMDdom	0.46	8.3	0.27	
		HTquart	0.4	35.4	0.23	
		HTsd	0.3	57.4	0.18	
Region 4 Lodgepole Pine	0.49	ddiscore	0.62	14.7	0.3	R4 Lodgepole Pine
		HTquart	0.55	23.5	0.26	
		badom	0.54	41.8	0.26	
		HTsd	0.37	18.1	0.18	
Region 4 Pinyon Juniper NW - Others	0.8	ddiscore	0.57	24	0.42	R4 Pinyon-Juniper-NW-High; R4 Pinyon-Juniper-NW-Low; R4 Woodland hardwoods group; R4 Other hardwoods group; R4 Other western softwoods group
		QMDdom	0.54	8	0.39	
		tpadom	-0.26	90.3	0.19	
	0.8	QMDdom	0.47	9.2	0.52	R4 Pinyon-Juniper-SE-High

Mature vegetation class	Walkdown	Indicators	Correlation	Threshold	Weight	Old-growth regional vegetation types
Region 4 Pinyon-Juniper-SE-High		ddiscore	0.44	32.9	0.48	
Region 4 Pinyon-Juniper-SE-Low	0.8	ddiscore	0.4	24	0.56	R4 Pinyon-Juniper-SE-Low
		QMDdom	0.32	8.3	0.44	
Region 4 Ponderosa Pine	0.83	QMDdom	0.54	14.2	0.38	R4 Ponderosa Pine-N-Climax; R4 Ponderosa Pine-N-Seral; R4 Ponderosa Pine-RM-Climax; R4 Ponderosa Pine-RM-Seral
		ddiscore	0.31	30.7	0.22	
		HTquart	0.3	49	0.21	
		HTsd	0.27	50.2	0.19	
Region 5 Douglas-fir/Tanoak/Madrone	0.8	ddiscore	0.57	53.3	0.45	R5 Douglas-fir/Tanoak/Madrone
		QMDdom	0.37	14.8	0.29	
		tpadom	-0.32	76.6	0.25	
Region 5 Jeffrey Pine	0.83	QMDdom	0.52	10.3	0.52	R5 Jeffrey Pine
		ddiscore	0.25	30.8	0.25	
		HTsd	0.23	31.5	0.23	
Region 5 Mixed Conifer	0.75	QMDdom	0.41	13.1	0.6	R5 Conifer Mixed Forests; R5 Interior Ponderosa Pine; R5 Lodgepole Pine; R5 Mixed Subalpine (Western White Pine Association), R5 Mixed Subalpine (Mountain Hemlock Association)
		ddiscore	0.27	42.1	0.4	
Region 5 Pacific Conifers	0.83	ddiscore	0.55	52.6	0.4	R5 Coast Redwood; R5 Pacific Douglas-fir; R5 Pacific Ponderosa Pine
		QMDdom	0.48	25.3	0.35	
		snagbatot	0.36	2.7	0.26	
Region 5 Region ed Fir	0.79	ddiscore	0.52	48.3	0.32	R5 Red Fir
		QMDdom	0.46	18.1	0.28	
		HTquart	0.38	66.2	0.23	
		HTsd	0.28	43.6	0.17	
Region 5 White Fir	0.79	ddiscore	0.4	47.5	0.31	R5 White Fir
		HTquart	0.4	68.5	0.31	
		badom	0.27	150	0.21	

Mature vegetation class	Walkdown	Indicators	Correlation	Threshold	Weight	Old-growth regional vegetation types
		snagbatot	0.2	24.9	0.16	
Region 5 Region 6 Hardwoods (FIA Western Oak Group[a])	0.73	ddiscore	0.56	38.1	0.58	R5 Alder/maple group; R5 Tanoak/laurel group; R5 Mixed Subalpine (Quaking Aspen Association); R5 Elm/ash/cottonwood group; R5 Western oak group; R5 Other hardwoods group; R5 Woodland hardwoods group; R6 Elm/ash/cottonwood group; R6 Aspen/birch group; R6 Hardwoods; R6 Western oak group; R6 Other hardwoods group
		QMDdom	0.41	6.8	0.42	
Region 5 Region 6 Pinyon Juniper - Western Softwoods	0.8	QMDdom	0.43	14.2	0.54	R5 Pinyon/juniper group; R5 Mixed Subalpine (Western Juniper Association); R5 Other western softwoods group; R6 Other western softwoods group; R6 Pinyon/juniper group
		badom	0.36	30.9	0.46	
Region 6 Douglas-fir (eastside)	0.75	QMDdom	0.44	11.1	0.42	R6 Douglas-fir (eastside); R6 Douglas-fir (interior); R6 Douglas-fir group
		ddiscore	0.4	30.2	0.38	
		badom	0.22	60.1	0.21	
Region 6 Douglas-Fir (NWFP)	0.79	QMDdom	0.61	12.7	0.45	R6 Douglas-Fir (NWFP)
		ddiscore	0.45	32.6	0.33	
		HTsd	0.31	42.3	0.23	
Region 6 Mountain Hemlock	0.79	QMDdom	0.58	13.1	0.29	R6 Mountain Hemlock; R6 Fir/spruce/mountain hemlock group
		badom	0.4	126.6	0.2	
		HTsd	0.4	58.5	0.2	
		HTquart	0.37	42.7	0.19	
		tpadom	-0.23	77.4	0.12	
Region 6 Ponderosa Pine - Lodgepole Pine	0.78	QMDdom	0.43	7.7	0.34	R6 Ponderosa Pine; R6 Jeffrey Pine; R6 Ponderosa pine group; R6 Lodgepole Pine
		ddiscore	0.36	15.3	0.28	
		HTsd	0.28	31.2	0.22	
		tpadom	-0.21	31.7	0.16	
	0.71	QMDdom	0.4	8.7	0.43	

Mature vegetation class	Walkdown	Indicators	Correlation	Threshold	Weight	Old-growth regional vegetation types
Region 6 Ponderosa pine (very late decadent)		ddiscore	0.3	23.1	0.33	R6 Ponderosa pine (very late decadent)
		tpadom	-0.22	51.2	0.24	
Region 6 Port Orford cedar - redwood	0.74	ddiscore	0.44	44.4	0.62	R6 Port Orford Cedar; R6 Redwood
		QMDdom	0.27	13	0.38	
Region 6 Silver Fir	0.83	QMDdom	0.62	17.1	0.29	R6 Pacific silver fir; R6 Silver Fir; R6 California Red Fir -Shasta Red Fir
		HTsd	0.42	72.2	0.2	
		badom	0.41	161.6	0.19	
		snagbatot	0.38	39.7	0.18	
		tpadom	-0.31	53.1	0.14	
Region 6 Sitka Spruce	0.85	QMDdom	0.56	24.3	0.3	R6 Sitka Spruce
		HTsd	0.42	63.5	0.22	
		badom	0.38	184.6	0.2	
		tpadom	-0.28	37.6	0.15	
		snagbatot	0.25	54.5	0.13	
Region 6 Subalpine fir	0.74	ddiscore	0.55	27.8	0.4	R6 Subalpine fir
		HTquart	0.44	39.8	0.32	
		HTsd	0.4	41.3	0.29	
Region 6 Subalpine Fir - Engelmann Spruce	0.74	ddiscore	0.39	33.2	0.42	R6 Subalpine Fir - Engelmann Spruce
		QMDdom	0.33	8.8	0.35	
		HTsd	0.21	42.9	0.23	
Region 6 Tanoak	0.82	QMDdom	0.6	15.3	0.29	R6 Tanoak
		ddiscore	0.5	56	0.24	
		HTquart	0.34	51.7	0.16	
		tpadom	-0.33	55.9	0.16	
		HTsd	0.32	64	0.15	
	0.79	QMDdom	0.64	19.9	0.33	R6 Western Hemlock

Mature vegetation class	Walkdown	Indicators	Correlation	Threshold	Weight	Old-growth regional vegetation types
Region 6 Western hemlock		badom	0.38	156.2	0.2	
		HTsd	0.32	25.9	0.17	
		snagbatot	0.32	63.2	0.17	
		tpadom	-0.27	42	0.14	
Region 6 White/Grand fir	0.78	QMDdom	0.51	12.3	0.33	R6 White Fir - Grand Fir; R6 White/Grand fir
		ddiscore	0.48	40.1	0.31	
		HTsd	0.3	46.8	0.2	
		snagbatot	0.24	8.6	0.16	
Region 8 Conifer southern hardwood	0.8	QMDdom	0.41	8.3	0.42	R8 Eastern hemlock; R8 Shortleaf pine/oak; R8 Eastern redcedar; R8 Eastern redcedar/hardwood; R8 Slash pine/hardwood; R8 Eastern white pine/northern red oak/white ash; R8 Loblolly pine/hardwood; R8 Other pine/hardwood; R8 Virginia pine/southern red oak
		tpadom	-0.29	111.6	0.3	
		HTquart	0.27	39.2	0.28	
Region 8 Longleaf pine	0.88	QMDdom	0.61	10.2	0.31	R8 Longleaf pine; R8 Longleaf pine/oak
		ddiscore	0.45	19	0.23	
		tpadom	-0.45	54.7	0.23	
		HTsd	0.24	24	0.12	
		badom	0.23	44.7	0.12	
Region 8 Oaks	0.76	QMDdom	0.46	9.5	0.3	R8 Chestnut oak; R8 Scarlet oak; R8 Chestnut oak/black oak/scarlet oak; R8 Southern scrub oak; R8 Northern red oak; R8 White oak; R8 White oak/red oak/hickory; R8 Post oak/blackjack oak
		ddiscore	0.42	22.8	0.28	
		HTquart	0.33	44.1	0.22	
		badom	0.31	55	0.2	
Region 8 Pines - Conifers	0.93	QMDdom	0.57	11.4	0.38	R8 Eastern white pine; R8 Eastern white pine/eastern hemlock; R8 Pond pine; R8 Slash pine; R8 Red spruce; R8 Table Mountain pine; R8 Loblolly pine; R8 Sand pine; R8 Virginia pine; R8 Pitch pine; R8 Shortleaf pine
		tpadom	-0.39	60.4	0.26	
		HTquart	0.29	65.8	0.19	
		HTsd	0.25	38.6	0.17	
	0.8	ddiscore	0.5	30.1	0.31	

Mature vegetation class	Walkdown	Indicators	Correlation	Threshold	Weight	Old-growth regional vegetation types
Region 8 southern hardwoods		HTquart	0.41	43.8	0.26	R8 Baldcypress/pondcypress; R8 Mixed upland hardwoods; R8 Sassafras/persimmon; R8 Cherry/white ash/yellow-poplar; R8 Red maple/lowland; R8 Sweetbay/swamp tupelo/red maple; R8 Baldcypress/water tupelo; R8 Other hardwoods; R8 Sugar maple/beech/yellow birch; R8 Cottonwood; R8 Red maple/oak; R8 Sweetgum/Nuttall oak/willow oak; R8 Yellow-poplar; R8 Black cherry; R8 Overcup oak/water hickory; R8 Sugarberry/hackberry/elm/green ash; R8 Elm/ash/black locust; R8 Red maple/upland; R8 Sweetgum/yellow-poplar; R8 Yellow-poplar/white oak/northern red oak; R8 Black walnut; R8 Pin cherry; R8 Swamp chestnut oak/cherrybark oak; R8 Willow; R8 Hard maple/basswood; R8 River birch/sycamore; R8 Sycamore/pecan/American elm
		badom	0.35	59.1	0.22	
		HTsd	0.33	48	0.21	
Region 8 Wet and rain forest[b]	NA	NA	NA	NA	NA	R8 Lower montane wet and rain forest; R8 Palms; R8 Wet and rain forest
Region 9 Conifer northern hardwood	0.82	QMDdom	0.63	14	0.3	R9 Conifer northern hardwood; R9 Oak/pine group
		badom	0.47	104.3	0.22	
		snagbatot	0.39	14.5	0.19	
		tpadom	-0.34	73.4	0.16	
		HTsd	0.27	32	0.13	
Region 9 northern hardwood	0.74	QMDdom	0.67	9.9	0.29	R9 northern hardwood; R9 Aspen/birch group; R9 Beech maple basswood; R9 Oak/gum/cypress group; R9 Oak/hickory group; R9 Other hardwoods group; R9 wetland hardwood
		HTquart	0.46	43.3	0.2	
		badom	0.41	60.9	0.18	
		tpadom	-0.42	97.6	0.18	
		HTsd	0.33	32.9	0.14	
Region 9 Northern pine	0.85	QMDdom	0.65	11.9	0.3	R9 Northern pine; R9 Loblolly/shortleaf pine group; R9
		HTsd	0.49	67.4	0.22	

Mature vegetation class	Walkdown	Indicators	Correlation	Threshold	Weight	Old-growth regional vegetation types
		HTquart	0.45	38	0.21	Exotic softwoods group; R9 Other eastern softwoods group
		tpadom	-0.4	83.2	0.18	
		badom	0.2	81.5	0.09	
Region 9 oak	0.82	QMDdom	0.57	12.7	0.37	R9 dry oak; R9 mesic northern oak
		tpadom	-0.35	73.4	0.22	
		HTquart	0.33	52.9	0.21	
		HTsd	0.31	36.5	0.2	
Region 9 Spruce/fir group	0.74	ddiscore	0.36	22.2	0.4	R9 Spruce/fir group ; R9 Montane spruce; R9 sub-boreal spruce/fir
		badom	0.32	76.2	0.36	
		HTquart	0.22	32	0.24	
Region 10 Black Spruce	0.74	HTsd	0.54	8.3	0.43	R10 Black Spruce SAF 204
		snagbatot	-0.39	6.4	0.31	
		tpadom	0.32	13.4	0.26	
Region 10 Mixed conifer	0.71	ddiscore	0.51	21.3	0.58	R10 Mixed conifer; R10 Shore pine
		snagbatot	0.37	19.7	0.42	
Region 10 Mountain hemlock	0.82	HTsd	0.43	33.6	0.32	R10 Mountain hemlock; R10 Mountain Hemlock -SAF 225 Hi-elev; R10 Mountain Hemlock -SAF 225 low elev
		QMDdom	0.34	7	0.25	
		snagbatot	0.31	6.9	0.23	
		badom	0.27	64.4	0.2	
Region 10 Sitka Spruce - Alluvial	0.69	QMDdom	0.66	8.9	0.34	R10 Sitka Spruce - Alluvial ; R10 Sitka Spruce - SAF 223 Alluvial ; R10 Aspen - SAF 217
		HTsd	0.38	33.5	0.2	
		badom	0.34	87.5	0.18	
		snagbatot	0.31	3.9	0.16	
		tpadom	-0.25	82.9	0.13	
Region 10 Sitka Spruce - Other	0.82	ddiscore	0.45	42.8	0.35	R10 Sitka Spruce – Other; R10 Sitka Spruce - SAF 223 Other
		HTsd	0.37	49.6	0.29	
		tpadom	-0.24	81.8	0.19	

Mature vegetation class	Walkdown	Indicators	Correlation	Threshold	Weight	Old-growth regional vegetation types
		HTquart	0.23	43.5	0.18	
Region 10 Western Hemlock - poorly Drained	0.71	QMDdom	0.51	7.1	0.63	R10 Western Hemlock - poorly Drained; R10 Western Hemlock - SAF 224 poorly drained
		badom	0.3	48.1	0.37	
Region 10 Western Hemlock - well Drained	0.8	QMDdom	0.71	12.1	0.52	R10 Western Hemlock - well Drained ; R10 Western Hemlock - SAF 224 well Drained
		snagbatot	0.39	18.2	0.28	
		tpadom	-0.27	52.7	0.2	
Region 10 Western Hemlock/Alaska yellow cedar	0.82	HTsd	0.5	46.7	0.37	R10 Western Hemlock/Alaska yellow cedar
		badom	0.49	81.9	0.36	
		snagbatot	0.36	30.1	0.27	
Region 10 Western Hemlock/western red cedar	0.82	ddiscore	0.4	36.8	0.27	R10 Western Hemlock/western Redcedar - well Drained ; R10 Western Hemlock/western Redcedar - poorly Drained
		tpadom	-0.35	102.8	0.23	
		snagbatot	0.32	21.5	0.21	
		HTsd	0.23	56.6	0.15	
		HTquart	0.2	40.2	0.13	
Region 10 White spruce	0.66	HTquart	0.58	25.4	0.7	R10 White Spruce SAF 201
		HTsd	0.25	21.1	0.3	

[a] All plots are crosswalked to the FIA forest type group shown in parentheses due to less than 10 FIA old-growth plot records for the mature vegetation class

[b] No mature plots due to not enough plots in this FIA tropical hardwoods group on lands managed by the Forest Service and BLM

Appendix 3: FIA Evaluations and Inventory Years for Each State

Table 20.—FIA evaluations and inventory years for each state from FIA data used in the national inventory

State or Territory name	State code	EVAL_GRP	EVALID	Inventory start year	Inventory end year
Alabama	1	12021	12101	2014	2021
Alaska (coastal)	2	22019	21921	2014	2019
Alaska (interior)	2	220192	21901	2009	2019
Arizona	4	42019	41901	2010	2019
Arkansas	5	52021	52101	2017	2021
California	6	62019	61901	2008	2019
Colorado	8	82019	81901	2010	2019
Connecticut	9	92020	92001	2014	2020
Delaware	10	102020	102001	2014	2020
Florida	12	122019	121901	2014	2019
Georgia	13	132020	132001	2015	2020
Hawaii	15	152019	151901	2019	2019
Idaho	16	162019	161901	2010	2019
Illinois	17	172021	172101	2015	2021
Indiana	18	182020	182001	2014	2020
Iowa	19	192021	192101	2015	2021
Kansas	20	202020	202001	2014	2020
Kentucky	21	212018	211801	2012	2018
Louisiana	22	222018	221801	2009	2018
Maine	23	232021	232101	2017	2021
Maryland	24	242019	241901	2013	2019
Massachusetts	25	252019	251901	2013	2019
Michigan	26	262019	261901	2013	2019

State or Territory name	State code	EVAL_GRP	EVALID	Inventory start year	Inventory end year
Minnesota	27	272019	271901	2015	2019
Mississippi	28	282020	282001	2016	2020
Missouri	29	292021	292101	2015	2021
Montana	30	302019	301901	2010	2019
Nebraska	31	312020	312001	2014	2020
Nevada	32	322019	321901	2010	2019
New Hampshire	33	332020	332001	2014	2020
New Jersey	34	342019	341901	2015	2019
New Mexico	35	352019	351901	2010	2019
New York	36	362019	361901	2013	2019
North Carolina	37	372021	372101	2016	2021
North Dakota	38	382021	382101	2015	2021
Ohio	39	392019	391901	2013	2019
Oklahoma	40	402019	401901	2010	2019
Oregon	41	412019	411901	2008	2019
Pennsylvania	42	422020	422001	2014	2020
Rhode Island	44	442020	442001	2014	2020
South Carolina	45	452020	452001	2014	2020
South Dakota	46	462020	462001	2014	2020
Tennessee	47	472018	471801	2012	2018
Texas	48	482019	481901	2004	2019
Utah	49	492019	491901	2010	2019
Vermont	50	502020	502001	2014	2020
Virginia	51	512020	512001	2015	2020
Washington	53	532019	531901	2008	2019
West Virginia	54	542020	542001	2014	2020

State or Territory name	State code	EVAL_GRP	EVALID	Inventory start year	Inventory end year
Wisconsin	55	552021	552101	2015	2021
Wyoming	56	562019	561901	2011	2019
American Samoa	60	602012	601202	2012	2012
Federated States of Micronesia	64	646416	641622	2016	2016
Guam	66	662013	661322	2013	2013
Marshall Islands	68	682018	681802	2018	2018
Northern Mariana Islands	69	692015	691502	2015	2015
Palau	70	702014	701402	2014	2014
Puerto Rico	72	722019	721901	2016	2019
U.S. Virgin Islands	78	782014	781401	2014	2014

Evaluations used were consistent with the most recent inventory cycle available in FIADB as of December 2022; not all States listed in the table contained forested Forest Service or BLM land.

Exhibit 10

ADVANCE VERSION

United Nations

FCCC/PA/CMA/2021/10/Add.1

Framework Convention on Climate Change

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Conference of the Parties serving as the meeting of the Parties to the Paris Agreement

Report of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement on its third session, held in Glasgow from 31 October to 13 November 2021

Addendum

Part two: Action taken by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its third session

Contents

Decisions adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement

Decision 1/CMA.3

Glasgow Climate Pact

The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement,

Recalling Article 2 of the Paris Agreement,

Also recalling decisions 3/CMA.1 and 1/CMA.2,

Noting decision 1/CP.26,

Recognizing the role of multilateralism in addressing climate change and promoting regional and international cooperation in order to strengthen climate action in the context of sustainable development and efforts to eradicate poverty,

Acknowledging the devastating impacts of the coronavirus disease 2019 pandemic and the importance of ensuring a sustainable, resilient and inclusive global recovery, showing solidarity particularly with developing country Parties,

Also acknowledging that climate change is a common concern of humankind, Parties should, when taking action to address climate change, respect, promote and consider their respective obligations on human rights, the right to health, the rights of indigenous peoples, local communities, migrants, children, persons with disabilities and people in vulnerable situations and the right to development, as well as gender equality, empowerment of women and intergenerational equity,

Noting the importance of ensuring the integrity of all ecosystems, including in forests, the ocean and the cryosphere, and the protection of biodiversity, recognized by some cultures as Mother Earth, and *also noting* the importance for some of the concept of 'climate justice', when taking action to address climate change,

Expressing appreciation to the Heads of State and Government who participated in the World Leaders Summit in Glasgow and for the increased targets and actions announced and the commitments made to work together and with non-Party stakeholders to accelerate sectoral action by 2030,

Recognizing the important role of indigenous peoples, local communities and civil society, including youth and children, in addressing and responding to climate change and *highlighting* the urgent need for multilevel and cooperative action,

I. Science and urgency

1. *Recognizes* the importance of the best available science for effective climate action and policymaking;

2. *Welcomes* the contribution of Working Group I to the Intergovernmental Panel on Climate Change Sixth Assessment Report[1] and the recent global and regional reports on the state of the climate from the World Meteorological Organization and *invites* the Intergovernmental Panel on Climate Change to present its forthcoming reports to the Subsidiary Body for Scientific and Technological Advice in 2022;

3. *Expresses alarm and utmost concern* that human activities have caused around 1.1 °C of warming to date, that impacts are already being felt in every region and that carbon budgets consistent with achieving the Paris Agreement temperature goal are now small and being rapidly depleted;

[1] Intergovernmental Panel on Climate Change. 2021. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. V Masson-Delmotte, P Zhai, A Pirani, et al. (eds.). Cambridge: Cambridge University Press. Available at https://www.ipcc.ch/report/ar6/wg1/.

4. *Recalls* Article 2, paragraph 2, of the Paris Agreement, which provides that the Paris Agreement will be implemented to reflect equity and the principle of common but differentiated responsibilities and respective capabilities in the light of different national circumstances;

5. *Stresses* the urgency of enhancing ambition and action in relation to mitigation, adaptation and finance in this critical decade to address the gaps in the implementation of the goals of the Paris Agreement;

II. Adaptation

6. *Notes with serious concern* the findings from the contribution of Working Group I to the Intergovernmental Panel on Climate Change Sixth Assessment Report, including that climate and weather extremes and their adverse impacts on people and nature will continue to increase with every additional increment of rising temperatures;

7. *Emphasizes* the urgency of scaling up action and support, including finance, capacity-building and technology transfer, to enhance adaptive capacity, strengthen resilience and reduce vulnerability to climate change in line with the best available science, taking into account the priorities and needs of developing country Parties;

8. *Welcomes* the adaptation communications and national adaptation plans submitted to date, which enhance the understanding and implementation of adaptation actions and priorities;

9. *Urges* Parties to further integrate adaptation into local, national and regional planning;

10. *Requests* Parties that have not yet done so to submit their adaptation communications in accordance with decision 9/CMA.1 ahead of the fourth session of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (November 2022) so as to provide timely input to the global stocktake;

11. *Recognizes* the importance of the global goal on adaptation for the effective implementation of the Paris Agreement and *welcomes* the launch of the comprehensive two-year Glasgow–Sharm el-Sheikh work programme on the global goal on adaptation;

12. *Notes* that the implementation of the Glasgow–Sharm el-Sheikh work programme will start immediately after the third session of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement;

13. *Invites* the Intergovernmental Panel on Climate Change to present to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its fourth session the findings from the contribution of Working Group II to its Sixth Assessment Report, including those relevant to assessing adaptation needs, and *calls upon* the research community to further the understanding of global, regional and local impacts of climate change, response options and adaptation needs;

III. Adaptation finance

14. *Notes with concern* that the current provision of climate finance for adaptation remains insufficient to respond to worsening climate change impacts in developing country Parties;

15. *Urges* developed country Parties to urgently and significantly scale up their provision of climate finance, technology transfer and capacity-building for adaptation so as to respond to the needs of developing country Parties as part of a global effort, including for the formulation and implementation of national adaptation plans and adaptation communications;

16. *Recognizes* the importance of the adequacy and predictability of adaptation finance, including the value of the Adaptation Fund in delivering dedicated support for adaptation, and *invites* developed country Parties to consider multi-annual pledges;

17. *Welcomes* the recent pledges made by many developed country Parties to increase their provision of climate finance to support adaptation in developing country Parties in response to their growing needs, including contributions made to the Adaptation Fund and the Least Developed Countries Fund, which represent significant progress compared with previous efforts;

18. *Urges* developed country Parties to at least double their collective provision of climate finance for adaptation to developing country Parties from 2019 levels by 2025, in the context of achieving a balance between mitigation and adaptation in the provision of scaled-up financial resources, recalling Article 9, paragraph 4, of the Paris Agreement;

19. *Calls upon* multilateral development banks, other financial institutions and the private sector to enhance finance mobilization in order to deliver the scale of resources needed to achieve climate plans, particularly for adaptation, and *encourages* Parties to continue to explore innovative approaches and instruments for mobilizing finance for adaptation from private sources;

IV. Mitigation

20. *Reaffirms* the Paris Agreement temperature goal of holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels;

21. *Recognizes* that the impacts of climate change will be much lower at the temperature increase of 1.5 °C compared with 2 °C and *resolves* to pursue efforts to limit the temperature increase to 1.5 °C;

22. *Recognizes* that limiting global warming to 1.5 °C requires rapid, deep and sustained reductions in global greenhouse gas emissions, including reducing global carbon dioxide emissions by 45 per cent by 2030 relative to the 2010 level and to net zero around mid-century as well as deep reductions in other greenhouse gases;

23. *Also recognizes* that this requires accelerated action in this critical decade, on the basis of the best available scientific knowledge and equity, reflecting common but differentiated responsibilities and respective capabilities in the light of different national circumstances and in the context of sustainable development and efforts to eradicate poverty;

24. *Welcomes* efforts by Parties to communicate new or updated nationally determined contributions, long-term low greenhouse gas emission development strategies and other actions that demonstrate progress towards achievement of the Paris Agreement temperature goal;

25. *Notes with serious concern* the findings of the synthesis report on nationally determined contributions under the Paris Agreement,[2] according to which the aggregate greenhouse gas emission level, taking into account implementation of all submitted nationally determined contributions, is estimated to be 13.7 per cent above the 2010 level in 2030;

26. *Emphasizes* the urgent need for Parties to increase their efforts to collectively reduce emissions through accelerated action and implementation of domestic mitigation measures in accordance with Article 4, paragraph 2, of the Paris Agreement;

27. *Decides* to establish a work programme to urgently scale up mitigation ambition and implementation in this critical decade and *requests* the Subsidiary Body for Implementation and the Subsidiary Body for Scientific and Technological Advice to recommend a draft decision on this matter for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its fourth session, in a manner that complements the global stocktake;

[2] See document FCCC/PA/CMA/2021/8/Rev.1 and https://unfccc.int/sites/default/files/resource/message_to_parties_and_observers_on_ndc_numbers.pdf.

28. *Urges* Parties that have not yet communicated new or updated nationally determined contributions to do so as soon as possible in advance of the fourth session of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement;

29. *Recalls* Article 3 and Article 4, paragraphs 3, 4, 5 and 11, of the Paris Agreement and *requests* Parties to revisit and strengthen the 2030 targets in their nationally determined contributions as necessary to align with the Paris Agreement temperature goal by the end of 2022, taking into account different national circumstances;

30. *Also requests* the secretariat to annually update the synthesis report on nationally determined contributions under the Paris Agreement, referred to in decision 1/CMA.2, paragraph 10, to be made available to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at each of its sessions;

31. *Decides* to convene an annual high-level ministerial round table on pre-2030 ambition, beginning at the fourth session of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement;

32. *Urges* Parties that have not yet done so to communicate, by the fourth session of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement, long-term low greenhouse gas emission development strategies referred to in Article 4, paragraph 19, of the Paris Agreement towards just transitions to net zero emissions by or around mid-century, taking into account different national circumstances;

33. *Invites* Parties to update the strategies referred to in paragraph 32 above regularly, as appropriate, in line with the best available science;

34. *Requests* the secretariat to prepare a synthesis report on long-term low greenhouse gas emission development strategies referred to in Article 4, paragraph 19, of the Paris Agreement to be made available to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its fourth session;

35. *Notes* the importance of aligning nationally determined contributions with long-term low greenhouse gas emission development strategies;

36. *Calls upon* Parties to accelerate the development, deployment and dissemination of technologies, and the adoption of policies, to transition towards low-emission energy systems, including by rapidly scaling up the deployment of clean power generation and energy efficiency measures, including accelerating efforts towards the phasedown of unabated coal power and phase-out of inefficient fossil fuel subsidies, while providing targeted support to the poorest and most vulnerable in line with national circumstances and recognizing the need for support towards a just transition;

37. *Invites* Parties to consider further actions to reduce by 2030 non-carbon dioxide greenhouse gas emissions, including methane;

38. *Emphasizes* the importance of protecting, conserving and restoring nature and ecosystems to achieve the Paris Agreement temperature goal, including through forests and other terrestrial and marine ecosystems acting as sinks and reservoirs of greenhouse gases and by protecting biodiversity, while ensuring social and environmental safeguards;

39. *Recognizes* that enhanced support for developing country Parties will allow for higher ambition in their actions;

V. Finance, technology transfer and capacity-building for mitigation and adaptation

40. *Urges* developed country Parties to provide enhanced support, including through financial resources, technology transfer and capacity-building, to assist developing country Parties with respect to both mitigation and adaptation, in continuation of their existing obligations under the Convention and the Paris Agreement, and *encourages* other Parties to provide or continue to provide such support voluntarily;

41. *Notes with concern* the growing needs of developing country Parties, in particular due to the increasing impacts of climate change and increased indebtedness as a consequence of the coronavirus disease 2019 pandemic;

42. *Welcomes* the first report on the determination of needs of developing country Parties related to implementing the Convention and the Paris Agreement[3] and the fourth Biennial Assessment and Overview of Climate Finance Flows[4] by the Standing Committee on Finance;

43. *Emphasizes* the need to mobilize climate finance from all sources to reach the level needed to achieve the goals of the Paris Agreement, including significantly increasing support for developing country Parties, beyond USD 100 billion per year;

44. *Notes with deep regret* that the goal of developed country Parties to mobilize jointly USD 100 billion per year by 2020 in the context of meaningful mitigation actions and transparency on implementation has not yet been met and *welcomes* the increased pledges made by many developed country Parties and the *Climate Finance Delivery Plan: Meeting the US$100 Billion Goal*[5] and the collective actions contained therein;

45. *Calls upon* developed country Parties to provide greater clarity on their pledges referred to in paragraph 44 above through their next biennial communications under Article 9, paragraph 5, of the Paris Agreement;

46. *Urges* developed country Parties to fully deliver on the USD 100 billion goal urgently and through to 2025 and *emphasizes* the importance of transparency in the implementation of their pledges;

47. *Urges* the operating entities of the Financial Mechanism, multilateral development banks and other financial institutions to further scale up investments in climate action and *calls for* a continued increase in the scale and effectiveness of climate finance from all sources globally, including grants and other highly concessional forms of finance;

48. *Re-emphasizes* the need for scaled-up financial resources to take into account the needs of those countries particularly vulnerable to the adverse effects of climate change and in this regard *encourages* relevant multilateral institutions to consider how climate vulnerabilities should be reflected in the provision and mobilization of concessional financial resources and other forms of support, including special drawing rights;

49. *Welcomes with appreciation* the initiation of deliberations on a new collective quantified goal on climate finance and *looks forward* to the ad hoc work programme established under decision 9/CMA.3 and to engaging constructively in the actions contained therein;

50. *Underscores* the importance of the deliberations referred to in paragraph 49 above being informed by the need to strengthen the global response to the threat of climate change in the context of sustainable development and efforts to eradicate poverty and to make finance flows consistent with a pathway towards low greenhouse gas emission and climate-resilient development taking into account the needs and priorities of developing countries and building on the work of the Standing Committee on Finance;

51. *Emphasizes* the challenges faced by many developing country Parties in accessing finance and *encourages* further efforts to enhance access to finance, including by the operating entities of the Financial Mechanism;

52. *Notes* the specific concerns raised with regard to eligibility and ability to access concessional forms of climate finance and *re-emphasizes* the importance of the provision of scaled-up financial resources, taking into account the needs of developing country Parties that are particularly vulnerable to the adverse effects of climate change;

[3] See document FCCC/CP/2021/10/Add.2–FCCC/PA/CMA/2021/7/Add.2.
[4] See document FCCC/CP/2021/10/Add.1–FCCC/PA/CMA/2021/7/Add.1.
[5] See https://ukcop26.org/wp-content/uploads/2021/10/Climate-Finance-Delivery-Plan-1.pdf.

53. *Encourages* relevant providers of financial support to consider how vulnerability to the adverse effects of climate change could be reflected in the provision and mobilization of concessional financial resources and how they could simplify and enhance access to finance;

54. *Underscores* the urgency of enhancing understanding and action to make finance flows consistent with a pathway towards low greenhouse gas emission and climate-resilient development in a transparent and inclusive manner in the context of sustainable development and poverty eradication;

55. *Calls upon* developed country Parties, multilateral development banks and other financial institutions to accelerate the alignment of their financing activities with the goals of the Paris Agreement;

56. *Acknowledges* the progress made on capacity-building, particularly in relation to enhancing the coherence and coordination of capacity-building activities towards the implementation of the Convention and the Paris Agreement;

57. *Recognizes* the need to continue supporting developing country Parties in identifying and addressing both current and emerging capacity-building gaps and needs, and to catalyse climate action and solutions to respond;

58. *Welcomes* the outcomes of the "COP26 Catalyst for Climate Action" and the strong commitments made by many Parties to take forward action on capacity-building;

59. *Also welcomes* the joint annual reports of the Technology Executive Committee and the Climate Technology Centre and Network for 2020 and 2021[6] and *invites* the two bodies to strengthen their collaboration;

60. *Emphasizes* the importance of strengthening cooperative action on technology development and transfer for the implementation of mitigation and adaptation action, including accelerating, encouraging and enabling innovation, and the importance of predictable, sustainable and adequate funding from diverse sources for the Technology Mechanism;

VI. Loss and damage[7]

61. *Acknowledges* that climate change has already caused and will increasingly cause loss and damage and that, as temperatures rise, impacts from climate and weather extremes, as well as slow onset events, will pose an ever-greater social, economic and environmental threat;

62. *Also acknowledges* the important role of a broad range of stakeholders at the local, national and regional level, including indigenous peoples and local communities, in averting, minimizing and addressing loss and damage associated with the adverse effects of climate change;

63. *Reiterates* the urgency of scaling up action and support, as appropriate, including finance, technology transfer and capacity-building, for implementing approaches for averting, minimizing and addressing loss and damage associated with the adverse effects of climate change in developing country Parties that are particularly vulnerable to these effects;

64. *Urges* developed country Parties, the operating entities of the Financial Mechanism, United Nations entities and intergovernmental organizations and other bilateral and multilateral institutions, including non-governmental organizations and private sources, to provide enhanced and additional support for activities addressing loss and damage associated with the adverse effects of climate change;

[6] FCCC/SB/2020/4 and FCCC/SB/2021/5.

[7] It is noted that discussions related to the governance of the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts did not produce an outcome; this is without prejudice to further consideration of this matter.

65. *Recognizes* the importance of demand-driven technical assistance in building capacity to implement approaches to avert, minimize and address loss and damage associated with the adverse effects of climate change;

66. *Welcomes* the further operationalization of the Santiago network for averting, minimizing and addressing loss and damage associated with the adverse effects of climate change, including the agreement on its functions and process for further developing its institutional arrangements;

67. *Decides* that the Santiago network will be provided with funds to support technical assistance for the implementation of relevant approaches to avert, minimize and address loss and damage associated with the adverse effects of climate change in developing countries in support of the functions set out in paragraph 9 of decision 19/CMA.3;

68. *Also decides* that the modalities for the management of funds provided for technical assistance under the Santiago network and the terms for their disbursement shall be determined by the process set out in paragraph 10 of decision 19/CMA.3;

69. *Further decides* that the body providing secretarial services to facilitate work under the Santiago network to be determined in accordance with paragraph 10 of decision 19/CMA.3 will administer the funds referred to in paragraph 67 above;

70. *Urges* developed country Parties to provide funds for the operation of the Santiago network and for the provision of technical assistance as set out in paragraph 67 above;

71. *Acknowledges* the importance of coherent action to respond to the scale of needs caused by the adverse impacts of climate change;

72. *Resolves* to strengthen partnerships between developing and developed countries, funds, technical agencies, civil society and communities to enhance understanding of how approaches to averting, minimizing and addressing loss and damage can be improved;

73. *Decides* to establish the Glasgow Dialogue between Parties, relevant organizations and stakeholders to discuss the arrangements for the funding of activities to avert, minimize and address loss and damage associated with the adverse impacts of climate change, to take place each year at the first session of the Subsidiary Body for Implementation until it is concluded at its sixtieth session (June 2024);

74. *Requests* the Subsidiary Body for Implementation to organize the Glasgow Dialogue in cooperation with the Executive Committee of the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts;

VII. Implementation

75. *Resolves* to move swiftly with the full implementation of the Paris Agreement;

76. *Welcomes* the start of the global stocktake and *expresses its determination* for the process to be comprehensive, inclusive and consistent with Article 14 of the Paris Agreement and decision 19/CMA.1, in the light of paragraph 5 above;

77. *Encourages* the high-level champions to support the effective participation of non-Party stakeholders in the global stocktake;

78. *Recalls* the Katowice climate package and *welcomes with appreciation* the completion of the Paris Agreement work programme, including the adoption of decisions on the following:

(a) Common time frames for nationally determined contributions referred to in Article 4, paragraph 10, of the Paris Agreement (decision 6/CMA.3);

(b) Methodological issues relating to the enhanced transparency framework for action and support referred to in Article 13 of the Paris Agreement (decision 5/CMA.3);

(c) Modalities and procedures for the operation and use of a public registry referred to in Article 4, paragraph 12, of the Paris Agreement (decision 20/CMA.3);

(d) Modalities and procedures for the operation and use of a public registry referred to in Article 7, paragraph 12, of the Paris Agreement (decision 21/CMA.3);

(e) Guidance on cooperative approaches referred to in Article 6, paragraph 2, of the Paris Agreement (decision 2/CMA.3);

(f) Rules, modalities and procedures for the mechanism established by Article 6, paragraph 4, of the Paris Agreement (decision 3/CMA.3);

(g) Work programme under the framework for non-market approaches referred to in Article 6, paragraph 8, of the Paris Agreement (decision 4/CMA.3);

79. *Urges* Parties to swiftly make the necessary preparations for ensuring timely reporting under the enhanced transparency framework in line with Article 13 of the Paris Agreement and the timelines set out in decision 18/CMA.1;

80. *Acknowledges* the call from developing countries for increased support for the implementation of the enhanced transparency framework under Article 13 of the Paris Agreement in a timely, adequate and predictable manner;

81. *Welcomes* decision 7/CP.26, in which the Global Environment Facility is encouraged, as part of the eighth replenishment process, to duly consider ways to increase the financial resources allocated for climate, and *recognizes* that the Capacity-building Initiative for Transparency, established pursuant to decision 1/CP.21, paragraph 84, will continue to support developing country Parties, upon their request, in building their institutional and technical capacity in relation to the enhanced transparency framework;

82. *Welcomes* decision 12/CMA.3, in which the Global Environment Facility is requested to continue to facilitate improved access to the Capacity-building Initiative for Transparency by developing country Parties, and *encourages* the Global Environment Facility to work closely with other institutions and initiatives to enhance these efforts, such as the Taskforce on Access to Climate Finance and the "COP26 Catalyst for Climate Action";

83. *Takes note* of the revised terms of reference of the Consultative Group of Experts, contained in the annex to decision 14/CP.26;

84. *Recognizes* the need to take into consideration the concerns of Parties with economies most affected by the impacts of response measures, particularly developing country Parties, in line with Article 4, paragraph 15, of the Paris Agreement;

85. *Also recognizes* the need to ensure just transitions that promote sustainable development and eradication of poverty, and the creation of decent work and quality jobs, including through making financial flows consistent with a pathway towards low greenhouse gas emission and climate-resilient development, including through deployment and transfer of technology, and provision of support to developing country Parties;

VIII. Collaboration

86. *Notes* the urgent need to close the gaps in implementation towards the goals of the Paris Agreement and *invites* the Secretary-General of the United Nations to convene world leaders in 2023 to consider ambition to 2030;

87. *Recognizes* the importance of international collaboration on innovative climate action, including technological advancement, across all actors of society, sectors and regions, in contributing to progress towards the goals of the Paris Agreement;

88. *Also recognizes* the important role of non-Party stakeholders, including civil society, indigenous peoples, local communities, youth, children, local and regional governments and other stakeholders, in contributing to progress towards the goals of the Paris Agreement;

89. *Welcomes* the improvement of the Marrakech Partnership for Global Climate Action[8] for enhancing ambition, the leadership and actions of the high-level champions, and the work

[8] See https://unfccc.int/sites/default/files/resource/Improved%20Marrakech%20Partnership%202021-2025.pdf.

of the secretariat on the Non-State Actor Zone for Climate Action platform to support accountability and track progress of voluntary initiatives;

90. *Also welcomes* the high-level communiqué[9] on the regional climate weeks and *encourages* the continuation of regional climate weeks where Parties and non-Party stakeholders can strengthen their credible and durable response to climate change at the regional level;

91. *Urges* Parties to swiftly begin implementing the Glasgow work programme on Action for Climate Empowerment, respecting, promoting and considering their respective obligations on human rights as well as gender equality and empowerment of women;

92. *Also urges* Parties and stakeholders to ensure meaningful youth participation and representation in multilateral, national and local decision-making processes, including under the Paris Agreement;

93. *Emphasizes* the important role of indigenous peoples' and local communities' culture and knowledge in effective action on climate change and *urges* Parties to actively involve indigenous peoples and local communities in designing and implementing climate action;

94. *Expresses its recognition* of the important role observer organizations play, including the nine non-governmental organization constituencies, in sharing their knowledge, and their calls to see ambitious action to meet the goals of the Paris Agreement and in collaborating with Parties to that end;

95. *Encourages* Parties to increase the full, meaningful and equal participation of women in climate action and to ensure gender-responsive implementation and means of implementation, which are vital for raising ambition and achieving climate goals;

96. *Takes note* of the estimated budgetary implications of the activities to be undertaken by the secretariat referred to in this decision;

97. *Requests* that the actions of the secretariat called for in this decision be undertaken subject to the availability of financial resources.

12th plenary meeting
13 November 2021

9 Available at https://unfccc.int/regional-climate-weeks/rcw-2021-cop26-communique.

Decision 2/CMA.3

Guidance on cooperative approaches referred to in Article 6, paragraph 2, of the Paris Agreement

The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement,

Recalling the Paris Agreement,

Also recalling the tenth preambular paragraph of the Paris Agreement, in which Parties take into account the imperatives of a just transition of the workforce and the creation of decent work and quality jobs in accordance with nationally defined development priorities,

Further recalling the eleventh preambular paragraph of the Paris Agreement, acknowledging that climate change is a common concern of humankind, Parties should, when taking action to address climate change, respect, promote and consider their respective obligations on human rights, the right to health, the rights of indigenous peoples, local communities, migrants, children, persons with disabilities and people in vulnerable situations and the right to development, as well as gender equality, empowerment of women and intergenerational equity,

Recalling Article 2 of the Paris Agreement and decision 1/CP.21,

Also recalling Article 4, paragraph 2, of the Paris Agreement,

Further recalling Article 6 of the Paris Agreement and decisions 1/CP.21, paragraph 36, 8/CMA.1 and 9/CMA.2,

Cognizant of decision 5/CMA.3,

1. *Adopts* the guidance on cooperative approaches referred to in Article[1] 6, paragraph 2, as contained in the annex;

2. *Clarifies* that the annex requires information to be reported in the structured summary pursuant to paragraph 77(d) of the annex to decision 18/CMA.1 (Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement), including the information to be reported as per paragraph 77(d)(iii);

3. *Requests* the Subsidiary Body for Scientific and Technological Advice to undertake the following work, on the basis of the guidance in the annex, to develop recommendations, for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its fourth session (November 2022), on:

(a) The special circumstances of the least developed countries and small island developing States;

(b) Elaboration of further guidance in relation to corresponding adjustments for multi-year and single-year nationally determined contributions, in a manner that ensures the avoidance of double counting, on:

(i) Methods for establishing an indicative trajectory, trajectories or budget and for averaging, including with respect to relevant indicators, and for calculating cumulative emissions by sources and removals by sinks;

(ii) Methods for demonstrating the representativeness of averaging for corresponding adjustments by quantifying how much the yearly transaction volume differs from the average for the period;

(c) Consideration of whether internationally transferred mitigation outcomes could include emission avoidance;

[1] "Article" refers to an Article of the Paris Agreement, unless otherwise specified.

4. *Invites* submissions from Parties on options for the tables and outlines for the information required pursuant to chapter IV of the annex (Reporting) by 31 March 2022 via the submission portal;[2]

5. *Requests* the secretariat to organize a technical workshop, ensuring broad participation of Parties, to develop options for the tables and outlines for the information required pursuant to chapter IV of the annex (Reporting), including the agreed electronic format referred to in chapter IV.B of the annex (Annual information), on the basis of the information in those chapters, for consideration by the Subsidiary Body for Scientific and Technological Advice at its fifty-sixth session (June 2022);

6. *Also requests* the Subsidiary Body for Scientific and Technological Advice to develop tables and outlines for the information required pursuant to chapter IV of the annex (Reporting), including the agreed electronic format referred to in chapter IV.B of the annex (Annual information), on the basis of the submissions referred to in paragraph 4 above and taking into account the options developed pursuant to paragraph 5 above, for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its fourth session;

7. *Further requests* the Subsidiary Body for Scientific and Technological Advice to develop recommendations for guidelines for the reviews pursuant to chapter V of the annex (Review), including in relation to the Article 6 technical expert review team, in a manner that minimizes the burden on Parties and the secretariat, for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its fourth session, that include:

(a) Provisions ensuring that the reviews assess consistency of the information provided on the cooperative approach with that in the annex;

(b) That reviews are desk reviews or centralized reviews (as per the descriptions in paragraphs 152 and 154 of the annex to decision 18/CMA.1) and are conducted at regular intervals each year;

(c) Development of modalities for reviewing information that is confidential;

(d) That the reviews ensure consistency between the reporting of all of the Parties participating in a cooperative approach in respect of that cooperative approach;

(e) That the reviews specify recommended action to be taken when inconsistencies are identified, and provisions on how a Party should respond to those recommendations and the implications of non-responsiveness, if any;

(f) The composition of the Article 6 technical expert review team, how the team interacts with the participating Party when undertaking the review, the implications of paragraph 176 of the annex to decision 18/CMA.1 in respect of the composition of Article 13 review teams, and the training programme for the Article 6 technical experts;

(g) Coordination of the Article 6 technical expert review with the technical expert review referred to in chapter VII of the annex to decision 18/CMA.1, including ensuring that Article 6 technical expert reviews in a given review cycle are completed in advance of, and the relevant reports are provided to, the technical expert review referred to in chapter VII of the annex to decision 18/CMA.1;

8. *Invites* submissions from Parties on options for implementing the infrastructure requirements referred to in chapter VI of the annex (Recording and tracking) by 31 March 2022;

9. *Requests* the secretariat to organize a technical workshop, ensuring broad participation of Parties, to develop options for implementing the infrastructure requirements, including guidance for registries, the international registry, the Article 6 database and the centralized accounting and reporting platform referred to in chapter VI of the annex (Recording and tracking), for consideration by the Subsidiary Body for Scientific and Technological Advice at its fifty-sixth session;

[2] https://www4.unfccc.int/sites/submissionsstaging/Pages/Home.aspx.

10. *Also requests* the Subsidiary Body for Scientific and Technological Advice, on the basis of the submissions referred to in paragraph 8 above and taking into account the options developed pursuant to paragraph 9 above, to make recommendations relating to infrastructure, including guidance for registries, the international registry, the Article 6 database and the centralized accounting and reporting platform referred to in chapter VI of the annex (Recording and tracking), for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its fourth session;

11. *Affirms* that the guidance will not infringe on the nationally determined nature of nationally determined contributions;

12. *Requests* the secretariat to design and, following consultation with Parties, implement a capacity-building programme, including through its regional collaboration centres, to assist Parties, particularly developing country Parties, intending to participate in cooperative approaches, including to:

(a) Support the development of institutional arrangements, including in relation to reporting, in order to enable Parties to engage in cooperative approaches;

(b) Help Parties ensure that cooperative approaches in which they participate support ambition;

(c) Assist the least developed countries and small island developing States in meeting the participation requirements as set out in chapter II of the annex (Participation);

13. *Also requests* the secretariat to prepare annually a compilation and synthesis of the results of the Article 6 technical expert review, including identification of recurring themes and lessons learned, for consideration by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement, including in the context of its review of the guidance;

14. *Decides* to review the guidance at its tenth session (2028) and to complete the review by no later than at its twelfth session (2030) in order to coordinate the timing of the review with that of the review undertaken in accordance with paragraph 18 of decision 4/CMA.1;

15. *Requests* the Subsidiary Body for Scientific and Technological Advice to commence its work in 2028 to develop recommendations in relation to the review referred to in paragraph 14 above and *decides* that the relevant work of the Subsidiary Body for Scientific and Technological Advice shall include, but is not limited to:

(a) Participation responsibilities referred to in chapter II of the annex (Participation);

(b) Implementation of chapter III of the annex (Corresponding adjustments), including consideration of other methods in addition to those set out in chapter III.B of the annex (Application of corresponding adjustments) and elaboration of guidance to provide for a single method for corresponding adjustments, to be applied from 2031 onward;

(c) Implementation of chapter IV of the annex (Reporting);

(d) Implementation of chapter V of the annex (Review);

(e) Consideration of any need for safeguards and limits in addition to those already operationalized through the annex;

16. *Requests* the secretariat to support the forum on the impact of the implementation of response measures (referred to in para. 33 of decision 1/CP.21) in considering ways to address negative social or economic impacts, especially on developing country Parties, resulting from activities under Article 6, paragraph 2, as requested by the forum;

17. *Invites* the Adaptation Fund to report in its annual reports to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement on funding related to participation in cooperative approaches pursuant to paragraph 37 of chapter VII of the annex (Ambition in mitigation and adaptation actions);

18. *Takes note* of the estimated budgetary implications of the activities to be undertaken by the secretariat referred to in this decision;

19. *Requests* that the actions called for in this decision be undertaken subject to the availability of financial resources;

20. *Invites* Parties to make contributions to the Trust Fund for Supplementary Activities for operationalizing the guidance and for supporting the workshops referred to in paragraphs 5 and 9 above and the capacity-building programme referred to in paragraph 12 above.

Annex

Guidance on cooperative approaches referred to in Article 6, paragraph 2, of the Paris Agreement

I. Internationally transferred mitigation outcomes

1. Internationally transferred mitigation outcomes (ITMOs) from a cooperative approach are:

(a) Real, verified and additional;

(b) Emission reductions and removals, including mitigation co-benefits resulting from adaptation actions and/or economic diversification plans or the means to achieve them, when internationally transferred;

(c) Measured in metric tonnes of carbon dioxide equivalent (t CO_2 eq) in accordance with the methodologies and metrics assessed by the Intergovernmental Panel on Climate Change and adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA) or in other non-greenhouse gas (GHG) metrics determined by the participating Parties that are consistent with the nationally determined contributions (NDCs) of the participating Parties;

(d) From a cooperative approach referred to in Article[1] 6, paragraph 2, (hereinafter referred to as a cooperative approach) that involves the international transfer of mitigation outcomes authorized for use towards an NDC pursuant to Article 6, paragraph 3;

(e) Generated in respect of or representing mitigation from 2021 onward;

(f) Mitigation outcomes authorized by a participating Party for use for international mitigation purposes other than achievement of an NDC (hereinafter referred to as international mitigation purposes) or authorized for other purposes as determined by the first transferring participating Party (hereinafter referred to as other purposes) (international mitigation purposes and other purposes are hereinafter referred to together as other international mitigation purposes);

(g) Article 6, paragraph 4, emission reductions issued under the mechanism established by Article 6, paragraph 4, when they are authorized for use towards achievement of NDCs and/or authorized for use for other international mitigation purposes;

2. A “first transfer” is:

(a) For a mitigation outcome authorized by a participating Party for use towards the achievement of an NDC, the first international transfer of the mitigation outcome or;

(b) For a mitigation outcome authorized by a participating Party for use for other international mitigation purposes, (1) the authorization, (2) the issuance or (3) the use or cancellation of the mitigation outcome, as specified by the participating Party.

II. Participation

3. Each Party participating in a cooperative approach that involves the use of ITMOs (hereinafter referred as a participating Party) shall ensure that its participation in the cooperative approach and the authorization, transfer and use of ITMOs is consistent with this guidance and relevant decisions of the CMA and that it applies this guidance to all corresponding adjustments and cooperative approaches in which it participates.

4. Each participating Party shall ensure that:

(a) It is a Party to the Paris Agreement;

[1] “Article” refers to an Article of the Paris Agreement, unless otherwise specified.

(b) It has prepared, communicated and is maintaining an NDC in accordance with Article 4, paragraph 2;

(c) It has arrangements in place for authorizing the use of ITMOs towards achievement of NDCs pursuant to Article 6, paragraph 3;

(d) It has arrangements in place that are consistent with this guidance and relevant decisions of the CMA for tracking ITMOs;

(e) It has provided the most recent national inventory report required in accordance with decision 18/CMA.1;

(f) Its participation contributes to the implementation of its NDC and long-term low-emission development strategy, if it has submitted one, and the long-term goals of the Paris Agreement.

5. In relation to the least developed countries and small island developing States, pursuant to Article 4, paragraph 6, their special circumstances shall be recognized where this guidance relates to NDCs, and other aspects of their special circumstances may be recognized in further decisions of the CMA relating to this guidance.

III. Corresponding adjustments

A. Internationally transferred mitigation outcome metrics

6. For all ITMOs (ITMOs in a non-GHG metric determined by the participating Parties and ITMOs measured in t CO_2 eq), each participating Party shall apply corresponding adjustments consistently with this guidance and relevant future decisions of the CMA.

B. Application of corresponding adjustments

7. Each participating Party shall apply corresponding adjustments in a manner that ensures transparency, accuracy, completeness, comparability and consistency; that participation in cooperative approaches does not lead to a net increase in emissions across participating Parties within and between NDC implementation periods; and that corresponding adjustments shall be representative and consistent with the participating Party's NDC implementation and achievement. Each participating Party shall apply one of the following methods consistently throughout the NDC period:

(a) Where the participating Party has a single-year NDC:

(i) Providing an indicative multi-year emissions trajectory, trajectories or budget for the NDC implementation period that is consistent with implementation and achievement of the NDC, and annually applying corresponding adjustments for the total amount of ITMOs first transferred and used for each year in the NDC implementation period;

(ii) Calculating the average annual amount of ITMOs first transferred and used over the NDC implementation period, by taking the cumulative amount of ITMOs and dividing by the number of elapsed years in the NDC implementation period and annually applying indicative corresponding adjustments equal to this average amount for each year in the NDC implementation period and applying corresponding adjustments equal to this average amount in the NDC year;

(b) Where the participating Party has a multi-year NDC, calculating a multi-year emissions trajectory, trajectories or budget for its NDC implementation period that is consistent with the NDC, and annually applying corresponding adjustments for the total amount of ITMOs first transferred and used each year in the NDC implementation period and cumulatively at the end of the NDC implementation period.

8. Each participating Party with an NDC measured in t CO_2 eq shall apply corresponding adjustments pursuant to paragraph 7 above, resulting in an emissions balance as referred to

in paragraph 77(d)(ii) of the annex to decision 18/CMA.1, reported pursuant to paragraph 23 below for each year, by applying corresponding adjustments in the following manner to the anthropogenic emissions by sources and removals by sinks from the sectors and GHGs covered by its NDC consistently with this chapter and relevant future decisions of the CMA:

(a) Adding the quantity of ITMOs authorized and first transferred, for the calendar year in which the mitigation outcomes occurred, pursuant to paragraph 7 above;

(b) Subtracting the quantity of ITMOs used pursuant to paragraph 7 above for the calendar year in which the mitigation outcomes are used towards the implementation and achievement of the NDC, ensuring that the mitigation outcomes are used within the same NDC implementation period as when they occurred.

9. Each participating Party with an NDC containing non-GHG metrics determined by the participating Parties engaging in a cooperative approach involving ITMOs traded in non-GHG metrics shall apply corresponding adjustments pursuant to paragraph 7 above, on the basis of ITMOs recorded in a metric-specific registry account, resulting in an annual adjusted indicator, reported pursuant to paragraph 23 below, by applying corresponding adjustments to the annual level of the relevant non-GHG indicator that was selected pursuant to paragraph 65 of the annex to decision 18/CMA.1 and is being used by the Party to track progress towards the implementation and achievement of its NDC, consistently with this chapter and relevant future decisions of the CMA, in the following manner:

(a) Subtracting the quantity of ITMOs authorized and first transferred, for the calendar year in which the mitigation outcomes occurred, pursuant to paragraph 7 above;

(b) Adding the quantity of ITMOs used pursuant to paragraph 7 above for the calendar year in which the mitigation outcomes are used towards the implementation and achievement of the NDC, ensuring that the mitigation outcomes are used within the same NDC implementation period as when they occurred.

10. Each participating Party with a first or first updated NDC consisting of policies and measures that are not quantified shall apply corresponding adjustments pursuant to paragraph 7 above, resulting in an emissions balance, as referred to in decision 18/CMA.1, reported pursuant to paragraph 23 below for each year, by applying corresponding adjustments in the following manner to the anthropogenic emissions by sources and removals by sinks for those emission or sink categories affected by the implementation of the cooperative approach and its mitigation activities and by those policies and measures that include the implementation of the cooperative approach and its mitigation activities, as applicable, consistently with this chapter and relevant future decisions of the CMA:

(a) Adding the quantity of ITMOs authorized and first transferred, for the calendar year in which the mitigation outcomes occurred, pursuant to paragraph 7 above;

(b) Subtracting the quantity of ITMOs used pursuant to paragraph 7 above for the calendar year in which the mitigation outcomes are used towards the implementation and achievement of the NDC, ensuring that the mitigation outcomes are used within the same NDC implementation period as when they occurred.

11. Where, in this annex, the terms sectors and GHGs apply in relation to an NDC, that provision shall be read as referring to sectors and GHGs, or categories in the case referred to in paragraph 10 above.

12. Additions and subtractions for an NDC implementation period shall be considered final, prior to the initiation of the review of the first biennial transparency report that contains information on the end year or end of the period of the NDC, by a date to be determined by the CMA.

13. A participating Party that first transfers ITMOs from emission reductions and removals covered by its NDC shall apply corresponding adjustments consistently with this guidance.

14. A participating Party that first transfers ITMOs from emission reductions and removals that are not covered by its NDC shall apply corresponding adjustments consistently with this guidance.

15. This chapter shall not require a participating Party to update its NDC.

C. Other international mitigation purposes

16. Where a participating Party authorizes the use of mitigation outcomes for other international mitigation purposes, it shall apply a corresponding adjustment for the first transfer of such mitigation outcomes consistently with this guidance.

D. Safeguards and limits to the transfer and use of internationally transferred mitigation outcomes

17. Each participating Party shall ensure that the use of cooperative approaches does not lead to a net increase in emissions of participating Parties within and between NDC implementation periods or across participating Parties, and shall ensure transparency, accuracy, consistency, completeness and comparability in tracking progress in implementation and achievement of its NDC by applying safeguards and limits set out in further guidance from the CMA.

IV. Reporting

A. Initial report

18. Each participating Party shall submit an Article 6, paragraph 2, initial report (hereinafter referred to as an initial report) no later than authorization of ITMOs from a cooperative approach or where practical (in the view of the participating Party) in conjunction with the next biennial transparency report due pursuant to decision 18/CMA.1 for the period of NDC implementation. The initial report shall contain comprehensive information to:

(a) Demonstrate that the participating Party fulfils the participation responsibilities referred to in chapter II above (Participation);

(b) Provide, where the participating Party has not yet submitted a biennial transparency report, the information referred to in paragraph 64 of the annex to decision 18/CMA.1;

(c) Communicate the ITMO metrics and the method for applying corresponding adjustments as per chapter III.B above for multi- or single-year NDCs that will be applied consistently throughout the period of NDC implementation and where the method is a multi-year emissions trajectory, trajectories or budget, describe the method;

(d) Quantify the Party's mitigation information in its NDC in t CO_2 eq, including the sectors, sources, GHGs and time periods covered by the NDC, the reference level of emissions and removals for the relevant year or period, and the target level for its NDC; or, where this is not possible, provide the methodology for the quantification of the NDC in t CO_2 eq;

(e) Quantify the NDC, or the portion in the relevant non-GHG indicator, in a non-GHG metric determined by each participating Party, if applicable;

(f) For a first or first updated NDC consisting of policies and measures that is not quantified, quantify the emission level resulting from the policies and measures that are relevant to the implementation of the cooperative approach and its mitigation activities for the categories of anthropogenic emissions by sources and removals by sinks as identified by the host Party pursuant to paragraph 10 above, and the time periods covered by the NDC;

(g) Provide, for each cooperative approach, a copy of the authorization by the participating Party, a description of the approach, its duration, the expected mitigation for each year of its duration, and the participating Parties involved and authorized entities;

(h) Describe how each cooperative approach ensures environmental integrity, including:

(i) That there is no net increase in global emissions within and between NDC implementation periods;

(ii) Through robust, transparent governance and the quality of mitigation outcomes, including through conservative reference levels, baselines set in a conservative way and below ‘business as usual’ emission projections (including by taking into account all existing policies and addressing uncertainties in quantification and potential leakage);

(iii) By minimizing the risk of non-permanence of mitigation across several NDC periods and how, when reversals of emission reductions or removals occur, the cooperative approach will ensure that these are addressed in full;

(i) Describe how each cooperative approach will:

(i) Minimize and, where possible, avoid negative environmental, economic and social impacts;

(ii) Reflect the eleventh preambular paragraph of the Paris Agreement, acknowledging that climate change is a common concern of humankind, Parties should, when taking action to address climate change, respect, promote and consider their respective obligations on human rights, the right to health, the rights of indigenous peoples, local communities, migrants, children, persons with disabilities and people in vulnerable situations and the right to development, as well as gender equality, empowerment of women and intergenerational equity;

(iii) Be consistent with the sustainable development objectives of the Party, noting national prerogatives;

(iv) Apply any safeguards and limits set out in further guidance from the CMA pursuant to chapter III.D above (Safeguards and limits to the transfer and use of internationally transferred mitigation outcomes);

(v) Contribute resources for adaptation pursuant to chapter VII below (Ambition in mitigation and adaptation actions), if applicable;

(vi) Deliver overall mitigation in global emissions pursuant to chapter VII below (Ambition in mitigation and adaptation actions), if applicable.

19. For each further cooperative approach, each participating Party shall submit the information referred to in paragraph 18(g–i) above in an updated initial report and for inclusion in the centralized accounting and reporting platform referred to in chapter VI.C below (Centralized accounting and reporting platform) and include it in the next biennial transparency report due.

B. Annual information

20. Each participating Party shall, on an annual basis by no later than 15 April of the following year and in an agreed electronic format, submit for recording in the Article 6 database referred to in chapter VI.B below (Article 6 database):

(a) Annual information on authorization of ITMOs for use towards achievement of NDCs, authorization of ITMOs for use towards other international mitigation purposes, first transfer, transfer, acquisition, holdings, cancellation, voluntary cancellation, voluntary cancellation of mitigation outcomes or ITMOs towards overall mitigation in global emissions, and use towards NDCs;

(b) In respect of the above, the cooperative approach, the other international mitigation purpose authorized by the Party, the first transferring participating Party, the using participating Party or authorized entity or entities, as soon as known, the year in which the mitigation occurred, the sector(s) and activity type(s), and the unique identifiers.

C. Regular information

21. Each participating Party shall include, as an annex to its biennial transparency reports that are submitted in accordance with paragraph 10(b) of the annex to decision 18/CMA.1 and no later than 31 December of the relevant year, the following information in relation to its participation in cooperative approaches:

(a) How it is fulfilling the participation responsibilities referred to in chapter II above (Participation);

(b) Updates to the information provided in its initial report as per chapter IV.A above (Initial report), and any previous biennial transparency reports for any information that is not included in the biennial transparency report pursuant to paragraph 64 of the annex to decision 18/CMA.1;

(c) Authorizations and information on its authorization(s) of use of ITMOs towards achievement of NDCs and authorization for use for other international mitigation purposes, including any changes to earlier authorizations, pursuant to Article 6, paragraph 3;

(d) How corresponding adjustments undertaken in the latest reporting period, pursuant to chapter III above (Corresponding adjustments), ensure that double counting is avoided in accordance with paragraph 36 of decision 1/CP.21 and are representative of progress towards implementation and achievement of its NDC, and how those corresponding adjustments ensure that participation in cooperative approaches does not lead to a net increase in emissions across participating Parties within and between NDC implementation periods;

(e) How it has ensured that ITMOs that have been used towards achievement of its NDC or mitigation outcome(s) authorized for use and that have been used for other international mitigation purposes will not be further transferred, further cancelled or otherwise used.

22. Each participating Party shall also include, as an annex to its biennial transparency reports that are submitted in accordance with paragraph 10(b) of the annex to decision 18/CMA.1 and no later than 31 December of the relevant year, the following information on how each cooperative approach in which it participates:

(a) Contributes to the mitigation of GHGs and the implementation of its NDC;

(b) Ensures environmental integrity, including:

(i) That there is no net increase in global emissions within and between NDC implementation periods;

(ii) Through robust, transparent governance and the quality of mitigation outcomes, including through conservative reference levels, baselines set in a conservative way and below ‘business as usual’ emission projections (including by taking into account all existing policies and addressing uncertainties in quantification and potential leakage);

(iii) By minimizing the risk of non-permanence of mitigation across several NDC periods and when reversals of emission removals occur, ensuring that these are addressed in full;

(c) Where a mitigation outcome is measured and transferred in t CO_2 eq, provides for the measurement of mitigation outcomes in accordance with the methodologies and metrics assessed by the Intergovernmental Panel on Climate Change and adopted by the CMA;

(d) Where a mitigation outcome is measured and first transferred in a non-GHG metric determined by the participating Parties, ensures that the method for converting the non-GHG metric into t CO_2 eq is appropriate for the specific non-GHG metric and the mitigation scenario in which it is applied, including how the conversion method:

(i) Represents the emission reductions or removals that occur within the geographical boundaries and time frame in which the non-GHG mitigation outcome was generated;

(ii) Is appropriate for the specific non-CO_2 eq metric, including a demonstration of how the selection of the conversion method and conversion factor(s) applied take into consideration the specific scenario in which the mitigation action occurs;

(iii) Is transparent, including a description of the method, the source of the underlying data, how the data are used, and how the method is applied in a conservative manner that addresses uncertainty and ensures environmental integrity;

(e) Provides for, as applicable, the measurement of mitigation co-benefits resulting from adaptation actions and/or economic diversification plans;

(f) Minimizes and, where possible, avoids negative, environmental, economic and social impacts;

(g) Reflects the eleventh preambular paragraph of the Paris Agreement, acknowledging that climate change is a common concern of humankind, Parties should, when taking action to address climate change, respect, promote and consider their respective obligations on human rights, the right to health, the rights of indigenous peoples, local communities, migrants, children, persons with disabilities and people in vulnerable situations and the right to development, as well as gender equality, empowerment of women and intergenerational equity;

(h) Is consistent with and contributes to the sustainable development objectives of the Party, noting national prerogatives;

(i) Applies any safeguards and limits set out in further guidance from the CMA pursuant to chapter III.D above (Safeguards and limits to the transfer and use of internationally transferred mitigation outcomes);

(j) Contributes resources for adaptation pursuant to chapter VII below (Ambition in mitigation and adaptation actions), if applicable;

(k) Delivers overall mitigation in global emissions pursuant to chapter VII below (Ambition in mitigation and adaptation actions), if applicable.

23. Each participating Party shall submit the following annual information (reported biennially) in a manner consistent with chapter III.B above (Application of corresponding adjustments) and any updates to information submitted for previous years in the NDC implementation period to the Article 6 database pursuant to chapter VI.B below (Article 6 database) and shall include it in the structured summary (required pursuant to paragraph 77(d) of the annex to decision 18/CMA.1 as part of the biennial transparency report):

(a) Annual anthropogenic emissions by sources and removals by sinks covered by its NDC or, where applicable, for the emission or sink categories as identified by the host Party pursuant to paragraph 10 above (as part of the information referred to in para. 77(d)(i) of the annex to decision 18/CMA.1);

(b) Annual anthropogenic emissions by sources and removals by sinks covered by its NDC or, where applicable, from the portion of its NDC in accordance with paragraph 10 above;

(c) Annual quantity of ITMOs first transferred;

(d) Annual quantity of mitigation outcomes authorized for use for other international mitigation purposes and entities authorized to use such mitigation outcomes, as appropriate;

(e) Annual quantity of ITMOs used towards achievement of its NDC;

(f) Net annual quantity of ITMOs resulting from paragraph 23(c–e) above;

(g) Total quantitative corresponding adjustments used to calculate the emissions balance and/or annual adjusted indicator referred to in paragraph 23(k) below, in accordance with the Party’s method for applying corresponding adjustments consistent with chapter III.B above (Application of corresponding adjustments);

(h) The cumulative information in respect of the annual information referred to in paragraph 23(f) above, as applicable;

(i) The annual level of the relevant non-GHG indicator that is being used by the Party to track progress towards the implementation and achievement of its NDC and was selected pursuant to paragraph 65 of the annex to decision 18/CMA.1;

(j) For the information referred to in paragraph 23(c–e) above, the amounts per the cooperative approach, sector, transferring Party, using Party and vintage of the ITMO for each cooperative approach (in the annex referred to in para. 22 above);

(k) For metrics in:

(i) Tonnes of CO_2 eq or non-GHGs, an annual emissions balance consistent with chapter III.B above (Application of corresponding adjustments) (as part of the information referred to in para. 77(d)(ii) of the annex to decision 18/CMA.1);

(ii) Non-GHGs, for each non-GHG metric determined by participating Parties, annual adjustments resulting in an annual adjusted indicator, consistently with paragraph 9 in chapter III.B above (Application of corresponding adjustments) and future decisions of the CMA (as part of the information referred to in para. 77(d)(iii) of the annex to decision 18/CMA.1);

(l) In biennial transparency reports that contain information on the end year of the NDC implementation period, in its assessment of whether it has achieved the target(s) for its NDC pursuant to paragraphs 70 and 77 of decision 18/CMA.1, the application of the necessary corresponding adjustments consistently with chapter III above (Corresponding adjustments) and consistently with future decisions of the CMA.

24. Information submitted by a Party pursuant to this chapter that is not identified by that Party as confidential (non-confidential information) shall be made public on the centralized accounting and reporting platform.

V. Review

25. An Article 6 technical expert review consists of a desk or centralized review of the consistency of the information submitted by the Party under chapter IV.A and C above (Reporting) with this guidance. An Article 6 technical expert review shall be undertaken in a manner that minimizes burden on Parties and the secretariat.

26. An Article 6 technical expert review team shall review the information submitted pursuant to chapter IV.A and C above (Reporting) in accordance with guidelines adopted by the CMA. To the extent possible, information submitted by all the participating Parties on a cooperative approach shall be reviewed as part of the review.

27. The Article 6 technical expert review team shall prepare a report on its review, pursuant to paragraph 26 above, that shall, if applicable, include recommendations to the participating Party on how to improve consistency with this guidance and relevant decisions of the CMA, including on how to address inconsistencies in quantified information that is reported under chapter IV.B–C above (Reporting) and/or identified by the secretariat as part of the consistency check.

28. The Article 6 technical expert review team shall forward its reports for consideration in the technical expert review referred to in chapter VII of the annex to decision 18/CMA.1 in accordance with the guidelines referred to in paragraph 26 above, and the reports shall be made publicly available on the centralized accounting and recording platform.

VI. Recording and tracking

A. Tracking

29. Each participating Party shall have, or have access to, a registry for the purpose of tracking and shall ensure that such registry records, including through unique identifiers, as applicable, authorization, first transfer, transfer, acquisition, use towards NDCs,

authorization for use towards other international mitigation purposes, and voluntary cancellation (including for overall mitigation in global emissions, if applicable), and shall have accounts as necessary.

30. The secretariat shall implement an international registry for participating Parties that do not have or do not have access to a registry. The international registry shall be able to perform the functions set out in paragraph 29 above. Any Party may request an account in the international registry.

31. The international registry shall be part of the centralized accounting and reporting platform referred to in chapter VI.C below (Centralized accounting and reporting platform).

B. Article 6 database

32. For transparency in relation to cooperative approaches, to record and compile the information submitted by participating Parties pursuant to chapter IV.B–C above (Reporting) and to support the review referred to in chapter V above (Review), the secretariat shall implement an Article 6 database as part of and integrated with the centralized accounting and reporting platform referred to in chapter VI.C below (Centralized accounting and reporting platform). The Article 6 database shall enable the following:

(a) Recording of corresponding adjustments and emissions balances and information on ITMOs first transferred, transferred, acquired, held, cancelled, cancelled for overall mitigation in global emissions, if any, and/or used by participating Parties, through identification of ITMOs by unique identifiers that identify, at the minimum, the participating Party, vintage of underlying mitigation, activity type and sector(s);

(b) Identifying inconsistencies to be notified to the participating Party or participating Parties, as applicable.

33. The secretariat shall:

(a) Check the consistency of information reported by a participating Party pursuant to chapter IV above (Reporting) for recording in the Article 6 database with the requirements of this guidance and across the participating Parties in a cooperative approach (consistency check);

(b) Notify the participating Party(ies) of any inconsistencies identified in the information reported by the Party, including compared with information reported by another participating Party;

(c) Provide information relevant to the participating Party's cooperative approach(es) (and other participating Parties, as relevant), including the consistency check to the Article 6 technical expert review team in accordance with the guidelines referred to in paragraph 26 above;

(d) Make non-confidential information in the consistency check publicly available on the centralized accounting and reporting platform.

34. Any amendments to the information recorded in the Article 6 database, including in response to any inconsistencies raised by the secretariat through the consistency check or as a result of recommendations arising from the Article 6 technical expert review pursuant to chapter V above (Review), shall be submitted by the participating Party to be recorded in the Article 6 database.

C. Centralized accounting and reporting platform

35. For transparency in relation to cooperative approaches and to support the review referred to in chapter V above (Review), the secretariat shall establish and maintain a centralized accounting and reporting platform for publishing information submitted by participating Parties pursuant to chapter IV above (Reporting).

36. The secretariat shall:

(a) Maintain public information on cooperative approaches and ITMOs by extracting relevant non-confidential information from the information submitted by participating Parties pursuant to chapter IV above (Reporting);

(b) Maintain links to the publicly available information submitted by participating Parties on the cooperative approaches in which they participate;

(c) Provide an annual report to the CMA on the activities in relation to this chapter, including information on recorded ITMOs, corresponding adjustments and emission balances.

VII. Ambition in mitigation and adaptation actions

37. Participating Parties and stakeholders using cooperative approaches are strongly encouraged to commit to contribute resources for adaptation, in particular through contributions to the Adaptation Fund, and to take into account the delivery of resources under Article 6, paragraph 4, to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation.

38. Each participating Party shall report as part of their reporting in accordance with chapter IV.C above (Regular information) on any contributions made pursuant to paragraph 37 above.

39. Participating Parties and stakeholders are strongly encouraged to cancel ITMOs that are not counted towards any Party’s NDC or for other international mitigation purposes, to deliver overall mitigation in global emissions, and to take into account the delivery of overall mitigation in global emissions under the mechanism established by Article 6, paragraph 4.

40. Each participating Party shall report as part of their reporting in accordance with chapter IV.C above (Regular information) on any delivery of overall mitigation in global emissions related to its participation in cooperative approaches.

12th plenary meeting
13 November 2021

Decision 3/CMA.3

Rules, modalities and procedures for the mechanism established by Article 6, paragraph 4, of the Paris Agreement

The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement,

Recalling the Paris Agreement,

Also recalling the tenth preambular paragraph of the Paris Agreement, in which Parties take into account the imperatives of a just transition of the workforce and the creation of decent work and quality jobs in accordance with nationally defined development priorities,

Further recalling the eleventh preambular paragraph of the Paris Agreement, acknowledging that climate change is a common concern of humankind, Parties should, when taking action to address climate change, respect, promote and consider their respective obligations on human rights, the right to health, the rights of indigenous peoples, local communities, migrants, children, persons with disabilities and people in vulnerable situations and the right to development, as well as gender equality, empowerment of women and intergenerational equity,

Recalling the mechanism established by Article 6, paragraph 4, of the Paris Agreement and the aims referred to therein,

Also recalling decisions 1/CP.21, 8/CMA.1, 13/CMA.1 and 9/CMA.2,

Cognizant of decision 2/CMP.16,

1. *Adopts* the rules, modalities and procedures for the mechanism established by Article[1] 6, paragraph 4, as contained in the annex;

2. *Designates* the body that will supervise the mechanism with its membership and rules of procedure as set out in the annex and names it the Supervisory Body;

3. *Invites* the nomination of members and alternate members for the Supervisory Body pursuant to paragraph 9 of the annex;

4. *Decides* that at least two meetings of the Supervisory Body shall be held in 2022;

5. *Requests* the Supervisory Body to:

(a) Develop provisions for the development and approval of methodologies, validation, registration, monitoring, verification and certification, issuance, renewal, first transfer from the mechanism registry, voluntary cancellation and other processes pursuant to chapters V.B–L and VIII of the annex (Delivering overall mitigation in global emissions);

(b) In the context of developing and approving new methodologies for the mechanism:

(i) Review the baseline and monitoring methodologies in use for the clean development mechanism under Article 12 of the Kyoto Protocol with a view to applying them with revisions, as appropriate, pursuant to chapter V.B of the annex (Methodologies) for the activities under the mechanism (hereinafter referred to as Article 6, paragraph 4, activities);

(ii) Consider the baseline and monitoring methodologies used in other market-based mechanisms as a complementary input to the development of baselines and monitoring methodologies pursuant to chapter V.B of the annex (Methodologies);

(c) Review the sustainable development tool in use for the clean development mechanism and other tools and safeguard systems in use in existing market-based

[1] "Article" refers to an Article of the Paris Agreement, unless otherwise specified.

mechanisms to promote sustainable development with a view to developing similar tools for the mechanism by the end of 2023;

(d) Review the accreditation standards and procedures of the clean development mechanism with a view to applying them with revisions, as appropriate, for the mechanism by the end of 2023;

(e) Expeditiously accredit operational entities as designated operational entities;

(f) Ensure the implementation of the requirements referred to in paragraph 29 of the annex in relation to the least developed countries and small island developing States;

(g) Consider ways to encourage participation by small and micro businesses in the mechanism, in particular in the least developed countries and small island developing States;

(h) Consider opportunities to engage with the Local Communities and Indigenous Peoples Platform and its Facilitative Working Group;

(i) Consider the gender action plan and the incorporation of relevant actions into the work of the Supervisory Body;

6. *Also requests* the Supervisory Body to elaborate and further develop, on the basis of the rules, modalities and procedures contained in the annex, recommendations, for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its fourth session (November 2022), on:

(a) Its rules of procedure (including in relation to transparency of meetings), and to operate and hold meetings on the basis of the annex pending any further decisions by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement on the rules of procedure;

(b) Appropriate levels for the share of proceeds for administrative expenses and its operation, including in order to enable a periodic contribution to the share of proceeds for adaptation for the Adaptation Fund;

(c) Activities involving removals, including appropriate monitoring, reporting, accounting for removals and crediting periods, addressing reversals, avoidance of leakage, and avoidance of other negative environmental and social impacts, in addition to the activities referred to in chapter V of the annex (Article 6, paragraph 4, activity cycle);

(d) The application of the requirements referred to in chapter V.B of the annex (Methodologies);

7. *Further requests* the Subsidiary Body for Scientific and Technological Advice to develop, on the basis of the rules, modalities and procedures contained in the annex, recommendations, for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its fourth session, on:

(a) Further responsibilities of the Supervisory Body and of Parties that host Article 6, paragraph 4, activities (hereinafter referred to as host Parties) in order for such host Parties to elaborate and apply national arrangements for the mechanism under the approval and supervision of the Supervisory Body;

(b) Processes for implementation of the transition of activities from the clean development mechanism to Article 6, paragraph 4, in accordance with chapter XI.A of the annex (Transition of clean development mechanism activities);

(c) Processes for implementation of chapter XI.B of the annex (Use of certified emission reductions towards first or first updated nationally determined contributions);

(d) Reporting by host Parties on their Article 6, paragraph 4, activities and the Article 6, paragraph 4, emission reductions issued for the activities, while avoiding unnecessary duplication of reporting information that is already publicly available;

(e) The operation of the mechanism registry referred to in chapter VI of the annex (Mechanism registry);

(f) The processes necessary for implementation of the share of proceeds to cover administrative expenses and the share of proceeds to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation in accordance with chapter VII of the annex (Levy of share of proceeds for adaptation and administrative expenses);

(g) The processes necessary for the delivery of overall mitigation in global emissions in accordance with chapter VIII of the annex (Delivering overall mitigation in global emissions);

(h) The consideration of whether activities could include emission avoidance and conservation enhancement activities;

8. *Requests* the Supervisory Body to evaluate the implementation of the share of proceeds set out in chapter VII of the annex (Levy of share of proceeds for adaptation and administrative expenses) no later than in 2026 and every five years thereafter and, following such review, to make recommendations on possible improvements in order to optimize the resources available to the Adaptation Fund for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement;

9. *Also requests* the Supervisory Body to evaluate the implementation and delivery of overall mitigation in global emissions set out in chapter VIII of the annex (Delivering overall mitigation in global emissions), including the percentage applied, no later than in 2026 and every five years thereafter and, following such review, to make recommendations on possible improvements in order to optimize the delivery of overall mitigation in global emissions for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement;

10. *Decides* that the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall review the rules, modalities and procedures for the mechanism at its tenth session (2028) with a view to completing the review by no later than at its twelfth session (2030);

11. *Requests* the Subsidiary Body for Scientific and Technological Advice to develop recommendations with respect to the review referred to in paragraph 10 above taking into account:

(a) Any recommendations of the Supervisory Body pursuant to paragraphs 8–9 above;

(b) Consideration of any need for further safeguards;

12. *Also requests* the Supervisory Body to support the forum on the impact of the implementation of response measures (referred to in para. 33 of decision 1/CP.21) in considering ways to address any negative social or economic impacts, especially those on developing country Parties, resulting from Article 6, paragraph 4, activities, as requested by the forum;

13. *Notes with appreciation* decision 2/CMP.16, pursuant to which the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol allocated funds from the Trust Fund for the Clean Development Mechanism under Article 12 of the Kyoto Protocol to the Trust Fund for Supplementary Activities for the purpose of expediting implementation of the Article 6, paragraph 4, mechanism;

14. *Requests* the secretariat, including through its regional collaboration centres and in consultation with the Supervisory Body, to design and implement, in consultation with Parties, a capacity-building programme to assist Parties wishing to voluntarily participate in the mechanism to, inter alia:

(a) Establish the necessary institutional arrangements to implement the requirements contained in the annex;

(b) Develop the technical capacity to design and set baselines for application in host Parties;

15. *Takes note* of the estimated budgetary implications of the activities to be undertaken by the secretariat referred to in this decision;

16. *Requests* that the actions called for in this decision be undertaken subject to the availability of financial resources;

17. *Invites* Parties to make contributions to the Trust Fund for Supplementary Activities for the purpose of operationalizing the mechanism, which shall be reimbursed upon request.

Annex

Rules, modalities and procedures for the mechanism established by Article 6, paragraph 4, of the Paris Agreement

I. Definitions

1. For the purpose of these rules, modalities and procedures:

(a) An "**Article 6, paragraph 4, activity**" is an activity that meets the requirements of Article[1] 6, paragraphs 4–6, these rules, modalities and procedures, and any further relevant decisions of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA);

(b) An "**Article 6, paragraph 4, emission reduction**" (A6.4ER) is issued for mitigation achieved pursuant to Article 6, paragraphs 4–6, these rules, modalities and procedures, and any further relevant decisions of the CMA. It is measured in carbon dioxide equivalent and is equal to 1 tonne of carbon dioxide equivalent calculated in accordance with the methodologies and metrics assessed by the Intergovernmental Panel on Climate Change and adopted by the CMA or in other metrics adopted by the CMA pursuant to these rules, modalities and procedures;

(c) "**International mitigation purposes**", "**other purposes**" and "**other international mitigation purposes**" have the same meanings as provided in paragraph 1(f) of the annex to decision 2/CMA.3.

II. Role of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement

2. The CMA shall provide guidance to the Supervisory Body by taking decisions on, inter alia:

(a) The rules of procedure of the Supervisory Body;

(b) Recommendations made by the Supervisory Body relating to these rules, modalities and procedures;

(c) Matters relating to the operation of the mechanism established by Article 6, paragraph 4, as appropriate.

III. Supervisory Body

3. The Supervisory Body shall supervise the mechanism under the authority and guidance of the CMA and be fully accountable to the CMA.

A. Rules of procedure

4. The Supervisory Body shall comprise 12 members from Parties to the Paris Agreement, ensuring broad and equitable geographical representation and striving to ensure gender-balanced representation, as follows:

(a) Two members from each of the five United Nations regional groups;

(b) One member from the least developed countries;

(c) One member from small island developing States.

[1] "Article" refers to an Article of the Paris Agreement, unless otherwise specified.

5. The CMA shall elect members and an alternate for each member of the Supervisory Body on the basis of nominations by the respective groups and constituencies.

6. Members and alternate members shall serve in their individual expert capacity.

7. Members and alternate members shall possess relevant scientific, technical, socioeconomic or legal expertise.

8. Members and alternate members shall serve for a term of two years.

9. Notwithstanding paragraph 8 above, in the first election of members and alternate members, the CMA shall elect half of the members and their alternate members for a term of three years and the other half for a term of two years. At the expiry of the term of these members and their alternate members and thereafter, the CMA shall elect replacement members and their alternate members for a term of two years. The members and their alternate members shall remain in office until their successors have been elected.

10. The term of service of a member shall start at the first meeting of the Supervisory Body in the calendar year following their election and shall end immediately before the first meeting of the Supervisory Body in the calendar year in which the term ends.

11. The maximum number of terms of any individual shall be two terms, whether consecutive or not and including any period as an alternate member.

12. If a member or alternate member resigns or is otherwise unable to continue as a member or alternate member, the Supervisory Body may decide, bearing in mind the proximity to the next session of the CMA, to appoint a replacement member or replacement alternate member from the same constituency to serve the remainder of the term on the basis of a nomination from the relevant constituency, in which case the appointment shall count as one term.

13. Members and alternate members may be suspended, or their membership terminated by the CMA, if:

(a) They fail to disclose a conflict of interest;

(b) They fail to attend two consecutive meetings without proper justification.

14. Participation costs for members and alternate members will be covered by the share of proceeds for administrative expenses.

15. Members and alternate members shall avoid actual, potential and perceived conflicts of interest and shall:

(a) Declare any actual, potential or perceived conflict of interest at the start of a meeting;

(b) Recuse themselves from participating in any work of the Supervisory Body, including decision-making, in relation to which they have an actual, potential or perceived conflict of interest;

(c) Refrain from behaviour that may be incompatible with the requirements of independence and impartiality.

16. Members and alternate members shall ensure confidentiality, in line with relevant best practice and decisions of the CMA and the Supervisory Body.

17. At least three fourths of the members, including alternate members only when they are acting as members, shall constitute a quorum for meetings of the Supervisory Body.

18. Each year, the Supervisory Body shall elect a Chair and a Vice-Chair from among its members. The Chair and the Vice-Chair shall remain in office until their successors have been elected.

19. Meetings of the Supervisory Body shall be open to the public, including via electronic means, and a recording shall be made available via electronic means unless closed for reasons of confidentiality.

20. Documents for meetings of the Supervisory Body shall be made publicly available, unless they are confidential.

21. The Supervisory Body shall ensure transparency of decision-making and make publicly available its decision-making framework and decisions, including standards, procedures and related documents.

22. Decisions of the Supervisory Body shall be taken by consensus whenever possible. If all efforts at reaching consensus have been exhausted, decisions shall be put to vote and adopted by a majority of three fourths of the members, including alternate members only when they are acting as members, present and voting.

23. The Supervisory Body shall adopt reports on its meetings and make them publicly available.

B. Governance and functions

24. The Supervisory Body shall, in accordance with relevant decisions of the CMA:

(a) Establish the requirements and processes necessary to operate the mechanism, relating to, inter alia:

(i) The accreditation of operational entities as designated operational entities;

(ii) The development and/or approval of methodologies (hereinafter referred to as mechanism methodologies) and standardized baselines for Article 6, paragraph 4, activities;

(iii) The registration of activities as Article 6, paragraph 4, activities, the renewal of crediting periods of registered Article 6, paragraph 4, activities and the issuance of A6.4ERs;

(iv) Ensuring that activities follow reasonable maximum time intervals between the steps in the activity cycle;

(v) The registry for the mechanism;

(vi) The share of proceeds levied to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation as set out in chapter VII below (Levy of share of proceeds for adaptation and administrative expenses);

(vii) The delivery of overall mitigation in global emissions as set out in chapter VIII below (Delivering overall mitigation in global emissions);

(viii) The approval and supervision of host Party national arrangements for accreditation of operational entities; development of mechanism methodologies, including applying baselines and other methodological requirements as defined in chapter V.B below (Methodologies); and application of the crediting periods and renewal of crediting periods consistent with or more stringent than as set out in chapter V.A, C and I below;

(ix) The eleventh preambular paragraph of the Paris Agreement, acknowledging that climate change is a common concern of humankind, Parties should, when taking action to address climate change, respect, promote and consider their respective obligations on human rights, the right to health, the rights of indigenous peoples, local communities, migrants, children, persons with disabilities and people in vulnerable situations and the right to development, as well as gender equality, empowerment of women and intergenerational equity;

(x) The application of robust, social and environmental safeguards;

(xi) The development of tools and approaches for assessing and reporting information about how each activity is fostering sustainable development, while acknowledging that the consideration of sustainable development is a national prerogative;

(xii) Ensuring that the mechanism facilitates achievement of the long-term goals of the Paris Agreement;

(b) Accredit operational entities as designated operational entities;

(c) Support the implementation of the mechanism by, inter alia:

(i) Developing and maintaining a public website for information related to proposed and registered Article 6, paragraph 4, activities, subject to confidentiality;

(ii) Taking appropriate measures to promote the regional availability of designated operational entities in all regions;

(iii) Promoting public awareness of the mechanism;

(iv) Facilitating dialogue with host Parties and other stakeholders in the mechanism;

(v) Providing public information to the CMA on all registered Article 6, paragraph 4, activities hosted by each Party and all A6.4ERs issued for those activities;

(vi) Implementing capacity-building activities;

(d) Report annually to the CMA.

C. Role of the secretariat

25. Pursuant to Article 17 and in accordance with relevant decisions of the CMA, the secretariat shall serve as the secretariat of the Supervisory Body and perform its functions in the operation of the mechanism in accordance with these rules, modalities and procedures.

IV. Participation responsibilities

26. Each host Party of Article 6, paragraph 4, activities shall, prior to participating in the mechanism, ensure that:

(a) It is a Party to the Paris Agreement;

(b) It has prepared, has communicated and is maintaining a nationally determined contribution (NDC) in accordance with Article 4, paragraph 2;

(c) It has designated a national authority for the mechanism and has communicated that designation to the secretariat;

(d) It has indicated publicly to the Supervisory Body how its participation in the mechanism contributes to sustainable development, while acknowledging that the consideration of sustainable development is a national prerogative;

(e) It has indicated publicly to the Supervisory Body the types of Article 6, paragraph 4, activity that it would consider approving pursuant to chapter V.C below (Approval and authorization) and how such types of activity and any associated emission reductions would contribute to the achievement of its NDC, if applicable, its long-term low greenhouse gas (GHG) emission development strategy, if it has submitted one, and the long-term goals of the Paris Agreement.

27. A host Party may specify to the Supervisory Body, prior to participating in the mechanism:

(a) Baseline approaches and other methodological requirements, including additionality, to be applied for Article 6, paragraph 4, activities that it intends to host, in addition and subject to and consistent with these rules, modalities and procedures, under the supervision of the Supervisory Body, and subject to further relevant decisions of the CMA, with an explanation of how those approaches and requirements are compatible with its NDC and, if it has submitted one, its long-term low GHG emission development strategy;

(b) Crediting periods to be applied for Article 6, paragraph 4, activities that it intends to host, including whether the crediting periods may be renewed, subject to these rules, modalities and procedures and under the supervision of the Supervisory Body, and in accordance with further relevant decisions of the CMA, with an explanation of how those crediting periods are compatible with its NDC and, if it has submitted one, its long-term low GHG emission development strategy.

28. Each host Party shall ensure that, on a continuing basis:

(a) It is maintaining an NDC in accordance with Article 4, paragraph 2;

(b) Its participation in the mechanism contributes to the implementation of its NDC and its long-term low GHG emission development strategy, if it has submitted one.

29. In relation to the least developed countries and small island developing States, pursuant to Article 4, paragraph 6, their special circumstances shall be recognized where these rules, modalities and procedures relate to NDCs, and other aspects of their special circumstances may be recognized in further decisions of the CMA relating to these rules, modalities and procedures.

V. Article 6, paragraph 4, activity cycle

A. Activity design

30. The public or private entities participating in an activity (hereinafter referred to as activity participants) that wish to register the activity as an Article 6, paragraph 4, activity shall design the activity according to the requirements in this chapter and any other relevant requirements adopted by the CMA or the Supervisory Body.

31. The activity:

(a) Shall be designed to achieve mitigation of GHG emissions that is additional, including reducing emissions, increasing removals and mitigation co-benefits of adaptation actions and/or economic diversification plans (hereinafter collectively referred to as emission reductions), and not lead to an increase in global emissions;

(b) May be a project, programme of activities or other type of activity approved by the Supervisory Body;

(c) Shall be designed to achieve emission reductions in the host Party;

(d) Shall also:

(i) Deliver real, measurable and long-term benefits related to climate change in accordance with decision 1/CP.21, paragraph 37(b);

(ii) Minimize the risk of non-permanence of emission reductions over multiple NDC implementation periods and, where reversals occur, ensure that these are addressed in full;

(iii) Minimize the risk of leakage and adjust for any remaining leakage in the calculation of emission reductions or removals;

(iv) Minimize and, where possible, avoid negative environmental and social impacts;

(e) Shall undergo local and, where appropriate, subnational stakeholder consultation consistent with applicable domestic arrangements in relation to public participation and local communities and indigenous peoples, as applicable;

(f) Shall apply a crediting period for the issuance of A6.4ERs, that is a maximum of 5 years renewable a maximum of twice, or a maximum of 10 years with no option of renewal, that is appropriate to the activity, or, in respect of activities involving removals, a crediting period of a maximum of 15 years renewable a maximum of twice that is appropriate to the activity, and that is subject to approval by the Supervisory Body, or any shorter crediting period specified by the host Party pursuant to paragraph 27(b) above. The crediting period shall not start before 2021.

32. The activity shall apply a mechanism methodology that has been developed in accordance with chapter V.B below (Methodologies) and approved by the Supervisory Body following its technical assessment, in order to:

(a) Set a baseline for the calculation of emission reductions to be achieved by the activity;

(b) Demonstrate the additionality of the activity;

(c) Ensure accurate monitoring of emission reductions;

(d) Calculate the emission reductions achieved by the activity.

B. Methodologies

33. Mechanism methodologies shall encourage ambition over time; encourage broad participation; be real, transparent, conservative, credible and below ‘business as usual’; avoid leakage, where applicable; recognize suppressed demand; align with the long-term temperature goal of the Paris Agreement; contribute to the equitable sharing of mitigation benefits between the participating Parties; and, in respect of each participating Party, contribute to reducing emission levels in the host Party, and align with its NDC, if applicable, its long-term low GHG emission development strategy, if it has submitted one, and the long-term goals of the Paris Agreement.

34. Mechanism methodologies shall include relevant assumptions, parameters, data sources and key factors and take into account uncertainty, leakage, policies and measures, and relevant circumstances, including national, regional or local, social, economic, environmental and technological circumstances, and address reversals, where applicable.

35. Mechanism methodologies may be developed by activity participants, host Parties, stakeholders or the Supervisory Body. Mechanism methodologies shall be approved by the Supervisory Body where they meet the requirements of these rules, modalities and procedures and the requirements established by the Supervisory Body.

36. Each mechanism methodology shall require the application of one of the approach(es) below to setting the baseline, while taking into account any guidance by the Supervisory Body, and with justification for the appropriateness of the choices, including information on how the proposed baseline approach is consistent with paragraphs 33 and 35 above and recognizing that a host Party may determine a more ambitious level at its discretion:

A performance-based approach, taking into account:

(i) Best available technologies that represent an economically feasible and environmentally sound course of action, where appropriate;

(ii) An ambitious benchmark approach where the baseline is set at least at the average emission level of the best performing comparable activities providing similar outputs and services in a defined scope in similar social, economic, environmental and technological circumstances;

(iii) An approach based on existing actual or historical emissions, adjusted downwards to ensure alignment with paragraph 33 above.

37. Standardized baselines may be developed by the Supervisory Body at the request of the host Party or may be developed by the host Party and approved by the Supervisory Body. Standardized baselines shall be established at the highest possible level of aggregation in the relevant sector of the host Party and be consistent with paragraph 33 above.

38. Each mechanism methodology shall specify the approach to demonstrating the additionality of the activity. Additionality shall be demonstrated using a robust assessment that shows the activity would not have occurred in the absence of the incentives from the mechanism, taking into account all relevant national policies, including legislation, and

representing mitigation that exceeds any mitigation that is required by law or regulation, and taking a conservative approach that avoids locking in levels of emissions, technologies or carbon-intensive practices incompatible with paragraph 33 above.

39. The Supervisory Body may apply simplified approaches for demonstration of additionality for any least developed country or small island developing State at the request of that Party, in accordance with requirements developed by the Supervisory Body.

C. Approval and authorization

40. The host Party shall provide to the Supervisory Body an approval of the activity, prior to a request for registration. The approval shall include:

(a) Confirmation that and information on how the activity fosters sustainable development in the host Party;

(b) Approval of any potential renewal of the crediting period, if the Party intends to allow the activity to continue beyond the first crediting period, where the Party has specified that the crediting periods of Article 6, paragraph 4, activities that it intends to host may be renewed pursuant to paragraph 27(b) above;

(c) Explanation of how the activity relates to the implementation of its NDC and how the expected emission reductions or removals contribute to the host Party's NDC and the purposes referred to in Article 6, paragraph 1.

41. The host Party shall provide to the Supervisory Body the Article 6, paragraph 4(b), authorization of public or private entities to participate in the activity as activity participants under the mechanism.

42. The host Party shall provide a statement to the Supervisory Body specifying whether it authorizes A6.4ERs issued for the activity for use towards achievement of NDCs and/or for other international mitigation purposes as defined in decision 2/CMA.3. If the host Party authorizes any such uses, the Party may provide relevant information on the authorization, such as any applicable terms and provisions. If the host Party authorizes A6.4ERs for use for other international mitigation purposes, it shall specify how it defines "first transfer" consistently with paragraph 2(b) of the annex to decision 2/CMA.3.

43. A6.4ERs may only be used towards NDCs or towards international mitigation purposes if they are authorized in accordance with paragraph 42 above. The host Party shall apply corresponding adjustments for such A6.4ERs first transferred in accordance with chapters IX (Avoiding the use of emission reductions by more than one Party) and X (Use of emission reductions for other international mitigation purposes) below and shall apply corresponding adjustments for the associated A6.4ERs levied for a share of proceeds in accordance with chapter VII below (Levy of share of proceeds for adaptation and administrative expenses) and cancelled for overall mitigation of global emissions in accordance with chapter VIII below (Delivering overall mitigation in global emissions).

44. The host Party shall apply a corresponding adjustment for A6.4ERs that are authorized for other purposes, in accordance with chapter X below (Use of emission reductions for other international mitigation purposes), and shall apply corresponding adjustments for the associated A6.4ERs levied for a share of proceeds in accordance with chapter VII below (Levy of share of proceeds for adaptation and administrative expenses) and cancelled for overall mitigation of global emissions in accordance with chapter VIII below (Delivering overall mitigation in global emissions).

45. Other participating Parties shall provide to the Supervisory Body the Article 6, paragraph 4(b), authorization for public or private entities to participate in the activity as activity participants under the mechanism prior to any first transfer of any A6.4ERs to the mechanism registry account of such Party or public or private entity.

D. Validation

46. A designated operational entity shall independently assess the activity against the requirements set out in these rules, modalities and procedures, further relevant decisions of the CMA and relevant requirements adopted by the Supervisory Body (hereinafter referred to as validation).

E. Registration

47. If the designated operational entity concludes that the outcome of the validation is positive, it shall submit to the Supervisory Body a request for registration with the validation outcome in accordance with the relevant requirements adopted by the Supervisory Body.

48. The activity participants shall pay a share of proceeds, at a level determined by the CMA, taking into account the likely scale of the activity, to cover the administrative expenses for registering the activity when submitting a request for registration.

49. If the Supervisory Body decides that the validation and its outcome meet the relevant requirements adopted by the Supervisory Body, it shall register the activity as an Article 6, paragraph 4, activity.

F. Monitoring

50. The activity participants shall monitor emission reductions achieved by the activity during each monitoring period, in accordance with the relevant requirements adopted by the Supervisory Body. The activity participants shall also monitor potential reversals over a period to be decided by the Supervisory Body.

G. Verification and certification

51. A designated operational entity shall independently review and determine the implementation of, and the emission reductions achieved by, the Article 6, paragraph 4, activity during the monitoring period (hereinafter referred to as verification) against the requirements set out in these rules, modalities and procedures, further relevant decisions of the CMA and relevant requirements adopted by the Supervisory Body, and provide written assurance of the verified emission reductions (hereinafter referred to as certification).

H. Issuance

52. For the issuance of A6.4ERs, the designated operational entity shall submit to the Supervisory Body a request for issuance with the verification outcome and certification in accordance with the relevant requirements adopted by the Supervisory Body.

53. If the Supervisory Body decides that the verification, certification and their outcome meet the relevant requirements adopted by the Supervisory Body, it shall approve the issuance of A6.4ERs.

54. The mechanism registry administrator shall, in accordance with the relevant requirements adopted by the Supervisory Body, issue the A6.4ERs into the mechanism registry.

55. The mechanism registry shall distinguish A6.4ERs that are authorized for use towards the achievement of NDCs and/or for use for other international mitigation purposes pursuant to chapter V.C above (Approval and authorization), including any specified uses for which the A6.4ERs are authorized.

I. Renewal of the crediting period

56. The crediting period of a registered Article 6, paragraph 4, activity may be renewed in accordance with further relevant decisions of the CMA and relevant requirements adopted by the Supervisory Body, if the host Party has approved such renewal in accordance with paragraph 27(b) above.

57. The renewal of a crediting period shall be approved by the Supervisory Body and the host Party following a technical assessment by a designated operational entity to determine necessary updates to the baseline, the additionality and the quantification of emission reductions.

J. First transfer from the mechanism registry

58. At issuance, the mechanism registry administrator shall effect a first transfer of 5 per cent of the issued A6.4ERs to an account held by the Adaptation Fund in the mechanism registry for assisting developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation.

59. At issuance, the mechanism registry administrator shall also effect a first transfer, for cancellation, of a minimum of 2 per cent of the issued A6.4ERs to the account for cancellation for delivering overall mitigation in global emissions in accordance with chapter VIII below (Delivering overall mitigation in global emissions).

60. The mechanism registry administrator shall forward or effect a first transfer, as applicable, of the remaining issued A6.4ERs in accordance with the instructions of the activity participants and with any further modalities adopted by the CMA and relevant requirements adopted by the Supervisory Body.

K. Voluntary cancellation

61. Activity participants may voluntarily request the mechanism registry administrator to cancel in the mechanism registry a specified amount of A6.4ERs issued in respect of their Article 6, paragraph 4, activity.

L. Other processes associated with Article 6, paragraph 4, activities

62. Stakeholders, activity participants and participating Parties may appeal decisions of the Supervisory Body or request that a grievance be addressed by an independent grievance process.

VI. Mechanism registry

63. The mechanism registry shall contain at least a pending account, holding account, retirement account, cancellation account, account for cancellation towards overall mitigation in global emissions and a share of proceeds for adaptation account, as well as a holding account for each Party and each public or private entity authorized per Article 6, paragraph 4(b), by a Party that requests an account where that entity meets the requisite identification requirements developed by the Supervisory Body. The mechanism registry shall be connected to the international registry referred to in decision 2/CMA.3.

64. The mechanism registry shall be developed and operationalized in accordance with the relevant requirements adopted by the Supervisory Body that shall include operating at best practice standards for registries.

65. The secretariat shall serve as the mechanism registry administrator and maintain and operate the mechanism registry under the supervision of the Supervisory Body.

VII. Levy of share of proceeds for adaptation and administrative expenses

66. The share of proceeds that is levied to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation shall be delivered to the Adaptation Fund pursuant to decisions 13/CMA.1 and 1/CMP.14.

67. The share of proceeds to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation shall be comprised of:

(a) A levy of 5 per cent of A6.4ERs at issuance;

(b) A monetary contribution related to the scale of the Article 6, paragraph 4, activity or to the number of A6.4ERs issued, to be set by the Supervisory Body;

(c) After the mechanism becomes self-financing, a periodic contribution from the remaining funds received from administrative expenses as per paragraph 68 below, after setting aside the operating costs for the mechanism and an operating reserve, at a level and frequency to be determined by the CMA.

68. The share of proceeds to cover administrative expenses shall be set in monetary terms at a level and implemented in a manner to be determined by the CMA.

VIII. Delivering overall mitigation in global emissions

69. Delivery of overall mitigation in global emissions shall be enhanced through mandatory cancellation of A6.4ERs that are also accounted for in accordance with the following:

(a) The mechanism registry administrator shall effect a first transfer of a minimum of 2 per cent of the issued A6.4ERs to the cancellation account in the mechanism registry for overall mitigation in accordance with chapter V above (Article 6, paragraph 4, activity cycle), where those A6.4ERs shall be cancelled;

(b) The cancelled A6.4ERs shall not be further transferred or used for any purpose, including towards achievement of any NDC or for other international mitigation purposes or for other purposes;

(c) At first transfer of the remaining issued A6.4ERs, the host Party shall make a corresponding adjustment consistently with decision 2/CMA.3 for the number of issued A6.4ERs first transferred.

70. In addition to the above, Parties, activity participants and stakeholders may also request the voluntary cancellation of A6.4ERs in the mechanism registry for the purpose of delivering further overall mitigation in global emissions that have been correspondingly adjusted in accordance with chapter III.B of decision 2/CMA.3.

IX. Avoiding the use of emission reductions by more than one Party

71. Where a host Party has authorized A6.4ERs for use towards the achievement of NDCs pursuant to chapter V.C above (Approval and authorization), it shall apply a corresponding adjustment for the first transfer of all authorized A6.4ERs, consistently with decision 2/CMA.3.

X. Use of emission reductions for other international mitigation purposes

72. Where a host Party has authorized A6.4ERs for use for other international mitigation purposes pursuant to chapter V.C above (Approval and authorization) above, it shall apply a corresponding adjustment for the first transfer of all authorized A6.4ERs, consistently with decision 2/CMA.3.

XI. Transition of clean development mechanism activities and use of certified emission reductions towards first nationally determined contribution

A. Transition of clean development mechanism activities

73. Project activities and programmes of activities registered under the clean development mechanism under Article 12 of the Kyoto Protocol (CDM) or listed as provisional as per the temporary measures adopted by the Executive Board of the CDM may transition to the mechanism and be registered as Article 6, paragraph 4, activities subject to all of the following conditions:

(a) The request to transition the CDM project activity or programme of activity being made to the secretariat and the CDM host Party as defined by decision 3/CMP.1 by or on behalf of the project participants that were approved by that CDM host Party by no later than 31 December 2023;

(b) The approval for such transition of the CDM project activity or programme of activity being provided to the Supervisory Body by the CDM host Party by no later than 31 December 2025;

(c) Subject to paragraph 73(d) below, the compliance with these rules, modalities and procedures, including on the application of a corresponding adjustment consistent with decision 2/CMA.3, relevant requirements adopted by the Supervisory Body and any further relevant decisions of the CMA;

(d) The activity may continue to apply its current approved CDM methodology until the earlier of the end of its current crediting period or 31 December 2025, following which it shall apply an approved methodology pursuant to chapter V.B above (Methodologies).

74. The Supervisory Body shall ensure that small-scale CDM project activities and CDM programmes of activities undergo an expedited transition process in accordance with decisions of the Supervisory Body by prioritizing the requests to transition from such activities following the approval referred to in paragraph 73(b) above.

B. Use of certified emission reductions towards first or first updated nationally determined contributions

75. Certified emission reductions (CERs) issued under the CDM may be used towards achievement of an NDC provided the following conditions are met:

(a) The CDM project activity or programme of activities was registered on or after 1 January 2013;

(b) The CERs shall be transferred to and held in the mechanism registry and identified as pre-2021 emission reductions;

(c) The CERs may be used towards achievement of the first NDC only;

(d) The CDM host Party shall not be required to apply a corresponding adjustment consistently with decision 2/CMA.3 in respect of the CERs and not be subject to the share of proceeds pursuant to chapter VII above (Levy of share of proceeds for adaptation and administrative expenses);

(e) CERs not meeting the conditions referred to in paragraph 75(a–d) above may only be used for achievement of an NDC in accordance with a relevant future decision of the CMA;

(f) Temporary CERs and long-term CERs shall not be used towards NDCs.

12th plenary meeting
13 November 2021

Decision 4/CMA.3

Work programme under the framework for non-market approaches referred to in Article 6, paragraph 8, of the Paris Agreement

The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement,

Recalling the framework for non-market approaches to sustainable development referred to in Article 6, paragraph 9, of the Paris Agreement,

Also recalling the tenth preambular paragraph of the Paris Agreement, in which Parties take into account the imperatives of a just transition of the workforce and the creation of decent work and quality jobs in accordance with nationally defined development priorities,

Further recalling the eleventh preambular paragraph of the Paris Agreement, acknowledging that climate change is a common concern of humankind, Parties should, when taking action to address climate change, respect, promote and consider their respective obligations on human rights, the right to health, the rights of indigenous peoples, local communities, migrants, children, persons with disabilities and people in vulnerable situations and the right to development, as well as gender equality, empowerment of women and intergenerational equity,

Recalling the objective, referred to in decision 1/CP.21, paragraph 39, of the work programme under the framework for non-market approaches referred to in Article 6, paragraph 8, of the Paris Agreement,

Recognizing that the work programme is to be implemented in the context of the Paris Agreement in its entirety, including its preamble,

1. *Recognizes* the importance of integrated, holistic and balanced non-market approaches to enable voluntary cooperation being available to Parties to assist in the implementation of their nationally determined contributions, in the context of sustainable development and poverty eradication, in a coordinated and effective manner;

2. *Adopts* the work programme under the framework for non-market approaches referred to in decision 1/CP.21, paragraph 39, as contained in the annex;

3. *Decides* that initial focus areas of the work programme activities, referred to in paragraph 8(a)(i).a of the annex, include, but are not limited to, the following:

(a) Adaptation, resilience and sustainability;

(b) Mitigation measures to address climate change and contribute to sustainable development;

(c) Development of clean energy sources;

4. *Requests* the Glasgow Committee on Non-market Approaches to develop and recommend a schedule for implementing the work programme activities referred to in chapter V of the annex (Work programme activities), which may contain the timeline and expected outcomes for each activity, including specifications for the UNFCCC web-based platform referred to in paragraph 8(b)(i) of the annex, such as its functions, form, target users and information to be contained thereon, with a view to supporting the effective implementation of the work programme, for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its fourth session (November 2022);

5. *Encourages* Parties, public and private sector stakeholders and civil society organizations to actively engage in the research, development and implementation of non-market approaches;

6. *Invites* Parties and observers to submit via the submission portal[1] by 28 February 2022 views and information on:

(a) Existing relevant non-market approaches that may be facilitated under the framework in the initial focus areas referred to in paragraph 3 above that are in accordance with the provisions referred to in chapter II of the annex (Non-market approaches under the framework);

(b) Examples of potential additional focus areas of non-market approaches that may be facilitated under the framework (e.g. social inclusivity, financial policies and measures, circular economy, blue carbon, just transition of the workforce, adaptation benefit mechanism) and existing relevant non-market approaches that may be facilitated under the framework in the potential additional focus areas that are in accordance with the provisions referred to in chapter II of the annex (Non-market approaches under the framework);

(c) The UNFCCC web-based platform referred to in paragraph 8(b)(i) of the annex, including how to operationalize it (e.g. functions, form, target users, information to be contained thereon, timeline for development and implementation, and lessons learned from existing relevant tools, including under the Convention and the Paris Agreement);

(d) The schedule for implementing the work programme activities;

7. *Requests* the secretariat to prepare a synthesis report on the matters referred to in paragraph 6 above for consideration by the Glasgow Committee on Non-market Approaches at its 1st meeting, to be held in June 2022;

8. *Also requests* the secretariat to:

(a) Organize an in-session workshop, with the broad participation of relevant experts, on the matters referred to in paragraph 6 above, taking into consideration the submissions and synthesis report on the matters, to be held in conjunction with the fifty-sixth session of the Subsidiary Body for Scientific and Technological Advice (June 2022);

(b) Prepare a report on that workshop for consideration by the Glasgow Committee on Non-market Approaches at its 2nd meeting, to be held in November 2022;

9. *Decides* to review the report of the Glasgow Committee on Non-market Approaches and provide guidance on the framework and the work programme, as appropriate;

10. *Requests* the Subsidiary Body for Scientific and Technological Advice to review the work programme, including its activities, at its sixty-fourth (June 2026) and sixty-fifth (November 2026) sessions with a view to enhancing the effectiveness of the work programme, taking into account relevant inputs, including the outcomes of the global stocktake, and to make recommendations thereon for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement by no later than at its eighth session (2026);

11. *Takes note* of the estimated budgetary implications of the activities to be undertaken by the secretariat referred to in this decision;

12. *Requests* that the actions called for in this decision be undertaken subject to the availability of financial resources;

13. *Invites* Parties to make contributions to the Trust Fund for Supplementary Activities for implementing the work programme.

[1] https://www4.unfccc.int/sites/submissionsstaging/Pages/Home.aspx.

Annex

Work programme under the framework for non-market approaches referred to in Article 6, paragraph 8, of the Paris Agreement

I. Principles

1. The following principles, in addition to the elements reflected in Article[1] 6, paragraphs 8–9, and decision 1/CP.21, paragraph 39, guide the implementation of the framework for non-market approaches (NMAs) referred to in Article 6, paragraph 9, and the work programme under the framework referred to in decision 1/CP.21, paragraph 39:

(a) The framework:

(i) Facilitates the use and coordination of NMAs in the implementation of Parties' nationally determined contributions (NDCs) in the context of sustainable development and poverty eradication;

(ii) Enhances linkages and creates synergies between, inter alia, mitigation, adaptation, finance, technology development and transfer, and capacity-building, while avoiding duplication of the efforts under the framework with the work of the subsidiary and constituted bodies under the Convention and the Paris Agreement, taking into account the mandates of these bodies;

(b) NMAs facilitated under the framework represent:

(i) Voluntary cooperative actions that are not reliant on market-based approaches and that do not include transactions or quid pro quo operations;

(ii) Integrated, innovative and transformational actions that have significant potential to deliver higher mitigation and adaptation ambition;

(iii) Actions that support the implementation of NDCs of Parties hosting NMAs (hereinafter referred to as host Parties) and contribute to achieving the long-term temperature goal of the Paris Agreement;

(c) The work programme, consistently with its objective referred to in decision 1/CP.21, paragraph 39, aims to identify measures to facilitate NMAs and enhance linkages and create synergies as referred to in paragraph 1(a) above.

II. Non-market approaches under the framework

2. Each NMA facilitated under the framework, in the context of Article 6, paragraph 8:

(a) Aims to:

(i) Promote mitigation and adaptation ambition;

(ii) Enhance participation of public and private sector and civil society organizations in the implementation of NDCs;

(iii) Enable opportunities for coordination across instruments and relevant institutional arrangements;

(b) Assists participating Parties in implementing their NDCs in an integrated, holistic and balanced manner, including through, inter alia:

(i) Mitigation, adaptation, finance, technology development and transfer, and capacity-building, as appropriate;

[1] "Article" refers to an Article of the Paris Agreement, unless otherwise specified.

(ii) Contribution to sustainable development and poverty eradication.

3. In addition, each NMA facilitated under the framework:

(a) Is identified by the participating Parties on a voluntary basis;

(b) Involves more than one participating Party;

(c) Does not involve the transfer of any mitigation outcomes;

(d) Facilitates the implementation of NDCs of host Parties and contributes to achieving the long-term temperature goal of the Paris Agreement;

(e) Is conducted in a manner that respects, promotes and considers respective obligations of Parties on human rights, the right to health, the rights of indigenous peoples, local communities, migrants, children, persons with disabilities and people in vulnerable situations and the right to development, as well as gender equality, empowerment of women and intergenerational equity, consistently with the eleventh preambular paragraph of the Paris Agreement;

(f) Minimizes and, where possible, avoids negative environmental, economic and social impacts.

III. Governance of the framework

4. The Glasgow Committee on Non-market Approaches is hereby established to implement the framework and the work programme by providing Parties with opportunities for non-market-based cooperation to implement mitigation and adaptation actions in their NDCs.

5. The Glasgow Committee will be convened by the Chair of the Subsidiary Body for Scientific and Technological Advice (SBSTA) and operate in accordance with the procedures applicable to contact groups and under the guidance of the Chair. It will meet in conjunction with the first and second sessional period meeting of the SBSTA each year, with its 1st meeting to take place in conjunction with SBSTA 56 (June 2022).

6. The SBSTA will consider whether institutional arrangements for the framework that will supersede the Glasgow Committee are needed and make recommendations for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA) at its ninth session (2027).

IV. Modalities of the work programme

7. The modalities of the work programme may include, as appropriate:

(a) Workshops;

(b) Engagement with public and private sector stakeholders, including technical experts, businesses, civil society organizations and financial institutions;

(c) Submissions from Parties, observers and public and private sector stakeholders;

(d) Technical papers and synthesis reports prepared by the secretariat;

(e) The collaboration, where needed, of the Glasgow Committee with relevant bodies, institutional arrangements and processes under or related to the Convention and the Paris Agreement, taking into account their mandates.

V. Work programme activities

8. The work programme will be initiated in 2022 and include, but not be limited to, the following activities:

(a) Identifying measures for enhancing existing linkages, creating synergies and facilitating coordination and implementation of NMAs:

(i) Identification of NMAs:

a. Identifying focus areas of the work programme activities;

b. Identifying existing NMAs under the framework that are in accordance with the provisions referred to in chapter II above (Non-market approaches under the framework);

(ii) Identification of measures:

a. Identifying and evaluating positive and other experience of existing linkages, synergies, coordination and implementation in relation to NMAs;

b. Identifying measures for enhancing existing linkages, creating synergies and facilitating coordination and implementation of NMAs, including in the local, subnational, national and global context;

(b) Implementing measures:

(i) Developing and implementing tools, with the assistance of the secretariat, including a UNFCCC web-based platform for recording and exchanging information on NMAs, including information identified through the work programme, and supporting the identification of opportunities for participating Parties to identify, develop and implement NMAs;

(ii) Identifying and sharing information, best practices, lessons learned and case studies in relation to developing and implementing NMAs, including on how to:

a. Replicate successful NMAs, including in the local, subnational, national and global context;

b. Facilitate enabling environments and successful policy frameworks;

c. Enhance the engagement in NMAs by the private sector, civil society organizations and vulnerable and impacted sectors and communities;

d. Leverage and generate mitigation co-benefits resulting from adaptation actions and/or economic diversification plans that assist the implementation of NDCs;

e. Promote cooperation on NMAs between Parties that supports the implementation of ambitious NDCs contributing to the achievement of the long-term temperature goal of the Paris Agreement, including in relation to the development of NMAs;

f. Estimate and report the impacts of NMAs on mitigation and adaptation;

g. Establish guidelines, procedures and safeguards to facilitate NMAs;

(iii) Identifying initiatives, programmes and projects for facilitating NMAs that support the implementation of NDCs to allow for higher mitigation and adaptation ambition in NDCs by:

a. Establishing linkages with bodies, institutional arrangements and processes under or related to the Convention and the Paris Agreement in relation to, inter alia, mitigation, adaptation, finance, technology development and transfer, and capacity-building, as appropriate;

b. Mapping the initiatives, programmes and projects at the local, subnational and national level, including those that support Parties in meeting the requirements for receiving support and provide capacity-building for the implementation of NMAs.

VI. Reporting

9. The progress and outcomes of the work programme will be reported at each session of the CMA, as appropriate, on the basis of information resulting from implementation of the work programme activities, which will also serve as inputs to the review of the work programme at CMA 7 (November 2025), with the report to include the following, as relevant:

(a) Results of the implementation of the work programme activities;

(b) Recommendations on how to enhance existing linkages and create synergies and how to facilitate coordination and implementation of NMAs;

(c) Recommendations on how to facilitate support for NMAs, including through engagement with relevant bodies, institutional arrangements and processes under the Convention and the Paris Agreement related to, inter alia, mitigation, adaptation, finance, technology development and transfer, and capacity-building;

(d) Recommendations on work programme activities in implementing the framework.

12th plenary meeting
13 November 2021

The Status of Science on Forest Carbon Management to Mitigate Climate Change (June 1, 2020)

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Forest Carbon and Climate Change

1. To keep climate and temperatures within a safe range, it is necessary to simultaneously **reduce emissions** of greenhouse gases from all sources, including fossil fuels and bioenergy, and **accelerate storage** of atmospheric carbon in forests, soils and other plant-based systems. To prevent the most serious consequences of climate change, removals of atmospheric carbon dioxide must equal additions no later than 2050, and must not exceed emissions after that (IPCC 2018, 2019).

2. *Increasing cumulative carbon in forests is essential for keeping carbon dioxide out of the atmosphere.* It has been found world-wide that forests hold half of the carbon in the largest 1% diameter trees (Lutz et al, 2018), and can store twice the carbon they do now (Erb et al. 2018). Increasing forest reserves and allowing forests to meet their ecological carbon storage potential (proforestation) are the most effective climate mitigation strategies (Law et al. 2018; Moomaw et al 2019). Letting forests grow and halting land conversions would bring carbon dioxide removal rates closer to current emission rates globally (Houghton and Nassikas, 2018).

3. *Increased harvesting of forests for wood products and burning wood for bioenergy adds more carbon dioxide to the atmosphere than growing secondary forests and protecting older forests.* It takes at least 100 to 350+ years to restore carbon in forests degraded by logging (Law et al. 2018, Hudiburg et al. 2009). If we are to prevent the most serious consequences of climate change, we need to keep carbon in the forests because we don't have time to regain it once the forest is logged (IPCC, 2018).

4. *We have to get the Carbon accounting right*:
   a. It is essential that independent carbon cycle experts provide analysis for federal policy decisions. *65% of the forest carbon removed by logging Oregon's forests in the past 115 years has been returned to the atmosphere,* just 19% is stored in long-lived products and 16% is in landfills (Hudiburg et al. 2019). Half of harvested carbon is emitted to the atmosphere almost immediately after logging (Harmon, 2019). Increased harvesting of forests does not provide climate change mitigation.
   b. *Context of forest carbon emission sources* - Harvest is the major source of forest emissions in the US. Across the lower 48 states, direct harvest-related emissions are 7.6 times higher than all-natural disturbances (e.g., fire, insects) combined (Harris et al. 2016). In the West Coast states (OR, CA, WA), harvest-related emissions average 5 times fire emissions for the three states combined (Hudiburg et al. 2019).
   c. *There is absolutely no evidence that thinning forests increases biomass stored (Zhou et al. 2013).* It takes decades to centuries for carbon to accumulate in forest vegetation and soils (Sun et al. 2004, Hudiburg et al. 2009, Schlesinger 2018), and it takes decades to centuries for dead wood to decompose. We must preserve medium to high biomass (carbon-dense) forest not only because of their carbon potential but also because they have the greatest biodiversity of forest species (Krankina et al. 2014, Buotte et al. 2019, 2020).
   d. Burning wood for energy produces as much or more emissions as burning coal, so it is not an effective climate mitigation solution (Law et al. 2018, Hudiburg et al. 2011, 2019, Sterman et al. 2018). It always takes

longer for the forest to regrow and recover all of the carbon released than the age of the forest that was harvested (Schlesinger 2018). It is incorrect to describe burning of wood for energy as *carbon neutral*, because it increases carbon emissions now, when we can least afford such increases to the atmosphere. Alternatively, if the original trees continued to grow, without logging, there would be more than twice as much carbon in the trees and that much less in the atmosphere.

e. Especially troubling is the export of woodchips from deciduous forests in the Southeastern USA to Europe. These forests are rich in biodiversity. They have taken many decades to grow, constitute a large standing crop of carbon, and one that will also take many decades to recover.

f. Building or converting a power facility to use beetle and fire-killed trees ("salvage logging") immediately releases CO_2 to the atmosphere while causing severe damage to wildlife habitat (DellaSala and Hanson 2015) and soils. Once the dead trees have been burned, harvesting live trees would be required to sustain the supply needed to run the facility. This will not keep carbon out of the atmosphere.

Proposed Solutions

To address climate, biodiversity and additional ecosystem service needs, we propose designating carbon reserves on both public and private lands, and concentrating forest product production on specified timberlands - a two-track solution.

The current system where most *forestlands* are available for logging keeps too many trees at a smaller size that do not store much carbon. Providing incentives to lengthen rotation harvest cycles will increase carbon storage in production forests, and reduce atmospheric carbon dioxide.

Forest carbon accounting and verification should be done as part of climate and forest policy implementation and in Environmental Impact Analysis by independent groups of scientists with carbon accounting expertise following life cycle assessment protocols (Hudiburg et al. 2019).

Aligning policies with climate goals is essential. Rescind the requirement that all federal agencies treat forest bioenergy as carbon neutral if it comes from sustainably managed forests and remove subsidies for bioenergy facilities. 'Sustainable forest management' refers only to maintaining harvested biomass at or below the rate of annual growth. It does not maximize accumulated forest carbon storage or maintain full biodiversity and other ecosystem services.. The US government should re-engage in the Paris Climate Agreement by enhancing and maintaining natural carbon sinks.

Proposals for Federal Forest Lands

How can public lands policy be improved to help meet climate goals?

1. Establish Federal Forest Carbon Reserves on public forestlands with moderate to high carbon density potential. Old growth forests and roadless areas on public lands should be included in a federal carbon reserve. For example, the Tongass National Forest in Alaska contains approximately 10% of all carbon stored in US forests (USFS, 2020). The carbon stored in 9.2 million acres of at-risk roadless areas on the Tongass has a potential value of at least $234 million in future carbon markets, which exceeds the one-time timber value by orders of magnitude (DellaSala and Burma, 2020). Protecting more public lands from logging benefits private landowners by reducing competition for lower cost timber on public lands.
2. Redirect the billions of dollars currently being spent annually on harvesting public forestlands into a green jobs program to help communities become more fire-safe. Enhance the Youth Conservation Corps and/or establish a CCC. For example, the corps could work with independent expert groups to quantify and verify forest carbon on federal and private lands, help with fire-planning in communities via defensible space and home hardening, monitor forest usage and roadside idling during peak fire season, and remove old timber roadbeds that are impacting watersheds.

Proposals for Private Lands

How do we help communities that have become reliant on forests while reaching the goal of successful climate mitigation?

1. Rural counties with higher proportions of protected public lands that emphasize tourism and recreation have higher per capita incomes and more jobs than those that rely on logging (Rasker 2017). Enhance eco-friendly tourism and recreation in the vicinity of national forests and parks.
2. The USFS found in a survey that most private non-industrial land owners do not really want to cut their timber, but have to for financial reasons (USFS 2016). Forest Carbon Reserves on non-industrial private lands could be encouraged by providing incentives (subsidies, health care or tax abatements) to private land owners to manage for increased carbon storage.
3. Carbon offsets programs for landowners. A carbon offsets program has been demonstrated in California using private lands across the country (Anderson et al. 2017), and a California-type offsets program has been demonstrated to be feasible and sustainable for forest lands within Oregon (Law et al. 2018) and Alaska (e.g., Sealaska Native Corporation carbon transaction).

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Wandering grizzly leaves Bitterroot, returns to Idaho

A grizzly bear roams near Beaver Lake in Yellowstone National Park. - Associated Press, file

17jul19 by PERRY BACKUS / Missoulian

Update: On July 15, the grizzly bear was due west of the Hamilton on the Idaho side in the Big Flat Creek area.

A 3-year-old male grizzly bear that has gone walkabout since leaving the Cabinet Mountains this spring crossed the divide last week to visit the area around Big Creek Lakes about 15 miles west of Stevensville.

No one can say for certain that he'll settle down in the Bitterroot National Forest.

Equipped with a satellite tracking collar, Grizzly 927 has been on the go since he was first released into the Cabinet Mountains last year. The bear moved into Idaho, where he was captured and returned to Montana in the fall of 2018.

This spring, it headed south. Avoiding humans by traveling high on the ridgetops, it made its way to the northern end of the Selway-Bitterroot Wilderness on the Idaho side. It kept moving south, including a visit to the Kelly Creek area where a mature grizzly was killed by a black bear hunter in 2007.

Last Friday, U.S. Fish and Wildlife Service biologist Wayne Kasworm reported the bear had crossed the Divide and moved onto the Bitterroot National Forest by about a mile near Big Creek Lakes.

Bitterroot Forest biologist Dave Lockman said that while the distance traveled by the bear is impressive, it's not unprecedented to see one move that far.

"Male grizzlies do tend to disperse further than females," Lockman said. "It's kind of atypical to have a bear travel that far, but it's something we've seen before."

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In 2014, a female grizzly bear that biologists named Ethel wandered through the Florence area before turning back around and heading north to the Mission Valley.

"She was last heard of somewhere north of Flathead, where her transmitter quit," Lockman said. "She was a little bit different because females don't usually go quite that far."

Last October, a young **grizzly bear was captured** at the Whitetail Golf Course near Stevensville. It was relocated out of the valley.

Lockman said it's anyone's guess whether Grizzly 927 will find Montana to his liking.

"He's already covered quite a lot of territory," Lockman said. "He's spent some time in different areas in Idaho. I don't think there is any reason to think that he will set up camp and live in Big Creek. I think it's more likely that he will continue to explore."

Lockman said there was a 1990s environmental impact statement that proposed introducing grizzlies into the Bitterroot Grizzly Recovery Zone as a "non-essential experimental population."

"Had that happened, it would have given managers more control, but that effort, even though it was approved, was defunded and never occurred," Lockman said. "It took a little bit longer, but they are here now."

Having a grizzly bear in the Bitterroot Mountains shouldn't cause anyone to change how they use the area, he said. There are no official food storage orders on the Bitterroot National Forest other than in the Anaconda Pintler Wilderness.

"I would encourage people to use **bear-safe techniques** to keep black bears away," Lockman said. "While people might get a little more emotionally wound up because it's a grizzly, there are a lot more people killed and injured every year by black bears than grizzlies. They can be a problem, just like a grizzly, if you don't keep your camp clean or make lots of noise while you're out in the woods.

"I think it's kind of exciting to see one show up in the recovery zone where they are supposed to be," he said. "The Bitterroot is the only one out of six recovery zones that is yet to be occupied."

Grizzly bear captured Saturday at golf course near Stevensville

The grizzly captured on the Whitetail Golf Course north of Stevensville on Saturday. - Courtesy photo

29oct18 by Perry Backus / Missoulian

STEVENSVILLE — A young male grizzly bear was a captured and relocated from the Whitetail Golf Course north of Stevensville Saturday.

The golf course's pro, Jason Lehtola, said the first indication that something was amiss at Whitetail came after they saw a broken flag stick on one of the greens. The next morning they found two more snapped off at their base.

“We thought it was probably a vandal at first,” Lehtola said. “And then we saw some tracks in a bunker and some scat piles. I couldn’t tell that it was a grizzly, though, at that point.”

The decision that something needed to be done about the flagpole snapper came last Wednesday when they found another flag stick broken on the seventh green — and this time, the bear had dug a large hole in the manicured grass.

A biologist would later say the bear was after worms.

“I figured that was enough,” Lehtola said. “We called Fish and Game on Wednesday. They brought out a trap Thursday.”

There had been a lot of golfers on the course over the past few weeks, but none reported seeing a bear lurking about. The course set up a trail camera, but it never did get a photograph of the bruin.

Lehtola arrived early Saturday morning to open up the course. He was walking into the shop when he heard an odd noise coming from the direction of the trap that sat about 100 yards from the clubhouse’s front door between the seventh green and eighth tee.

“I could tell we had something in the trap,” Lehtola said. “I started walking over there to take a look. I got about 30 yards away, when it must have smelled me. It was facing the other way in the trap and then all of a sudden it turned. It hit the end of the cage and gave me a growl.

“I turned around and went back and hopped in my car,” he said. “I pulled around the back side where there was a bigger screen.”

At that point, Lehtola could actually get a good look.

“I knew right away that it was a grizzly,” he said. “Its claws were really big. Its head was massive. It was standing in there and I could see the hump on its back.”

When Lehtola called the local warden to report what he’d seen, he said Justin Singleterry wasn’t so sure.

“I told him, ‘You’re not going to believe this. I think it’s a griz,’” Lehtola said. “He just kind of laughed at me and said he hears that all the time.”

Lehtola said the warden changed his mind right away after the bear hit the side of the culvert trap when he arrived to take a look.

“It was pretty scary,” Lehtola said. “I’m feeling pretty lucky we didn’t have anyone hurt. We’ve had tons of people out golfing. … I know that it scared the hell out of me when it smacked up against the cage. It’s not something that I want to run into the wild.”

Montana Fish, Wildlife and Parks Wildlife Specialist Jamie Jonkel said the 249-pound bear was probably about 2½ years old. It was released in the lower Blackfoot, east of the Rattlesnake Wilderness.

This isn’t the first time that grizzly bear has found its way to the valley floor in the Bitterroot Valley.

In 2003, an unmarked grizzly bear came over the Sapphire Mountains from the Rock Creek area.

Jonkel remembers following its tracks down a cow trail to a road near Sunset Bench northeast of Stevensville and finally to the place where he saw its dusty tracks cross the pavement on the Eastside Highway.

It stayed down in the river bottom for a couple of weeks. Jonkel received several reports of sightings of the bear in the Stevensville area before it trekked back over the mountains to Rock Creek.

Three years ago, the famous traveling grizzly bear called Ethyl tried to cross the valley just downstream of Florence as part of its 2,800-mile walkabout.

“She got hung up there,” he said. “There were too many houses so she backtracked.”

Jonkel said it’s not uncommon for bears to head to the river bottoms this time of year.

“Most of our black bears in the Bitterroot come down off the foothills in the fall to follow the drainages down to the river,” he said. “They want to try to spend time in the river bottoms where the lushest habitat is located.

“Sadly, along the way they have to go through 300 to 400 backyards with all their apple trees, garbage and bird feeders,” Jonkel said.

The bear biologist said the message hasn’t really spread far and wide in the Bitterroot that landowner can do more to keep bears at bay.

“Once an area get urbanized and fractured by a lot of development, it’s just hard to get organized,” he said. “We’ve had some good luck around Lolo Creek and Missoula in getting that message out. We could use a group to spread the word in the Bitterroot about being bear aware.”

Exhibit 13

The Grizzly Bear Promised Land

Past, Present & Future of Grizzly Bears in the Bitterroot, Clearwater, Salmon & Selway Country

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Report GBRP-2021-1

2021

The Grizzly Bear Recovery Project

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Table of Contents

1. Introduction

Idaho has some of the most extensive tracts of remote wild country in the contiguous United States, including 21,690 km^2 of designated Wilderness Areas, 39,928 km^2 of inventoried roadless or wilderness study areas, and 3,472 km^2 of other protected areas. Even so, barring peripheral areas along its northern and eastern borders and the recent appearance of a few colonizers, Idaho has no grizzly bears (*Ursus arctos*). Yet the potential is enormous. John Craighead and Chuck Jonkel—esteemed grizzly bear researchers of their day—recognized this potential as far back as the early 1970s, and helped convince the U.S. Fish & Wildlife Service to specifically reference wildlands of central Idaho in its initial 1975 rule protecting grizzly bears under the U.S. Endangered Species Act (ESA)[1]. The Service later designated portions of these vacant wildlands as a Recovery Area in 1982[2].

I arrived in Idaho during 1972 to pursue undergraduate studies at the University of Idaho—shortly before grizzly bears received ESA protections. It didn't take long for my imagination to be fired by initial forays into Idaho's backcountry, and then for me to make the connection with grizzly bears after starting to work for the Interagency Grizzly Bear Study Team in 1979. My interest in bringing grizzly bears back to central Idaho led me to collaborate with Troy Merrill on projects modeling potential suitable habitat, including one effort we reported in a paper published during 1999[3] in the midst of efforts by the Fish & Wildlife Service to reintroduce grizzlies into the Bitterroot Recovery Area[4].

Decades have passed, but my attention has returned to Idaho after spending the last several years grappling with issues surrounding grizzly bear restoration and recovery in the contiguous United States. These efforts have brought the obvious into focus. The wildlands of central Idaho are a lynchpin—an absolutely critical piece of geography with enormous potential, as well as a fascinating past. This report hopefully brings Idaho into appropriate focus for grizzly bear recovery efforts.

But first, a thumbnail sketch—an overview—of what I cover in this report, and a brief description of my scope and intent.

1.a. An Overview

At the time of European colonization, the area that would eventually become Idaho supported thriving populations of grizzly bears everywhere except perhaps in arid lower-elevation shrublands along the Snake River (Figure 1). Although this basic fact has been contested during recent decades by people focused on advancing political and ideological agendas, the supporting circumstantial and direct evidence for the presence of several thousand grizzly bears in Idaho is incontestable.

The diets, densities, and behaviors of ancestral Idaho grizzly bears must have been diverse. Although there is scant direct evidence for this assertion—largely because Europeans who left written records

[1] https://ecos.fws.gov/docs/federal_register/fr65.pdf

[2] U.S. Fish & Wildlife Service (1982). Grizzly bear recovery plan. Fish & Wildlife Reference Unit, Denver, Colorado. https://www.biodiversitylibrary.org/item/137553#page/4/mode/1up

[3] Merrill, T., Mattson, D. J., Wright, R. G., & Quigley, H. B. (1999). Defining landscapes suitable for restoration of grizzly bears *Ursus arctos* in Idaho. Biological Conservation, 87(2), 231-248.

[4] https://www.federalregister.gov/documents/2000/11/17/00-29531/record-of-decision-concerning-grizzly-bear-recovery-in-the-bitterroot-ecosystem; U.S. Fish & Wildlife Service (2000). Grizzly bear recovery in the Bitterroot Ecosystem: Final environmental impact statement. U.S. Fish & Wildlife Service, Missoula, Montana.

focused almost exclusively on their exploits killing grizzly bears rather than on bear behaviors—historical and contemporary variation in abundance and types of bears foods provides a compelling circumstantial basis for reconstructing the life-ways of grizzly bears in Idaho.

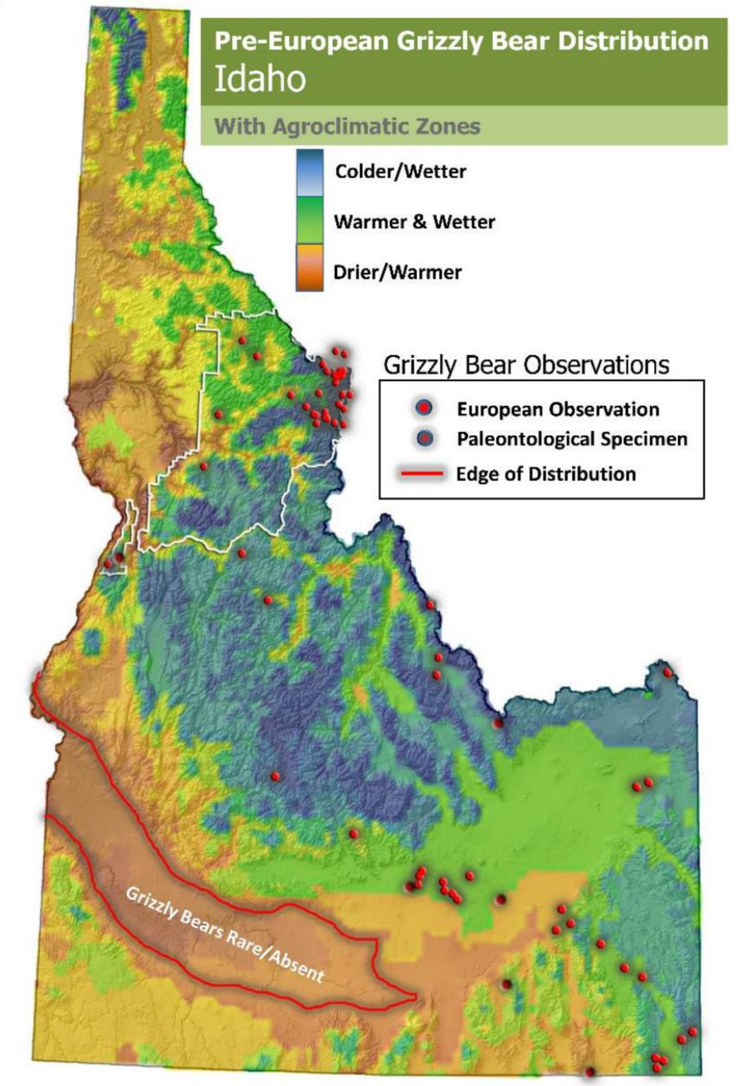

Figure 1. This map shows the physical environment of Idaho around the time of first European contact along with evidence of grizzly bear distribution outside of currently occupied areas in the Selkirk Mountains of far northern Idaho. A color-coded scheme for agroclimate zones is overlain on shaded relief to provide a snap-shot of the topographic and climatic diversity of Idaho. Agroclimate zones (from Godfrey 1999) represent potential vegetal productivity as a function of temperature and precipitation. Sources for grizzly bear observations and specimens can be found in the captions of Figures 5 and 9, below. The white line delineates the current Nez Perce-Clearwater National Forests.

Grizzly bear habitats in Idaho are indeed diverse, a reflection of diverse climates, landscapes, vegetation, and even configurations of river drainages (Figure 1). At higher latitudes, inland rain forests typified by western hemlock (*Tsuga heterophylla*) and western red cedar (*Thuja plicata*) continue to sustain abundant fruit-bearing shrubs and other vegetal foods. Grasslands of the Palouse prairie farther south and west once supported herds of bison (*Bison bison*). Higher-elevation mountains of central Idaho host abundant whitebark pine (*P. albicaulis*)—a source of fat-rich seeds. Farther south, austere shrub steppe vegetation carpeting the Snake River plains encompasses enclaves of roots such as biscuitroot (*Lomatium cous*)—and at one time also supported scattered herds of bison. Last but not least, basins drained by the Columbia River were once host to teaming populations of anadromous salmonids, including steelhead trout (*Oncorhynchus mykiss*) and multiple runs of chinook salmon (*Oncorhynchus tshawytscha*) throughout much of central Idaho, and coho salmon (*Oncorhynchus kisutch*) in lower reaches of the Clearwater and Snake Rivers.

Yet despite abundant and diverse bears foods, grizzly bears virtually disappeared from Idaho within a short 120-year period—between roughly 1830 and 1950. By 1950, only a handful of grizzlies survived in the Selkirk Mountains of the far northwestern corner of the state. The reason for this sudden demise is no mystery. Grizzly bears were slaughtered by newly-arrived Europeans at every opportunity, whether during chance encounters or as a result of deliberate pursuit. At the most fundamental level, grizzly bears almost disappeared from Idaho because of trauma and blood loss caused by high-velocity projectiles delivered from firearms held mostly by white men. At the most esoteric level, grizzly bears nearly vanished because of intolerance sustained by narratives of Manifest Destiny that ostensibly entitled believers to cleanse landscapes of all impediments to profitable exploitation.

Although the ultimate cause of grizzly bear extirpations is incontestable, the rapid and nearly complete loss of grizzlies from Idaho still poses a mystery. Most of Idaho has always been rugged, wild, roadless, and unpopulated by humans. Regions of comparable remoteness elsewhere sustained grizzly bears throughout periods of intensive persecution by Europeans—including areas that would later be called the Greater Yellowstone and Northern Continental Divide Ecosystems. But not the wilds of central Idaho.

Something unique happened in Idaho involving humans, bears, and bear habitats that led to the loss of grizzly bears in an area that, on the face of it, seems ideal for sustaining large populations of these animals. In fact, central Idaho has so much self-evident potential that the Selway-Bitterroot portion was the only area identified for recovery of grizzly bears by the U.S. Fish & Wildlife Service in the absence of grizzly bears[5]. Moreover, modeling of potential grizzly bear habitat since designation of the Selway-Bitterroot Ecosystem Recovery Area in 1982 has shown that there is perhaps as much potential outside the Recovery Area as there is inside, and that central Idaho occupies an area critical to achieving meaningful connectivity among grizzly bear populations in the Greater Yellowstone, Northern Continental Divide, Cabinet-Yaak, and Selkirk Ecosystems.

1.b. Scope and Intent

This report contains information relevant to understanding the past history, present conditions, and future prospects of grizzly bears and grizzly bear habitat in Idaho south of the Selkirk and Cabinet-Yaak Ecosystems, with an emphasis on pivotal landscapes encompassed by the 16,109 km^2 Nez Perce-Clearwater National Forests (Figure 1). This single National Forest unit, administratively combined from the Clearwater National Forest and Nez Perce National Forest in 2012, is comparable in size to that of our largest grizzly bear Recovery Areas[6], and is also at the crossroads of colonization by grizzly bears dispersing from the Selkirk, Cabinet-Yaak, and Northern Continental Divide Ecosystems.

I also focus here on unravelling the mystery of grizzly bear extirpations during the late 1800s and early 1900s, which is critical to any realistic assessment of current and future prospects for grizzlies in central Idaho for the region encompassing the St. Joe River drainage south to the Snake River Plains. Without understanding why grizzly bears disappeared in the first place, any evaluation of recovery potential and related recovery challenges is certain to be compromised.

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[5] U.S. Fish & Wildlife Service (1982). Grizzly bear recovery plan. Fish & Wildlife Reference Unit, Denver, Colorado. https://www.biodiversitylibrary.org/item/137553#page/4/mode/1up

[6] https://www.fws.gov/mountain-prairie/es/grizzlybear.php

I contend, moreover, that a full appreciation of Idaho's grizzly bears is not possible without a meaningful understanding of deep history—prospectively going back to the Pleistocene. Grizzly bears were a prominent presence on Idaho's landscapes for thousands of years, very likely pre-dating the Last Glacial Maximum, which began roughly 26,500 years ago. Although their ancient remains are intrinsically scarce, grizzly bears no doubt survived rapid environmental changes during the late Pleistocene and early Holocene, the rigors of the hot-dry Altithermal, and the bounteous conditions thereafter…up until the arrival of Europeans.

In what follows, I do not claim to be comprehensive, but rather parsimonious, although with occasional indulgent interludes where I dig more deeply into topics that intrigue me. Nor is what follows definitive, although I aspire to offer an analysis that is more contextual, complete, and relevant than any I have encountered elsewhere, including the U.S. Fish & Wildlife Service's compendious plan for reintroducing grizzlies into the Selway-Bitterroot Ecosystem[7].

I hope to populate an ecological canvas with evidence-based depictions of what we once had, and could yet again have again, in a landscape so rich with potential that I have been inspired to call it "The Grizzly Bear Promised Land."

[7] U.S. Fish & Wildlife Service (2000). Grizzly bear recovery in the Bitterroot Ecosystem: Final environmental impact statement. U.S. Fish & Wildlife Service, Missoula, Montana.

2. Deep History

For my purposes here, Deep History is encompassed by the Late Pleistocene, which lasted from roughly 26,500 to 11,700 years ago, although only the latter half of this period is relevant to the history of grizzly bears in North America and, more recent yet, the history of grizzly bears in ancestral Idaho. The Pleistocene is the epoch of Ice Ages, the last of which marked the arrival of grizzly bears—equivalent to brown bears—in North America.

2.a. Arrival and Evolutionary Decent

Grizzly bears first arrived in North America during the Late Pleistocene, perhaps as early as 70,000 years ago (Barnes et al. 2002). These first colonizers came from Siberia across the Bering Land Bridge when Europe, Asia, and North America formed a super-continent that emerged out of shallower oceans created by capture of ocean water in massive continental ice sheets of the Northern Hemisphere. This arrival predated onset of the Last Glacial Maximum (LGM) roughly 26,500 years ago, and the related blockage of free passage from Beringia to mid-latitudes by coalescence of the Cordilleran and Laurentide Ice Sheets.

Although reconstruction of ice sheet margins prior to the LGM is intrinsically problematic—simply because much of the direct evidence was erased by subsequent ice sheet growth—the best available modeling based on terrain features and climate simulations suggests that there was an ephemeral ice-free corridor south from Beringia to mid-latitudes of North America roughly 40,000 years ago (Kleman et al. 2010, Batchelor et al. 2019). As a bottom line, grizzlies must have somehow gotten south because the remains of a bear were found near what is now Edmonton, Alberta, dating to around 27,000-30,000 years ago (Matheus et al. 2004), consistence with more circumstantial genetic evidence suggesting that viable populations of grizzly bear existed south of the continental ice sheet throughout the LGM (Miller et al. 2006, Davis et al. 2011).

All of this is noteworthy because, up until the remains of the Edmonton grizzly were found and recent genetic analyses were published, the prevailing consensus was that grizzlies first arrived at mid-latitudes roughly 13,000 years ago, after an ice-free corridor had opened during terminal melt of the Cordilleran and Laurentide Ice Sheets (e.g., Kurtén & Anderson 1980). Of more specific relevance here, the best available evidence suggests that grizzly bears roamed Idaho's ancestral landscape for perhaps as long as 40,000 years rather than a mere 13,000 years.

Equally notable, the grizzly bears that roamed mid-latitudes of North America during the LGM and the subsequent 40 millennia were—and continue to be—evolutionarily unique. All of the grizzlies in what was to become the contiguous United States and adjacent portions of Canada and Mexico were of a single evolutionary lineage called Clade 4[8]. Clade 4 grizzlies belonged to one of three clades and

[8] Clades are commonly defined as a natural group of organisms descended from a common ancestor, able to be differentiated genetically, denoting a distinct evolutionary history. Clades are explicitly relational and expressive of evolution, which makes them more tractable than earlier approaches based on subspecies, which are less explicitly relational and require unambiguous demarcations. Because of this implicit need for clearly demarked boundaries, the concept of subspecies—and even species—has been beset by controversy, as has application to specific taxa. In the case of *Ursus arctos*, this sort of contention is evident in the fact that at one time C. Hart Merriam defined 84 "species" of grizzlies in North America alone (Merriam 1918), subsequently winnowed down to two (Rausch

subclades comprising the first wave of bears colonizing eastern Beringia—before the LGM (Barnes et al. 2002). The other two clades represented by these colonists were 2 and 3c. All three of these clades arose in eastern Asia (Tumendemberel et al. 2019). Of importance to this story, Clade 4 grizzlies have since disappeared everywhere on Earth with the exception of a small isolate on the Japanese island of Hokkaido and at mid-latitudes of North America (Davis et al. 2011, Hirata et al. 2017). Similarly, Clade 3c grizzlies are entirely extinct, whereas Clade 2 bears are currently represented only by populations on Admiralty, Baranof, and Chichagof Islands in Alaska. By contrast, the big evolutionary winners among grizzlies in North America belong to Clades 3a and 3b, which emigrated across the Bering Land Bridge to eastern Beringia as the LGM was waning between 25,000 and 15,000 years ago, and currently occupy all of Alaska and northern Canada as well as most of British Columbia and Alberta (Barnes et al. 2002, Davis et al. 2011).

The grizzly bears that occupied Idaho for millennia—and continue to hold on in Idaho's portions of the Selkirk, Cabinet-Yaak, and Yellowstone ecosystems—are members of a unique evolutionary and biogeographic lineage that has disappeared virtually everywhere else on Earth.

2b. Ancient Diets and Life-ways

Whereas modern genetic variation can provide reliable insights into evolutionary histories, and preserved remains can provide definitive evidence of primordial distributions, reconstructions of ancient diets and life-ways are necessarily based on circumspect extrapolations of often circumstantial evidence. In other words, reconstructions of pre-historic diets and lifeways are necessarily speculative, but ideally achieving veracity through maximal leveraging of scant direct evidence, knowledge of contemporary ecological relations, and reconstructions of paleo-environments.

Regardless of the specific geography, remains of *Ursus arctos* are rare. Remains with retrievable organic material are rarer still. Even so, enough such remains have been retrieved from higher latitudes to provide some direct evidence of proportionately how much meat and vegetation were in the diets of Pleistocene grizzly bears occupying frigid steppe tundra or mixed tundra-woodland environments[9]. As a modality, Pleistocene grizzlies in such environments were relatively carnivorous (e.g., Rey-Iglesia et al. 2019), more so than is typical of contemporary grizzly bear diets in temperate and boreal environments outside of areas supporting anadromous salmon (Hilderbrand et al. 1999, Jacoby et al. 1999, Mowat & Heard 2006). Even so, there is also evidence that grizzlies in some areas, for example eastern Beringia, France, and northern Spain, were omnivorous much like contemporary brown and grizzly bears (Bocherans et al. 2004, Fox-Dobbs et al. 2008, Garcia-Vázquez et al. 2018, Rey-Iglesia et al. 2019).

During the Pleistocene, variation in grizzly bear diets was very likely shaped not only by differences in abundance of foods, by also by divergences in assemblages of competitors and predators. It is a truism of ecology that this trio of factors largely configures animal foraging behaviors.

1963), and then expanded back to nine (Hall 1984), none of which correlated well with genetic differences, evolutionary descent, or historical biogeography.

[9] Consumption of vegetation and meat from terrestrial and marine sources can be estimated from judicious interpretation of concentrations and ratios of isotopic nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) in organic remains, as in this case.

Despite the fact that grizzly bears are currently the largest terrestrial carnivore in the Northern Hemisphere, barring perhaps the Siberian tiger (*Panthera tigris*), during the Pleistocene grizzlies were not dominant. They shared space with a number of very large carnivores, some of which lived in prides or packs, including giant short-faced bears (*Arctodus simus*), lions (*Panthera spelaea* and *P. atrox*), saber-toothed cats (*Smilodon fatalis*), scimitar-toothed cats (*Homotherium serum*), cave hyenas (*Crocuta crocuta spelaea*), and dire wolves (*Canis dirus*). Of these, short-faced bears, cave hyenas, and dire wolves would have been formidable competitors for scavenging opportunities. All but perhaps dire wolves would have been potential predators.

In light of this, it makes sense that grizzly bears would have been more carnivorous in areas without any of the species that could dominate scavenging opportunities (e.g., dire wolves, cave hyenas, and short-faced bears), as in western Beringia (Rey-Iglesia et al. 2019); and more herbivorous in areas where these competing species were present, as in eastern Beringia (with short-faced bears) and France and Spain (with cave hyenas) (Bocherans et al. 2004, Garcia-Vázquez et al. 2018, Rey-Iglesia et al. 2019).

It is not clear how much of the meat that grizzlies ate during the Pleistocene was from predation or scavenging, but given the numbers of large-bodied herbivores occupying grassland and woodland environments of that time[10], it is likely that much of their meat was obtained by scavenging kills made by other carnivores or animals that died of causes such as starvation, disease, and exposure (see Mattson 1997). And unit area concentrations of biomass on large herbivores during the Pleistocene were not only remarkable, but also far more than might be expected based on contemporary concentrations (Zhu et al. 2018).

Of specific relevance to ancient Idaho, Pleistocene grizzly bears shared much of this area with large carnivores that would have been potential predators as well as fierce competitors, including short-faced bears, American lions, scimitar-toothed cats, and saber-toothed cats (Figure 2). As a consequence, grizzly bears probably needed to carefully negotiate a potentially lethal landscape, and would have likely availed themselves of scavenging opportunities only during fleeting safe intervals when they managed to find carrion before other dominant scavengers did. Even so, these opportunities might have been relatively common given the abundance of large-bodied herbivores (Figure 2), including Columbian mammoths, bison, camels (*Camelops hesternus*), giant ground sloths (*Megalonyx jeffersoni*), horses (*Equus conversidens* and *E. ferus*), and helmeted muskox (*Bootherium bombifrons*).

That having been said, Pleistocene grizzly bears in ancestral Idaho were probably distinctly omnivorous, including a substantial number of bears that likely relied predominately on roots, fruits, and other vegetation. If so, this begs the question of what specific vegetal foods would have been staples in the relatively arid environments that typified ice-age Idaho (Dyke 2005). Although there is virtually no direct evidence of changes in landscape-level abundance of grizzly bear foods through the millennia, there is some basis in models and judicious extrapolation from current distributions for inferring what some of the major vegetal bear foods in ancestral Idaho might have been. Regarding

[10] For example, bison (*Bison priscus*, *B. latifrons*, and *B. antiquus*), mammoths (*Mammuthus primigenius* and *M. columbi*), aurochs (*Bos primigenius*), and woolly rhinos (*Coelodonta antiquitatis*) (Kurtén 1968, Kurtén & Anderson 1980).

Late-Pleistocene Distributions Mega-Fauna

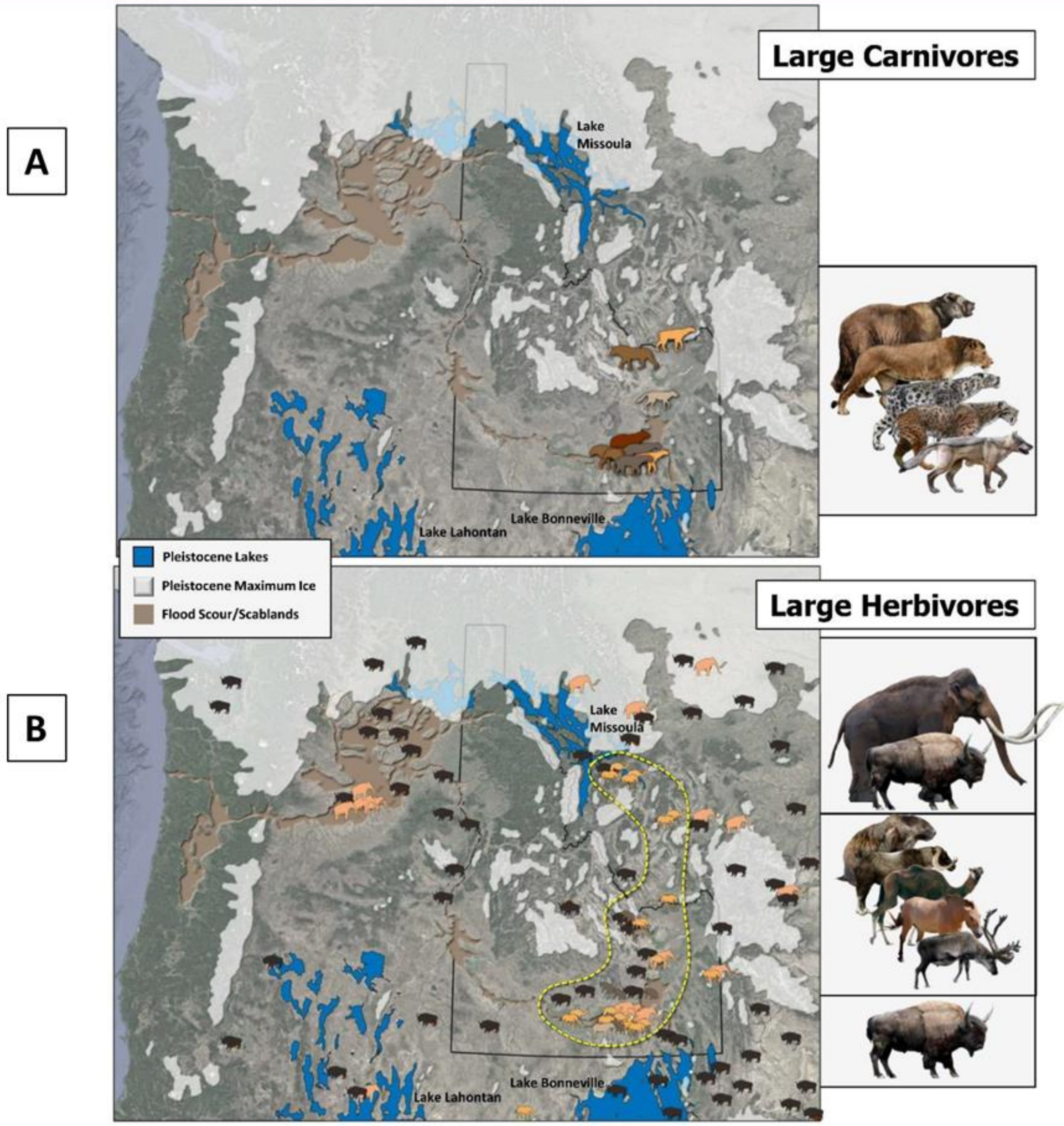

Figure 2. These two maps summarize key facets of the environment occupied by grizzly bears in the Pacific Northwest during the Late Pleistocene, roughly 40,000-10,000 years ago. Both maps show defining geophysical features, including the maximum extent of glacial ice, both in the form of mountain glaciers and continental ice-sheets (in dusky white, from Pierce [2003], Dyke [2004]); the maximum extent of glacial lakes, featuring Lakes Lahontan, Bonneville, and Missoula (in blue, from Matsubara & Howard [2009], Hanson et al. [2012]); and the extent of areas subject to scour (e.g., scablands) from outbursts of Lakes Missoula and Bonneville (in beveled tan, from Hanson et al. [2012], O'Connor et al. [2020]). Map (**A**) shows locations of remains from large carnivores, including, as illustrated from top to bottom, the giant short-faced bear (*Arctodus simus*), American lion (*Panthera leo atrox*), simitar-toothed cat (*Homoterium serum*), saber-toothed cat (*Smilodon fatalis*), and dire wolf (*Canis dirus*). Map (**B**) shows locations of—also as illustrated top to bottom—mammoths (predominantly *Mammuthus columbi*), bison (predominantly *Bison antiquus*), Jefferson's ground sloth (*Megalonyx jeffersonii*), helmeted muskox (*Bootherium bombifrons*), western camel (*Camelops hesternus*), horses (*Equus* sp.), and caribou (*Rangifer tarandus*). The yellow dashed line delineates a region with maximum density and diversity of remains from large herbivores. Locations were obtained from the Neotoma Paleoecology Database (https://www.neotomadb.org/), augmented by locations of bison from Grayson (2006a). Idaho is outlined in black.

this latter point, the distribution of Yellowstone foods and related grizzly bear foraging on them provides a relevant benchmark.

More specifically, there are a handful of plants that Yellowstone grizzly bears exploit predominantly in high-elevation cold environments, comparable to environments that were probably more widespread at lower elevations during the Pleistocene south of the Cordilleran Ice Sheet. These notably include biscuitroot (*Lomatium cous*), horsetail (*Equisetum arvense*), and whitebark pine (*Pinus albicaulis*): the roots of the first, the stems of the second, and the fat-rich seeds of the third (Mattson 2000, Mattson et al. 2004; https://www.allgrizzly.org/pleistocene-holocene-diet). The probable importance of whitebark pine is given greater weight by recent modeling showing that whitebark pine would likely have been abundant during the LGM in lower-elevation areas such as the Snake River plain (Robert & Hamann 2015). Insofar as important fruits are concerned, the most likely candidate is buffaloberry or soopolallie (*Shepherdia canadensis*). Although regional evidence is scant, the widespread contemporary consumption of buffaloberries by grizzlies in drier boreal and subarctic environments[11] implicate the potential importance of these fruits to bears during the Pleistocene.

Grizzly bears in Pleistocene Idaho were, first, probably relegated to using marginal habitats, foods, and temporal windows as means of avoiding other predatory carnivores; second, obtained meat primarily by scavenging large-bodied herbivores in amounts likely to constitute an important food for many bears; and, third, despite this, relied primarily on vegetal foods for the bulk of their diet, with whitebark pine seeds also of prominent importance.

[11] For example, Hamer & Herrero (1987), MacHutcheon & Wellwood (2003), and Munro et al. (2006).

3. The Pre-European Holocene

The Holocene is conventionally considered to start around 11,700 years ago, marking the end of the Pleistocene and the advent of our current warmer epoch. Even so, the Holocene got off to a rocky start punctuated by wild swings in climate driven partly by melt of the continental ice sheets—which in North America lasted up until roughly 6,000 years ago (Dyke 2004). Early outflow of melt water around 13,000 years ago from Lake Agassiz likely cooled the north Atlantic and sent the Earth back into a mini-ice age called the Younger Dryas (Leydet et al. 2018; although arguments have been fielded implicating an extraterrestrial impact as a trigger[12]). Several millennia later, accelerated ice melt coupled with release of water from Lake Agassiz by catastrophic failure of ice dams again shut down a strengthening Gulf Stream and plunged the Earth back into yet another cold episode (Matero et al. 2017). These oscillations in climate triggered rapid changes in vegetation (as per in Figure 3) that dramatically reconfigured North America's fauna. Among the most dramatic changes was extirpation of almost all of North America's large herbivores and carnivores in a relatively brief period between 12,000 and 10,000 years ago (Faith & Surovell 2009)—an event partly driven by burgeoning populations of highly efficient human hunters. In North America, the largest terrestrial carnivore left standing was the grizzly bear. The largest remaining herbivore was the bison. One of the most notable features of the Holocene was the relationship between these two surviving members of the Pleistocene mega-fauna that lasted up until Europeans nearly eliminated both in what was to become the western United States (see: https://www.allgrizzly.org/the-bison-factor).

3.a. Changes in Climate and Vegetation

There are numerous proxies for changes in paleoclimates, but perhaps one of the best is changes in vegetation. Since the end of the Pleistocene, variations in relative and absolute concentrations of pollen from different plant genera and families captured by sediments in the bottoms of wetlands have provided a tableau of change. Thanks largely to studies by Cathy Whitlock and her students, we have a comprehensive palynological history from in and near the northern U.S. Rocky Mountains, which gives a rich and nuanced view of how climates and vegetation varied during the Holocene, with implications for grizzly bear foods and grizzly bear populations.

Figure 3 summarizes results from the many palynological studies undertaken in the northern U.S. Rocky Mountains[13]. The main patterns, regardless of elevation or latitude, are an initial colonization of recently deglaciated or periglacial environments by a woodland of Engelmann spruce (*Picea engelmannii*), with grasses, sedges, and forbs below, happening later—as would be expected—in areas that were deglaciated later (Figure 3b); and a substantial increase in cover of Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), sagebrush (*Artemisia* sp.), and drier grasslands during the long-lasting hot dry period called the Altithermal that dominated the middle of the Holocene between roughly 10,500 and 6,000 years ago. Forests characteristic of present times bracketed this period, with the exception of areas to the north and west that experienced delayed

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[12] For more on the controversy surrounding the Younger Dryas impact hypothesis, see Petaev et al. (2013), Moore et al. (2017), Wolboch et al. (2018a, 2018b), and Holliday et al. (2020).

[13] Sources for Figure 3b are Mack et al. (1978a, 1978b, 1978c), Whitlock 1992, and Power et al. (2011); for Figure 3c are Mehringer et al. (1977, 1985), Karsian (1995), and Brunelle et al. (2005); and for Figure 3d, Mack et al. (1983), Dorener & Carrera (2001), Whitlock et al. (2011), and Alt et al. (2018).

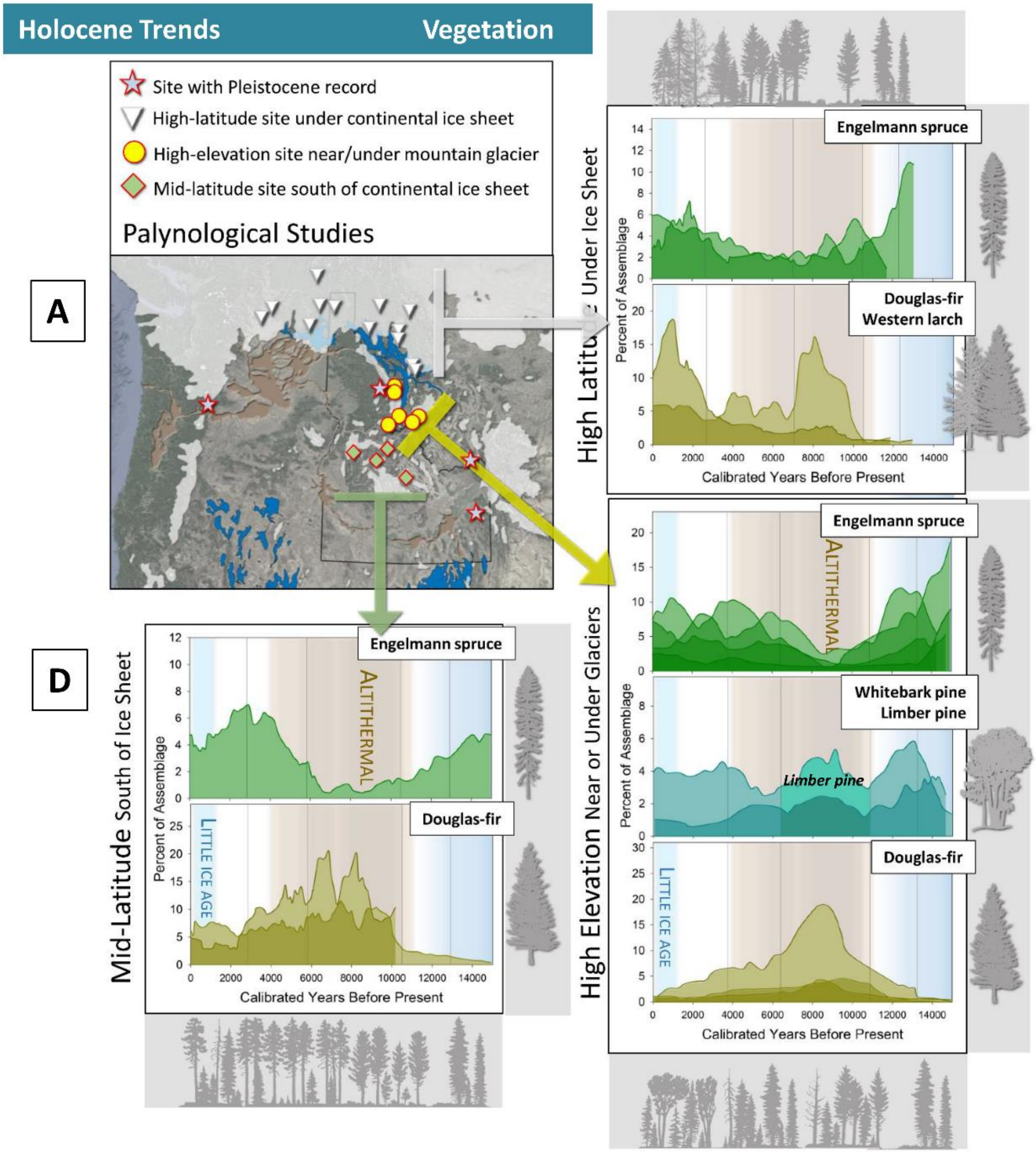


Figure 3. These panels illustrate major trends in vegetation during the Holocene and Late-Pleistocene (14,000-0 years before present) based on studies of pollen deposits in wetlands (i.e., palynology). The map in (**A**) shows the locations of studies from which results were summarized for (**B**) higher latitudes that were under the continental ice-sheets; (**C**) lower-latitude sites at high elevations; and (**D**) mid-latitude sites at moderate to low elevations. The study sites denoted by stars include records spanning the last glacial maximum. Trends in relative abundance of trees species that signify changes in environmental conditions are shown in each panel: Engelmann spruce (*Picea engelmannii*) at top of each; Douglas-fir (*Pseudotsuga menziesiii*) and western larch (*Larix occidentalis*)—that produce indistinguishable pollen—at bottom; and whitebark and limber pines (*Pinus albicaulis & P. flexilis*) in the middle of (**C**). Trends from each study site are overlain within each of the three strata, with greater overlap denoted by darker hues. The silhouetted profiles above, below, and to the side illustrate either changes in vegetation structure and composition or featured tree species. Background areas shaded progressively darker brown in each panel denote periods of greater warmth and drought, culminating during the Altithermal; areas shaded blue denote colder periods, beginning with emergence from glacial conditions.

Holocene Trends **Wildfire**

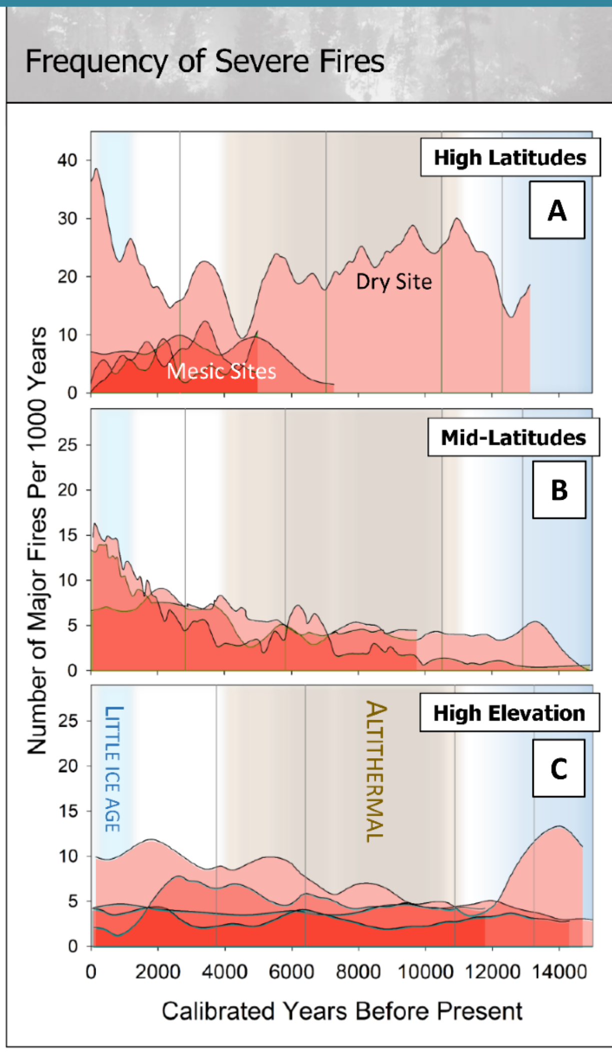


Figure 4. These panels show trends in frequency of wildfires during the Holocene and late Pleistocene, 14,000-0 years before present. These records are based on either depositions of charcoal in wetlands or depositions of sediment in alluvial fans, both of which signify major stand-replacing upland fires. The locations of studies used as sources for these records are shown in figure 3a. The strata shown here, in (**A**)-(**C**), are the same as used in figure 3 to illustrate regional trends in vegetation. Strata-specific records from individual study sites are overlain in each panel, with darker hues denoting greater overlap of results. The record in (**A**) from a drier lower-elevation site in Montana is differentiated from sites farther north in wetter areas typified by the presence of western hemlock (*Tsuga heterophylla*) and grand fir (*Abies grandis*). Background areas shaded progressively darker brown in each panel denote periods of greater warmth and drought, culminating during the Altithermal; areas shaded blue denote colder periods, beginning with emergence from glacial conditions. Vertical gray lines denote major changes in vegetation structure and composition in each stratum.

colonization by tree species adapted to wetter maritime climates and with limited migration potential—such as western hemlock (*Tsuga heterophylla*) and western red-cedar (*Thuja plicata*).

Other patterns are noteworthy, especially for reconstructing changes in amounts of vegetal bear foods. Figure 3c shows relatively constant abundance of 5-needled hapoxylon pines throughout the Holocene—which for much of this Epoch have been widespread in the northern U.S. Rocky Mountains (see Figure 5a). These pines include not only whitebark pine, an important source of bear food, but also limber pine (*Pinus flexilis*) which is only rarely exploited by bears for food and also fares better than whitebark pine under warmer drier conditions (Minore 1979). Although the pollen of these two species cannot be reliably differentiated, the pulse of hapoxylon pollen during the Altithermal was very likely not from whitebark pine but rather from limber pine (e.g., Whitlock et al. 2011, Iglesias et al. 2018), consistent with increased concentrations of Douglas-fir and western larch pollen.

As might be expected, the frequency of wildfires extensive enough and hot enough to leave traces of charcoal in wetland sediments has also changed substantially during the Holocene, but not always as might be expected from changes in ambient temperatures and precipitation. In fact, with the exception of intrinsically drier sites that have always been typified by grassy woodlands (Figure 4a), large fires tended to be less frequent during the Altithermal, especially in contrast to more recent millennia (Figure 4). The last 3,000-4,000 years have seen a substantial increase in fire activity in most areas, presumably because wetter conditions have promoted more productive forests and increased accumulation of large fuels (Brunelle et al. 2005). The other notable pattern was a pulse of more frequent fires early in the sediment record during the Younger Dryas period between 14,000 and 13,000 years ago, coincident with the emergence of Engelmann spruce and whitebark pine woodlands—possibly linked to global repercussions of an extraterrestrial impact (see footnote 12).

The Altithermal was probably a stressful period for grizzly bears caused by hot-dry conditions that reduced amounts of vegetal foods—including the abundance of whitebark pine—for perhaps as long as 3,500 years. By contrast, the generally cooler and wetter conditions that followed the Altithermal not only resulted in greater herbaceous productivity, but also an increased frequency of forest fires that likely resulted in greater amounts of available fruit on shrub species such as huckleberry (*Vaccinium membranaceum*) and buffaloberry—both of which tend to flourish in more open conditions—and thus in the wake of forest fires, with maximum amounts of fruit produced 20-40 years afterwards[14].

3.b. Availability of Meat from Marine and Terrestrial Sources

The amount of meat in contemporary grizzly bear diets varies substantially from one location to another as a predictable function of access to anadromous salmonids and high densities of large-bodied herbivores (Mowat & Heard 2006). As a proxy, consumption of meat from terrestrial sources is positively correlated with colder, drier climates in less rugged terrain (Mowat et al. 2006, Niedziałkowska et al. 2019)—which during pre-European times correlated in turn with higher densities of ungulates such as bison, caribou (*Rangifer tarandus*), and even elk (*Cervus canadensis*).

Of the ungulates, there is compelling evidence that, given equal availability, grizzly and brown bears preferentially consume meat from the largest-bodied species, notably moose and bison (Mattson 1997, 2017; Green et al. 1997). Of these two species, meat from moose is acquired mostly by outright predation (Gassaway et al. 1992, Mattson 1997, Dahle et al. 2013) whereas meat from bison is acquired primarily by scavenging (Green et al. 1997; Mattson 1997, 2017). Observations by early European travelers provide further evidence that, wherever bison were historically available, they were likely a locally importance source of food for grizzly bears (e.g., Burroughs 1961; https://www.allgrizzly.org/the-bison-factor).

All of this is relevant to determining where and when meat was prominent in diets of grizzly bears occupying Idaho during the early and middle Holocene—and from what sources. Runs of anadromous salmon colonizing Holocene habitats that had been previously scoured or otherwise made inhospitable during the Pleistocene (Waples et al. 2008; see Figure 2) almost certainly rapidly emerged as important sources of meat for grizzlies, as was the case for native peoples (Campbell & Butler 2010). Bison and perhaps elk were also very likely important sources of meat for grizzly bears in lower elevation steppes.

Figure 5 shows distributions of these meat resources during the Holocene, featuring salmonids in Figure 5a and bison and elk in Figure 5b. These figures also show locations of grizzly bear remains from

[14] See Martin (1979, 1983), Hamer (1996), Anzinger (2002), and Proctor et al. (2018)

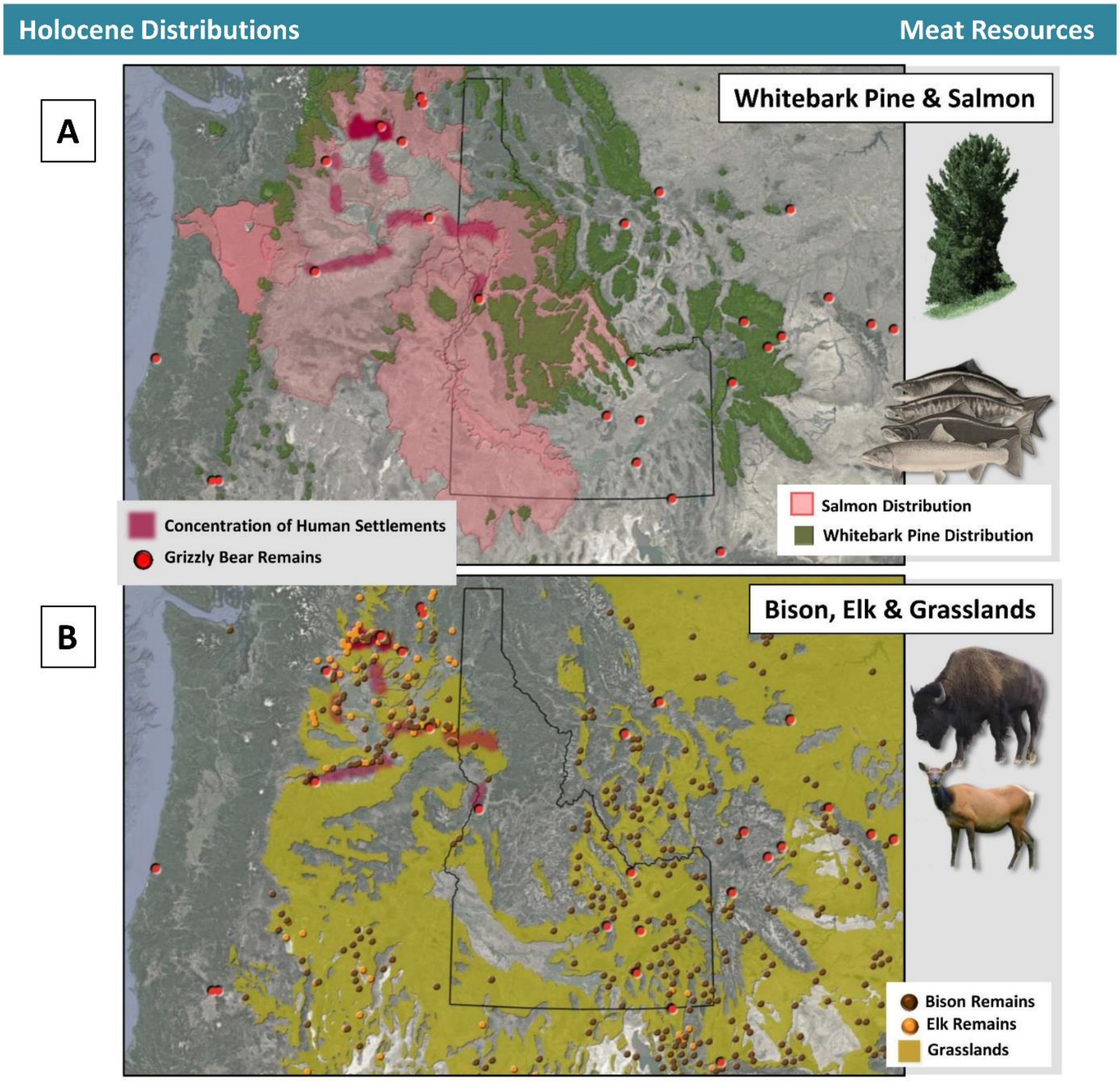


Figure 5. These two maps show major configurations of habitat as well as distributions of major grizzly bear foods during the Holocene, 10,000-350 years before present, exclusive of fruit-producing shrubs and herbaceous foods (see figure 7). Areas with high concentrations of human settlement in the Columbia River Basis are also shown in lavender (from Chatters [1995]) along with locations of Holocene remains of grizzly bears from archeological and paleontological study sites, shown as large red dots (from Lyman [1986] and the Neotoma Paleoecology Database (https://www.neotomadb.org/). The distribution of salmon in (**A**) is from NOAA 5-year status reviews published during 2016 for each of the protected anadromous salmonids in the Pacific Northwest (NOAA National Marine Fisheries Service, 2016a-2016d), with darker pink denoting greater overlap in distributions. The distribution of whitebark pine (*Pinus albicaulis*) in (**A**) is from the Whitebark Pine Foundation (https://whitebarkfound.org/wp-content/uploads/2019/05/WBP_April23_2019_1.jpg), with refinements based on interpretations from Google Earth imagery. Map (**B**) shows the distribution of non-forest vegetation types with a comparative abundance of perennial grasses (in dusky green, from US Environmental Protection Agency, state-specific Level III and IV ecoregion maps; https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-state), together with Holocene locations of elk (orange dots) and bison (dark-brown dots). Elk and bison locations are from the Neotoma Paleoecology Database augmented by locations from Bailey (2016), Dixon & Lyman (1996), Grayson (2006a), Grayson & Fisher (2009), and Lyman (2004, 2016).

archeological and paleontological sites dated to the pre-European Holocene (as red dots), suggesting that grizzlies were indeed widespread in the Pacific northwest.

The occurrence of numerous runs of spawning salmonids throughout drainages of the Columbia River suggest that fish were probably an important source of food for grizzlies in a large portion of ancestral Idaho, especially in tributaries to the Snake River. However, humans introduce an important proviso. There is circumstantial evidence suggesting that native peoples may have limited access by grizzly bears to concentrated riparian food resources well before the arrival of Europeans (Mattson et al. 2005). Hence both maps show concentrations of human settlements, many of which date back to the middle Holocene. However, even if humans interfered with grizzly bear access to spawning salmon, this would have likely applied only to lower-elevation reaches of the Columbia and Snake Rivers (Figure 5a), leaving grizzly bears a free hand along spawning streams in central and southwestern portions of central Idaho.

Bison, in particular, and elk, to a lesser extent, were clearly widespread and in some place relatively abundant during the Holocene at lower elevations of the Pacific Northwest (Figure 5b). This possibility wasn't given much credence at one time, but a conclusive body of historical, archeological, and paleontological evidence has emerged showing that bison were common, especially in the Columbia Basin, southeastern Idaho, and adjacent northwestern Utah (see the caption of Figure 5 for sources). Elk were likewise relatively common in the Columbia Basin. Even though this rapidly changed with the arrival of Europeans, grizzly bears almost certainly had access to meat from bison and perhaps elk during most the Holocene throughout the extensive shrub steppe environments in and around ancestral Idaho—barring the height of the Altithermal.

Figures 6a-c shows trends in meat resources for grizzly bears in the Pacific Northwest during the Holocene—specifically remains of bison and different proxies for abundance of spawning salmon. As has been documented pretty much everywhere at mid-latitudes in North America, bison reached a nadir of abundance during the hot-dry Altithermal (https://www.allgrizzly.org/the-bison-factor). Populations exploded thereafter, in the Pacific Northwest delayed until around roughly 1,500 years ago, coincident with the comparatively cool-wet Little Ice Age (Figure 6c). The pattern for salmon was quite different, with apparent abundance during the last 7,000 years peaking during the Altithermal and then again at roughly 3,000 and 1,300 years ago, with several measures suggesting a significant decline that began with onset of the Little Ice Age but accelerated 500 years ago—around 1500 A.D. Put together, these patterns suggest that the offset abundances of bison and salmon may have allowed for compensatory diet shifts by grizzly bears, although direct evidence for such shifts is lacking.

Insofar as the human factor is concerned, all of the reconstructions of human population size that I've encountered for North America, the northern U.S. Rocky Mountains, and the Pacific Northwest also suggest that the Altithermal was a challenging if not brutal time for people (e.g., Figure 6e)—perhaps less so in the Pacific Northwest where people had access to spawning salmon (Figure 6d). Human populations were at undisputed lows during the Altithermal and experienced a steady if not dramatic upturn beginning between 4,000 and 3,000 years ago, but with the onset of a dramatic *decline* beginning around 1500 A.D., coincident with the arrival of European diseases and the devastating impacts that followed (Hutchinson & Hall 2020). Of specific relevance to grizzlies, at the same time that they were challenged by the Altithermal climate and a dearth of foods from terrestrial sources,

Holocene Trends **Meat Resources & Humans**

Meat Resources | Human Populations

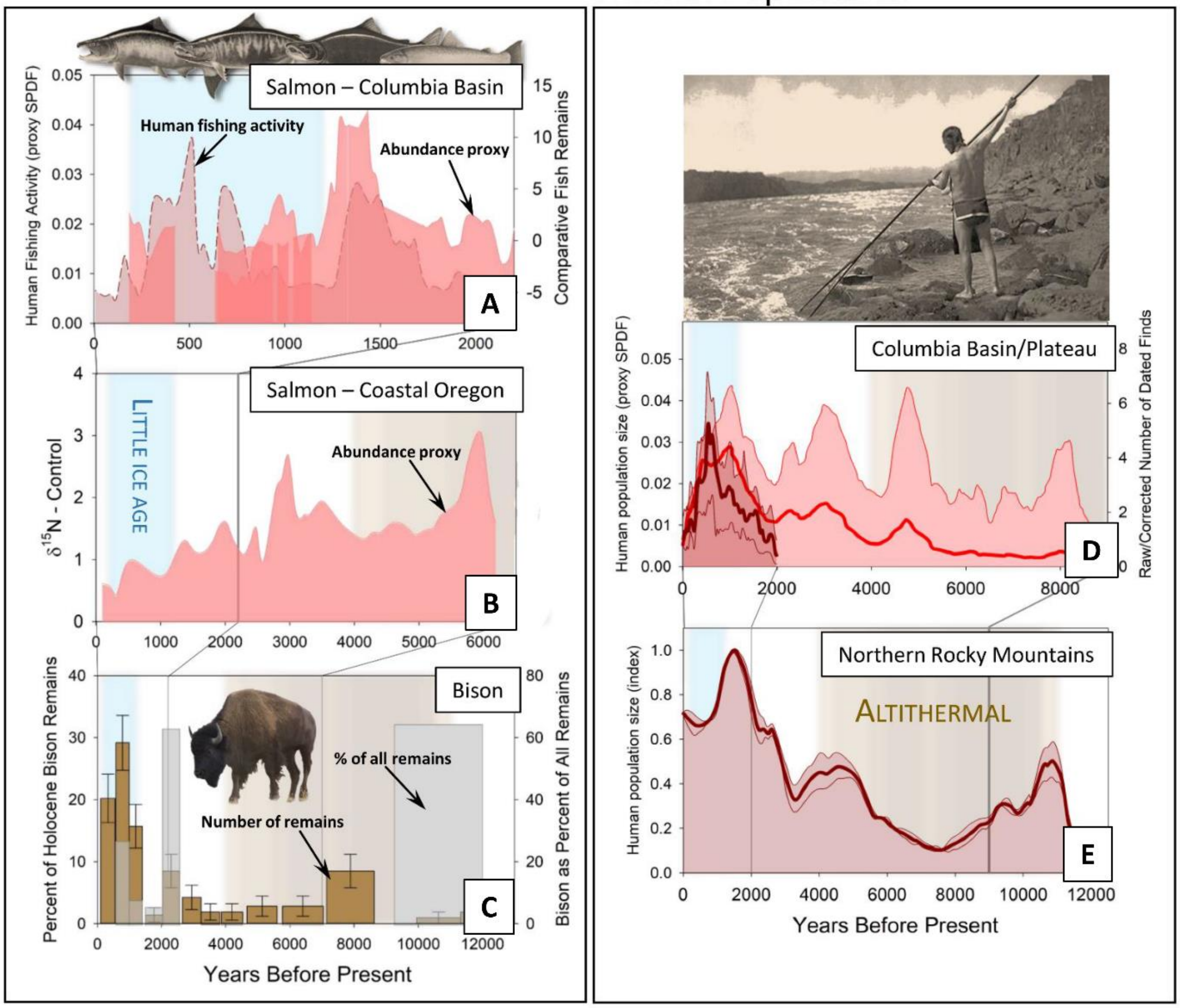


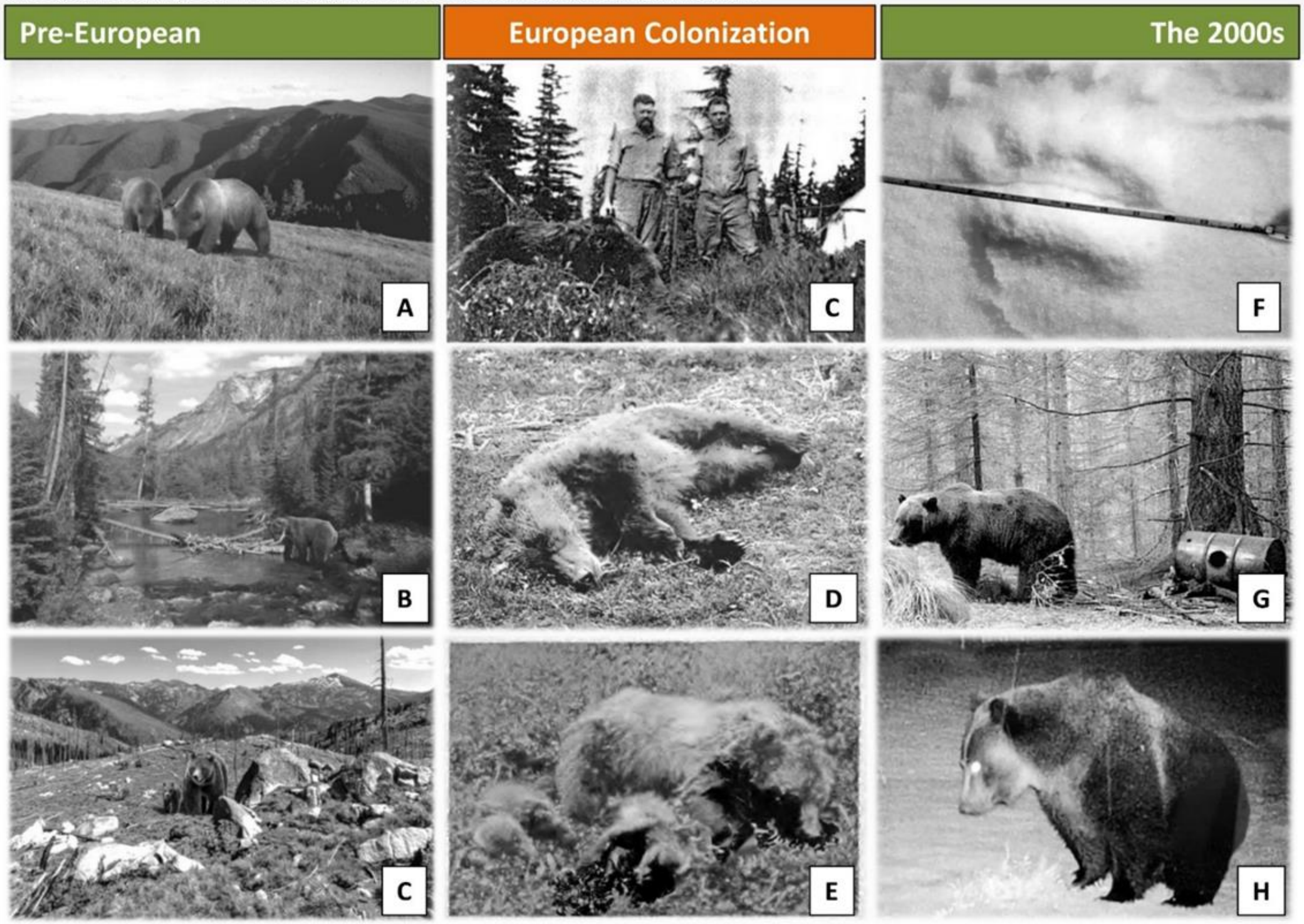
Figure 6. These graphics show Holocene trends in either (**A**-**C**) sources of dietary meat or (**D**-**E**) numbers of humans in the Pacific Northwest. The trend lines in (**A**) show a proxy for relative abundance of salmon based on fish remains in sediment cores (Finney et al. 2002) together with levels of human fishing activity at Kettle Falls along the Columbia River (from Hutchinson & Hall [2020]). Panel (**B**) shows a proxy for abundance of salmon going back 6,000 years based on nitrogen inputs from salmon reckoned as the difference between $\delta^{15}N$ inputs in lake systems with and without spawning salmon (Gavin et al. 2018). Panel (**C**) shows two different representations of bison abundance in the Columbia and Great Basins. The dark-brown bars show the distribution of dated bison remains *among* Holocene time-periods (from Stutte 2004) whereas the lighter gray bars show the *proportion of all remains* from larger mammals *during a given time period* that were attributable to bison (Lyman 2004). Panel (**D**) shows trends in proxies for human populations in the Columbia River Basin, with the longer time-line based on radiocarbon-dated archeological finds both corrected (pink) and uncorrected (red) for presumed decay in detection probabilities (Chatters 1995), together with a proxy for a shorter timeline corresponding with that shown in panel (**A**) (from Hutchinson & Hall [2020]). Panel (**E**) shows yet another proxy for human populations in the ancestral Bighorn Basin of the U.S. northern Rocky Mountains spanning the entire Holocene (Kelly et al. 2013) based on models driven by climate and radiocarbon-dated records. The darker burgundy lines in (**D**) and (**E**) are central tendencies of estimates whereas the bounding finer lines are 95th percentile confidence or credibility intervals. Background areas shaded progressively darker brown in each panel denote periods of greater warmth and drought, culminating during the Altithermal; areas shaded blue denote colder periods.

competition from and predation by humans was also lessening, which may have allowed grizzlies greater access to spawning salmon in lower-elevation stream and river reaches.

Grizzly bears in most parts of ancestral Idaho probably had access to abundant meat during the Holocene either from spawning anadromous salmonids or from large-bodied herbivores such as bison and elk, with these two sources complementary in both time and space. The challenges to grizzlies posed by humans, at least up until the arrival of European horses[15] and then Europeans themselves, tended to be spatially concentrated along specific reaches of the Columbia and Salmon Rivers, leaving bears ample access to salmon in mountainous areas of central Idaho. There may even have been a brief Edenic time for grizzlies that lasted a couple of centuries between when European diseases took their toll on indigenous human populations and lethal Europeans arrived in person.

[15] See Haines (1938) and Worcester (1945) for a review and Secoy (1992) for a map of the spread of horses and firearms in North America after arrival of Europeans. Horses fundamentally changed the lives and economies of native peoples, in ways that probably increased their impacts on bison as well as their lethality to grizzly bears (Flores 1991; Hämäläinen 2003, 2008; Isenberg 2020).

Box 1. This triptych of photos is illustrative of three eras of relations between grizzly bears and people in *The Grizzly Bear Promised Land*. Photos (A)-(C) are somewhat fanciful reconstructions of grizzly bears in pre-European times set against real backgrounds in the region: (A) near the crest of the Sapphire Mountains east of the Bitterroot Valley; (B) along a small spawning stream tributary to the Selway River; and (C) along Beaver Ridge in the Bitterroot Mountains. Photos (C)-(E) are emblematic of the slaughter that accompanied European colonization. Photos (D) and (E) were taken by William Wright during the late 1800s, representative of the dozens he alone killed during a few decades. Photo (C) shows one of the last grizzly bears killed during the early 1900s in the Clearwater drainage—on Wallow Mountain. Photos (F)-(H) are emblematic of recent colonization by grizzly bears, including a track found near Grangeville, Idaho, during 2020; (G) a grizzly photographed during 2019 near a bait set to attract black bears in the same area; and (H) a grizzly bear photographed during 2020 in the backyard of a residence near Lolo Hot Springs in Montana.



4. The Arrival of Europeans

The arrival of Europeans in North America triggered complex, multi-faceted, and ultimately cataclysmic changes for humans, animals, and plants that had occupied the continent in relative isolation since closure of the Bering Land Bridge roughly 11,000 years ago (Jakobbson et al. 2017). Although native peoples and grizzly bears had endured environmental upheavals of the Pleistocene-Holocene transition, as well as rigors of the subsequent Altithermal period, both were nearly extirpated in what was to become the United States by diseases, economic disruptions, mass migrations, violence, and environmental changes unleashed by European colonists. Native peoples and grizzly bears in nascent Idaho were no exception, although the catastrophe unfolded here later than in most other places.

The verifiable history of Europeans in the area that was to become Idaho began with passage of the Lewis & Clark expedition during 1805 down the Lochsa and Clearwater Rivers, followed by occasional incursions of fur trappers between 1812 and 1840 that led to establishment during the early 1830s of small European settlements at Fort Boise and Fort Hall in southern Idaho[16]. Missions followed shortly after during the mid-1830s in northern Idaho. The first small settlements of Mormons were established in southern Idaho during the 1850s. But these intrusions by Europeans were of little consequence compared to the massive impacts associated with operation of the Oregon Trail between 1843 and 1868, with annual traffic peaking at around 24,000 people during 1848-1857 (Unruh 1993). These concentrations of heavily-armed hungry transients along the Snake River Plain are unambiguously implicated in early extirpations of bison and elk in this region. But the biggest impacts on grizzly bears were probably unleashed by a flood of miners into the Clearwater, Boise, and Salmon River drainages that began during 1860-1863 and resulted in the near overnight establishment of cities with thousands of people in previously remote areas.

By the 1870s and 1880s agricultural settlements were widespread in southern Idaho, on the Palouse Prairie, and in more accessible and verdant portions of the Clearwater and Coeur d'Alene River drainages in the north. By 1910, there were numerous cattle and over 3,000,000 sheep in Idaho, mostly in southern portions of the state (U.S. Census of Agriculture, https://www.nass.usda.gov/AgCensus/). Sheep numbers only dropped significantly by 1940—to roughly 1,300,000 animals. Meanwhile, another explosion of mining activity had occurred in the Coeur d'Alene drainage during the late 1870s and early 1880s centered on silver mining in the Wallace and Mullan areas.

Impacts of Europeans in nascent Idaho likely unfolded in pulses organized around different episodes of colonization and exploitation with different geographic foci. Traffic on the Oregon Trail probably unleashed an early devastation of fauna on the Snake River Plain during the 1840s-1860s. Miners flooded remote mountains of central and north-central Idaho during 1860s-1880s. Agriculture followed during the 1870s and 1880s, most dramatically on the Palouse Prairie where a native grassland that had previously supported bison was almost completely converted to non-native wheat. Barring the effects of subsequent dams on the Columbia and Snake Rivers, perhaps the most severe environmental impacts caused by European colonization played out during a remarkably brief 40-year period.

4.a. Setting the Stage, *circa* 1800

It is difficult to estimate how many grizzly bears live in a given area under the best of circumstances. Even so, a ballpark estimate of how many grizzly bears likely roamed Idaho at the time of first contact with Europeans is potentially useful. If nothing else, this kind of estimate serves as a baseline for determining how many bears were lost—and how many we could potentially still have. Perhaps the

[16] My sources for this brief summary of Idaho history include a number of books devoted to the topic. Some of the earliest include Bancroft (1890) and Hailey (1910). These books along with Wells (1983) and Western Mining History https://westernmininghistory.com/ also cover the history of mining in Idaho.

best approach to such a calculation is to summarize contemporary density estimates for unexploited grizzly bear populations and then judiciously apply averaged densities to areas with approximately the same intrinsic productivity—which is the approach I've taken here[17].

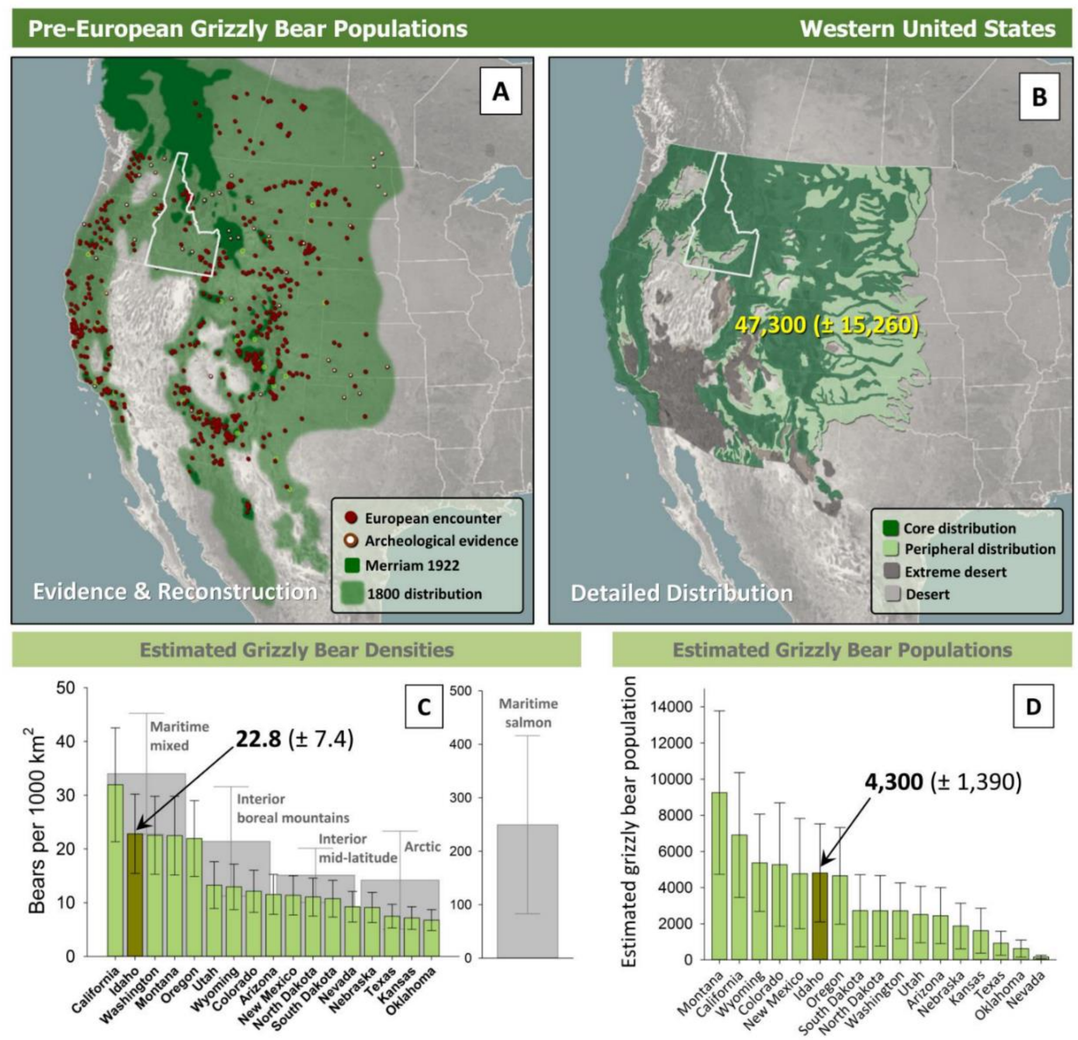


Figure 7. Map (**A**) shows the estimated distribution of grizzly bears *circa* 1800 along with supporting evidence. Solid dots represent documented encounters by Europeans; orange dots, archeological grizzly bear remains dating *ca.* 500-1000 years before present (see Mattson [2020a] for sources); and dark green, estimated distribution circa 1910 (from Merriam [1922], Leopold [1959, 1967], and Trevino & Jonkel [1986]). Map (**B**) shows a detailed reconstruction of grizzly bear distribution circa 1800, including core and peripheral distributions based on ecoregions and climate; estimated total population of grizzly bears is shown based on details in (D) (see Mattson [2020a] for sources). The future state of Idaho is outlined in white in both maps. The bar graph in (**C**) shows estimated contemporary densities of grizzly bears in portions of ecoregions relatively unaffected by humans (light gray bars) as a basis for estimating total numbers of grizzly bears in the contiguous United States *circa* 1800, stratified by core and peripheral habitat (see Mattson [2020a] for sources). Light green bars represent estimated densities of grizzly bears in each state, accounting for core and peripheral habitat. The bars in (**D**) are proportional to estimated numbers of grizzly bears in each state of the contiguous U.S. *circa* 1800 based on density estimates and relative amounts of core and peripheral habitats. Estimates for Idaho in (**C**) and (**D**) are shown as dark green bars.

[17] I lack the space here to provide a comprehensive list of references or grizzly bear density estimates, so the best I can do is refer readers to this web page-- https://www.allgrizzly.org/bear-density --where I've posted a document with relevant details, most raw data coming from Mowat et al. (2013).

The results of these calculations are shown in Figure 7, where I show Idaho in context of other future western states, including in Figure 7a a reconstruction of grizzly bear distribution based on recorded encounters between Europeans and grizzly bears, augmented by locations of grizzly bear remains documented at archeological sites; in Figure 7b, a representation of grizzly bear habitat differentiated by whether it likely supported core or peripheral grizzly bear populations[18]; and in Figures 7c and 7d, resulting estimates of average grizzly bear densities as well as total population sizes on a per state basis, realizing that none of these states existed in 1800. Figure 1 also shows an approximation of grizzly bear distribution in Idaho circa 1800.

These results suggest that ancestral Idaho supported one of the highest densities of grizzly bears in the future western United States (approximately 23 bears per 1000km^2), second only to California, yielding a total population estimate (roughly 4,300 grizzlies) comparable to that of other second tier states, including Wyoming, Colorado, New Mexico, and Oregon. The map in Figure 7b is also consistent with the agroclimate zones depicted in Figure 1, suggesting that the Snake River Plain was marginal—or "peripheral"—habitat for grizzly bears compared to everywhere else in the future state of Idaho.

In addition to having some estimate of grizzly bear numbers to work with, another salient benchmark is the approximate nature and distribution of grizzly bear dietary economies in Idaho at the time of European contact. Figure 8 shows my best attempt at reconstructing these economies for most of the northern U.S. Rocky Mountains, including all but the southern-most portion of Idaho.

Far northern Idaho and adjacent northwestern Montana were probably typified by a dietary economy based on consumption of fruit and forbs (see Figures 15 and 16 for relevant details)—likely the default consequence of a dearth of spawning anadromous salmon, whitebark pine, and bison as it was the more affirmative consequence of a comparatively wet maritime climate and resulting lush vegetation (see Figure 1). Farther south, central and southwestern Idaho were almost certainly characterized by a salmon-based economy (see Hilderbrand et al. 1999), but grading from wetter areas to the north, where fruit was also a staple, to drier colder areas farther to the south and east, where whitebark pine seeds were probably a prominent food. Further south and east yet, outside the distribution of anadromous salmonids, grizzly bears likely exhibited what I call a "mixed-mountain" dietary economy. This economy would have been typified by varied consumption of various foods, but with whitebark pine seeds, fruit, roots (e.g., biscuitroot and yampa [*Perideridia gairdneri*]), and bison prominent[19]—with army cutworm moths (*Euxoa auxilliaris*)[20] and cutthroat trout (*Oncorhynchus clarki*)[21] potentially also locally important. Finally, farther east yet, on the Great Plains, grizzly bear diets likely transitioned to dominance by meat from bison plus fruit from species typical of this environment, including

[18] I based this determination for the most part on maps of U.S. Environmental Protection Agency Level III and IV Ecoregions (https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-state) cross-walked to a somewhat subjective reckoning of whether each of the ecoregion types would have more likely supported higher versus lower densities of grizzly bears.
[19] See https://www.allgrizzly.org/pre-european-diets-i and https://www.allgrizzly.org/pre-european-diets-ii
[20] For more about grizzly bear consumption of army cutworm moths, see this web page: https://www.mostlynaturalgrizzlies.org/army-cutworm-moths
[21] For more about grizzly bear consumption of cutthroat trout, see this web page: https://www.mostlynaturalgrizzlies.org/cutthroat-trout

serviceberry (*Amelanchier alnifolia*), chokecherry (*Prunus virginiana*), and plums (*P. americana*)[22]. Parenthetically, an expression of this bison-based economy might have also existed in upper elevations of the Snake River Plain (as per Figure 5).

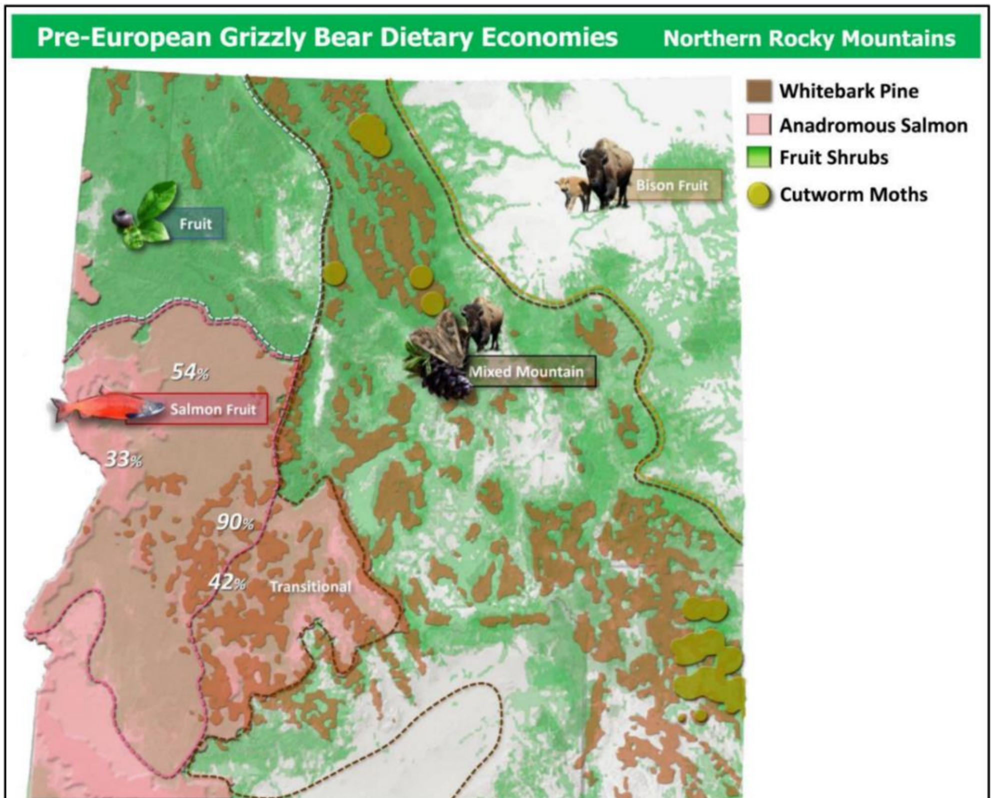


Figure 8. This map shows the distributions of four grizzly bear dietary economies at the time of first contact with Europeans in and near what was to become the northern Rocky Mountains of the United States. Each dietary economy is labeled and delineated by a different-colored dashed line that accounts for the distribution of grizzly bears as well as transitions to other dietary economies that are not labeled. This map represents the synthesis of information from Mattson (2020a). Distributions of spawning salmon are from U.S. Department of Commerce (2013a,b) and Idaho Department of Fish & Game (2018). White italicized percentages are estimates of metabolized energy obtained from salmon, with each number corresponding to an individual grizzly bear. Estimates were based on analysis of isotopes obtained from grizzly bear remains recovered from museum collections (Hilderbrand et al. 1996). Distribution of huckleberry is from Prevéy et al (2020). Distributions of other important fruit-producing shrubs are from Ironside & Mattson (2014). Distribution of whitebark pine is from Crookston, *Plant Species and Climate Profile Predictions*. Distributions of army cutworm moth aggregation sites are from Chapman et al. (1955), Craighead et al. (1982), Aune & Kasworm (1989), Mattson et al. (1991a), White et al. (1998), and Robison (2009).

The future state of Idaho almost certainly supported several thousand grizzly bears at the time of European contact, with highest bear densities likely occurring in portions of the state north of the Snake River Plain. Central and northern ancestral Idaho were probably more productive environments for grizzly bears compared to the arid and semi-arid Snake River Plain, largely as a consequence of abundant fruit, anadromous salmonids, and whitebark pine. Central portions of the Snake River Plain may have only supported significant numbers of grizzly bears when bison roamed this region prior to the 1830s-1840s.

[22] See https://www.allgrizzly.org/pre-european-diets-ii and https://www.allgrizzly.org/the-bison-factor

4.b. Extirpations

Grizzly bears in Idaho were extirpated from over 90% of the state by newly arrived Europeans in a startlingly brief 100-year period, between roughly 1850 and 1950 (see Figure 9 for a mapped synopsis of these extirpations). The proximal causes were trauma caused by bullet wounds, injuries from massive spring-loaded traps, and toxicity from poisons laced into baited carcasses. Grizzly bears whose ancestors had lived in the newly-defined area of Idaho for perhaps 40,000 years were shot, trapped, and poisoned at every turn as part of a sanctioned eradication effort.

Behind all this was unqualified intolerance of large carnivores justified by well-honed narratives that ascribed virtue to these extirpations as means of removing obstacles to civilization and otherwise cleansing the Earth in preparation for a superior European culture. There is ample evidence of this cultural program in the many journals and recollections of Europeans who traveled through and settled in the Rocky Mountains, although perhaps best documented in specific reference to grizzly bears by authors such as Storer & Tevis (1955; for California) and Brown (1985; for the Southwest), but also by Robinson (2005) generally for the history of government subsidized programs to eliminate predators.

In some respects, the cause(s) of grizzly bear extirpations in Idaho are pretty straight-forward, with perhaps nothing left to be explained.

But the *pattern* of extirpations begs a number of questions (Figure 10). Most prominently, why did grizzly bears disappear from the extensive remote mountainous region between the Snake River Plains and the St. Joe River drainage at the neck of Idaho's panhandle? Most of this area is currently roadless, and much of it is designated Wilderness Area. It is remarkably rugged. The question is thrown into even sharper relief by the fact that viable populations of grizzly bears managed to survive persecution by Europeans in areas comparably remote and rugged, notably in the current Greater Yellowstone and Northern Continental Divide Ecosystems. Why did grizzly bears survive in these areas, but not in central and north-central Idaho? What was different? Why did grizzly bears disappear from their last stronghold in the Clearwater-Lochsa River drainage when their numbers (*c*. 40) were not that dissimilar from populations that survived in the Selkirk (*c*. 20) and Cabinet (*c*. 25) Mountains as well as in the Yaak region (*c*. 30) of far northwestern Montana (Figure 9b)?

The maps in Figure 10 highlight the most prominent geospatial anomalies, as well as providing cause to dismiss the ready invocation of densities of resident humans as an explanation for extirpations. Humans were not that numerous in central Idaho, although the nature of their presence and interactions with grizzlies was perhaps singular, especially in contrast to the ancestral Greater Yellowstone and Northern Continental Divide Ecosystems.

The history of invasion and occupancy by Europeans, together with unique configurations of habitats and foods, provide clues to why early extirpations of grizzly bears happened in an otherwise wild remote landscape. As shown in Figure 11a, the area of anomalous grizzly bear extirpations coincided with where spawning anadromous salmon were a staple food for grizzly bears. These extirpations also coincided with areas where there were early intrusions by miners into the mountainous areas of central and north-central Idaho between the 1860s and 1880s (Figure 11b).

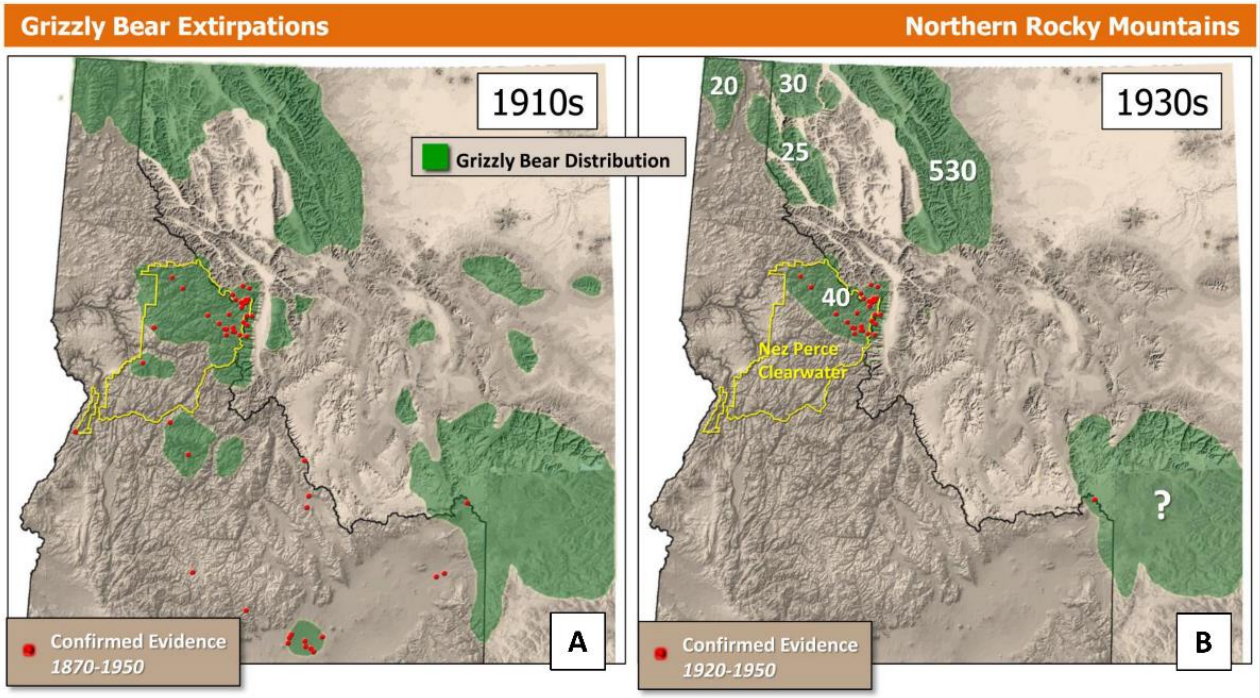


Figure 9. These two maps show documented locations (as red dots) as well as estimated total distributions (in green) of grizzly bears in the U.S. Northern Rocky Mountains during two time periods that encompass the period of terminal grizzly bear extirpations in this region. The boundary of the future Nez Perce-Clearwater National Forests is shown in yellow . The estimated distribution of grizzly bears in (A) is from Merriam (1922); individual locations are from Merriam (1891), Wright (1909), Mills (1919), Cochrell (1970), Smith (1973), Space (1981), Moore (1996), and collections held by the Smithsonian National Museum of National History. The distribution of grizzly bears in (B) was estimated by interpolating between 1910s and 1970s distributions ; the latter estimated from U.S. Forest Service (1933), Layser (1972, 1978), Kasworm (1985), U.S. Fish & Wildlife Service (1982), and Moore (1996). Population estimates in (B) are from Forest-specific estimates of game populations in U.S. Forest Service (1933).

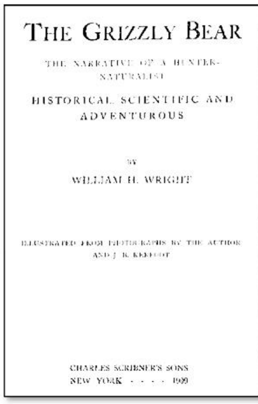
As a general—even axiomatic—proposition, grizzly bears are killed by humans as a joint function of how frequently they encounter people and the likelihood that these encounters will be lethal to the involved bears (Mattson et al. 1996a). There is no doubt that encounters with Europeans during the 1800s and early 1900s were almost always lethal for grizzlies, which meant that persistence of grizzly bear populations largely became a function of conditions that minimized the likelihood they would encounter people in the first place.

Not surprisingly, the most prominent driver of contact is numbers of people in a given area (Mattson & Merrill 2002). But local distributions of bear foods are also important, especially if they attract grizzlies to areas where they are more likely to encounter people, whether they be few or many. Aside from anthropogenic foods, the native foods that most often brought bears into contact with Europeans during the 1800s were bison carcasses, by being concentrated in riparian areas used as primary travel routes by people, and spawning salmonids, by being concentrated in streams confined to valley bottoms, which were likewise used by people for both travel and habitation (Mattson & Merrill 2002). By contrast, grizzly bears survived best during the late 1800s and early 1900s in areas where whitebark pine seeds were a principal food (Mattson & Merrill 2002).

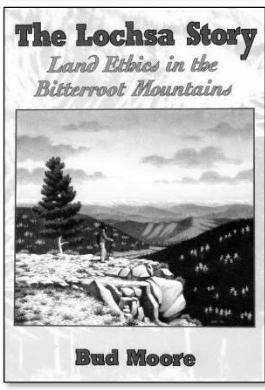
Whitebark pine is exploited by grizzly bears in rugged high-elevation areas that are infrequently occupied or visited by people (Mattson et al. 1994). As a result, grizzly bears that forage on the seeds

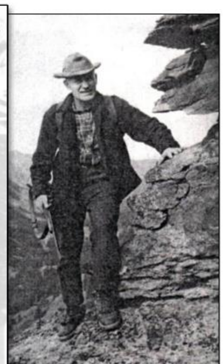
Documenting Extirpations of Grizzly Bears in the Bitterroot and Clearwater Country

Box 2. William Wright (1856-1934) and Bud Moore (1917- 2010) probably contributed more than anyone else to documenting the pre-extirpation ecology of grizzly bears in Bitterroot Mountains and north-central Idaho as well as the final demise of grizzlies in this area. Photos of both men are below, along with illustrative quotes from each of their books. The covers of their seminal books are also shown at left.



Page 74
"I accordingly fired at the small bear, and hitting him square in the shoulder, he dropped promptly and without a murmur, but he dropped into the pool. Before the other one on the log had time to make much of an investigation I hit him near the same place, but a little further back, and he made for the shore. I paid no attention to him, as I knew that he was fatally wounded and would not go far, and slapping my third cartridge in place, I turned to look for the third bear, but all I could see was the swaying of the bushes where he had disappeared. The second one shot went some fifty yards after reaching the bank, when he fell, and was quite dead when I got to him."





Page 278
"The last track I saw was along the Spruce Creek Fork of the Brushy in 1946. There was no life in its wake. The mud had dried around the imprint of the big paw and its long claws in what seemed to me an attempt by nature to preserve some sign of the last of the great bear's passing. That year the Idaho Fish and Game Department, for the first time, closed the season for hunting grizzlies. But it was already too late."

of whitebark pine end up being attracted to *de facto* refuges from humans where they in turn have a greater likelihood of surviving (Mattson et al. 1992, Pease & Mattson 1999). As a result, grizzly bear populations with access to whitebark pine have a greater likelihood of persisting (Mattson & Merrill 2002).

All of this is relevant to interpreting the early extirpations of grizzly bears in central portions of Idaho, especially between 1860 and 1909. Spawning salmon were almost certainly an important food in this region that attracted grizzlies to predictable places at predictable times, all located in valley bottoms where people were more likely to be active. Of even greater relevance, this spatial and temporal predictably would have made grizzlies acutely vulnerable to people deliberately setting out to kill them (as described by Wright 1909; also see Box 2). Compounding this dynamic, prospectors in Idaho are described as visiting virtually every corner of even the most remote regions in their quest for exploitable mineral deposits (Wells 1983)—a pattern that differentiated them from people intent on pursuing a living in agriculture. Many of the mining claims, mines, and mining camps were, moreover, located deep in the mountains (Figure 11b) where they would have functioned as bases of operations offering hunters, prospectors, and miners easier access to grizzly bears.[23] The concurrent and subsequent establishment of scattered remote homesteads along the main stem and tributaries of the Salmon and Boise Rivers, many sustained by subsistence hunting and income from trapping (e.g., Smith 1973), almost certainly did not help.

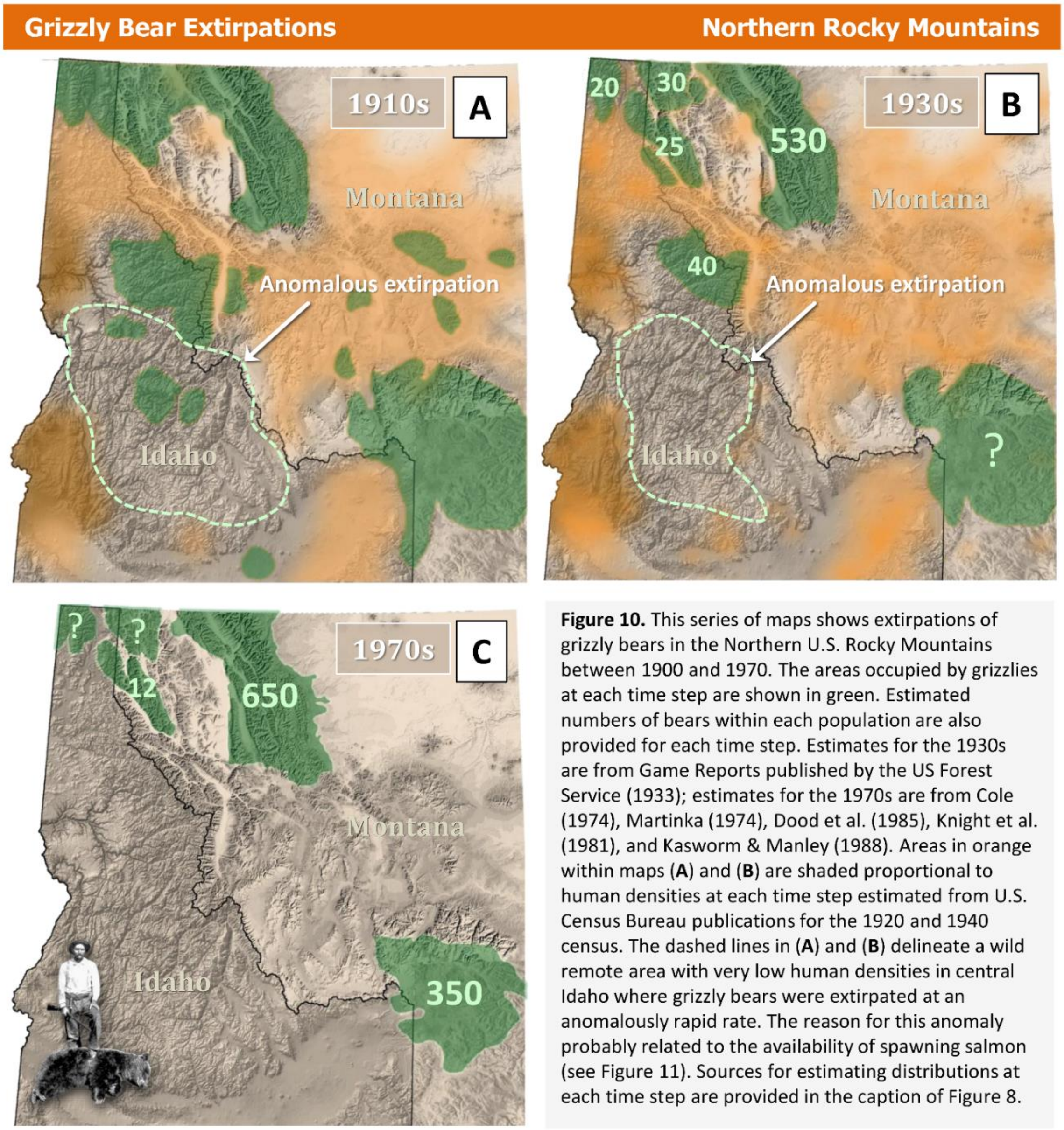


Figure 10. This series of maps shows extirpations of grizzly bears in the Northern U.S. Rocky Mountains between 1900 and 1970. The areas occupied by grizzlies at each time step are shown in green. Estimated numbers of bears within each population are also provided for each time step. Estimates for the 1930s are from Game Reports published by the US Forest Service (1933); estimates for the 1970s are from Cole (1974), Martinka (1974), Dood et al. (1985), Knight et al. (1981), and Kasworm & Manley (1988). Areas in orange within maps (**A**) and (**B**) are shaded proportional to human densities at each time step estimated from U.S. Census Bureau publications for the 1920 and 1940 census. The dashed lines in (**A**) and (**B**) delineate a wild remote area with very low human densities in central Idaho where grizzly bears were extirpated at an anomalously rapid rate. The reason for this anomaly probably related to the availability of spawning salmon (see Figure 11). Sources for estimating distributions at each time step are provided in the caption of Figure 8.

[23] Interestingly—and for somewhat inexplicable reasons—some of the last grizzly bears to be killed in southern Idaho occupied areas in and near Craters of the Moon. According to records kept by the Smithsonian National Museum of Natural History, three bears were killed during 1917, one during 1922, two during 1923, and one during 1928 in this relatively small area thanks to the collecting and predator control efforts of Luther Goldman (of the Bureau of Biological Survey), Carlos McIntosh, G. W. Bryson, R. Williams, L. Twichel, S. Driggs, and J. Moran—egged on from afar by C. Hart Merriam (Merriam 1904). What were grizzlies eating in this area? Clues are offered by Luther Goldman and Harold Stearns who each respectively observed that focal foods at the time seemed to be livestock (Goldman 1922) and biscuitroot (or “parsley,” *Lomatium cous*; Stearns 1928).

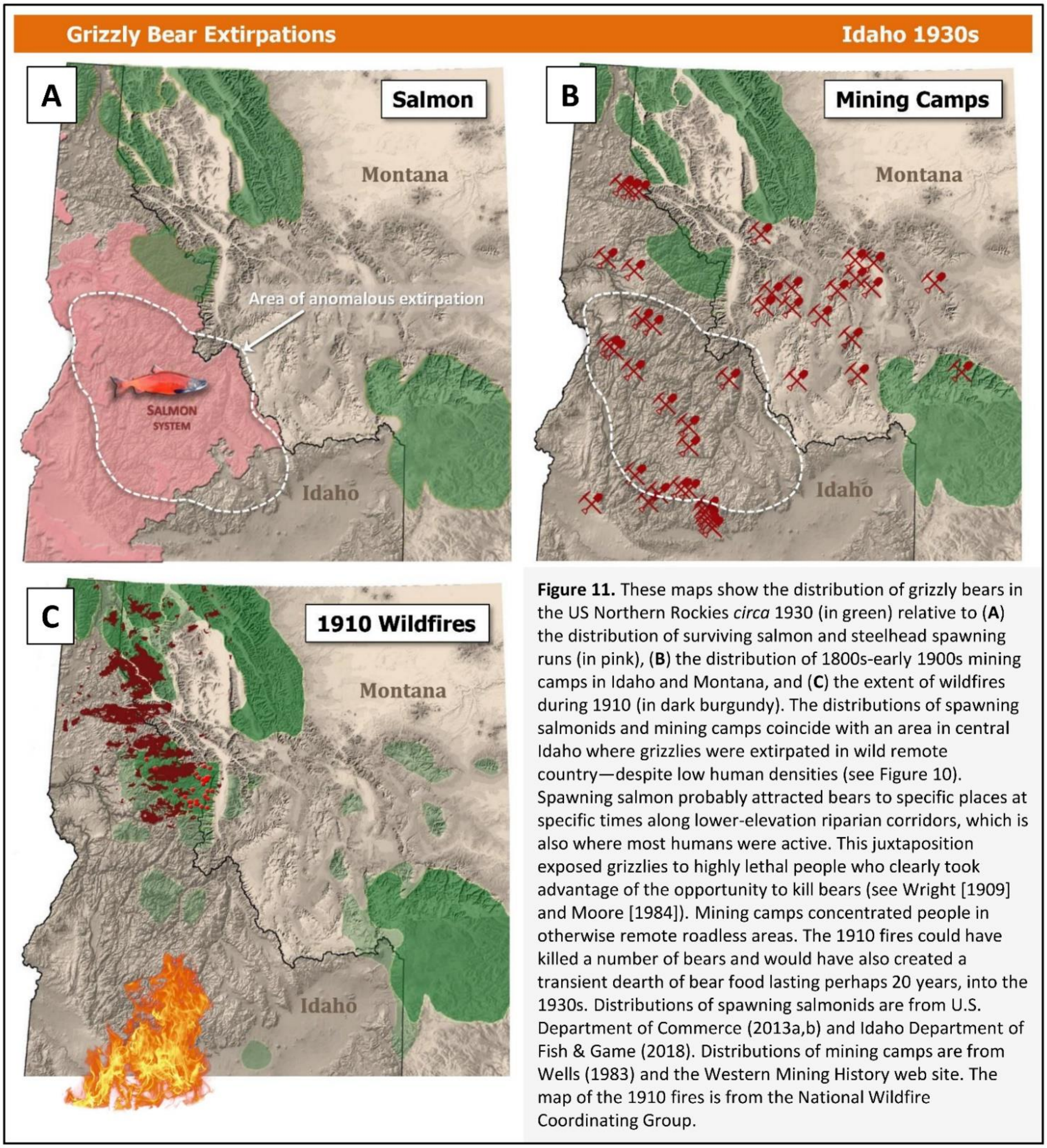


Figure 11. These maps show the distribution of grizzly bears in the US Northern Rockies *circa* 1930 (in green) relative to (**A**) the distribution of surviving salmon and steelhead spawning runs (in pink), (**B**) the distribution of 1800s-early 1900s mining camps in Idaho and Montana, and (**C**) the extent of wildfires during 1910 (in dark burgundy). The distributions of spawning salmonids and mining camps coincide with an area in central Idaho where grizzlies were extirpated in wild remote country—despite low human densities (see Figure 10). Spawning salmon probably attracted bears to specific places at specific times along lower-elevation riparian corridors, which is also where most humans were active. This juxtaposition exposed grizzlies to highly lethal people who clearly took advantage of the opportunity to kill bears (see Wright [1909] and Moore [1984]). Mining camps concentrated people in otherwise remote roadless areas. The 1910 fires could have killed a number of bears and would have also created a transient dearth of bear food lasting perhaps 20 years, into the 1930s. Distributions of spawning salmonids are from U.S. Department of Commerce (2013a,b) and Idaho Department of Fish & Game (2018). Distributions of mining camps are from Wells (1983) and the Western Mining History web site. The map of the 1910 fires is from the National Wildfire Coordinating Group.

But there is a final peculiarity. Why did grizzly bears disappear from their last enclave in north-central Idaho in upper reaches of the Clearwater River drainage between 1910 and 1950? On the one hand, there were so few grizzlies left here that a few chance events could have led to their demise. Yet comparably small populations of grizzly bears managed to persist in three other areas—the Yaak region and in the Cabinet and Selkirk Mountains. Aside from on-going human-caused attrition, there are not many obvious candidates to explain the disappearance of grizzlies in the Clearwater country—except for two.

Wildfire is not often thought of as a hazard for grizzly bears. Yet there was one wildfire event that no doubt affected the last enclave of grizzly bears in the Clearwater drainage—the unprecedented fires of 1910. These fires were so explosive and so large that they killed nearly 90 people and injured hundreds more (Egan 2009; see the map in Figure 11c for the extent of these fires). Given how rapidly these massive fires spread during just a few days, it is easy to imagine that some grizzly bears fell victim as well, not only in the Clearwater country, but also in the nearby Cabinet Mountains of northwestern Montana. But aside from this, many spawning streams would have likely been impaired by sediment pollution during subsequent erosion events[24], and vegetal bear foods would have been eliminated for at least a few years after, with recovery of fruit crops probably not occurring until 20-40 years later[25] during the 1930s-1950s.

The other factor that would have likely harmed grizzly bears in the Clearwater drainage during their final decades was construction of the Lewiston Dam in 1927 near Lewiston, Idaho. The dam impaired steelhead trout runs and essentially barred passage of chinook salmon farther upstream into the reaches yet occupied by grizzlies (Davis et al. 1986). At the same time, domestic sheep were being grazed in the Lochsa River and Clearwater River drainages as means of capitalizing on the forage that flourished in open conditions following the 1910 fires. Sheep would have been a prime and easily obtained alternative food for grizzly bears trying compensate for short-falls in salmon and fruit, with the unfortunate consequence of triggering persecution by sheep-herders intent on preventing or retaliating for depredations (Moore 1984).

It is probably not by coincidence that the last plausible evidence of grizzlies in the Clearwater country was documented during 1946 (Moore 1984, 1996).

Extirpations of grizzly bears from Idaho by newly-arrived Europeans were rapid, widespread, and anomalous, with some anomalies plausibly explained by the concentration of grizzlies near lethal people in pursuit of spawning salmon, but with prospects of mineral-related wealth also sending people into even the most remote refuges left to grizzlies. The massive wildfires of 1910 and the near end of chinook salmon spawning runs might have contributed to delivering a *coup de grâce* to the last grizzlies left in the Clearwater country.

[24] There is a compendious body of research on how wildfires of varying intensities and sizes can differentially affect influx of sediments as well as other hydrologic conditions in spawning streams. A few relevant references include Ice et al. (2004), Rieman et al. (2012), and Riley et al. (2015).

[25] For more on successional patterns of relevance to fruit production see: https://www.mostlynaturalgrizzlies.org/habitat-associations

5. Prospects and Potential

By 1970 there was no verifiable evidence of grizzly bears living anywhere in Idaho between the Selkirk Mountains in the far north and the Targhee National Forest in the far southeast, despite a peculiar reference to the presence of grizzlies in the Clearwater River drainage in the U.S. Fish & Wildlife's 1975 rule that gave ESA protections to this species[26]. Regardless, the vast wildlands of this region begged for the presence of grizzly bears, either lurking in some hidden corner, or somehow resurrected by ESA protections. This self-evident potential led the U.S. Fish & Wildlife Service to designate the Selway-Bitterroot Wilderness Area and its neighborhood as the only grizzly bear Recovery Area in the contiguous United States without resident grizzly bears (U.S. Fish & Wildlife Service 1982). The Recovery Area was subsequently enlarged to include the Frank Church-River of No Return Wilderness Area during an effort in the late 1990s to reintroduce grizzlies. This effort led to a compendious Environmental Impact Statement (U.S. Fish & Wildlife Service 2000) that has since been purged from all offical sources as a result of political fall-out from this failed undertaking[27]. But the redrawn Recovery Area boundaries survived as did recognition of the ample potential of this region.

5a. What the Models Show

With the passage of time, modeling methods have improved to a point where useful spatially-explicit representations of suitable grizzly bear habitat can be made. Among the first was Merrill et al. (1999), who tackled projections for Idaho (Figure 12a). Modeled estimates of potential grizzly bear densities and population sizes followed, with one by Boyce & Waller (2003) specifically for the Selway-Bitterroot Recovery Area—subsequently more or less replicated by Mowat et al. (2013). These two estimates came in at around 300-500 bears (Figure 12b), far more than potential population sizes estimated for Cabinet-Yaak Recovery Area (Mattson & Merrill 2004, Mowat et al. 2013).

But this isn't the whole picture. Modeling efforts that liberated themselves from the confines of Recovery Area boundaries drawn by the U.S. Fish & Wildlife Service—largely for political reasons—showed much greater potential (e.g., Merrill et al. 1999; Carroll et al. 2001, 2003; Merrill 2005; Craighead et al. 2005) encompassing almost all of the roadless wildlands of north-central, central, and southern Idaho (Figure 12a). Importantly, these models considered not only remoteness from humans, but also habitat productivity—absent any consideration of meat resources such as elk and spawning salmonids. An estimate of potential numbers of grizzlies for this more expansive representation of potential suitable habitat suggests that between 500 and 1,100 grizzlies could live in portions of Idaho that are remote enough, productive enough, and also contiguous enough to support grizzlies (as per Merrill 2005). The pivotal Nez Perce-Clearwater National Forests alone could probably support between 250 and 500 grizzlies (Figure 12).

Even in the wake of all this modeling, a question still remained. Could grizzly bear actually make it to this Grizzly Bear Promised Land absent the heavy intervening hand of a reintroduction effort? Other

[26] 40 FR 31734-31736, July 28, 1975; "verifiable" is the key word here, as typically used by the U.S. Fish & Wildlife Service to mean that confirmation requires either a carcass, DNA evidence, or an irrefutable photograph. Tracks are considered to be intrinsically suspect. Even so, investigators such as Melquist (1985) and Groves (1987) provide credible evidence that grizzly bears were present in north-central Idaho during the 1970s and 1980s.
[27] The fraught history of this effort has been covered by authors such as Smith (2003), Dax (2015), and Nadeau (2020)—with varying degrees of veracity, bias, and self-reference.

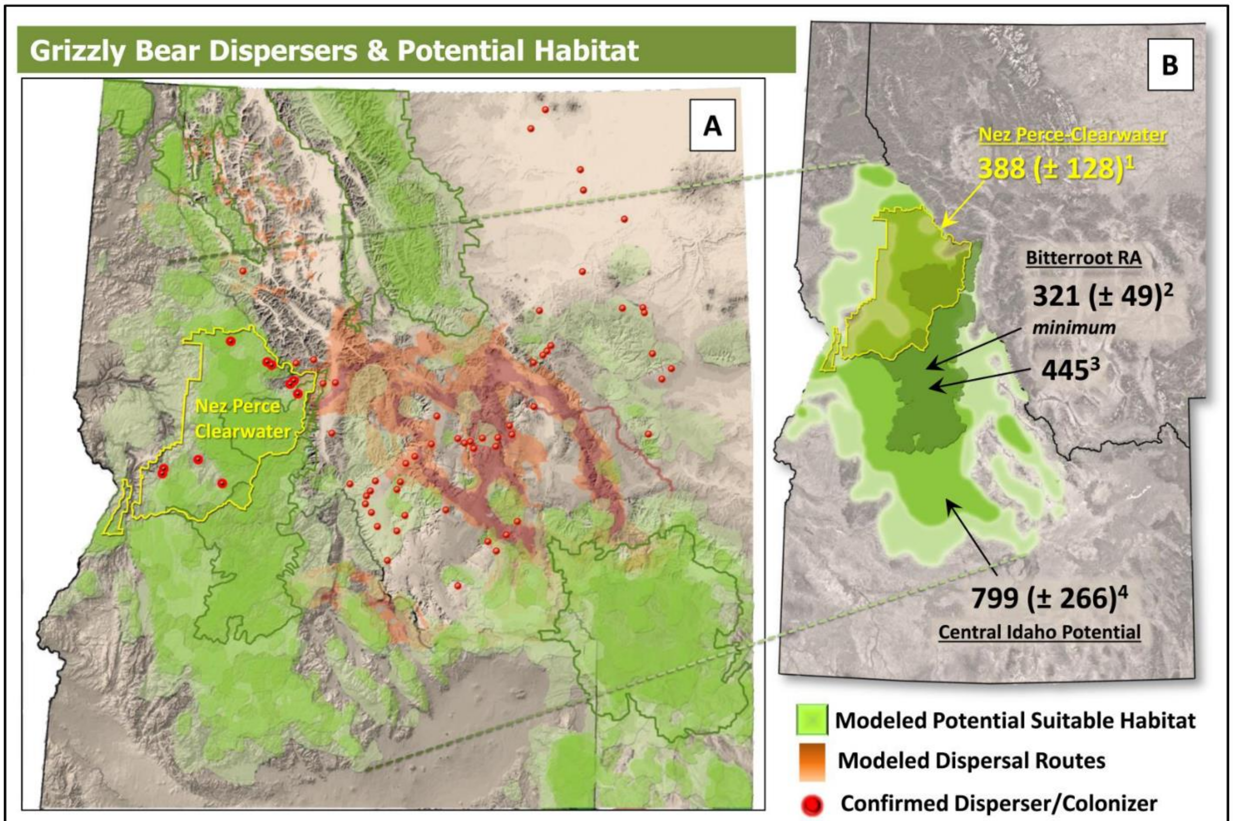


Figure 12. Map (**A**) shows the distribution of potential suitable habitat (in shades of green) and potential dispersal routes (in shades of orange) for grizzly bears in the U.S. Northern Rocky Mountains along with the distribution of dispersing/colonizing grizzly bears documented since 2005 (red dots). Potential suitable habitat is based on models that incorporate habitat productivity and remoteness from humans, with darker green indicating greater replication of results (from Merrill et al. [1999]; Carroll et al. [2001, 2003]; Merrill & Mattson [2003]; Mattson & Merrill [2004]; Merrill [2005]; and Craighead et al. [2005]). Dispersal routes were modeled by Walker & Craighead (1997), Servheen et al. (2001), Proctor et al. (2015), and Peck et al. (2017). Documented locations of dispersers/colonizers are from Groves (1987), Nokkentved (2007), Costello et al. (2014, 2019), Barker (2020), Backus (2020), Phillips (2020), Angelamontana (2020), and Kasworm et al. (2020). Map (**B**) shows estimated potential population sizes for grizzly bears in north-central and central Idaho relative to different delineations. Estimates for the Bitterroot Recovery Area (in darkest green) are from Boyce & Waller (2003)[2] and Mowat et al. (2013)[3]. The estimate for potential suitable habitat in central Idaho by Merrill et al. (1999)[4] was obtained by applying average densities of unexploited grizzly bear populations in interior North America to areas delineated in light-green (low density) and medium-green (moderate density), respectively (from Figure 7). The estimate for the Nez Perce-Clearwater National Forests (in yellow)[1] was obtained using the same methods.

modeling has attempted to answer this question, although grizzly bears themselves have provided an even more definitive response. Figure 12a shows the results of various efforts to model "dispersal" habitat for grizzlies, most usefully by Walker & Craighead (1997). These results, together with models of potential suitable habitat, showed potential connections between the Cabinet-Yaak Ecosystem to the north, the Northern Continental Divide Ecosystem to the northeast, and the Greater Yellowstone Ecosystem to the east.

But these are only models. Verified observations of dispersers have shown that grizzly bears are, in fact, making the journy (Figure 12a). Perhaps most surprising, at least one grizzly bear made it as far south as the breaks of the Salmon River drainage in the Nez Perce National Forest. But all of these dispersers are probably male bears—certainly that's the case for all of the dispersers of known sex.

This gender bias is not surprising given that the average dispersal distance of young males (55 km, averaged over 7 studies) is 5-times farther than the average dispersal distance of females (11 km, averaged over 6 studies)[28]—which translates into a considerable time lag between when female and male bears show up in an area. It may be several decades before female grizzlies arrive in central Idaho, but they will get here provided they survive hazardous encounters with highways, agricultural lands, roaded landscapes, human settlements, and hunters.

5b. How Much Will Be Enough?

A political calculus that gives priority to the backward-looking politics of Idaho (as described by Smith [2003]) would suggest that ambitions for grizzly bears should be confined to the current Selway-Bitterroot Recovery Area—a logical culmination of the political calculus that led to drawing these boundaries in the first place. However, there are practical consequences for following such a course, especially when one considers the likelihood that any population of naturally-established grizzly bears might persist for an evolutionarily meaningful period of time within such bounds.

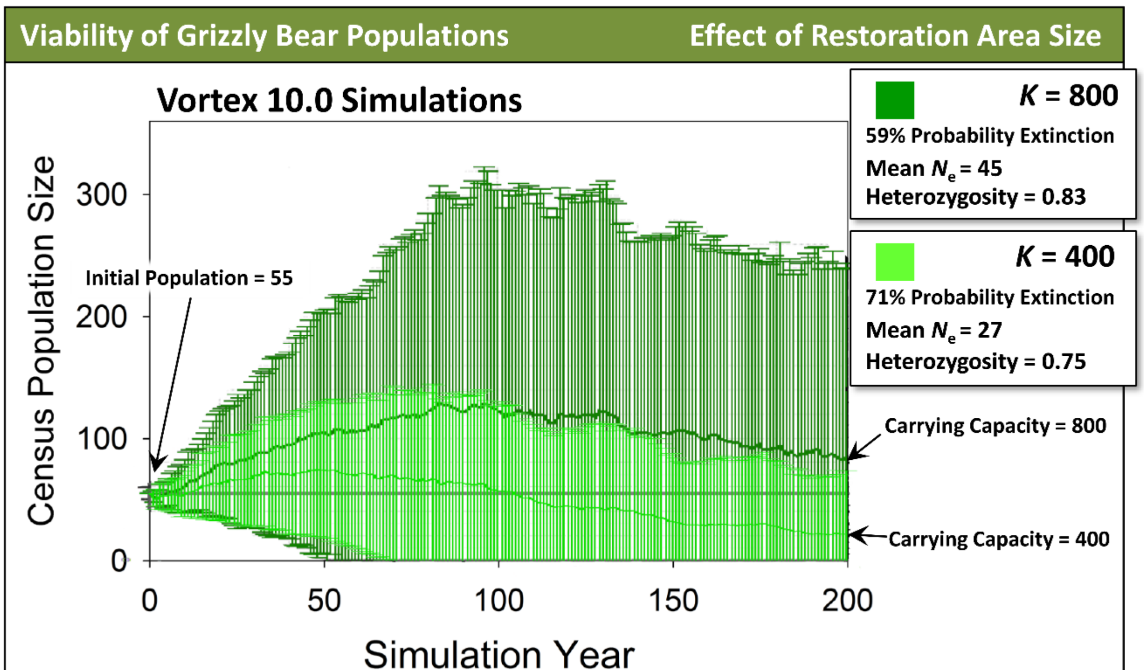


Figure 13. The graphic above shows the results of simulations run with Vortex 10 (Lacy et al. 2018) in which the effect of carrying capacity on population viability is explored with all other set parameters equal, including an initial population size of 55. One simulation was run with carrying capacity set at 800 (dark green), which approximates conditions where all of the suitable habitat identified by Merrill et al. (1999) was candidate for restoration of grizzly bears in central Idaho (see Figure 12a). The other simulation was run with carrying capacity set at 400 (light green), which approximates conditions where recovery of grizzly bears is confined to the existing Recovery Area defined by the Selway-Bitterroot and Frank Church-River of No Return Recovery Areas (see Figure 12b). Under the second scenario, extinction probability is 20% higher, ending population sizes an average 34% lower, and loss of genetic heterozygosity 11% greater compared to the first scenario. The bars for each set of simulations are Standard Deviations of population size at each time step. Population parameters were taken from the Northern Continental Divide Ecosystem grizzly bear population (Mace et al. 2012, Costello et al. 2014) with intrinsic rate of growth (λ) set at approximately 1 and with no emigration or immigration.

[28] These figures were calculated from Blanchard & Knight 1991; McLellan & Hovey (2001); Proctor et al. (2004, 2012), Støen et al. (2006); Zedrosser et al. (2007); and Lamb et al. (2020).

At the most basic level, the parameters for such a consideration devolve down to the prospective carrying capacity (also known among academics as *k*) of the current Recovery Area, in contrast to the prospective carrying capacity for a more liberated assessment of potential suitable habitat, as per Merrill (2005).

With these two basic parameters in hand, I undertook an evaluation of prospective population persistence for grizzly bears that naturally established themselves in central and north-central Idaho—in one scenario limited to the 400 bears and in the other limited to 800 bears (Figure 13). I input plausible demographic parameters from a nearby ecosystem (the Northern Continental Divide) into a well-established bit of software used to estimate population viability (Vortex) to project what would likely happen with plausible environmental variation as well as the the occasional perturbations introduced by inevitable catastrophes. I also considered the effects of genetic heterozygosity, a key determinant of long-term (100s of years) viability. The results are shown in Figure 13.

Even with an equal initial numbers of bears, effective population size (N_e)[29] under a scenario with k = 800 was nearly twice that under a scenario with k = 400, although in both scenarios census population sizes (N) struggled to exceed roughly 20% of ostensible carrying capacity (k). A predictable toll was taken not only by environmental variation, but also by periodic catastropes—which are an inevitable part of real life. Perhaps surprisingly, probabilities of extinction were high under both scenarios, and reached an alarming 71% when carrying capacity was limited to 400 grizzlies.

These results are consistent with the current scientific consensus regarding long-term population viability, realistically defined as what's required to achieve roughly 99% probability of persistence (versus 29-41% probability, as per the two scenarios in Figure 13) for a period of approximately 40 generations (Reed et al. 2003, Frankham & Brook 2004, Reed & McCoy 2013), which for grizzly bears, with average generation lengths of approximately 10 years, equates to around 400 years—twice the time considered here. This consensus suggests that for a species such as the grizzly bear, with a low reproductive rate and a low N_e:N ratio, around 2,500-9,000 animals in a contiguous inter-breeding population are needed to attain long-term, evolutionarily meaningful, viability[30].

This population goal is clearly not attainable within the confines of potential suitable habitat modeled for grizzly bears in Idaho (as per Figure 12b). However, a contiguous population of thousands of bears is feasible if the geographic scope is expanded beyond state and international boundaries to include consideration of occupied as well as potential suitable habitat inclusive of the Greater Yellowstone ecosystem, central and north-central Idaho, northwest Montana, the Northern Continental Divide ecosystem, and contiguous portions of southeastern British Columbia and southwestern Alberta (as

[29] Effective population size is almost always less than census population size. Very simplistically, N_e is the number of breeding individuals in a population—which excludes juveniles, females accompanied by younger offspring, and unsuccessful male breeders—which, when small, has predictable effects on genetic diversity through processes such as inbreeding, purging, genetic mutation, and genetic drift.

[30] The following authors provide an entrée into supporting scientific literature: Lande (1995), Reed et al. (2003), Cardillo et al. (2004, 2005), Frankham (2005), Brook et al. (2006), O'Grady et al. (2006), Traill et al. (2007), and Frankham et al. (2014).

per Proctor et al. [2012] and Apps et al. [2016]). Figure 14b offers a visual representation of what this potential would look like if realized, in contrast to the current distribution of grizzly bears in the contiguous United States. This more encompassing vision not only accommodates the dispersal and colonization by grizzly bears that has alread happened (Figure 14b), but also throws into relief imperatives to preserve as well as restore connectivity among current populations and areas such as central and north-central Idaho that have such self-evident potential.

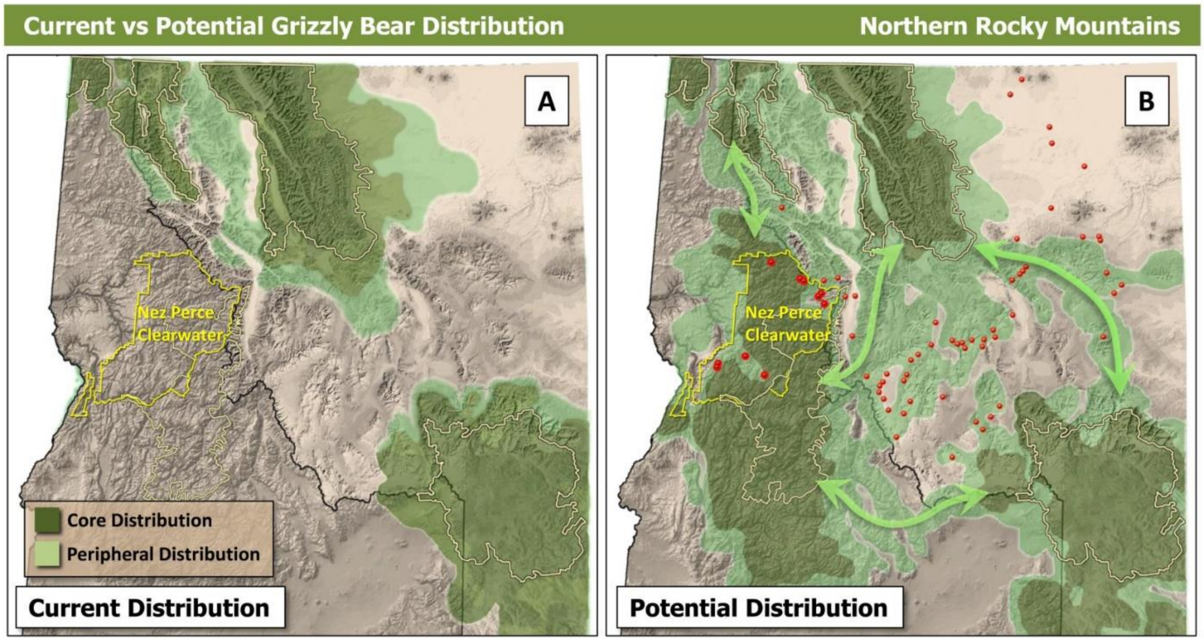


Figure 14. Map (**A**) shows the estimated current distribution of grizzly bears in the U.S. Northern Rocky Mountains, with core distributions denoted by dark green and peripheral distributions denoted by light green (from Costello et al. [2019]; Kasworm et al. [2019, 2020]; and Van Manen et al. [2019]). Map (**B**) shows the estimated potential distribution of grizzly bears in the Northern Rockies with full occupancy of potential suitable habitat shown in Figure 11a. The red dots in (**B**) are dispersing/colonizing grizzly bears documented between 2005 and 2018 (see Figure 12 caption for sources). The green arrows show main connectors between ecosystems. The Nez Perce-Clearwater National Forests are delineated in yellow.

Vacant wildlands of central and north-central Idaho have the potential to support as many as 1,000 grizzly bears which, if realized, would offer significantly greater odds of population persistence compared to if grizzlies were confined to the current Selway-Bitterroot Recovery Area. However, long-term viability will require a contiguous interbreeding population of several thousand grizzly bears, which could be achieved if current populations were connected by on-going colonization of interstitial potential suitable habitat throughout the northern Rockies into Canada.

6. Prospective Diets

During the public debate surrounding plans to reintroduce grizzly bears into the Selway-Bitterroot Recovery Area, contention arose over whether there would be enough food for bears to eat in this region. At the time, this issue seemed a bit inane given that there are ample black bears (*Ursus americanus*) here—eating essentially the same foods that grizzlies will eat—and that brown bears in Asia (the same species as grizzlies) occupy environments of the Gobi Desert, Tibetan Plateau, and nearby Pamir Mountains that are far more austere than any in central Idaho. Closer to home, grizzlies living in the harsh unproductive arctic regions of North America are also instructive.

Even so, this debate served to highlight the entirely reasonable question of whether anadromous salmon would play a role in grizzly bear recovery, and also catalyzed efforts to more explicitly evaluate grizzly bear habitat in this region. Several models offered relatively esoteric representations of habitat productivity based on coarse-grain proxies for vegetation patterns (notably Merrill et al. [1999] and Boyce & Waller [2003]). Early on, the Craighead Wildlife-Wildlands Institute (CWWI), among others, tackled assessment of prospective bear foods at the level of species and habitat types (Scaggs 1979, Butterfield & Almack 1985), later translated into modeled distributions of key vegetal foods by CWWI (Hogg et al. 2000). However, with the exception of passing references by Butterfield & Almack (1985) and Davis et al. (1986), none of these efforts explicitly considered animal foods, which play an important role in the diets of grizzly and brown bears throughout the northern Hemisphere (Mowat & Heard 2006, Niedziałkowska et al. 2019).

In this section I tackle the issue of clarifying temporal-spatial configurations of prospective grizzly bear diets, inclusive of animals as well as plants, not only in the Selway-Bitterroot Recovery Area, but also throughout Idaho's potential suitable habtiat. I devote considerable space to factors that will likely shape grizzly bear diets in pivotal landscapes of the Nez Perce-Clearwater National Forests, not only because this area is critical to recovery efforts, but also for the practical reason that much relevant information has been generated during recent efforts to update and revise the official Plan for these forests (e.g., Nez Perce-Clearwater National Forests (2014a, 2014b, 2019a, 2019b).

Why the lengthy focus here on foods and diets? Diets offer important insights, not only regarding where and when grizzly bears will be active, but also why, with relevance to anticipating and preventing human-bear conflicts. Diets are also essential grounding for any explanation of historical extirpation dynamics (Section 4b) as well as projections of what the future might hold (Section 9).

6.a. Grizzly Bear Diets in the Northern Rocky Mountains

There is still no subsitute for looking at the contents of fecal matter (i.e., scats) to obtain high-resolution information about what bears eat—often to the level of species. Even though poking around in feces has become *passé* among wildlife researchers more enamored with the latest Bayesian modeling methods than with the details of bear behaviors, there have been enough feces-based food habits studies in the various ecosystems of the nothern U.S. Rockies to allow for judicious extrapolations of grizzly bear diets to vacant habitats in Idaho.

Seasonal results of the five most relevant and comprehensive food habitats studies are summarized in Figure 15, ordered from farthest north and west in Figure 15a (the Cabinet-Yaak ecosystem) to farthest south and east in Figure 15e (the Greater Yellowstone ecosystem). These seasonal fractions

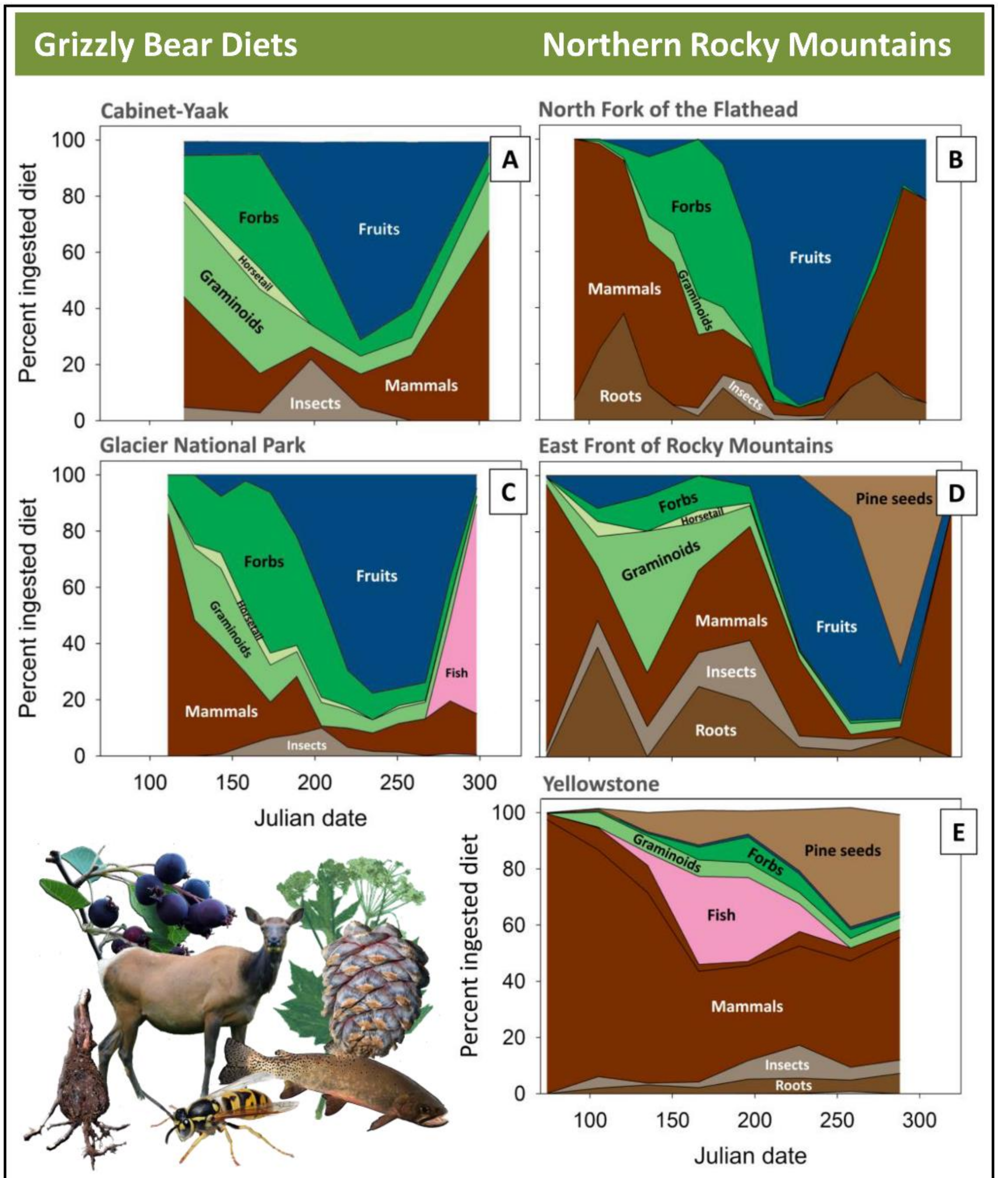


Figure 15. This series of graphics shows seasonal trends in fractional composition of ingested diets for grizzly bears in 5 different study areas to the north, east, and south of central Idaho: (**A**) the Cabinet-Yaak ecosystem (Kasworm et al. 2018); (**B**) the North Fork of the Flathead River spanning the U.S.-Canadian border (McLellan & Hovey 1995); (**C**) Glacier National Park (Kendall 1986); (**D**) the East Front of the Rocky Mountains in Montana (Aune & Kasworm 1989); and (**E**) the Yellowstone ecosystem (Mattson et al. 1991b). Different colors denote different major food groups. Month-specific fractions are estimated from fecal analysis and corrected for differential passage through the gut to calculate relative ingested volumes (Hewitt & Robbins 1996; Mattson et al. 2004).

represent estimates of *ingested* diets, obtained by applying correction factors to fecal contents that account for the differential attrition of foods with passage through the digestive tract (as per Hewitt & Robbins [1996]). As might be expected, the greatest corrections are for meat from fish and mammals and the smallest are for fibrous vegetation—reflecting orders-of-magnitude differences in digestibilities of these foods.

There are a few major themes of relevance to central and nort-central Idaho. First, fruit will almost certainly be a critically important food in most regions, but moreso farther north, with greatest fruit consumption occurring during July and August[31]. Second, perhaps surprisingly, meat from mammals will also be important regardless of the locale, eaten primarily during the spring and fall, but of proportionately greater prominance in drier areas farther south[32]. Third, whitebark pine seeds will probably be heavily consumed wherever healthy stands of mature cone producing trees survive, with most of these seeds eaten during September-October[33]. Finally, of the grazed foods, forbs[34] will be comparatively more important in areas with greater maritime climatic influence farther north, whereas grasses and sedges (i.e. "graminoids") will be more important in areas with continental climates farther south and east—with the bulk of grazing throughout the region occurring during late spring and early summer.

Figure 16 more expressly deals not only with geospatial differences in diets of grizzly bear in the northern U.S. Rockies, but also underlying patterns in distributions of key foods and habitats. The pie diagrams in each panel represent the fractional composition of annual diets, which accounts not only for differential passage of foods through the gut, but also for seasonal differences in population-level feeding activity (as per Roth [1980] and Mattson et al. [1991b]). The dietary portions of relevance to the underlying distributions in each panel are highlighted different colors: blue for fruit, with the darkest blue denoting the modeled distribution of fruit-bearing shrubs by Hogg et al. (2000; Figure 16a); reddish-brown for ungulates, but additionally with highly productive spring habitats shown in shades of green (Figure 16b); brown for whitebark pine, with the darkest brown denoting the modeled distribution of this species by Hogg et al. (Figure 16c); and pink for fish (Figure 16d), which I address below. Idaho's potential suitable grizzly bear habitat is also shown in each of these panels.

The patterns are relatively straight-forward. Fruit-bearing shrubs tend to be more abundant and diverse farther to the north and west, reflected in fruits comprising 33% to 42% of the entire annual grizzly bear diet in these regions; meat from terrestrial sources becomes more prominent farther south, notably in the Greater Yellowstone ecosystem, which is consistent with the greater extent of elk winter ranges in areas subject to more continental climates in drier portions of Idaho; and the

[31] In north and central regions huckleberry (*Vaccinium membranaceum*) will predictably be a mainstay augmented by mountain ash (*Sorbus* sp.); with proportionately greater consumption of serviceberry (*Amelanchier alnifolia*), chokecherry (*Prunus viriginiana*), and hawthorn (*Crataegus* sp.) farther south; and consumption of buffaloberry (*Shepherdia canadensis*) wherever conditions are auspicious; see https://www.mostlynaturalgrizzlies.org/fruit

[32] White-tailed deer (*Odocoileus virginianus*) are a comparatively more important source of meat in areas with greater maritime climatic influence, often obtained during the fall by scavenging remains left by hunters; elk (*Cervus canadensis*) are important wherever there are large populations, but especially in more open environments with drier climates; consumption of bison (*Bison bison*) is unique to the Yellowstone region; moose (*Alces alces*), although rarely abundant, are preferentially exploited by grizzlies (Mattson 1997). Exploitation of cattle is increasingly common in agricultural areas recently colonized by grizzly bears; see Mattson (2017) and https://www.mostlynaturalgrizzlies.org/spatial-patterns-1

[33] For more details, see https://www.mostlynaturalgrizzlies.org/whitebark-pine

[34] Most notably, cow parsnip (*Heracleum sphondylium*), angelica (*Angelica arguta*), sweet cicely (*Osmorhiza occidentalis*), dandelion (*Taraxacum officinale*) and clover (*Trifolium* sp.); see the caption of Figure 15 for references.

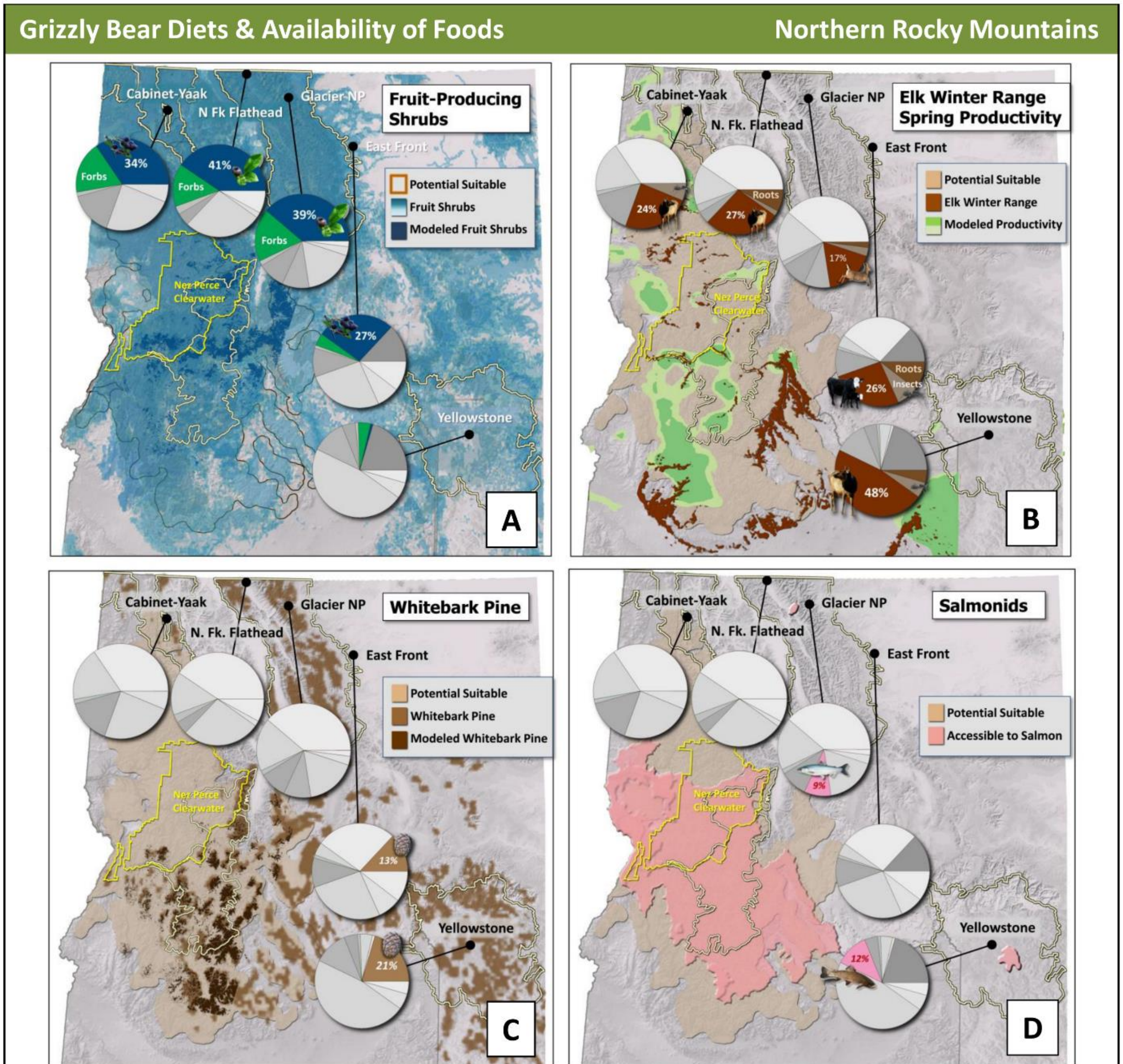


Figure 16. This series of graphics shows fractional composition of total ingested diets for grizzly bears in 5 different study areas (sources in Figure 15) shown as pie diagrams with featured foods highlighted in each panel. These estimated fractions not only account for differential passage of food through the gut (as per in Figure 12), but also seasonal variation in population-wide levels of feeding (Roth 1980, Mattson et al. 1991b, Haroldson et al. 2002, Mattson 2020b). Consumption and availability of different foods or food groups are highlighted in each panel: (**A**) fruits and forbs (e.g., *Heracleum spondophyllum, Angelica arguta*), characteristic of wetter regions with a maritime-influenced climate; (**B**) ungulates, most of which are characteristically exploited during spring (see Figure 12), featuring elk winter range and estimated spring habitat productivity; (**C**) whitebark pine (*Pinus albicualis*), a common source of bear food in areas with more pronounced continental climates; and (**D**) spawning salmonids, historically including kokanee (*Oncorhynchus nerka*) in Glacier National Park and cutthroat trout (*O. clarkii*) in Yellowstone National Park. Modeled distributions of fruit-producing shrubs in (A) are from Hogg et al. (1999; the darkest blue), Ironside et al. (2014), and Prevéy et al. (2020). Distribution of Idaho's elk winter range in (**B**) is from Bergen et al. (2016), shown juxtaposed with modeled spring habitat productivity from Merrill et al. (1999). Distribution of whitebark pine in (C) is from Crookston *Plant Species and Profile Predictions*, with darkest brown showing the distribution modeled by Hogg et al. (1999). Locations where bears exploited salmonids in Glacier and Yellowstone in (**D**) are from Shea (1973) and Reinhart & Mattson (1990), respectively. The extent of current spawning habitat for chinook salmon (*O. tshawytscha*) and steelhead (*O. mykiss*) is from U.S. Department of Commerce (2013a,b) and Idaho Department of Fish & Game (2018).

abundance of whitebark pine increases to the south and east, reflected in substantial fractions of whitebark pine seeds in grizzly bear diets in Yellowstone and along the East Front of Montana's Rocky Mountains. Not surprisingly, aside from the spring scavenging opportunities offered by elk carrion (see Green et al. [1997]), spring vegetal productivity in Idaho tends to be concentrated in warmer lower-elevation areas that only roughly correlate with the distribution of elk winter ranges.

Roughly translated for unoccupied grizzly bear habitat in Idaho: fruit will undoubtedly be a prominent if not dominate source of energy and nutrients north of the Salmon River, but also potentially in an arc further south stretching from central portions of the Frank Church-River of No Return Wilderness Area southwest through the Boise River drainage; meat from elk in particular will likely be proportionately more important south of the Salmon River compared to north; and whitebark pine seeds are likely to be important in grizzly bear diets, but only south of the Salmon River, especially farther east in and near the Sawtooth, Lost River, and Lemhi Mountain Ranges. This last projection is tentative given that most mature whitebark pine may have died in this region during recent decades from an outbreak of native mountain pine beetles (*Dendroctonus ponderosae*; Macfarlane et al. [2013]) and the progressive spread of a highly lethal non-native disease (white pine blister rust, *Cronartium ribicola*; Retzlaff et al. [2016]; for more see: https://www.mostlynaturalgrizzlies.org/recent-trends).

The current distributions of major bear foods together with diets documented for grizzly bears in nearby ecosystems provide ample basis for anticipating what grizzlies would likely eat in different parts of central and north-central Idaho, ranging from a dominance of fruit and forbs to the north, to greater contributions of elk and whitebark pine seeds to the south—with salmon and trout of possible importance in between.

6.b. What About Salmon?

All of this still begs the question: What about salmon? The answer largely depends on the on-going toll taken on anadromous salmonids by dams along the Columbia and Snake Rivers, but some insight can also be gained by considering what we know about relations between grizzly bears and fish in the Glacier and Yellowstone ecosystems. Panel D in Figure 16 certainly drives home the point that anadromous salmonids could be significant in the future diets of grizzly bears if for no other reason than the extent of overlap between potential suitable grizzly bear habitat and drainages still open to spawning salmon or steelhead. Perhaps even more important, consequential portions of central and north-central Idaho still support comparatively healthy runs of anadromous salmonids as well as larger-bodied non-anadromous fish (for example, bull trout [*Salvelinus confluentus*] and kokonee [*Oncorhynchus nerka*]).

Almost all of the fish consumed by grizzly bears in Glacier and Yellowstone Parks were comparatively small-bodied (usually 0.4-0.9 kg), which may explain why in both environments bears preferentially fished smaller streams with higher volumetric densities of spawners (Reinhart & Mattson 1990, Mattson & Reinhart 1997)[35], consistent with William Wright's observations that grizzly bears in central

[35] Of parenthetical relevance, both species have been essentially eliminated as important bear foods during recent decades, primarily as a result of actions taken by people. For more on the reasons behind these declines, see Spencer et al. (1991, 1999), Ellis et al. (2011), and Devlin et al. (2017) for Flathead Lake kokanee, and see https://www.mostlynaturalgrizzlies.org/trends for Yellowstone Lake's cutthroat trout.

Idaho tended to concentrate along smaller streams to fish for spawning salmon (Wright 1909). In Glacier, nearly all of the fish consumed by grizzlies were non-native kokonee salmon from Flathead Lake that spawned during late fall in the shallow waters of McDonald Creek, below McDonald Lake, where they were not only vulnerable to bears, but also to a number of other predators, including a remarkable concentration of bald eagles (*Haliaeetus leucocephalus*; Shea 1973, Martinka 1974). In Yellowstone, almost all of the fish consumed by grizzly bears were cutthroat trout (*Oncorhynchus clarkii*) captured during late spring and early summer while spawning in streams tributary to Yellowstone Lake[36].

The point of all this is that contemporary grizzly bears in the northern U.S. Rockies have made substantial use of smaller-bodied trout and landlocked salmon, contigent on having access to smaller streams that supported high volumetric densities of spawners. Fish don't necessarily need to be large (for example, >1-2 kg), although large size would predictably play to a bear's advantage. But abundance is probably crucial, although the comparative importance of size and abundance is unclear.

Given the large sizes of adult chinook salmon, steelhead trout, and even bull trout—all often >4 kg—fishing by grizzly bears could probably be sustained in headwaters of the Clearwater and Salmon Rivers by even modest spawning runs—which could, in turn, result in salmonids playing a significant role in the diets of grizzly bears in central and north-central Idaho.

6.c. Modern Dietary Economies

In this concluding short section about prospective grizzly bear diets in central and north-central Idaho, I offer a synoptic and somewhat speculative view of contemporary dietary economies in occupied and potential suitable grizzly bear habitat of the northern U.S. Rocky Mountains (Figure 17). A dominant theme is the transition from a fruit and forb-dominated economy farther north and west to what I call a "mixed mountain agricultural" economy to the south and east. The first economy is self-explanatory, although the second probably is not.

Mixed Mountain Agricultural allows for a diminished although still noteworthy dietary role for whitebark pine seeds, while acknowledging an increasing role for agricultural foods, notably livestock, but also including grain crops and honey from beehives. These agricultural elements have largely arisen from grizzly bears colonizing both public lands with grazing allotments as well as private lands subject to various agricultural uses (as described for the Northern Continental Divide ecosystem by Mattson [2019a]). Meat from elk is also prominent in this economy as are, in places, army cutworm moths (*Euxoa auxilliaris*).

Army cutworm moths are heavily consumed by grizzlies in areas with extensive tracts of tundra and high-elevation talus (Mattson et al. 1991a, White et al. 1998). Cutworm moths concentrate in alpine areas during the summer to feed at night on nectar of tundra flowers. During the day they seek refuge in talus slopes, which is where grizzly bears excavate them—potentially consuming as many as 40,000 per day. The most notable concentrations of this feeding behavior are in the Absaroka Mountains of

[36] For more on relations between Yellowstone grizzlies and cutthroat trout, see: https://www.mostlynaturalgrizzlies.org/cutthroat-trout and https://www.mostlynaturalgrizzlies.org/spatial-arrangements

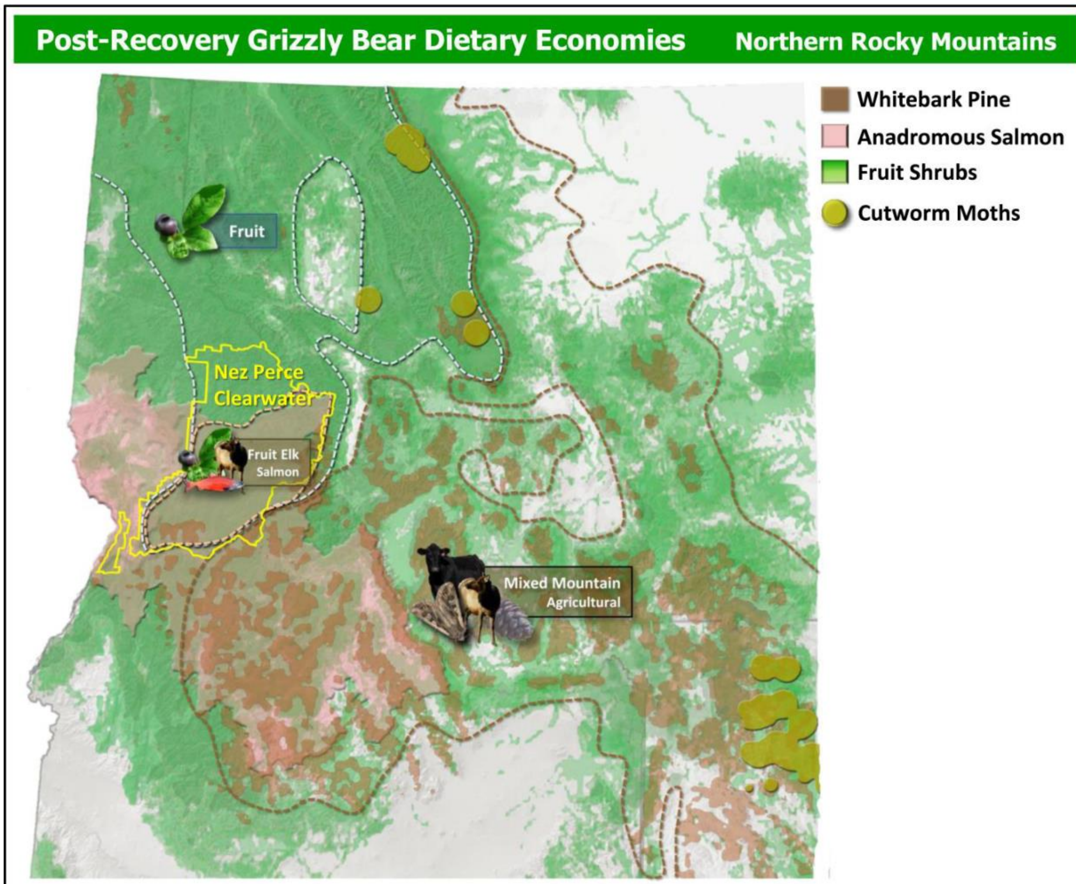


Figure 17. This map shows the extent of contemporary grizzly bear dietary economies in the U.S. Northern Rocky Mountains, inferred from information summarized in Figures 9, 15, and 16) and superimposed on the estimated availability of key grizzly bear foods, as per Figure 8. Each dietary economy is delineated by a different-colored dashed line, with the boundary of the Nez Perce-Clearwater National Forests shown in yellow. The dietary economies for central Idaho are largely speculative absent grizzly bear-specific data for this region. Even so, the diets of grizzly bears in this area promise to be unique relative to diets documented elsewhere in the Northern Rockies given the potential availability of spawning salmonids, juxtaposed with whitebark pine and numerous elk in the south and abundant fruit in the north.

Wyoming and in eastern portions of Glacier National Park[37]. Although concentrations of cutworm moths have not yet been found in Idaho, the possibility that they exist, and that at some future date grizzly bears might eat them, warrants further investigation, especially in the Bitterroot, Sawtooth, Little Lost River, and Lemhi Mountain Ranges of east-central and southern Idaho.

What stands out, though, is the somewhat confused denotation of a dietary economy in southern portions of the Nez Perce-Clearwater National Forests typified, not only by the transition from Fruit-Forb to Mixed Mountain Agricultural economies, but also by the potential role of spawning salmonids

[37] For more on grizzly bear consumption of army cutworm moths see: https://www.mostlynaturalgrizzlies.org/army-cutworm-moths

in grizzly bear diets. In other words, this area stands out as having a dietary economy that could be unique for grizzly bears, not only in the northern U.S. Rocky Mountains, but also, perhaps, globally.

Much has changed between 1800 and now in the tableau of grizzly bear foods (see Figure 8 juxtaposed with Figure 17). With the exception of a remnant in Yellowstone National Park (Mattson 1997, Green et al. 1997), the bison-based dietary economy has entirely disappeared, along with the bison, replaced by an economy centered on anthropogenic foods that engender conflict between bears and people. Whitebark pine is diminished everywhere and, in areas to the north and west, functionally extirpated as a bear food by white pine blister rust (Retzlaff et al. 2016). The distribution of spawning habitat for anadromous salmonids has been truncated in Idaho by high dams on the Snake River above Hells Canyon. Surviving salmon and steelhead populations elsewhere in Idaho have been dramatically reduced by impediments posed by numerous dams on the lower Columbia and Snake Rivers[38]. Even so, much bear food remains, with the fruit and forb-based dietary economy of north-central Idaho essentially intact.

6.d. Foods on the Nez Perce-Clearwater National Forests

The stakes are high for grizzly bear conservation on the Nez Perce-Clearwater National Forests, self-evidently because these jurisdictions encompass a critical geography that is host to essentially all of the recent colonization of central Idaho's wildlands by grizzly bears dispersing from the Northern Continental Divide ecosystem and Selkirk and Cabinet Mountains. As important, on-going revision of the Forest Plan for these newly-consolidated adminstrative units will determine whether there is meaningful consideration given to recovery and conservation of grizzly bears, especially in the codification of security standards as well as measures for preventing and managing human-bear conflicts. However, crafting such provisions requires understanding where, when, and why grizzly bears are likely to be active—which is ultimately rooted in knowing something about the spatial and temporal configuration of bear foods. Hence, this section focuses on bear foods and habitats of the Nez Perce-Clearwater National Forests[39], organized around spatial and temporal patterns shown in Figures 18 and 20, respectively.

The map in Figure 18a features spring habitats, including a comprehensive representation of spring productivity and predicted bear activity produced by Boyce & Waller (2003) for the Selway-Bitterroot Wilderness Area. Absent such a map for the rest of the Forests, elk winter ranges (shown as reddish-brown) offer a good proxy for where grizzly bears will likely be active during the spring, both because winter ranges tend to be in lower-elevation areas with advanced spring phenology, and because grizzlies predictably seek scavenging opportunities here (Green et al. 1997).

The implications of this are straight-forward. During spring, grizzly bears will likely be concentrated at low elevations throughout the Forests, coincident with the location of passable roads and trails and associated human activity. The result will be ample opportunity for displacement, conflict, and human-caused grizzly bear mortality early in the bears' active season.

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[38] https://en.wikipedia.org/wiki/List_of_dams_in_the_Columbia_River_watershed

[39] I don't show peripheral and highly fragmented Forest Service lands on the Palouse Ranger District to the northwest largely because *prima facie* there is little secure habitat for grizzly bears.

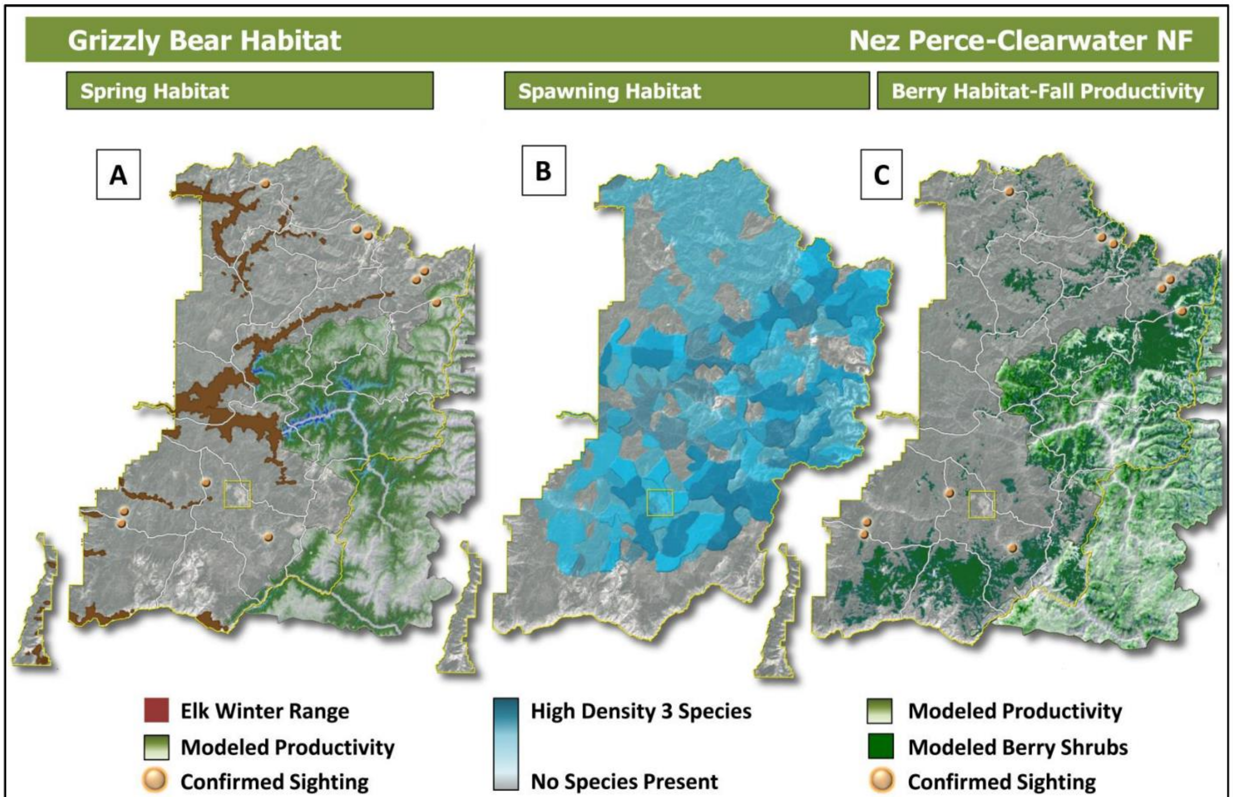


Figure 18. These maps show the seasonal distributions of key grizzly bear foods, habitats, or modeled habitat productivity for the Nez Perce-Clearwater National Forests. Spring and fall foods and habitat are featured given the importance of foods consumed during hyperphagia (mid-July through October) to reproductive success of grizzly bears (e.g., Hertel et al. 2018) and the potential of spring foods to concentrate bears near people at lower elevations. Confirmed grizzly bear sightings or sign (from Figure 12) are also shown as brown dots. Map (**A**) shows the distribution of elk winter ranges (Nez Perce-Clearwater National Forests (2019: Elk Habitat Effectiveness 3.2-3.4-16), where spring scavenging opportunities are likely to be concentrated (Green et al. 1997), together with spring habitat productivity modeled for the Selway-Bitterroot and Frank Church-River of No Return Wilderness Areas by Boyce & Waller (2003). Map (**B**) features the distribution of sub-watersheds supporting healthy populations of anadromous steelhead and spring-summer spawning chinook as well as resident bull trout (*Salvelinus confluentus*; from the Draft Clearwater Subbasin Assessment [Ecovista et al. 2003]). Darker blue denotes areas where a greater number of salmonids are present in "stronghold" habitats. Map (**C**) shows, darkest green, the distribution of fruit –producing shrubs modeled by Hogg et al. (1999)—including *Amelanchier alnifolia*, *Prunus virginiana*, *Sambucus* sp., *Shepherdia canadensis*, *Sorbus scopulina*, and *Vaccinium membranaceum*—overlain on predicted fall grizzly bear habitat productivity and use from Boyce & Waller (2003).

The maps in Figures 18b and 18c feature foods and habitats of likely importance to grizzly bears during summer and fall, including spawning salmonids and modeled productivity based primarily on the distribution of fruit-producing shrubs. As in Figure 18a, modeled fall habitat productivity and associated probabilities of bear activity in Figure 18c are restricted to the Selway-Bitterroot Wilderness Area, although the modeled aggregate distribution of fruit-producing shurbs (from Hogg et al. [1999]) is shown in dark green for the entire Forests. The blue in Figure 18b denotes watersheds of the Clearwater drainage that are strongholds for spawning steelhead, chinook salmon, or bull trout, with darkest blue denoting watersheds that support healthy runs of all three species. Information for watersheds draining into the Salmon River is notably absent.

Taken together, Figures 18b and 18c suggest that grizzly bears will likely concentrate during summer and fall at middle to higher elevations of the Forests, with much of the most productive habitat encompassed by the Selway-Bitterroot and Gospel Hump Wilderness Areas. Notable exceptions to this pattern include a swath of abundant fruit-producing shrubs and spawner strongholds east of Elk City and at upper elevations of the Salmon River Breaks, as well as another swath along and immediately below the divide between the Clark Fork River and North Fork of the Clearwater River.

The concentration of summer-fall foods and habitats in Wilderness Areas on the Nez Perce-Clearwater Forests is auspicious, at least insofar as conflicts with humans is concerned, but with an important proviso. Wilderness Areas do not provide any insurance against deaths resulting from mistaken identificiations by black bear hunters or from conflicts with big game hunters during the fall—both of which plausibly threaten grizzly bears in remote Forest Service jurisdictions (see Section 7.a.).

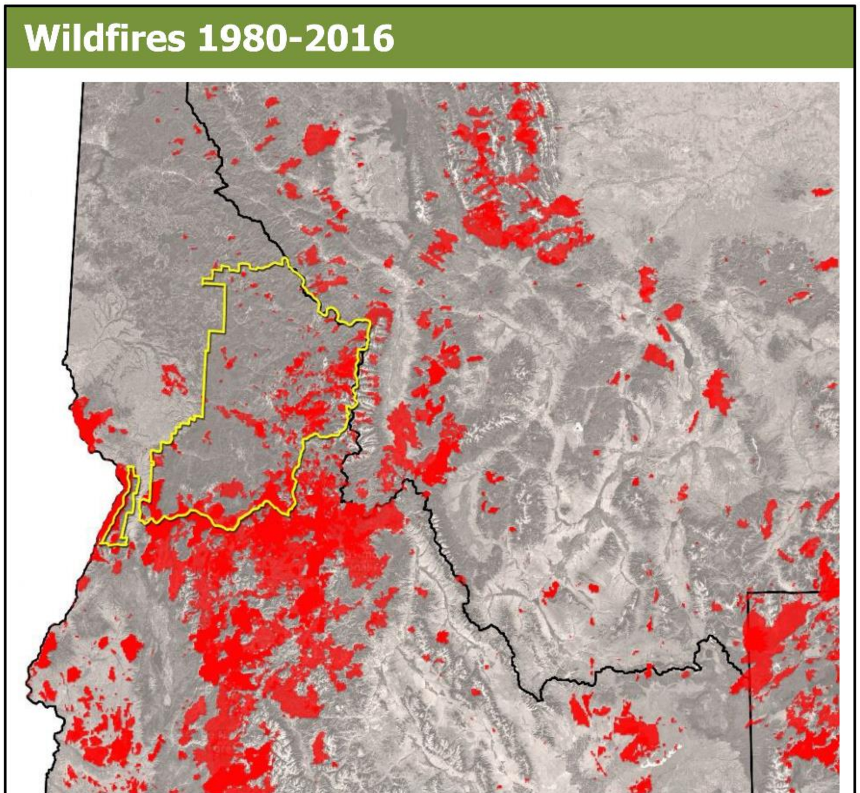


Figure 19. The map above shows, in red, the cumulative extent of wildfires that burned during 1980-2016. This timeframe is relevant to grizzly bears and grizzly bear foods because fruit production tends to peak roughly 20-40 or even 60 years post-fire on species such as huckleberry and buffaloberry (Martin [1979, 1983]; Hamer [1996]; Proctor et al. [2018]; and https://www.mostlynaturalgrizzlies.org/habitat-associations) This map highlights the extent to which areas south of the Salmon River Breaks have burned, sometime repeatedly, in contrast to areas farther north, including much of the Nez Perce-Clearwater National Forests, shown delineated in yellow. Parenthetically, fire intervals <40-60 years are predictably detrimental to fruit-producing shrubs and related availability of fruit for bears to eat, which could have affected fruit production in some parts of south-central Idaho. Fire perimeters are from National Interagency Fire Center, https://data-nifc.opendata.arcgis.com/datasets/interagency-fire-perimeter-history-all-years

Insofar as decadal trends are concerned, there is little explicit information about changes in abundance of key vegetal foods during the last 60-70 years, although, as I mention in Section 4.b. above, there is good reason to suspect that a period of abundant fruit production followed in the wake of the 1910 fires, probably peaking during the 1930s-1960s. A comparative dearth of wildfires since then on the Nez Perce-Clearwater National Forests—at least in contrast to areas south of the Salmon River Breaks—has probably led to a slow decline in Forest-wide fruit production outside of some recently-burned areas in the Selway-Bitterroot Wilderness Area (Figure

19) and a handful of harvest units on intrinsically productive sites that were minimally scarified and subsequently secured from human access by road closures[40].

In contrast to vegetal foods, there is a substantial amount of information available regarding trends in fish and elk populations on the Nez Perce-Clearwater Forests, not only because humans exploit these animals for food and trophies, but also because of the iconic status of threatened Pacific Northwest steelhead and salmon. Figures 20a and 20b show the result of my efforts to cobble together information from multiple sources on trends in numbers of salmonids and elk in the Clearwater River drainage.

Dams on the Columbia and Snake Rivers led to major if not catastrophic declines in numbers of "wild" chinook salmon and steelhead, with perhaps the greatest impact on fall runs of chinook. Severe declines that culminated during the 1980s have since been offset to a small extent by heroic efforts to improve passage structures on dams (Idaho Department of Fish & Game 2019), with an upsurge in populations during the 2000s that has recently—unfortunately—dramatically reversed (https://stateofsalmon.wa.gov/statewide-data/salmon/dashboard/).

Parenthetically, I also show numbers of kokanee salmon resident to Dworshak Reservoir in Figure 20a. These introduced landlocked salmon spawn upstream from the Reservoir in smaller streams tribuary to the North Fork of the Clearwater River, where they would potentially be available to grizzly bears. On a related note, a number of watersheds upstream from Dworhak are also strongholds for bull trout (as per Figure 18b), opening up the possibility that runs of both species could offset some of the harm caused by 1973 closure of Dworshak Dam to fish resources that were historically available to bears in upper reaches of the North Fork of the Clearwater.

Meat from elk is important to grizzly bears wherever there are significant numbers of elk for bears to exploit (https://www.mostlynaturalgrizzlies.org/spatial-patterns-1). This will probably be a factor for grizzlies colonizing the Nez Perce-Clearwater National Forests given the historical abundance of elk in the region. However, as Figure 20b shows, elk numbers have varied dramatically since at least the 1940s as a consequence of both hunter harvest and habitat changes (Peek et al. 2020). At least in the Lochsa drainage, peak elk numbers during the 1950s almost certainly resulted from favorable habitat conditions entrained by the 1910 wildfires (see Figure 11; Peek et al. [2020]). Declines during the

[40] The topic of whether and to what extent grizzly bears benefit from timber harvest through the stimulation of food production is contentious. It is also complicated by the fact that bears must choose to venture into harvest units, usually near roads, to benefit from any food that might be there. Even so, there is substantial body of scientific research that has delved into the comparative use of natural and human-created successional habitats by grizzly bears. There is no ambiguity in this research about the consistently strong positive selection by grizzlies for shrublands and timbered-shrublands roughly 40-50 years or even longer post-fire (see also Martinka [1976], McLellan [2015], Proctor et al. [2018a]). McLellan (2015) also observed that large wildfires in productive uplands are highly beneficial to grizzly bears, consistent with the long history of grizzly bears intensively exploiting huckleberries in the Apgar Mountains of Glacier National Park (Shaffer 1971, Martinka 1976). By contrast, observed selection of cutting units is vagarious, and more often strongly negative than even modestly positive. This result holds even when controlling for the effects of roads (e.g., Waller & Mace 1997; McLellan & Hovey 2001b; Apps et al. 2004, 2016; Proctor & Kasworm 2020), and is consistent with the results of Proctor et al. (2018a) regarding distribution of productive huckleberry patches in southeastern British Columbia: ""We found 74% of huckleberry patches were not in cut blocks. The ~26% of huckleberry patches that were in cut blocks occurred where the proportion of our focal area in cut blocks was only 18%."

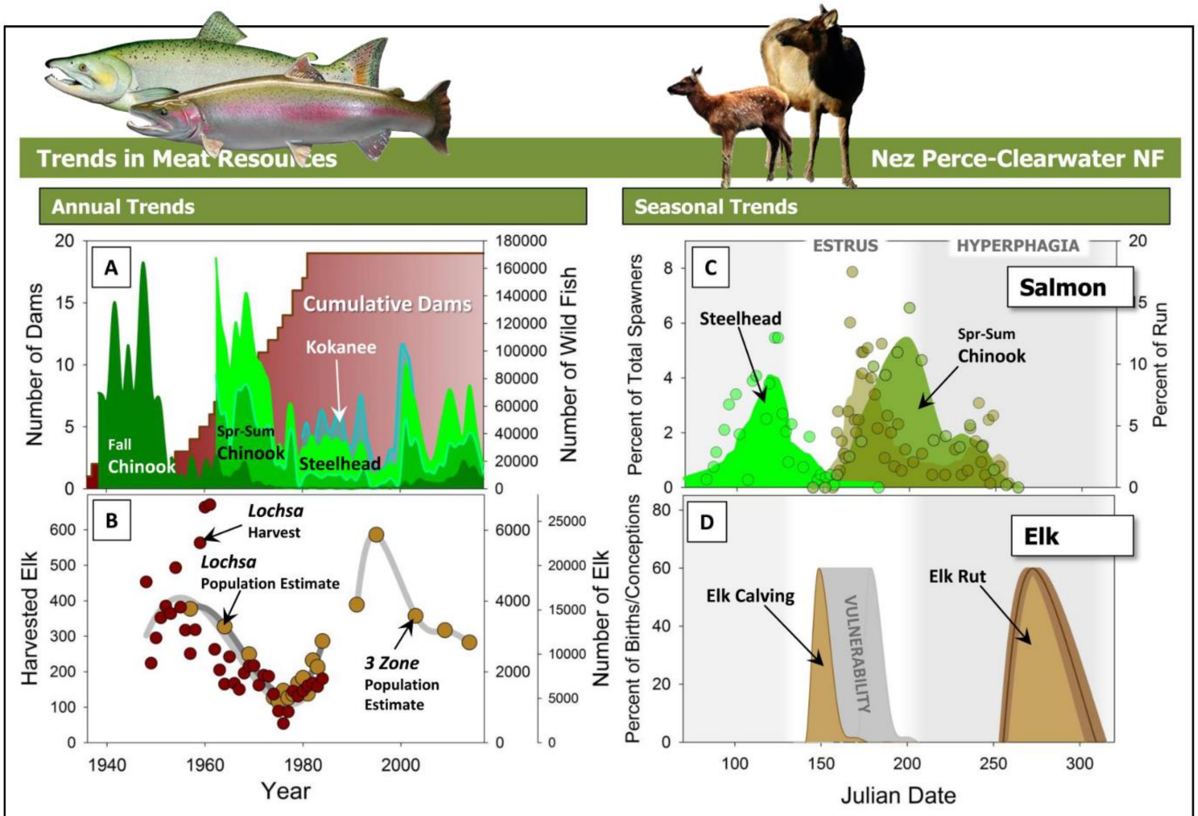


Figure 20. These time series graphs show annual trends (**A**-**B**) and seasonal availability (**C**-**D**) of meat resources for bears on the Nez Perce-Clearwater National Forests. Graph (**A**) shows trends in availability of wild-spawning (vs hatchery-raised) salmon of different species and seasonal runs in the Snake River drainage relative to cumulative closure of dams along the Columbia River system below the Snake River and along the Snake River up through the Salmon and Clearwater drainages. Dam closure dates are from Wikipedia *List of Dams in the Columbia River Watershed*. Estimates of spawner numbers are from Irving & Bjornn (1981), West Coast Chinook Salmon Biological Review Team (1997), Stark (2006), and Idaho Department of Fish and Game (2019). Graph (**B**) shows trends in indicators of elk abundance . The earlier time series, 1948-1984, shows estimates of total elk numbers (brown dots) and elk hunter harvest (burgundy dots) for the Lochsa River drainage (from Schlegel [1986a] and Peek et al. [2020]). The later time series, 1995-2018, shows estimates of total elk numbers for the Lolo, Dworshak, and Elk City Zones from Idaho Department of Fish & Game *Elk. Progress Reports*, 1990-2020. Graph (**C**) shows characteristic seasonal trends in numbers of spawning steelhead and spring-summer chinook salmon in tributary streams of the Forests (for steelhead adapted from Stark et al. [2016] using data for Fish Creek; for chinook from data collected at the Imnaha River by Hoffnagle et al. [2008] and South Fork Salmon River by Sullivan et al. [2018]). Graph (**D**) shows the distribution of elk calving dates (from Schlegel 1986b) and subsequent period of vulnerability during which most black bear mortality has historically occurred (White et al. 2010), along with the approximate duration and intensity of the fall elk rut (based on Noyes et al. [2002]).

1960s-1970s were probably caused in turn by deteriorating habitat conditions associated with succession of shrubfields to closed forest, with declines compounded by the effects of black bear predation on elk calves (White et al. 2010, Peek et al. 2020). More recent trends for Idaho Fish & Game's Lolo, Dwoshak, Selway, and Elk City Elk Management Zones, inclusive of the Nez Perce-Clearwater Forests, suggest that elk numbers recovered during the 1990s, only to decline again during the late 1990s and early 2000s, although elk in the last three of these Zones still number >11,000 (e.g., Idaho Department of Fish & Game, 2018 Elk Progress Report, https://collaboration.idfg.idaho.gov/WildlifeTechnicalReports/Elk%20Statewide%20FY2018.pdf).

The other temporal pattern of obvious importance to grizzly bears colonizing the Nez Perce-Clearwater Forests is seasonal availability of meat resources, summarized in Figures 20c and 20d for anadromous salmon and elk, respectively. Availability of anadromous salmon to bears is predictably dictated almost exclusively by when salmon spawn, which for steelhead peaks during April-May and, for spring-summer runs of chinook salmon peaks during July-August. Functional availability of elk, whether as carrion or prey, is largely dictated by numbers of animals dying from disease and starvation on winter ranges and available to scavengers primarily during April-May; the two-month-long period of calving and subsequent peak vulnerability of calves to predation beginning roughly during mid-May; and vulnerability of bull elk to predation during and after the September rut (Mattson 1997). When put together, these complementary seasonal patterns suggest that meat, whether from fish or elk, should be availabe to grizzly bears on the Nez Perce-Clearwater Forests throughout the bears' active season. This alone makes the environment here potentially unique among Grizzly Bear Recovery Zones in the contiguous United States.

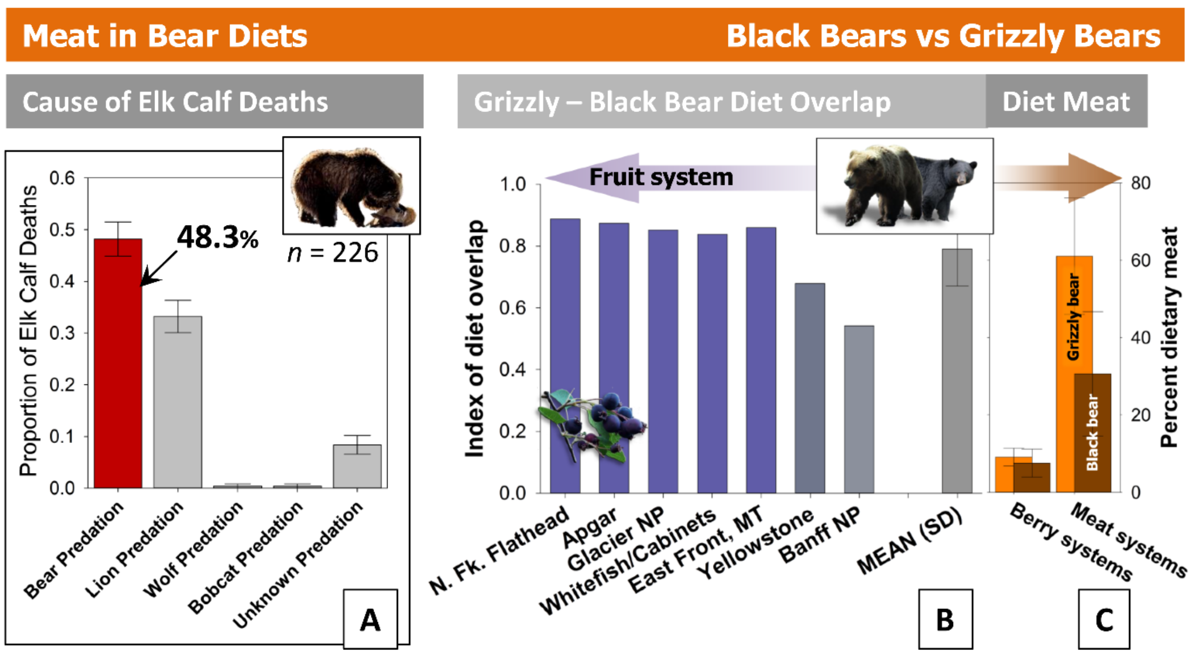


Figure 21. These graphics show information relevant to projecting the role of meat from large herbivores such as elk in the diets of grizzly bears in central Idaho, with an emphasis on the Nez Perce-Clearwater National Forests. The bar graph in (**A**) shows proportional causes of elk calf deaths documented during two time periods and in three different study areas on the Nez Perce-Clearwater National Forests (the Lochsa and North and South Forks of the Clearwater River; from Schegel [1986b] and Zager & White [2003]). Black bear predation accounted for 48% of deaths. The bar graph in (**B**) shows the overlap in diet between black and grizzly bears in 7 Rocky Mountain study areas, where an index of 1.0 indicates complete overlap and an index of 0.0 indicates no overlap. The study areas are ordinated from environments where fruit and forbs are dominate in diets, farthest left, to study areas where meat, whitebark pine seeds, and roots are increasingly important, farthest right (calculated from Shaffer [1971], Hamer & Herrero [1983], Aune & Kasworm [1989], Raine & Kansas [1990], McLellan & Hovey [1995], Fortin et al. [2007], Kasworm et al. [2018]). The bar graph in (**C**) shows average fractions of meat in black and grizzly bear diets, differentiating areas where fruit and forbs dominate the diet from areas where meat is a major source of energy and nutrients (from sources in [**B**] plus Jacoby et al. [1999], McLellan [2011], and Schwartz et al. [2013]).

One final observation is warranted regarding prospective exploitation of elk by grizzly bears on the Nez Perce-Clearwater Forests. A remarkably consistent pattern has been documented wherever grizzly and black bears coexist. On average, grizzly bears eat more meat, with the disparity between black and grizzly bears increasing the greater the reliance of both on animal versus plant resources. As the bar graph in Figure 21c shows, differences between the species are negligable in ecosystems where both species are reliant primarily on fruit and forbs, as in northwestern Montana and adjacent southeastern British Columbia (Figure 21b; Mattson et al. [2005]). By contrast, there is an average two-fold or more difference in meat consumption by black and grizzly bears in ecosystems with continental climates and more available meat.

There is already a long history of concern about how predation on elk calves by black bears and mountain lions (*Puma concolor*) affect elk populations in Idaho (e.g., Unsworth et al. 1993), with black bears accounting for the bulk of documented predation (Figure Figure 21a). There is increasing evidence that predation on elk calves can indeed have population-level effects (Raithel et al. 2007, Luckas et al. 2019), including on the Nez Perce-Clearwater Forests (White et al. 2010). Given these patterns, it is noteworthy that grizzly bears can be highly efficient predators on elk calves (e.g., French & French 1990, Gunther & Renkin 1990) and, in the case of some individual bears, even efficient predators on adult elk and moose (Gasaway et al. 1992, Mattson 1997, Dahle et al. 2013). This ability to predate on adult and calf ungulates allows grizzly bears to adopt a more predatory strategy inter-annually (Mattson 1997) as well as on a longer-term basis (Barber-Meyer et al. 2008, Middleton et al. 2013) when alternate foods are in short supply, and for some adult male grizzlies to adopt dietary strategies centered almost exclusively on eating meat—much of it obtained by predation (Mattson 1997, 2000; Schwartz et al. 2014).

Differences in exploitation of meat from ungulates by black and grizzly bears has potential implications for elk and even moose on the Nez Perce-Clearwater Forests. Grizzly bears establishing themselves in this region will very likely end up eating more meat compared to sympatric black bears. Whether this will be a consequence of grizzly bears usurping a meat-eating niche from black bears or simply eating more meat given the same available resources can't be reliably foreseen, largely because we have never had the opportunity to study diets of black bears before and after colonization by grizzly bears. Even so, whatever effects black bear predation may currently be having on elk populations will not be lessened with the arrival and establishment of grizzly bears.

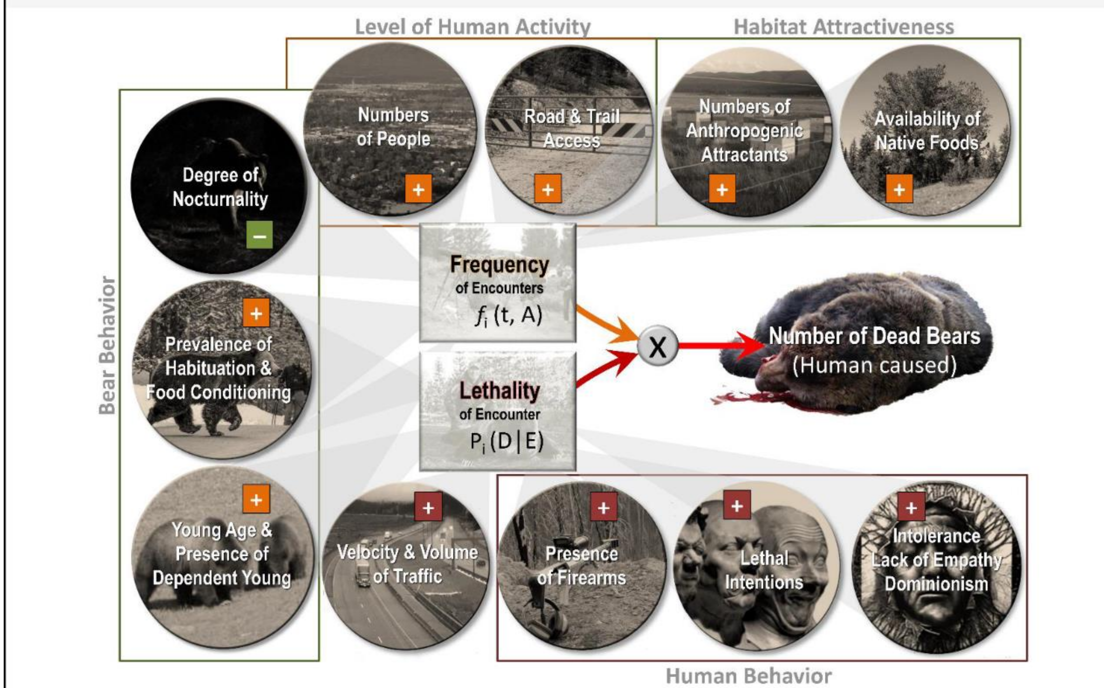
There are clearly ample foods for grizzly bears on the Nez Perce-Clearwater National Forests, including potentially substantial amounts of meat from either salmonids or elk throughout the bears' active season. During summer and fall, distributions of key foods will likely attract grizzlies to comparatively secure habitat, much of it in designated Wilderness Areas, whereas during spring productive habitats will probably attract grizzlies to lower elevations where conflicts with humans will be likely. Other conflicts could arise over foreseeable impacts of grizzly bear predation on iconic elk populations that some people see as existing primarily to provide a harvestable surplus for humans to kill.

7. Conflicts and Habitat Security

Relations with humans will continue to determine the fates of grizzly bears in the contiguous United States. Humans armed with firearms, traps, or poisons are highly lethal predators, evident even during modern times by the fact that 70-90% of adult and adolescent grizzly bear deaths are caused by humans[41]—even with protections afforded by the Endangered Species Act. Put another way, grizzly bears will or will not survive depending upon whether they have refuges from people or are attracted by human-associated foods into areas and situations that catalyze lethal conflict. But perhaps even more important, peoples' tolerance of bears as well as their willingness to accommodate them will determine where grizzlies can live and in what numbers.

Conceptualizing Factors That Determine How Many Grizzlies People Kill

Box 3. A conceptual model of factors driving the rate at which humans kill grizzly bears is potentially useful for assessing and managing threats to grizzlies, reducing conflicts, and developing a coexistence infrastructure. The model below builds on initial efforts by Mattson et al. (1996a, 1996b) while preserving the basic premise that bears are axiomatically killed by humans as a function of how often they encounter people and the likelihood that any given encounter will be lethal. Broadly speaking, frequency of encounter is dictated by levels of human activity, the attractiveness of habitats used by people, and bear behaviors, whereas encounter lethality is ultimately dictated by human worldviews, manifest by peoples' choices and behaviors.



One way of conceptualizing human-caused grizzly bear mortality is to deconstruct the rate at which people kill grizzlies into two components: (1) frequency of contact between the two species, and (2) the likelihood that any given encounter will be lethal for the involved bear (Mattson et al. 1996a, 1996b). In other words, the frequency and lethality of encounters with humans will jointly dictate the

[41] These percentages are based on the fates of radio-collared grizzly bears (e.g., McLellan et al. 1999, Wakkinen & Kasworm 2004, Schwartz et al. 2006, Mace et al. 2012, and Costello et al. 2016), which mitigates biases that otherwise arise from variation in the likelihood that deaths from different causes will be detected by humans absent some sort of real-time monitoring (Mattson 1998).

rate at which adult and adolescent grizzly bears are killed by people, with grizzlies potentially able to thrive despite frequent encounters with people, but only as long as those encounters are benign—as in National Parks. By contrast, where people are highly lethal, grizzlies will only survive if they have access to extensive areas free of human activity—as was the case during the 1800s and early 1900s (Mattson & Merrill 2002). Box 3 visualizes this conceptualization, along with key factors that drive frequency and lethality of contact.

Trade-offs between frequency and lethality of contact are relevant to assessing what measures are needed to sustain grizzly bears in places such as the Nez Perce-Clearwater National Forests, and whether or not these measures make major impositions on people. If even a handful of people are intolerant and disinclined to practice reasonable management of anthropogenic attractants, then conservation of grizzly bears will probably require large tracts of land free of human activity and access. If people are more uniformly willing to accommodate grizzly bears and engage in prudent behaviors, then there will be many fewer restrictions on access and activity (Mattson et al. 1996a). The choice is ours, individually and collectively, albeit constrained by fundamental worldviews (Kellert et al. 1996).

7.a. Prospective Conflicts on the Nez Perce-Clearwater National Forests

Management of lands and wildlife on the Nez Perce-Clearwater National Forests currently provides no explicit protections for grizzly bears, despite eastern portions of these Forests being in an officially designated Recovery Area (Nez Perce-Clearwater National Forests 2019a, 2019b). At best, protections are provided by Sections 7 and 9 of the Endangered Species Act (ESA)[42], but contingent on land and wildlife managers bothering to invoke these provisions—something notably absent from official deliberations for decades. State wildlife and federal land managers have essentially been given *carte blanche* by the U.S. Fish & Wildlife Service in matters related to the protection of grizzly bears and grizzly bear habitat.

These deficiencies are evident in the latest proposed revision of the the Nez Perce-Clearwater National Forests Plan, which perpetuates a regime that gives only parenthetical consideration to the appearance of colonizing grizzly bears and obligations incurred under the ESA (Nez Perce-Clearwater National Forests 2019a, 2019b). A meaningful reckoning with these obligations has yet to occur. More specifically, and in reference to Box 3, there is no explicit consideration given to management of anthropogenic attractants or people's behaviors and behavioral intentions—especially the practices of elk and black bear hunters.

Anthropogenic attractants have a long history of being at the center of conflicts between people and grizzly bears, perhaps best documented for Yellowstone National Park, where management transitioned from maintaining open pit garbage dumps that served as ecocenters for grizzlies; to aburpt closure of these dumps, with a dramatic spike in grizzly bear mortality after bears deprived of their traditional food source turned to exploiting other anthropogenic foods; to, during the past 15 years, a period of quietude resulting in part from thorough sanitation of the Park and nearby gateway communities (Schullery 1992, Craighead et al. 1995, Gunther et al. 2004).

[42] Endangered Species Act of 1973 (16 U.S.C. 1531-1544, 87 Stat. 884)

The threat posed by garbage and other anthropogenic foods to grizzly bears and grizzly bear recovery led managers to make sanitation efforts a centerpiece of the first Interagency Grizzly Bear Guidelines published in 1986 (Interagency Grizzly Bear Committee 1986). Since then, virtually every National Forest with documented grizzly bear occupancy has issued Forest-wide orders designed to limit availability of human foods to grizzlies, whether garbage, fresh food, or even hunter-killed big game carcasses (for example, Northern Continental Divide Ecosystem Flathead, Lewis & Clark, and Helena National Forests [2000], Kootenai National Forest [2011], and Custer-Gallatin National Forest [2014]).

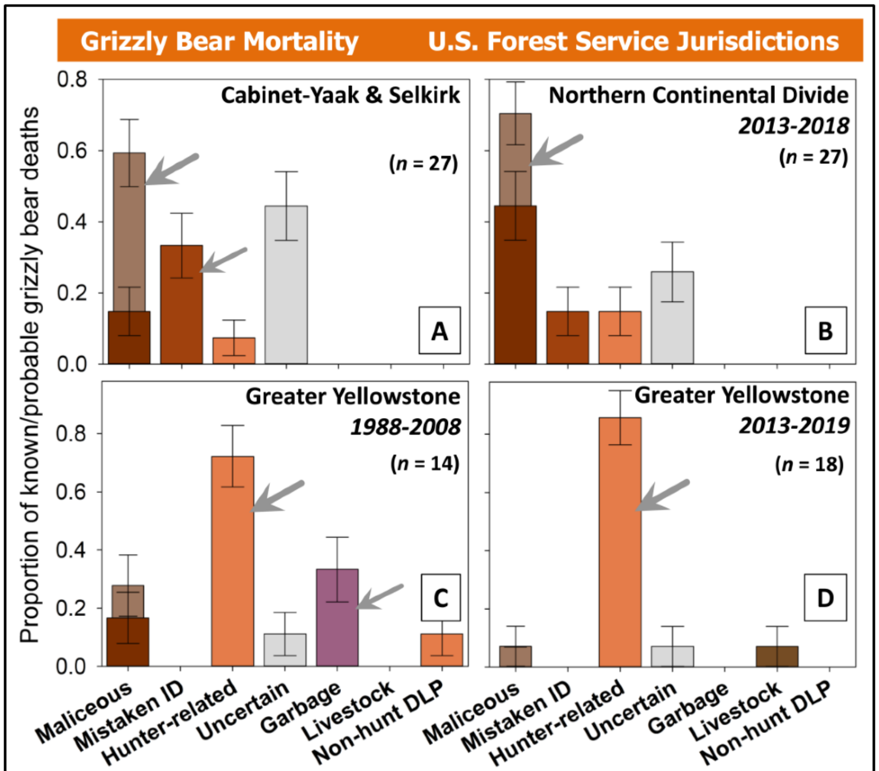


Figure 22. This series of four bar graphs shows the proportional composition of human-caused grizzly bear mortalities on Forest Service jurisdictions in (**A**) the Cabinet-Yaak (CYE) and Selkirk (SE) Ecosystems, combined; (**B**) the Northern Continental Divide Ecosystem (NCDE); and the Greater Yellowstone Ecosystem (GYE) during (**C**) years prior to major losses of whitebark pine (1988-2008) compared to (**D**) years after losses culminated in 2010 (2013-2019). Gray arrows in each graph identify prominent causes. Mortalities attributable to malicious causes are shown in two ways: including only those definitively determined to be deliberate poaching or illegal kills (dark burgundy); versus definite determinations plus other human-caused deaths that occurred under questionable circumstances implicating malicious intent or unwarranted human reactions (narrower brown bars). These latter mortalities are also differentiated and shown as gray bars labeled "uncertain." Jurisdictions of mortalities were determined from databases covering 1983-2014 (CYE and SE), 1998-2018 (NCDE), and 1988-2014 (GYE) obtained through federal Freedom of Information Act requests and Montana Open Documents requests. Information from these databases were augmented by information contained in *Cabinet-Yaak Grizzly Bear Recovery Area Research and Monitoring Progress Reports* for 2015-2019 and online databases of GYE mortalities maintained by the Interagency Grizzly Bear Study Team (https://www.usgs.gov/science/interagency-grizzly-bear-study-team?qt-science_center_objects=4#qt-science_center_objects).

These orders require that all human foods and garbage be stored in bear resistant containers, hard-sided vehicles, or hung from a tree at least 10' off the ground and 4' from the trunk at a safe distance from campsites. Considerable emphasis has been placed on disposition and storage of hunter-killed animals in National Forests of the Yellowstone ecosystem, aided by an aggressive program to install back-country "bear poles" designed to support the weight of big game carcasses hoisted a safe distance off the ground (e.g., Shoshone National Forest, Carcass Storage Order, 36 CFR 261.58[s]).

None of this holds for the Nez Perce-Clearwater National Forests, which currently do not have a Forest-wide food or carcass storage order in place. The Clearwater National Forest did make some uneven attempts during the early 2000s to distribute and maintain bear-resistant garbage dumpsters at front-country Forest Service facilities. However a recent inventory of this infrastructure at 40 campgrounds and other sites by the non-profit group, Friends of the Clearwater, documented problematic accumulations of refuse and widespread lack of maintenance that rendered the affected bear-resistant dumpsters ineffective.

The comparative lack of grizzly bear deaths related to conflicts over garbage on Forest Service jurisdictions in other grizzly bear ecosystems—especially since 2013—is testimony to both the effectiveness and importance of sanitation efforts (Figure 22). But the summaries of grizzly bear mortalities shown in Figures 22c and 22d highlight a major cause that has clearly not been adequately addressed in the Greater Yellowstone ecosystem, with potential relevance to the Nez Perce-Clearwater Forests: deaths attributable to encounters with big game hunters.

This cause has long been dominant on Forest Service jurisdictions in the Yellowstone region, largely because of the numerous problematic encounters that occur between grizzlies and elk hunters during September-November, many of which turn lethal for the involved bears. Some of these encounters are close-quarter surprises, although most involve bears contesting elk carcasses in the field or in backcountry camps. There is even evidence that grizzly bears actively seek out hunter-killed elk (Haroldson et al. 2004), plausibly because of the nutritional value of gut piles and other carcass remains (Mattson et al. 2004). This persisting problem motivated several agency-sponsored reports that recommended measures to reduce grizzly bear-hunter conflicts[43] (among them, Interagency Grizzly Bear Study Team [2000] and Servheen et al. [2009]), but to little avail given that most of the recommendations were not widely implemented—all of which is relevant to the Nez Perce-Clearwater National Forests given the extent of elk hunting in these jurisdictions (Nez Perce-Clearwater National Forests 2019b: Section 3.2.3.4).

The other category of hunting-related bear mortality that has clear relevance to conditions on the Nez Perce-Clearwater Forests is the frequency with which grizzly bears are killed by black bear hunters as a result of mistaken identification—a non-trivial cause of grizzly bears deaths in western portion of the Northern Continental Divide ecosystem as well as in the Cabinet-Yaak and Selkirk Recovery Areas (Figure 22a,b). Although bear identification programs are mandated for black bear hunters by Montana's Department of Fish, Wildlife, & Parks (https://fwp.mt.gov/hunt/education/bear-identification), deaths of grizzlies from mistaken identifications continue, which calls into question the effectiveness of such educational efforts. But of particular relevance to conditions in north-central Idaho, one of the first grizzlies known to have ventured into the Clearwater drainage since the 1940s was killed over bait during 2007 as the result of misidentification by an out-of-state black bear hunter (Nokkentved 2007).

And finally, of the conflict-related grizzly bear deaths, those arising from depredations of livestock on Forest Service grazing allotments are noteworthy. Although this cause has not been prominent in occupied grizzly bear Recovery Areas during recent decades, it was common-place up through the 1970s in the Yellowstone ecosystem, and has emerged yet again as a major cause since 2010 (Wells et

[43] Practices that could reduce lethal conflicts between bears and hunters include carrying non-lethal self-protection such as pepper spray (Herrero & Higgins 1998; Smith et al. 2008, 2020); securing carcasses and other attractants at hunting camps (see above); not leaving carcasses unattended overnight; not hunting late in the day; hunting in parties of least two; being better educated about grizzly bear behavior; and not archery hunting in areas occupied by grizzly bears.

al. 2019). Prior to the 1980s, domestic sheep were the victims of most grizzly bear depredation (Johnson & Griffel 1982, Jorgensen 1983, Knight & Judd 1983), although depredations on cattle date back to before the 1940s (Murie 1948). Depredations on sheep were virtually eliminated after sustained efforts by non-governmental organizations and the Forest Service led to the retirement or conversion of most sheep grazing allotments in areas occupied by grizzly bears[44]. But since then depredations on cow calves have increased exponentially as grizzlies colonize grazing allotments on the periphery of the Yellowstone ecosystem (Wells et al. 2019) and turn increasingly to eating meat (Schwartz et al. 2014, Ebinger et al. 2016).

Although only a comparatively small part of the Nez Perce-Clearwater Forests is allocated to grazing allotments—almost all in western portions of the Nez Perce Forest—the situation is radically different on the Salmon-Challis and Boise National Forests south of the Salmon River (https://idl.maps.arcgis.com/apps/View/index.html?appid=3f449b10713748eb90f2dd386751d28a). Conflicts over grizzly bear depredations on cattle and sheep are clearly a major potential issue in these southerly areas, but also a potential problem on the Nez Perce Forest, despite blithe dismissal in the 2019 Forest Plan Revision Draft EIS (Section 3.2.3.3) of any challenges for grizzly bear conservation associated with management of allotments.

Because of inattention to conflict prevention by state wildlife and federal land managers, current conditions on the Nez Perce-Clearwater Forests are ripe for grizzly bear-human conflicts over unsecured garbage and food; conflicts over livestock depredations; conflicts with big game hunters; and mortalities caused by black bear hunters mistaking a grizzly for a black bear. All of this promises to leave managers scrambling to deal with grizzly bear mortalities arising from foreseeable conflicts.

7.b. Habitat Security Standards

Perhaps the most attention-getting feature of Figures 22a and 22b is the predominance of poaching as a cause of grizzly bear deaths on Forest Service jurisdictions in the Selkirk and Cabinet-Yaak Ecosystems as well as on the west side of the Northern Continental Divide Ecosystem. I use "poaching" here in a broad sense to include, not only documented instances, but also cases where circumstantial evidence suggests illegality or just simply an unwarranted lethal response by someone to an encounter with a grizzly bear that was subsequently not reported to wildlife managers. Broadly speaking, these categories are unified by a predisposition on the part of involved people to respond lethally to encounters with grizzlies—often in ways that transgress or challenge legal boundaries. Put another way, these categories speak to underlying intolerance and fear, which is a problematic cocktail when mixing people with grizzly bears.

Poaching throws into sharp relief the challenge of preventing grizzly bear mortality and promoting grizzly bear recovery when there are significant numbers of lethal people in a local human population. As I suggest earlier (Box 3), the only means of addressing this problem, other than through aggressive law enforcement, is by limiting frequency of contact between bears and people of unpredictable predispositions. And the primary way of doing this, at least on public lands, is through limitations on

[44] Notable non-governmental organizations involved in this effort include the National Wildlife Federation, Wild Sheep Foundation, and Wyoming Wildlife Federation. Most of the buy-outs and retirements were to benefit bighorn sheep (*Ovis canadensis*), but with substantial collateral benefit for grizzly bears.

access—an externalized burden created by intolerant people, but borne by everyone, regardless of their attitudes towards grizzlies.

Given that there is little reason to expect major differences between the attitudes of people living in north-central and central Idaho and people living in the Selkirk, Cabinet-Yaak, and western Continental Divide ecosystems, restrictions on access are necessarily a paramount consideration in conservation of grizzly bears on jurisdictions such as the Nez Perce-Clearwater National Forests. With this consideration in mind, provisions offered by the revised Forest Plan Draft EIS for management of road access on these Forests warrant close scrutiny.

At this point its probably worth emphasizing the extent to which human-caused grizzly bear deaths are associated with roads and, as a logical correlate, with landscapes intensively managed for extraction of timber. I don't intend here to plumb the depths of the ample scientific research showing a concentration of grizzly bear deaths near—i.e., within 500-m of—roads, along with related population-level impacts. For a recent synthesis of road-related impacts on grizzly bears, see Proctor et al. (2018b, 2020). Reckoned in other geospatial terms, a large body of scientific research shows that, not only do road densities need to be <0.5 km/km^2, but also that additional portions of a grizzly bear's home range need to be entirely free of road access to ensure survival rates that sustain population growth (e.g., Proctor et al. 2018a).

But, for those who remain doubters, Figure 23b offers a map view of how grizzly bear mortalities correlate spatially with areas prioritized by the Forest Service for timber production and associated dense road networks in the Cabinet-Yaak and Northern Continental Divide ecosystems. Even on the basis of visual inspection, the association is striking. Grizzly bears die disproportionately more often in landscapes devoted to the industrial production of timber compared to landscapes without roads. Of relevance to prospects for grizzly bears in north-central Idaho, substantial portions of the Idaho Panhandle and Nez Perce-Clearwater National Forests have been provisionally relegated to timber production (Figure 23a). The gauntlet is daunting.

The impacts of roads and associated human activities are often encapsulated by grizzly bear managers into calculations of percent "secure" habitat. These calculations are done at the scale of individual Bear Management Units (BMUs) that are approximately the size of a female grizzly bear's life—around 900-km^2 (see Box 4). BMUs are used as spatial constraints for reckoning changes in secure habitat associated with the construction or retirement of roads. This approach serves to insure that the impacts of the road infrastruture are reckoned at a scale that is meaningful to individual bears. It debars, for example, using road closures on one side of a National Forest to "offset" road construction on the other side when the intervening distance is far greater than any one bear would likely move.

Reckonings of habitat security by grizzly bear managers in different grizzly bear ecosystems have long been marked by a number of peculiarities, most of which defy logic and the best available science. Initial approaches to assessing habitat security accounted for all types of human activities, road-bound or not, and for intersections of these activities with habitats of different attractiveness (e.g., Mattson et al. 1986, 2004; Weaver et al. 1986). However, this more replete approach was later abandoned and replaced by a simplified caricature that only accounted for roads—without any consideration of traffic levels—and did not account for differences in quality or attractiveness of intersected habitats. Unfortunately, this particular conception of "security", as a reckoning of both displacement and mortality risk for grizzly bears, is at odds with almost all of the credible research produced during the

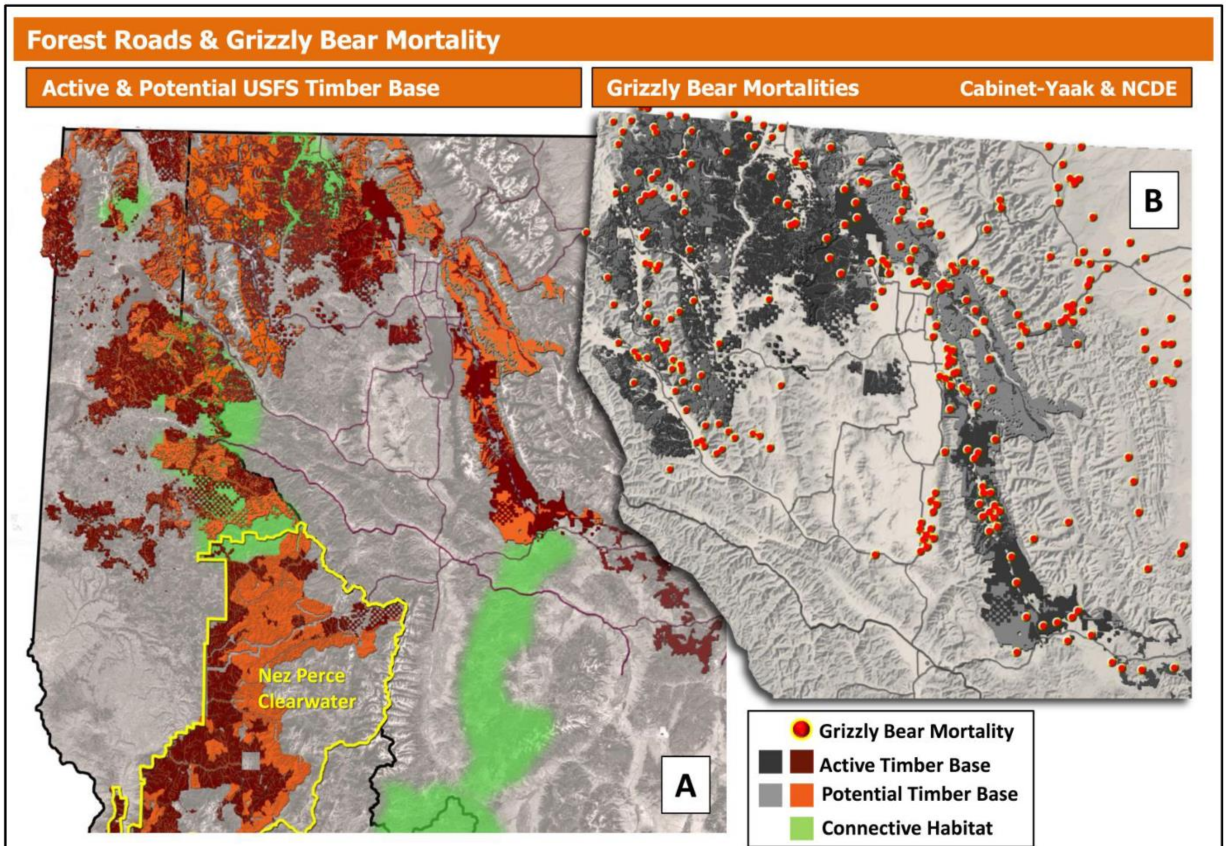


Figure 23. Map (**A**) shows areas suitable for timber harvest (in burgundy) and harvestable for other resource objectives (orange), for the Nez Perce-Clearwater National Forests (delineated in yellow), the Panhandle National Forests, Kootenai National Forest, Flathead National Forest, and Helena National Forest (from Forest Plans for each of the last four, and from the Draft EIS for the Nez Perce-Clearwater National Forests: Alternative W). The green in map (**A**) corresponds with the most promising connective habitat identified in Figures 12 & 14. Map (**B**) renders areas suitable for forest harvest in shades of black and white, with locations of grizzly bear mortalities shown as red dots, 1998-2018 in the Northern Continental Divide Ecosystem and 1983-2018 for the Cabinet-Yaak Ecosystem. Locations of mortalities are from databases covering 1983-2014 (CYE) and 1998-2014 (NCDE) obtained through federal Freedom of Information Act requests and Montana Open Documents requests. Locations from these databases were augmented by map locations from *Northern Continental Divide Ecosystem Grizzly Bear Population Monitoring Team Annual Reports* and *Cabinet-Yaak Grizzly Bear Recovery Area Research and Monitoring Progress Reports* for 2015-2019. Lands managed for some level of timber harvest are featured because of the close spatial correlation with road systems. Map (**B**) illustrates the extent to which grizzly bear mortalities are disproportionately associated with these lands; map (A) shows the extent of these lands in areas north and east of potential suitable grizzly bear habitat in central Idaho, exclusive of the Lolo National Forest.

last two decades showing, for example, that jurisdiction matters (as as surrogate for human lethality); that traffic levels on roads and trails matter; that diel timing of human activity matters; that people on foot have impacts; that the presence of attractants matters; and that the juxtapose of human facilities with bear habitats also powerfully configures impacts[45]. The upshot is that official calculations of "security" are a very crude as well as scientifically-indefensible representation of reality.

[45] A sampler of this research includes Mattson et al. (1987), Mace & Waller (1996), Mace et al. (1999), Merrill et al. (1999), Benn & Herrero (2002), Chruszcz et al. (2003), Merrill & Mattson (2003), Mattson & Merrill (2004), Apps et al. (2004, 2016), Johnson et al. (2004), Nielsen et al. (2004, 2010), Waller & Servheen (2005), Suring et al. (2006), Ciarniello et al. (2007), Roever et al. (2008), Graham et al. (2010), Schwartz et al. (2010), Northrup et al. (2012), Boulanger & Stenhouse (2014), Proctor et al. (2015, 2018a), Lamb et al. (2017, 2018, 2020), Ladle et al. (2019), and Mattson (2019b).

Setting this fundamental problem aside for the moment, there are additional inexplicable peculiarities that bedevil official calculations of habitat security for grizzly bears in different ecosystems. But first, a little more background. Calculations in all ecosystems are founded on the premise that "secure" habitat is defined by any area >500-m from a road, in some ecosystems contingent on the resulting isolated patches be of a minimum size. Additional standards impose limitations on the percentages of any given BMU that can have road densities exceeding 1 mile/mile^2 and 2 mile/mile^2. All of these benchmarks have some degree of scientific support (Proctor et al. 2018a, 2020).

However, these more-or-less valid benchmarks are called into question by vagarous specifications that inexplicably differ from one grizzly bear ecosystem to another. For example, the aspirational goal for habitat security in BMUs of the Yellowstone ecosystem is 75% (Yellowstone Ecosystem Subcommittee 2016). In the Northern Continental Divide ecosystem (NCDE), the goal is 68% (Northern Continental Divide Ecosystem Subcommittee 2020). In the Cabinet-Yaak ecosystem it is 55% (Kootenai National Forest 2015). Even standards set for portions of BMUs with greater than 1 and 2 miles/mile^2 are vagarious. In the Cabinet-Yaak ecosystem the respective percentages allowed for in each category are 33 and 26, whereas in the NCDE the percentages are 19 and 19—42% and 27% lower—despite the fact that the acutely vulnerable Cabinet and Yaak grizzly bear populations are 30-40-times smaller than the NCDE population (Costello & Roberts 2019, Kasworm et al. 2019). And so on.

Disregard for the best available science together with inexplicable variation in security standards among ecosystems complicate any assessment of whether conditions on the Nez Perce-Clearwater National Forests provide adequate security for grizzly bears—which is further complicated by being nested within the larger issue of what's needed at a broader scale to insure population viability (see Section 5.b. above). But these sorts of complications do not debar an evaluation of landscape conditions and useful comparisons with other ecosystems.

7.c. Habitat Security on the Nez Perce-Clearwater National Forests

The first challenge posed by any useful assessment of habitat security for grizzly bears on the Nez Perce-Clearwater National Forests is partitioning this large expanse into areas that logically comport with the scale of grizzly bear movements; i.e., Bear Management Units. Although I am not in a position to create authoritative boundaries, I am well-acquainted with the conceptual underpinnings. I was one of three people who literally stood around a table in 1983 drawing boundaries on a paper map for the first grizzly bear BMUs in the Greater Yellowstone Ecosystem, and was also involved in developing the initial logic and conceptualization for BMUs (as per Weaver et al. [1986], Mattson & Knight [1991], and Dixon [1997]), later applied to other grizzly bear ecosystems. Parenthetically, the maps showing seasonal distributions of habitat productivity in Figure 18 were vital to informing my delineations of provisional BMUs on the Nez Perce-Clearwater Forests given that BMUs ideally encompass habitats sufficient to support resident grizzlies year-round. The results of my effort are shown in Box 4.

With these boundaries in hand, it is possible to determine what portions of each candidate BMU are "secure," at least in the broadest sense of being outside areas with road densities >1 mile/mile^2 and >2 miles/mile^2. My crude calculations were complicated by not having access to the Nez Perce-Clearwater Forests GIS containing exact geospatial coordinates for all linear access features. Even so, calculations of road densities have been completed for evaluations of watershed conditions (Ecovista et al. 2003) and elk habitat security (Nez Perce Clearwater National Forests [2019b]: Section 3.2.3.4), shown in Figures 24a and 24b, overlain on boundaries of provisional BMUs (in white).

Candidate Bear Management Units
Nez Perce-Clearwater NFs

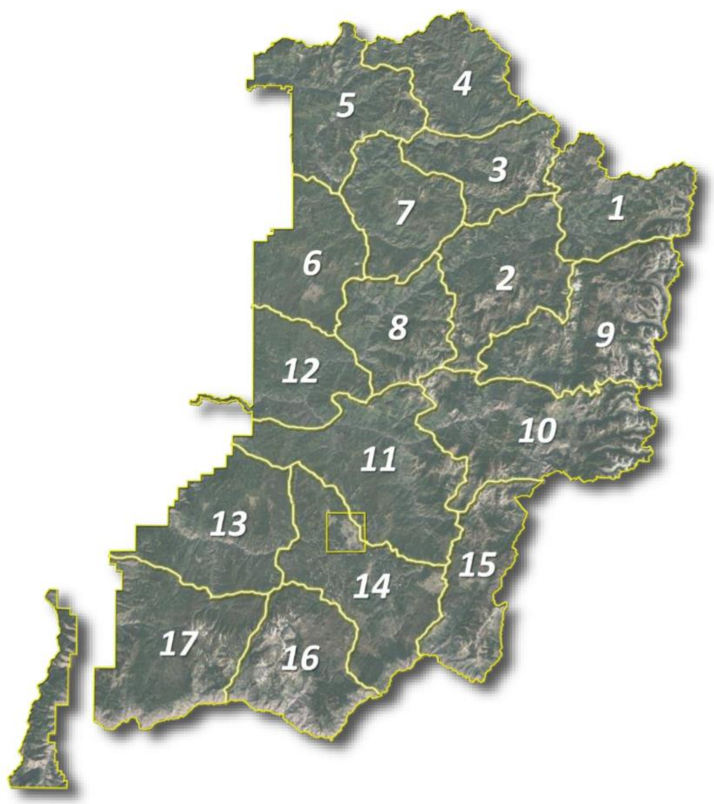


Figure 24. This map shows candidate Bear Management Units (BMU) delineated for the Nez Perce-Clearwater National Forests (yellow lines) and given provisional numeric identifiers. BMUs approximate the size of a female grizzly bear life range (Weaver et al. 1986, Mattson & Knight 1991, Dixon 1997) and, to the extent possible, are delineated to encompass high-quality spring and summer-fall habitat (see Figure 18).

The extact demarcations of watershed and elk security area boundaries differ, as do the bins for representing road densities, but the maps from each analysis show the same broad patterns. Road densities are uniformly high in western portions of both Forests, but also along lower-elevation portions of the North Fork of the Clearwater, in the area of interspersed Forest Service and private lands near Lolo Pass, and in a swath extending east through Elk City up to the Selway-Bitterroot Wilderness Area[46].

A crude estimate of habitat security for grizzly bears within each BMU can obtained by combining and averaging road density calculations for watersheds and elk security areas, and then using these averages to calculate the percentage of each BMU outside of areas with 1 mile/mile^2 and 2 miles/mile^2 road densities. These percentages are shown for each BMU in Figure 24c, ranging from 4-22% in the most heavily compromised BMUs (1, 6, 12, 13, and 14) to nearly 100% in those that are least compromised (3, 8, 9, and 10).

[46] Parenthetically, the importance of spatial partitioning at the scale of BMUs is highlighted the by the analysis of road densities presented in the Nez Perce-Clearwater National Forests Revised Plan, Draft EIS in Section 3.2.3.3. The Forest Service analysis encompasses portions of the Clearwater Forest south to the southern boundary of the Lochsa River, outside of the Selway-Bitterroot Wilderness Area, partitioned into two large areas, each equivalent to 4-5 of the BMUs shown in Box 4 and Figure 24. These large strata mask areas with exceptionally high road densities, yielding average road densities for each of 0.9-1.1 mile/mile^2. Yet these extensive strata contain home range-sized areas where road densities exceed 2 or even 4-5 miles/mile^2—where habitat security is substantially deficient.

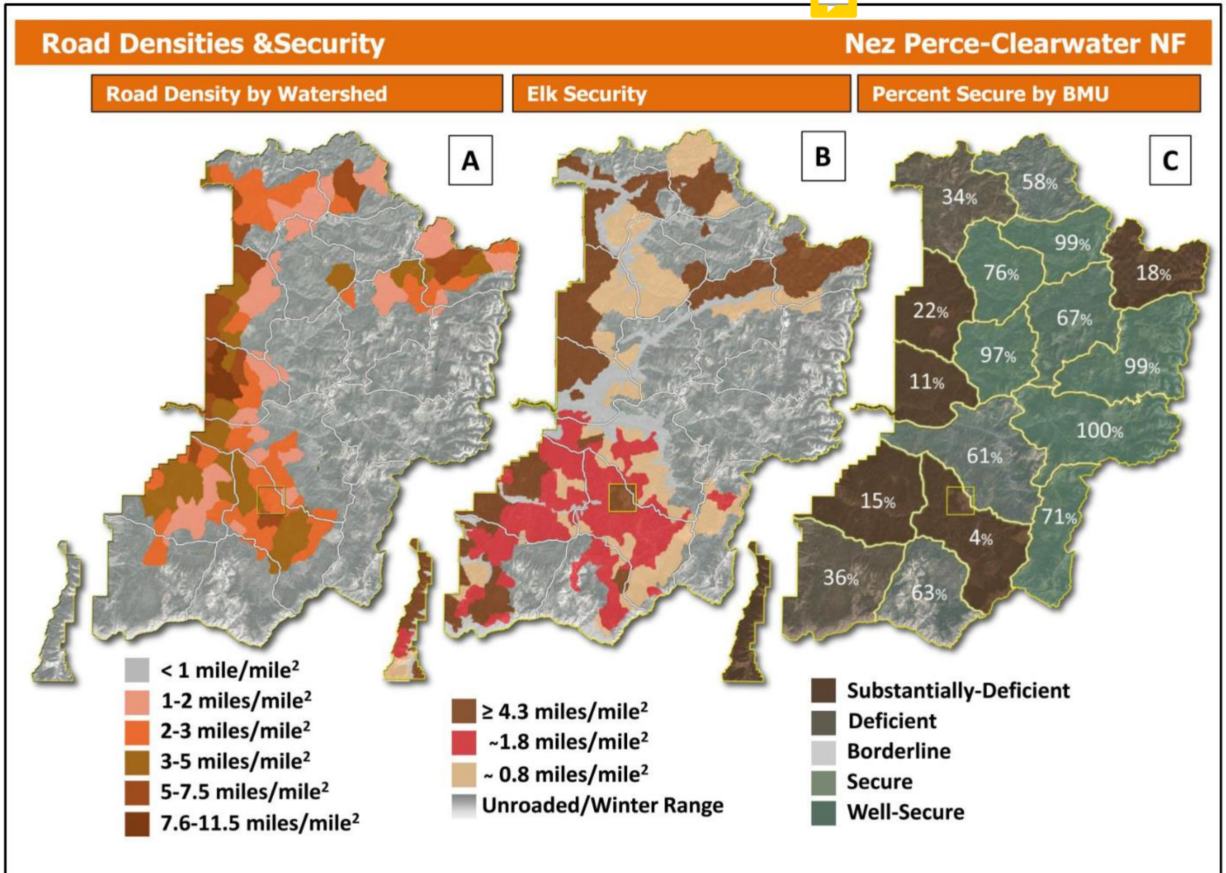


Figure 25. These maps show configurations of habitat security for grizzly bears on the Nez Perce-Clearwater National Forests, with an emphasis on road densities. Map (**A**) shows road densities averaged for sub-watersheds on portions of the Forests contained within the Clearwater River drainage (from the Draft Clearwater Subbasin Assessment [Ecovista et al. 2003]). Map (B) shows elk security areas differentiated by whether management objectives are 25, 50, or 75% security. Colors correspond with approximate road densities associated with each objective. Road densities averaged for the entire analysis areas were 1.1. miles/mile^2 for the North Fork and 0.9 miles/mile^2 for the Lochsa (Nez Perce-Clearwater National Forest 2019: 3.2 3.3-84). When corrected to estimate densities within roaded areas (areas shaded burgundy and beige), average densities were 4.3 miles/mile^2 for the North Fork and 2.9 miles/mile^2 for the Lochsa. Map (**C**) shows provisional Bear Management Units (BMUs) delineated by yellow lines and shaded to identify those that exceeded (dark burgundy) or were likely to exceed (light burgundy) security standards. BMUs were delineated to be around 900 km^{2}in size (based on life range criteria used to delineate BMUs in the Greater Yellowstone Ecosystem [Weaver et al. 1986, Mattson & Knight 1991, Dixon 1997]), follow topographic and drainage boundaries, and, if possible, encompass high-value spring and fall habitat (Weaver et al. [1986]; geospatial configurations are from Figure 24).

Without context or points of reference these percentages are difficult to interpret, other than in their denotation of the obvious: a higher precentage is better than a lower one. However, comparison with conditions in other grizzly bear ecosystems can provide insight into whether the Nez Perce-Clearwater National Forests currently provide security that is adequate for recovering a grizzly bear population. Figure 25 shows a summary of habitat security for BMUs along with habitat security standards for three occupied ecosystems (the Greater Yellowstone, Northern Continental Divide, and Cabinet-Yaak) as points for reference for a comparable summary of security for provisional BMUs on the Nez Perce-Clearwater Forests. This comparison offers noteworthy benchmarks given that the Yellowstone and NCDE grizzly bear populations are large and faring relatively well (Costello & Roberts 2019, Van Manen et al. 2019), whereas the Cabinet and Yaak populations are small and acutely vulnerable (Kasworm et al. 2019).

Security of BMUs by Ecosystem

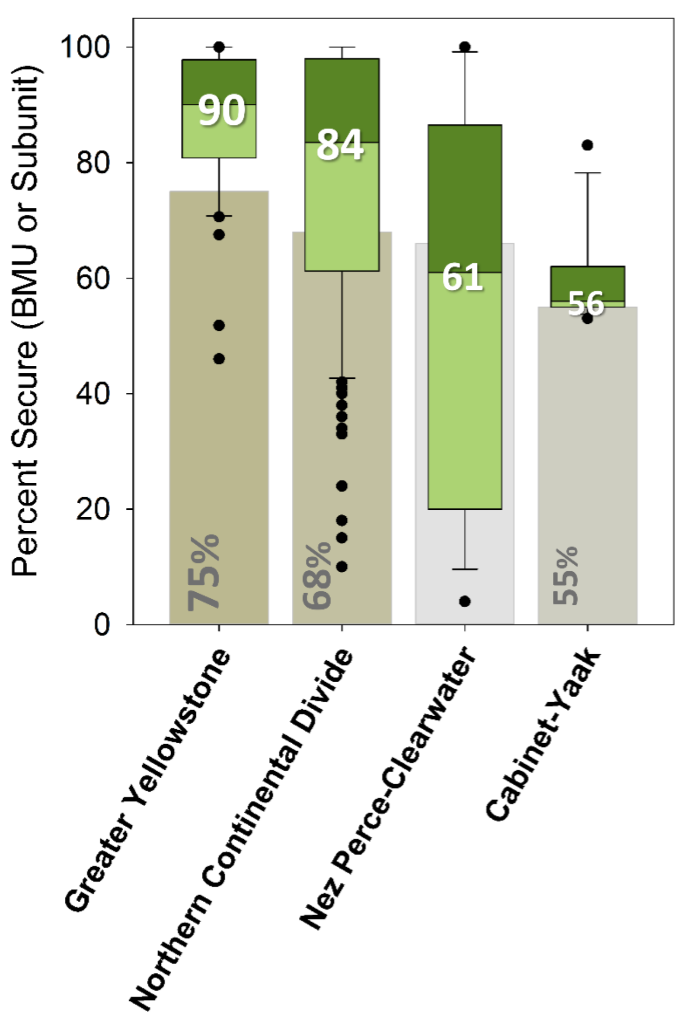


Figure 26. This graph combines bars (in shades of light dusky green) and box plots (in shades of darker green) to depict differences in security standards (secure % by Bear Management Unit [BMU]) and realized percent security by Grizzly Bear Recovery Area, including candidate BMUs on the Nez Perce-Clearwater National Forests. The bars denote standards, with standards also shown as percentages. The box plots show realized security on a BMU or BMU-Subunit basis. The numbers within each box plot are median percent security for each Ecosystem. Data are from Van Manen et al. (2019):115-116; NCDE Conservation Strategy, Appendix 3:27-29; Kootenai NF Plan Monitoring & Evaluation Report (2013):16-17; and, for the Nez Perce-Clearwater National Forests, from Figure 25c.

There are a few noteworthy take-aways from the comparison shown in Figure 25. The security of provisional BMUs on the Nez Perce-Clearwater Forests varies enormously, but inclusive of BMUs with levels comparable to that of the upper range for BMUs in the Greater Yellowstone and Northern Continental Divide ecosystems. On the other hand, median habitat security for the Forests is comparable to that in the Cabinet-Yaak ecosystem, suggesting that when viewed as a whole, the Nez Perce-Clearwater Forests are, at best, only marginally secure and, because of that, warranting major improvement.

Revisiting points I made in Sections 7.a. and 7.b., above, there is an imperative to reduce road access on the Nez Perce-Clearwater National Forests, not only because median levels of habitat security for grizzly bears are subpar, but also because measures to prevent conflicts are inadequate and likelihood of poaching and other illegal killing is comparatively high. In other words, heightened odds of prospectively lethal confrontions between humans and grizzly bears increases the need to reduce levels of contact through restrictive management of road access.

8. Fragmentation

Fragmentation of grizzly bear populations has long been a concern of managers, dating back to when ESA protections were first given to grizzlies. Although there are no explicit provisions in current government plans or strategies for securing connectivity among extant populations, the desirability of connectivity has nonetheless been routinely extolled not only by grizzly bear managers[47], but also by grizzly bear researchers, notably Walker & Craighead (1997), Craighead (1998), Proctor et al. (2004, 2005, 2012, 2015), Craighead et al. (2005), and Peck et al. (2017). Fragmentation potentially threatens the persistence of grizzly bears in the contiguous United States by reducing numbers of breeding individuals in any given population; decreasing genetic diversity through impaired gene flow and increased inbreeding and purging (Miller & Waits 2003, Lino et al. 2019); and lessening the likelihood of demographic rescue of one population by another when environmental catastrophes strike (Cosgrove et al. 2018, Millon et al. 2019).

These concerns have resulted in several investigations designed to indentify not only the location, nature, and severity of fracture zones for grizzly bear populations in the transboundary United States-Canada Rocky Mountains (Proctor et al. 2004, 2005, 2012, 2015; Waller & Servheen 2005; Graves et al. 2011; Graves 2012), but also the location of potential connective habitat at both coarse and fine scales (Gore et al. 2001, Servheen et al. 2001, Walker & Craighead 1997, Craighead & Olenicki 2006, Cushman et al. 2013, Peck et al. 2017).

In every instance, fracture zones were identified with major transportation corridors typified by heavily-trafficked highways and higher densities of human occupancy—notably along the Highway 2/Burlington Northern Santa Fe (BNSF) corridor through the Northern Continental Divide (NCDE) and Cabinet-Yaak Ecosystems; the Highway 200/Montana Rail Link corridor along the southwestern margin of the Cabinet Mountains; Highway 93 through Flathead, Mission, and Bitterroot Valleys along the west side of the NCDE and east side of the Selway-Bitterroot Ecosystem; and, most notably, Interstate Highway 90 (I-90), separating the Northern Continental Divide, Cabinet-Yaak, and Selkirk Ecosystems to the north from the Greater Yellowstone and Selway-Bitterroot Ecosystems to the south (Rutherford et al. 2014).

The map in Figure 27a shows the location of major fracture zones defined by the federal highway system. The width of red buffers is proportional to average daily traffic volume, most dramatically in and near the urban and exurban areas centered on Kalispell and Missoula in Montana and Coeur d'Alene and Boise in Idaho. The fracture zones of greatest relevance to recolonization of north-central Idaho by grizzly bears are I-90 between Missoula and Coeur d'Alene and Highway 93 south through the Bitterroot Valley (Servheen et al. 2001), although Highway 12 through the heart of the Clearwater National Forest is also of potential concern (Gore et al. 2001) given the extent to which Highway 2 through the NCDE has historically impeded movements of grizzly bears from north to south (Waller & Servheen 2005, Mikle et al. 2016).

[47] For example, U.S. Fish & Wildlife Service (1993, 2011), Servheen & Sandstrom (1993), Gore et al. (2001), Servheen et al. (2001), Montana Fish, Wildlife & Parks (2013), Yellowstone Ecosystem Subcommittee (2016), Northern Continental Divide Ecosystem Subcommittee (2020)

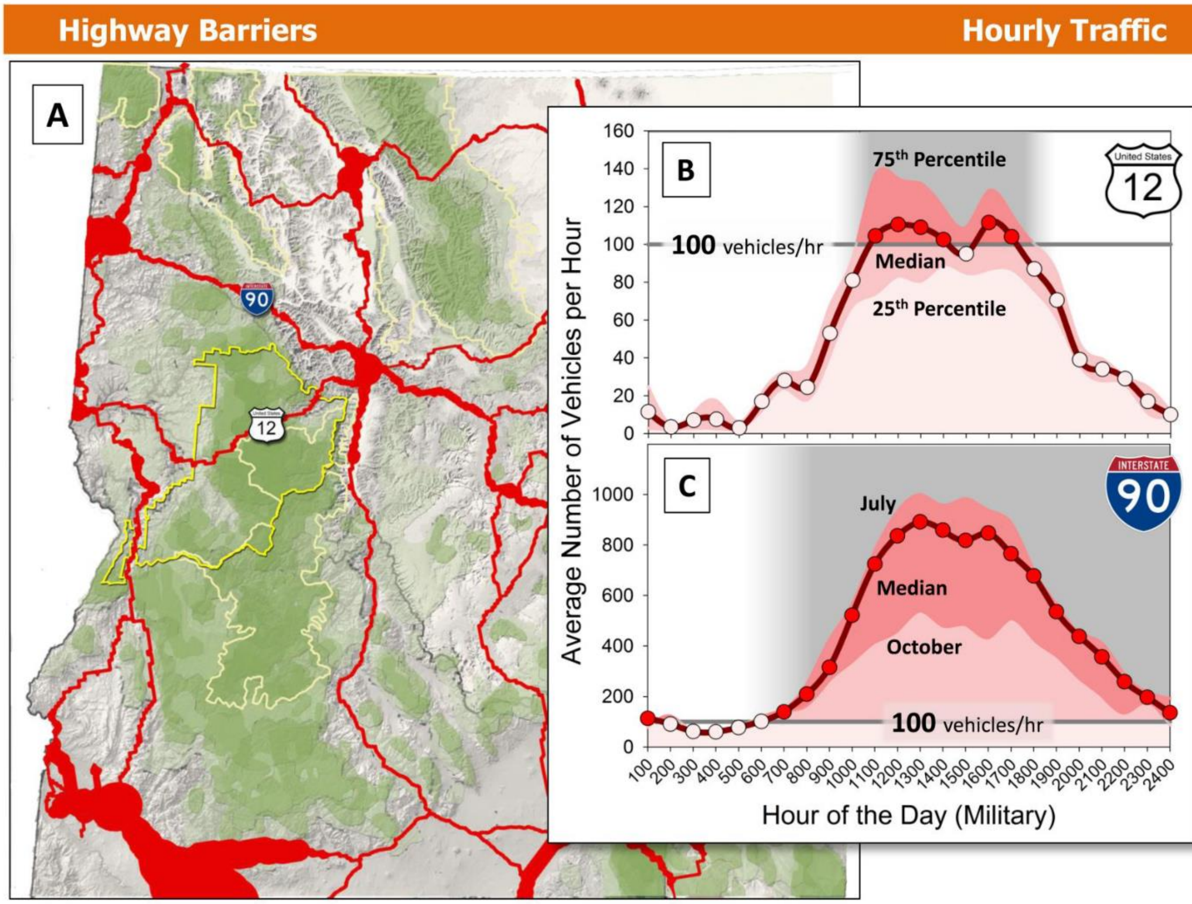


Figure 27. These graphics portray the spatial and temporal configuration of barriers posed to grizzly bear dispersal by major highways in the U.S. Northern Rocky Mountains, with an emphasis on highways located between central Idaho and source populations to the north. Map (**A**) shows major U.S. highways in red, with the width of red at any given point proportional to estimated daily traffic averaged for the entire year (U.S. Department of Transportation…(2016)). Interstate-90 to the immediate north of the Nez Perce-Clearwater National Forests (delineated in yellow) is featured because it is the most prominent barrier south and west of the Cabinet-Yaak, Selkirk, and Northern Continental Divide grizzly bear populations (Servheen et al. 2001). U.S. Highway 12 is also featured because it is the only potential highway-related barriers for grizzly bears moving north and south once bears have established in potential suitable habitat of central and north-central Idaho. Figures (**B**) and (**C**) show median hourly traffic for May-October for Highway 12 (**B**) and Interstate 90 (**C**) (Montana Department of Transportation, TCDC) relative to a threshold of 100 vehicles per hour. Waller & Servheen (2005) found that when traffic exceeded this threshold along US Highway 2 in Montana, highway crossings by grizzly bear dropped to near 0. Times of day when traffic likely poses an absolute barrier to bears are shaded gray for each highway. The red and pink-shaded area above and below the median in (**B**) represents 25th and 75th precentiles of traffic measured during various years, May-September. The shaded areas in (**C**) represent hourly traffic during 2019 for months with the greatest and least average daily traffic—July and October, respectively.

Inset Figures 27b and 27c provide visual depictions of the extent to which Interstate-90 and Higway 12 likely impede grizzly bear movements, drawing heavily on research along the Highway 2/BNSF corridor showing that grizzly bear crossings dropped to essentially nil when traffic exceeded roughly 100 vehicles per hour (Waller & Servheen 2005). The inset graphs show average or median traffic levels by time of day for different seasons, with times of day when median levels exceed 100 vehicles per hour shaded gray. The take-away from these graphs is that grizzly bears have ample opportunity to cross

Highway 12 in the Clearwater drainage between roughly 6 pm in the afternoon and 8 am in the morning, whereas opportunities to cross I-90 are restricted to between roughly 2 am and 6 am.

However, these hours only bracket periods during which *most* bears would likely attempt to cross a section of open road. Other opportunities clearly exist for grizzly bears with less aversion to attempt—and potentially survive—such a crossing, or for bears to safely cross through underpasses, overpasses, and drainage culverts. The fact that some bears have successfully navigated the seemingly impenetrable barrier posed by Interstate-90 is evident in the fact that at least four grizzlies have made the journey from either the Selkirk Ecosystem, Cabinet Mountains, or the Northern Continental Divide Ecosystem south across I-90 to north-central Idaho or the adjacent Bitterroot Mountains (see Section 5). Although the question has not been explicitly addressed, it seems plausible that, despite heavy traffic, I-90 near the Idaho-Montana border is more easily crossed by grizzly bears compared to Highway 93 in the Bitterroot Valley simply because the Bitterroot Valley has so many more human residences and associated opportunities for conflict—as evidenced by a young male grizzly that had its journey south from the NCDE abruptly terminated in 2018 when it chose to forage in a golf course near Stevensville, Montana (Backus 2018).

Natural colonization of north-central Idaho by grizzly bears will clearly depend on successful immigration of grizzly bears from the Selkirk, Cabinet-Yaak, and Northern Continental Divide Ecosystems. However, this on-going process will predictably proceed at a slow pace because of hazards created by I-90 to the north and human settlements in the Bitterroot Valley to the east. As much as natural colonization will depend on creation of *in situ* conditions that foster survival of newly-arrived grizzlies, it will also depend on making I-90 and the Bitterroot Valley more permeable to migrants. Fortunately, there is no shortage of knowledge and experience about how to do this, whether related to highway crossing structures[48] or human-grizzly bear coexistence[49].

[48] The research by Tony Clevenger and his colleagues has been perhaps the most notable contribution to refining design and effectiveness of highway crossing structures for grizzly bears (Clevenger & Waltho 2000, 2005; Clevenger et al. 2002; Ford et al. 2009, 2017; Sawaya et al. 2013), augmented by recent work along Highway 93 in Montana's Mission Valley (Hardy et al. 2007, Huijser et al. 2016, Andis et al. 2017).
[49] For example, see Primm & Wilson (2004), Wilson & Clark (2007), Clark et al. (2013), Clark & Rutherford (2014), Wilson et al. (2014), Miller et al. (2016), and Van Eeden et al. (2018).

9. The Future

Grizzly bears in the Northern Rockies face major environmental changes of a magnitude not seen since the Late Pleistocene and early and middle Holocene, but unfolding at a much faster pace[50]—faster even than the whipsaw changes of the Younger Dryas or 8.2k Episode (see Sections 2 and 3); faster perhaps than at any period in Earth's history other than during catastrophes triggered by impacts of extra-terrestrial objects; and of a severity that will likely rival the end-Permian early-Triassic transition that triggered mass extinctions[51].

These phenomenal environmental changes will challenge grizzly bears, although deep history would suggest not fatally—at least for the species as a whole. Grizzlies have managed to survive extreme environments served up by global change during the last million years or so. But grizzlies will be affected—through changes in the types, abundance, and nutritional quality of available foods[52] with prospectively orders-of-magnitude effects on bear densities[53]. At the very least, distributions and behavioral strategies of grizzly bears will be affected through changes in distributions of preferred foods and increases in potential heat stress[54].

But, even more importantly, the near future will be different in ways unlike any epoch in the past. The world occupied by grizzly bears in western North America will also be occupied by a non-trivial number of people who are armed to the teeth—disproportionately older, rural-dwelling, white males (Parker et al. 2017)—and who see themselves as entitled to dominate, use, or kill as they please. This statement may come across as being politically incorrect, nonetheless it is overwhelmingly supported by scientific research[55]. More hopefully, broader trends in human attitudes suggest that increasing

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[50] The scientific literature on the rapidity of climate warming and related ecological consequences is overwhelming. A couple of seminal papers and reports include Loarie et al. (2009), Burrows et al. (2011), LoPresti et al. (2011), Halpern et al. (2019), Oreskes et al. (2019), and Shukla et al. (2019). Even the most optimistic projections have been bleak, but recent evidence suggests that warming has, in fact, been remarkably fast since the 1970s when reckoned against an increasingly reliable specification of 1850-1950 temperatures (Li et al. 2020), and well on track to the worst-case RCP8.5 scenario of global warming (Schwalm et al. 2020).

[51] Ward (2007) provides an accessible introduction to the end-Permian environment and related extinctions. The essay that is linked at the end of this sentence provides an overview specifically in reference to grizzly bears as well as a link within (at the end) to a downloadable pdf with a list of references for those who want to dig deeper: https://www.grizzlytimes.org/single-post/2019/07/20/through-the-climate-looking-glass-into-grizzly-wonderland

[52] See Mattson et al. (2004) for a summary of the digestibilities and nutritional content of characteristic bear foods, all of which can vary by orders of magnitude.

[53] Miller et al. (1997) and Mowat et al. (2013) summarize orders of magnitude differences in North American grizzly bear densities that are directly linked to habitat productivity, with greatest differences between coastal regions where bears have access to anadromous salmon and interior regions without, but also with 10-fold or more differences in densities of interior grizzly bear populations.

[54] There is an increasing body of science offering insight into how climate change will likely affect bears, including through changes in regional configurations of productive habitat (Roberts et al. 2014, Su et al. 2018, Zhen et al. 2018, Penteriani et al. 2019, Dai et al. 2019), effects on phenology and productivity of bear foods (Holden et al. 2012, Carlson 2017, Deacy et al. 2017, Laskin et al. 2019), and effects on thermoregulatory (Pigeon et al. 2016a, Sawaya et al. 2016, Zhang et al. 2018, Schneider et al. 2020, Rogers et al. 2021) and denning behaviors (Pigeon et al. 2016b, Johnson et al. 2017, Delgado et al. 2018, Fowler et al. 2019, González-Bernardo et al. 2020).

[55] This essay https://www.grizzlytimes.org/single-post/2018/07/15/entrusting-grizzlies-to-a-basket-of-deplorables provides numerous links to articles that report research delving into social and psychological dynamics of political conservatism, especially as consolidated around an ideological agenda of social dominance, intolerance, authoritarianism, and allegiance to Donald Trump. This essay https://www.grizzlytimes.org/single-

Climate in the Clearwater Drainage

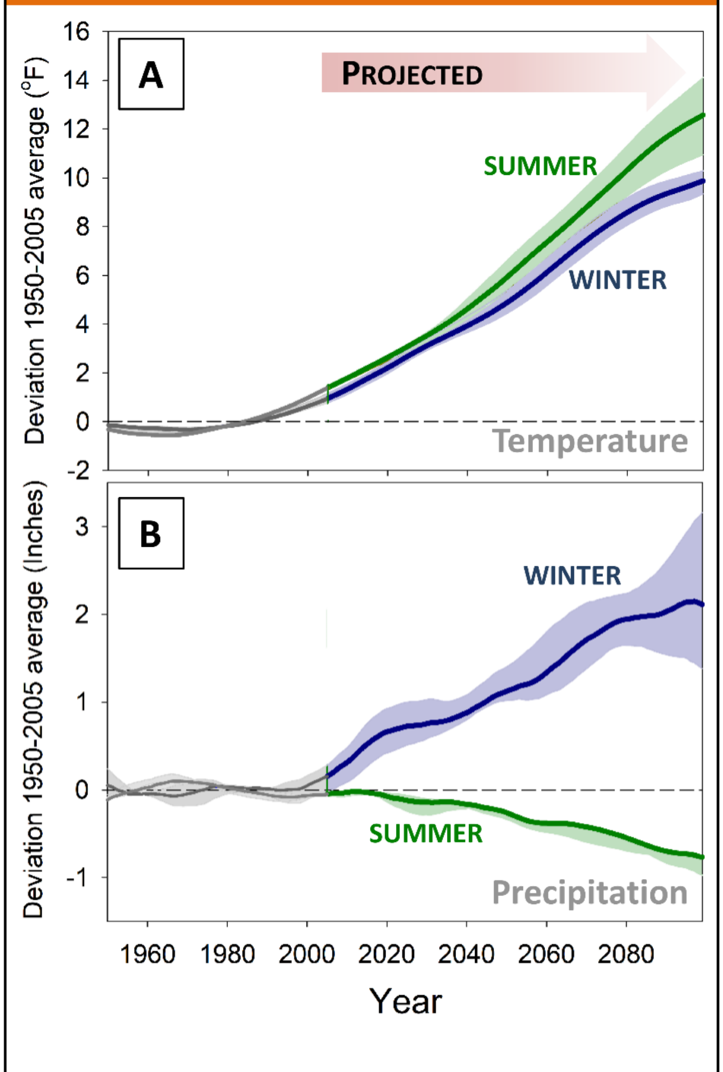

Figure 28. These two graphs show past (pre-2005) and projected future trends in average (A) temperature and (B) precipitation in Clearwater Country, Idaho, inclusive of the Clearwater River drainage (from the Applied Science Climate Lab and UW Hydro Groups' *The Climate Toolbox,* which provides county-resolution summaries of past and future climate). The graphs show trends in deviance of means and upper and lower quartiles from 1950-2005 averages. The blue-shaded lines and envelopes defined by quantile deviances show winter trends whereas the green-shaded lines and envelopes shows summer trends.

numbers of people see themselves and other animals as fellow inhabitants of a biosphere that is increasingly threatened (see Kellert & Wilson [1995], Kellert [1996], and Manfredo et al. [2020a] for insight into these trends).

The following two sections attempt to bring sharper focus to near-future projections for the northern U.S. Rocky Mountains, featuring not only on environmental change, but also prospective changes in human numbers and attitudes. The magnitude and nature of foreseeable environmental changes during the next 50-100 years will place a mounting burden on people to reconfigure attitudes and institutions if the rich biota of the Northern Rockies is to survive—including grizzly bears.

9.a. Environmental Changes

The climate of areas that could potentially support grizzlies in Idaho will change during the next 50-100 years, accelerating trends that have been evident since the 1970s. Figure 28 features projected climate changes for Clearwater County, Idaho—emblematic of what the future holds for potential suitable grizzly bear habitat throughout Idaho, as well as for the current locus of grizzly bear colonization in the Clearwater River drainage.

Foreseeable changes in seasonal temperatures are not subtle (Figure 28a), with projected increases of a staggering 12°F (6.7°C) during summer and 10°F (5.6°C) during winter. This change is tantamount to transporting the winter temperatures of St. George, Utah, and

post/2018/10/18/basket-of-deplorables-revisited-grizzly-bears-at-the-mercy-of-wyoming elaborates on how these social-psychological dynamics have been manifest more recently in relations with grizzly bears.

summer temperatures of Moab, Utah, roughly 9° latitude north to Moscow, Idaho. Although this projection is based on the International Panel on Climate Change's (IPCC's) worst-case RCP8.5 scenario, this prognosis is warranted by our current climate trajectory (Schwalm et al. 2020) and apparent inability, globally, to adequately curb greenhouse gas emissions (see Blanco et al. [2014] and Friedlingstein et al. [2020]).

Projected Changes in Stored Ecosystem Moisture

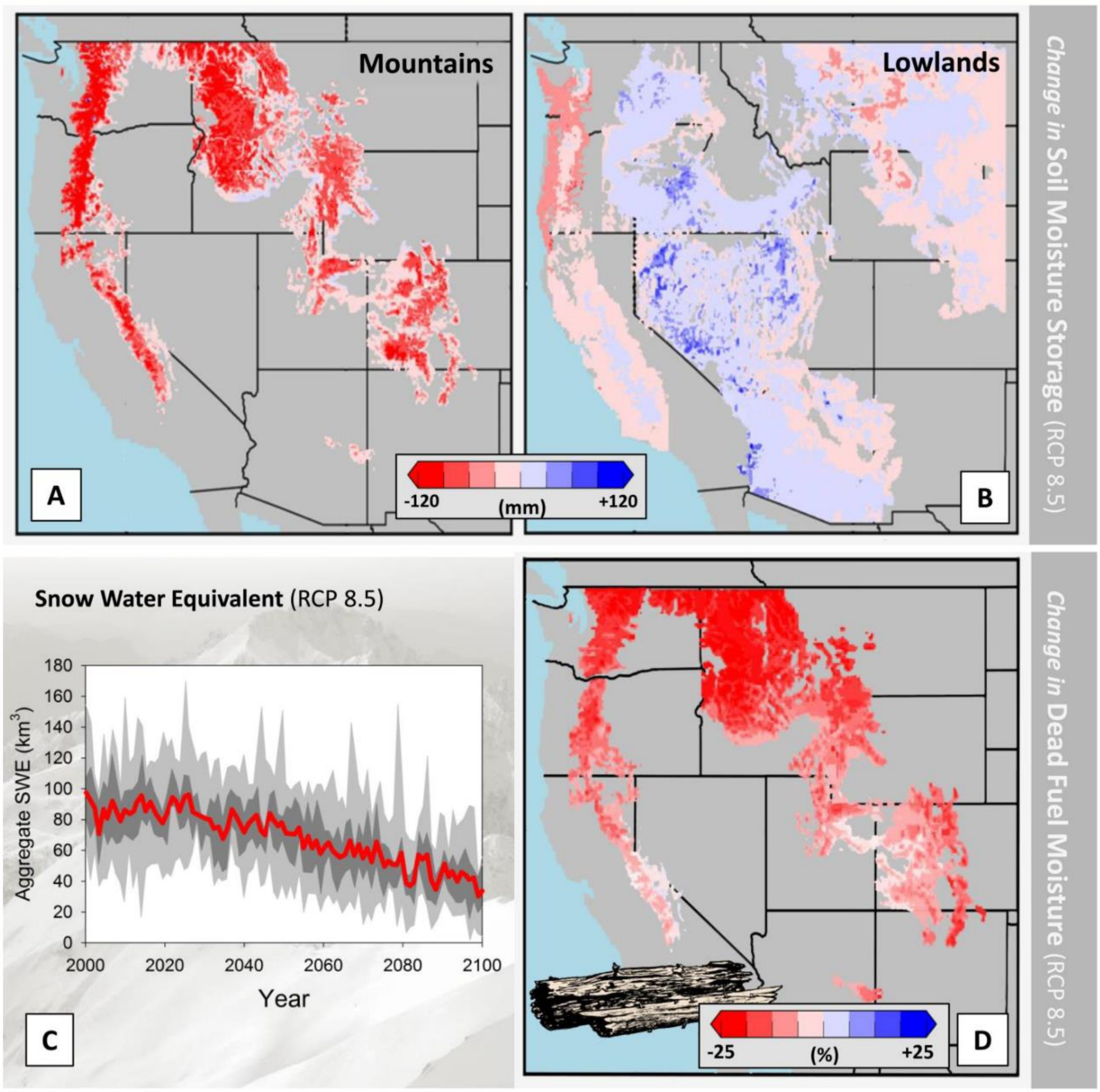

Figure 29. These four graphics show projected changes in moistures conditions during the next 80 years, with direct relevance to the ignition and spread of forest wildfires, including soil moisture storage (A) in mountainous and (B) in lowland areas, and related changes in (D) moisture content of woody fuels. Increases in moisture relative to current normals are shown as progressively darker shades of blue; comparative drying is shown as progressively darker shades of red. Figure (C) shows projected changes in moisture delivered and stored as snow (snow water equivalent), which is a direct driver of soil and fuel moisture in mountain areas. All of these graphics are adapted from Gergel et al. (2017).

Projected Forest Cover & Composition

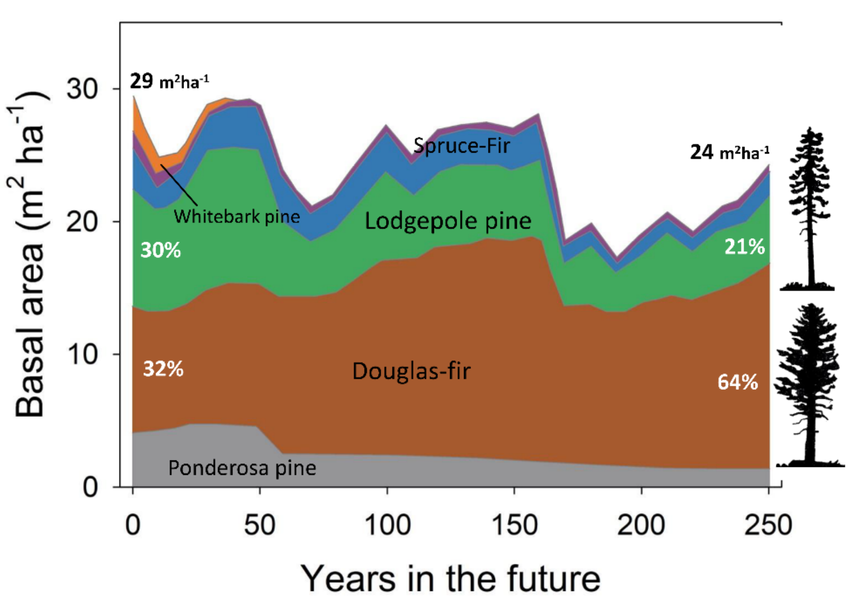

Figure 30. Climate change will interact in sometimes complex ways with wildfire, disease, and outbreaks of insects to shape forest composition and cover in the northern U.S. Rock Mountains. This graphic shows a 250-year projection for a watershed in the Bitterroot mountains simulating the effects of a warming climate, increasing wildfire frequency, outbreaks of mountain pine beetles (*Dendroctonus ponderosae*), and spread of white pine blister rust (*Cronartium ribicola*; Loehman et al. 2018). Total forest basal area in this watershed is projected to decrease by around 17%, although the biggest changes will be in forest composition, notably a doubling in the proportional representation of Douglas-fir (*Psuedotsuga menziesii*) and the disappearance of whitebark pine (*Pinus albicaulis*).

Projected changes in precipitation are not as dramatic, but still substantial, with a marked divergence in seasonal trends (Figure 28b). Winters will likely get wetter, although to an uncertain extent, whereas summers will more certainly get drier. The effects of sustantially warmer winter weather will have major impacts on the proportion of precipitation falling as rain versus snow, with loss of snow-dominated winter weather projected for almost all watersheds in the Columbia River Basin during the next 60-80 years (Mantua et al. 2010, Hamlet et al. 2013).

As a consequence, peak streamflows will occur earlier (e.g., Hamlet et al. 2013 U.S. Department of the Interior, Bureau of Reclamation 2016), accompanied by increasing stream temperatures and increased frequency of flood events (e.g., Mantua et al. 2010, Tohver et al. 2014, U.S. Environmental Protection Agency Region 10 2020).

But the synergistic impacts of drier hotter summers and proportionally reduced snowfall will not be limited to hyrologic regimes. Perhaps self-evidently, the water content (i.e., SWE), spatial extent, and seasonal duration of snow packs will decline substantially (Figure 29c; Hamlet et al. 2013, Gergel et al. 2017, Dalton & Fleishman 2021). The derivative effects of these changes will be reduced summer moisture storage and content of both soils and dead fuels in mountain areas (Figures 29a and 29d; Gregel et al. 2017), with resulting increases in the frequency and extent of wild fire, albeit it with some opportunities for limited mitigation (Barbero et al. 2015, Holden et al. 2018, Halofsky et al. 2020).

All of this will lead to inevitable effects on vegetation cover and composition, with a predictable shift to fire-adapted drought-tolerance species. Although there is not room here to summarize the compendious research on this topic (although, see Halofsky et al. [2018, 2020] and Halofsy & Peterson [2018] for summaries), Figure 30 is illustrative of prospective changes. The projections in this figure are based on simulations that include the effects of climate warming, wildfire, white pine blister rust (*Cronartium ribicola*), and mountain pine beetle (*Dendroctonus ponderosae*) for a watershed of the Bitterroot River drainage (Keane et al. 2015). The modeled dynamics result in a proportional increase of Douglas-fir—which is particularly well-adapted to frequent wildfire—along with an unsurprising loss of cold-adapted species (whitebark pine, subalpine fir, and Engelmann spruce) and a decrease in overall forest basal area. But, then, this is only the tip of the proverbial iceberg.

Dramatic increases in temperatures together with diminished snowpacks and substantial summer-time drying will predictably lead to deteriorating hydrologic regimes and increasingly frequent wildfires throughout most of Idaho. These and other environmental changes will almost certainly translate into foreseeable impacts on foods that are currently important to grizzly bears in Idaho's potential suitable habitat.

9.b. Changes in Bear Foods

First and foremost, the extent of environments hospitable to fruit-producing shrubs will likely shrink—including for huckleberry (*Vaccinium memberanaceum*), serviceberry (*Amelanchier alnifolia*), buffaloberry (*Shepherdia canadensis*), and chokecherry (*Prunus virginiana*). Figure 31 shows where climates suitable for these four species are projected to persist in and near the northern U.S. Rocky Mountains (Ironside & Mattson 2014, Prevéy et al. 2020). In all of the panels except for huckleberry, areas of likely persistence are shown in green, whereas areas of likely loss are shown in yellow. In the case of huckleberry, persistence is show in shades of blue and loss in shades of brown. As a point of reference, the boundary of the Nez Perce-Clearwater National Forests is also shown.

In a nutshell, greatest losses are projected for chokecherry and serviceberry whereas least losses are projected for buffaloberry. Of particular relevance to north-central and central Idaho, huckleberry will likely persist only in the highest-elevation areas; chokecherry will likely disappear altogether from most areas; whereas significant portions of the Nez Perce-Clearwater Forests will likely form a notable refugium for serviceberry. One important point that emerges from these projections is that persistence and loss of will not be a simple matter of species migrating up in elevation. Responses will likely be more complex than that, driven by interactions of species-specific adaptations to shifting seasonal climatic regimes. Even so, the overall picture is one of net losses in abundance of fruit-producing shrubs that are currently important to grizzly bears.

Insofar as anadromous salmonids are concerned, the scientific literature on how climate change will directly or indirectly affect species in the Pacific Northwest is so voluminous that NOAA's Northwest Fisheries Science Center devotes a 30 to 60 page-long publication each year to reviewing what was produced the year before (i.e., *Impacts of climate change on salmon in the Pacific Northwest: A review of the scientific literature published in*…). Needless to say there are many nuances and complexities.

Even so, there is an emerging consensus about fundamentals, notably reported in Crozier et al. (2019, 2020). According to the ranking system used by Crozier et al. (2019), 10 of 11 distinct population segments (DPSs) of chinook salmon are rated as being highly or very highly vulnerable to the impacts of climate change, whereas all 11 DPSs of steelhead are rated as being either highly or moderately vulnerable. More specifically for the Salmon and Clearwater River drainages, steelhead populations in almost all reaches are judged to be highly sensitive and exposed to either worsening thermal or flow regimes (Wade et al. 2013), although a more replete reckoning of vulnerability suggests that there are amplifying concerns related to genetic impoverishment (Wade et al. 2017). The upshot is that, although not as threatened by climate change as populations in middle reaches of the Columbia Basin, salmon and steelhead in Idaho will likely be diminished.

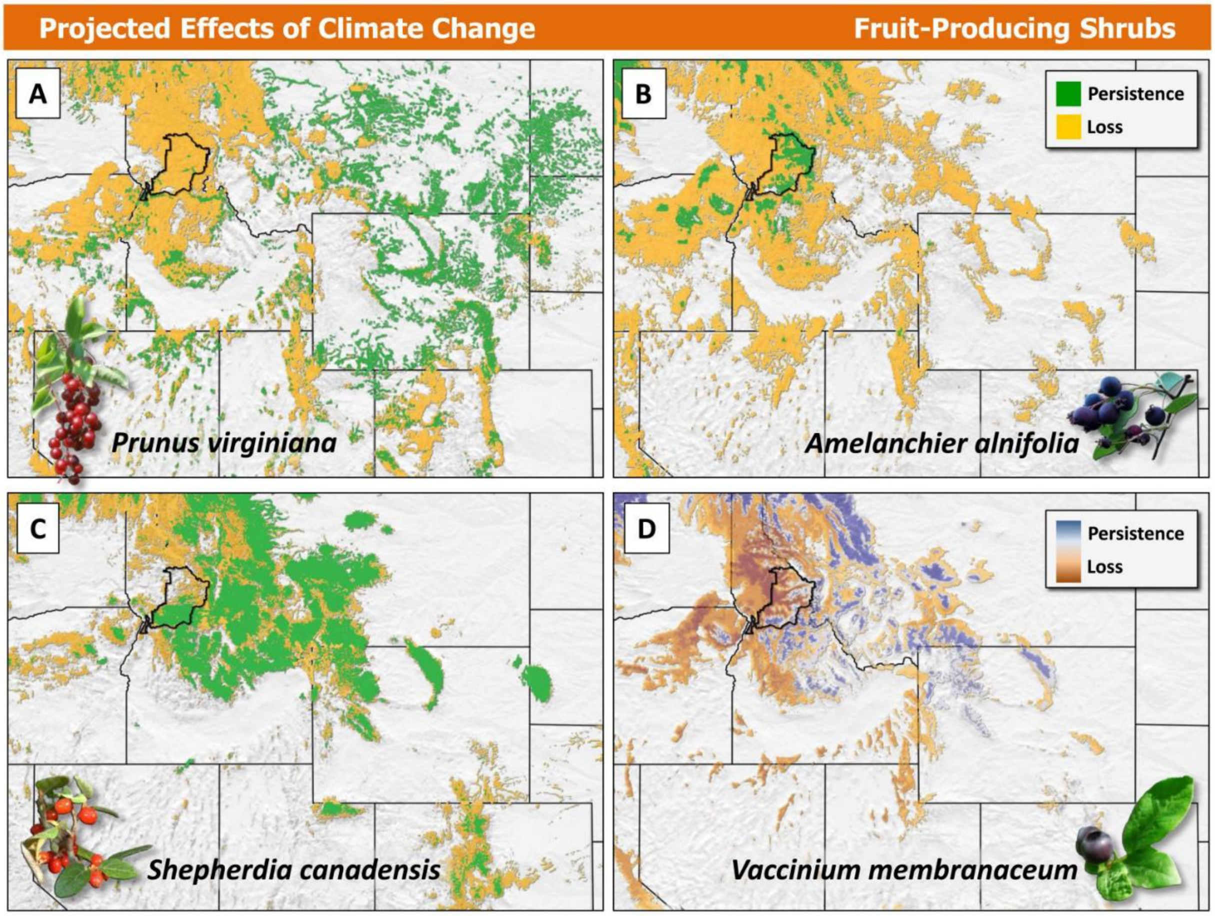

Figure 31. These maps show projected changes in distributions of four shrubs that are currently the source of most fruit eaten by grizzly bears in the U.S. Northern Rocky Mountains. Projections are based on anticipated changes in climate and related changes in climate envelope for each species, but without accounting for effects of altered fire regimes or changing abundance of pollinators. Projections in (**A**)-(**C**) are shown relative to a cutpoint above which the species' climate envelope has a >50% chance of persisting (green) and below which the envelope is unlikely to persist (yellow) by the end of 2050 (from Ironside & Mattson [2014]). Projections in (**D**) are shown in terms of increased or decreased joint probability of both shrub presence and fruit production for huckleberry during the next 80 years (adapted from Prevéy et al. [2020]). The boundary of the Nez Perce-Clearwater National Forests is shown as a thick black line in each of the panels.

Finally, and without being exhaustive, whitebark pine will almost certainly disappear during the next 100 years as an important bear food in central Idaho. There is a veritable cottage industry of research projecting the future of high-elevation haunts for whitebark pine, few of which have improved on an original prognosis by Romme & Turner (1991) showing a >90% attrition in the distribution of whitebark pine in the Yellowstone ecosystem due to climate warming. The numerous projections since then, deploying progressively more sophisticated models, have shown the same basic result (for example, Coops & Waring 2011, Chang et al. 2014, Smith-McKenna et al. 2014, Case & Lawler 2016)—which is much the same as has been shown for alpine habitats destined to be figuratively pushed off the mountain-tops (Diaz & Eischeid 2007, Rehfeldt et al. 2012, Hansen et al. 2015). As important, the devastation caused by a climate-driven mountain pine beetle outbreak in the Yellowstone ecosystem during 2000-2009 revealed how quickly whitebark pine could be functionally extirpated as a bear food (Macfarlane et al. 2013).

Other changes in the natural environment are foreseeable, including an abbreviation of the season and attrition of sites where succulent forbs are available for bears to graze. But one prospectively consequential change involves meat from terrestrial sources. A pattern has emerged in the Greater Yellowstone and Northern Continental Divide Ecosystems typified by increased consumption of meat by grizzly bears in places or at times when other high-quality foods are not abundant. In the past this occurred in the Yellowstone Ecosystem during years when whitebark pine seeds were scarce (Mattson 1997). But during the last few decades, with essentially permanent losses of whitebark pine in both the Yellowstone and eastern portions of the Northern Continental Divide Ecosystems, grizzly bears have substantially increased their consumption of meat, often as a result of colonizing peripheral areas populated by livestock (Mattson 2017, 2019a). In the NCDE, meat accounts for nearly 90% of ingested energy and nutrients for grizzlies occupying the High Plains (Mace & Roberts 2012).

Emerging patterns in the Yellowstone and Northern Continental Divide Ecosystems foreshadow a future in which additional vegetal foods are lost and grizzly bears switch to alternate high-quality foods that catalyze local changes in distribution—a future in which meat from terrestrial sources plays a prominent dietary role (see the dietary economies in Figure 17), as it likely did at lower elevations in Idaho during the late Pleistocene and early to middle Holocene (Sections 2.b. and 3.b.). If this future comes to pass, it will put human-bear relations increasingly to the test, especially when there are conflicts with livestock producers subject to depredation losses or hunters jealous of their preprogatives to kill harvestable elk.

9.c. The Future With Humans

Within the next 40 years there will almost certainly be more people living near and recreating in areas occupied by grizzly bears. However, if current drivers and past trends continue to hold, growth in human populations will not be geographically uniform. Figure 32 provides a summary of trends and projections broken down, not only by grizzly bear ecosystems, but also by counties within each ecosystem that have experienced the most and least growth during the last 40 years—between 1980 and 2020. Perhaps not surprisingly, populations of rural counties dependent on agriculture and extractive industries have grown very little, whereas populations of “amenity-rich” counties have exploded, especially in and near the Northern Continental Divide and Yellowstone Ecosystems. Interestingly, the fastest growing counties near the Selkirk, Cabinet-Yaak, and Selway-Bitterroot Ecosystems have grown at a significantly slower pace, but with potentially substantial increases in human populations projected for the next 40 years.

There is little reason to expect that the divergence in population gains between amenity-rich counties and the rest will change, largely because there is little reason to anticipate that drivers of growth will change. Past population increases have been linked to nearness of airports, interstate highways, universities, hubs of entrepreneurial activity, and destination resorts such as ski areas—more so even than to the presence of protected areas and dramatic scenery in the figurative backyard, although both also help (Rasker & Hansen 2000; Gude et al. 2006; Rasker et al. 2009, 2013). This configuration of drivers serves to explain not only low rates of population growth in counties dependent on extractive industries, but also lower rates of population growth in Valley and Ravallii counties compared to Missoula, Lewis & Clark, Flathead, Gallatin, and Teton (Wyoming) counties.

Projected Changes in Human Populations

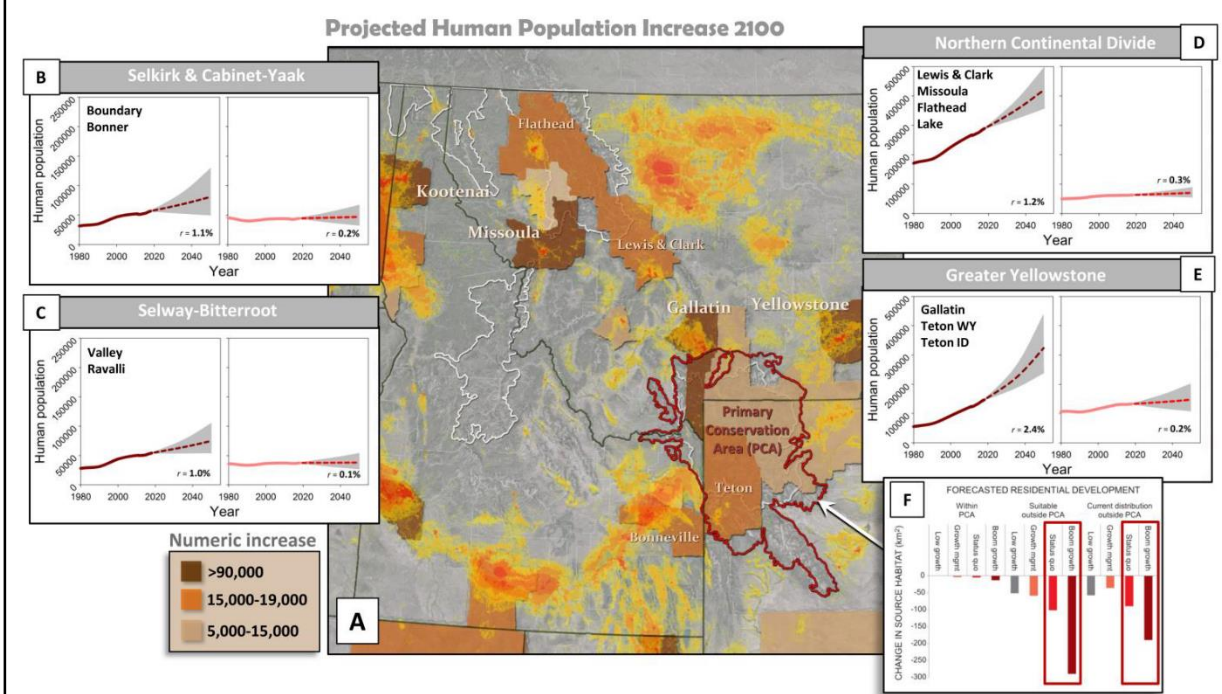

Figure 32. This set of graphics summarizes past and projected trends in human populations in the northern U.S. Rocky Mountains, 1980-2060, differentiated by counties encompassing different grizzly bear ecosystems, delineated by white lines. In addition, counties are differentiated for each ecosystem by those that are the fastest growing (left panel of each pair) versus the remainder (right panel). Human populations in and near (B) the Selkirk, (B) Cabinet-Yaak, and (C) Selway-Bitterroot Ecosystem have grown much slower than human populations in the (D) Northern Continental Divide and (E) Greater Yellowstone Ecosystems—a trend that is projected to for the next 40 years. (A) Counties that are projected to have the greatest numeric increases are shown in various shades of brown, with those colored darkest (Kootenai, Idaho; and Missoula and Gallatin, Montana), projected to gain >90,000 people during the next two decades. The impacts of this projected growth are shown for the Greater Yellowstone area in (F), including potential losses of 300-km^2 of source habitats for grizzly bears (Schwartz et al. 2012). The current human footprint, including impacts of human infrastructure and permanent conversions to agriculture, is shown in shades of orange (Leu et al. 2008; map data from Databasin, uploaded by Conservation Biology Institute). Historical trends in human populations are from U.S. Census Bureau; projected trends are from Hauer (2019).

Regardless of the locus of population increases, there are additional important nuances and dynamics. People who live in amenity-rich counties don't stay there. They typically travel regionally to recreate, and those who are most likely to participate in backcountry recreation fit the demographic profile of people disproportionately immigrating into amenity-rich counties of the northern U.S. Rockies[56]. All of these patterns have likely led to increasing rather than decreasing frequencies of contact between grizzly bears and people, regardless of where people have specifically been inclined to settle.

Even so, potential suitable grizzly bear habitat in Idaho is characterized by an auspicious configuration of formally protected and *de facto* protected wildlands, including Wilderness Areas, Wilderness Study Areas, and Inventoried Roadless Areas (IRAs)—all of which predictably mitigate against intrusions by

[56] Cordell (2012) and Mockin et al. (2012) provide useful summaries of participation in different outdoor recreational activities, not only by demographic group (i.e., age, sex, race, ethnicity, income, and region), but also over time. Young white people with even modest amounts of disposable income are the most likely of all groups to be active in the backcountry, especially in the Rocky Mountain region. Not surprisingly, this demographic accounts for much of the immigration into the northern U.S. Rocky Mountains during the last 20 years.

Roadless Areas & Suitable Grizzly Bear Habitat

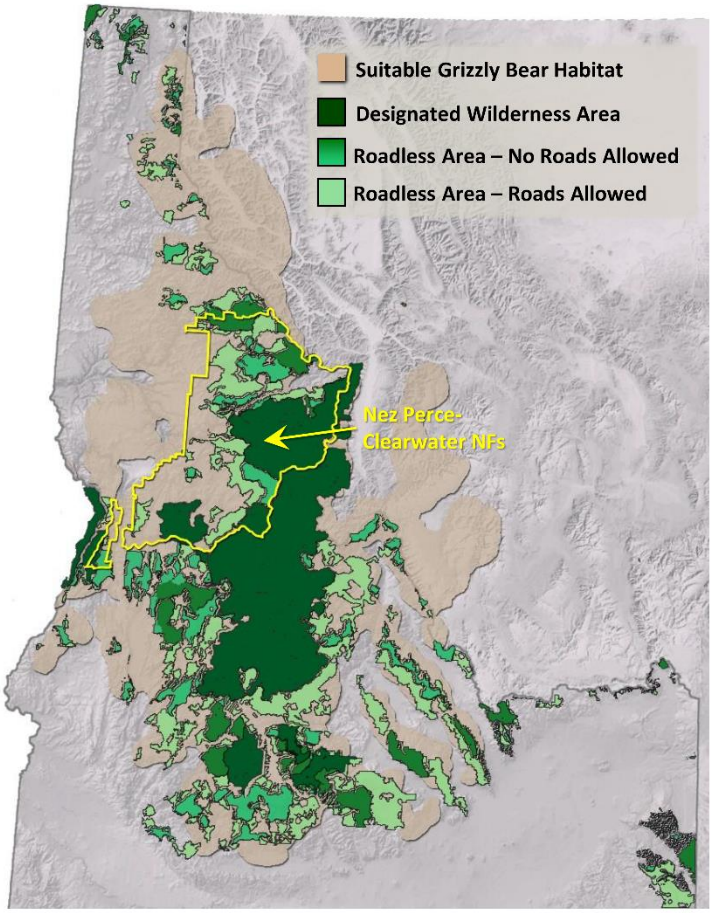

Figure 33. This map shows the extent of potential suitable habitat in Idaho, including contiguous areas in Montana (beige; see Figure 12) along with designated Wilderness Areas (darkest green), Inventoried Roadless Areas (IRAs) where road construction and maintenance are prohibited (medium shades of green), and IRAs where road construction and maintenance are allowed (lightest green). Maps of IRAs follow 2001 delineations and are from https://www.fs.usda.gov/detail/roadless/2001roadlessrule/maps/statemaps/?cid=fsm8_037707

people, especially beyond the likely distance of a day-hike or mountain bike foray. The map in Figure 33 provides a visual summary of the remarkable extent of these wildlands in Idaho. Insofar as grizzly bear conservation is concerned, the *status quo* turns out to be auspicious—unlike in much of the western United States. But this favorable situation will only provide future benefits if it is conserved, and much of that conservation will be contingent on whether and to what extent Wilderness Study Areas and IRAs are given permanent meaningful protections. In other words, preservation of these roadless wildlands offers perhaps the best means of offsetting foreseeable impacts of increasing regional human populations on recovering grizzly bear populations in north-central and central Idaho.

But perhaps even more important, human attitudes, values, and perspectives will matter. The newcomers who have fueled population growth have brought pursuits, behaviors, employments, and worldviews with them that differ from those of long-time residents (Shumway & Otterstrom 2001, Hansen et al. 2002, Ghose 2004). More specifically—as Manfredo et al. (2009) put it—they tend to be more "mutualistic" as opposed to personally identified with domination; or, as Kellert (1996) earlier characterized it, more likely to anthropomorphize animals and be concerned about their welfare rather than invested in using and dominating them. And those who are invested in domination and use also tend to be more lethal to wildlife, especially predators such as mountain lions (*Puma concolor*; Mattson & Ruther 2012).

The upshot is that proportionately fewer of those fueling human population growth in the northern U.S. Rockies are likely to kill grizzly bears compared to longer-term residents embued with traditional rural values espousing domination and use of wildlife, largely as a consequence of the differential prevalence of “domination” and “mutualism” values (Manfredo et al. 2020a). Or, as framed in Box 3 on page 49, grizzly bears stand a decent chance of weathering increasing numbers of encounters with people because each encounter, on average, will likely be less lethal for the involved bear.

But the key part of this equation is lethality, which derives not only from the attitudes being brought by newcomers, but also by shifting attitudes among longer-term residents. And there are indications that longer-term residents, as well as those identified with the cultures of hunting and ranching, are not becoming less but rather more lethal.

A major driver of prospective increases in lethality among hunters and rural residents is plausibly rooted in resentment—resentment of changes in culture, demographics, political privilege, and economic configurations being catalyzed by the influx of newcomers. These resentments and associated backlash and “revolts” are well-documented and well-scrutinized (for example, see Krannich & Smith [1998], Ulrich-Schad & Duncan [2018] and Berlet & Sunshine [2019]). But the link to grizzly bears—and other large carnviores—is plausibly through the extent to which those who identify with traditional lifeways and values identify newcomers with alien mutualistic orientations towards wildlife. In other words, resentment of newcomers and the changes they represent likely translates into resentment of the animals these newscomers value—especially large carnviores such as grizzly bears and wolves (*Canis lupus*; Nie 2003).

The result is plausibly a backlash among many hunters, ranchers, and other long-time rural residents against large carnivores that they identify with newcomers (e.g., Manfredo et al. 2017). In other words, real bears become “symbol bears” (Primm 2000), with symbolic loadings rather than objective realities driving people’s behaviors. Hence the likely prevalence of poaching as a cause of grizzly bear deaths in the Selkirk, Cabinet-Yaak, western Northern Continental Divide Ecosystems (see Section 7.a.)—in rural counties typified by stagnating extractive industries and dominated demographically by politically conservative people without a college education, who also happen to be white (U.S. Census Bureau; U.S. Federal Election Commission); i.e., those who are most inclined to feel “left behind” in the New West (Wuthnow 2018).

Relations with humans will continue to dictate whether grizzly bears survive and thrive in the northern U.S. Rocky Mountains, including in the wildlands of Idaho. Yet relations with people have become increasingly typified by volatile dynamics at the juncture of human population increases, socio-economic change, political conflict, and unstable attitudes. The future of grizzlies will likely depend on whether human resentments and population increases are offset by the preservation of wild places and continued emergence of benevolent attitudes towards large carnivores.

10. Summary of Conclusions

Deep History

The grizzly bears that occupied Idaho for millennia—and continue to hold on in Idaho's portions of the Selkirk, Cabinet-Yaak, and Yellowstone ecosystems—are members of a unique evolutionary and biogeographic lineage that has disappeared virtually everywhere else on Earth.

Grizzly bears in Pleistocene Idaho were probably relegated to using marginal habitats, foods, and temporal windows as means of avoiding other predatory carnivores and obtained meat primarily by scavenging large-bodied herbivores in amounts likely to constitute an important food for many bears. Despite this, most grizzlies probably relied primarily on vegetal foods for the bulk of their diet, with whitebark pine seeds also of prominent importance.

Pre-European Holocene

The Altithermal was probably a stressful period for grizzly bears caused by hot-dry conditions that reduced amounts of vegetal foods—including the abundance of whitebark pine—for perhaps as long as 3,500 years. By contrast, the generally cooler and wetter conditions that followed the Altithermal not only resulted in greater herbaceous productivity, but also an increased frequency of forest fires that likely resulted in greater amounts of available fruit on shrub species such as huckleberry and buffaloberry—both of which tend to flourish in more open conditions—and thus in the wake of forest fires.

Grizzly bears in most parts of ancestral Idaho probably had access to abundant meat during the Holocene either from spawning anadromous salmonids or from large-bodied herbivores such as bison and elk, with these two sources complementary in both time and space. The challenges to grizzlies posed by humans, at least up until the arrival of European horses and then Europeans themselves, tended to be spatially concentrated along specific reaches of the Columbia and Salmon Rivers, leaving bears ample access to salmon in mountainous areas of central Idaho. There may even have been a brief Edenic time for grizzlies that lasted a couple of centuries between when European diseases took their toll on indigenous human populations and lethal Europeans arrived in person.

The Arrival of Europeans

The future state of Idaho almost certainly supported several thousand grizzly bears at the time of European contact, with highest bear densities likely occurring in portions of the state north of the Snake River Plain. Central and northern ancestral Idaho were probably more productive environments for grizzly bears compared to the arid and semi-arid Snake River Plain, largely as a consequence of abundant fruit, anadromous salmonids, and whitebark pine. Central portions of the Snake River Plain may have only supported significant numbers of grizzly bears when bison roamed this region prior to the 1830s-1840s.

Impacts of Europeans in nascent Idaho likely unfolded in pulses organized around different episodes of colonization and exploitation with different geographic foci. Traffic on the Oregon Trail probably unleashed an early devastation of fauna on the Snake River Plain during the 1840s-1860s. Miners flooded remote mountains of central and north-central Idaho during 1860s-1880s. Agriculture followed during the 1870s and 1880s, most dramatically on the Palouse Prairie where a native grassland that had previously supported bison was almost completely converted to non-native wheat. Barring the effects of subsequent dams on the Columbia and Snake Rivers, perhaps the most severe environmental impacts caused by European colonization played out during a remarkably brief 40-year period.

Extirpations of grizzly bears from Idaho by newly-arrived Europeans were rapid, widespread, and anomalous, with some anomalies plausibly explained by the concentration of grizzlies near lethal people in pursuit of spawning salmon, but with prospects of mineral-related wealth also sending people into even the most remote refuges left to grizzlies. The massive wildfires of 1910 and the near end of chinook salmon spawning runs might have contributed to delivering a *coup de grâce* to the last grizzlies left in the Clearwater country.

Prospects and Potential

Vacant wildlands of central and north-central Idaho currently have the potential to support as many as 1,000 grizzly bears which, if realized, would offer significantly greater odds of population persistence compared to if grizzlies were confined to the Selway-Bitterroot Recovery Area. However, long-term viability will require a contiguous interbreeding population of several thousand grizzly bears, which could be achieved if current populations were connected by on-going colonization of interstitial potential suitable habitat throughout the northern Rockies into Canada.

Prospective Diets

Much has changed between 1800 and now in the tableau of grizzly bear foods. Whitebark pine is diminished everywhere and, in areas to the north and west, functionally extirpated as a bear food by white pine blister rust. The distribution of spawning habitat for anadromous salmonids has been truncated in Idaho by high dams on the Snake River above Hells Canyon. Surviving salmon and steelhead populations elsewhere in Idaho have been dramatically reduced by impediments posed by numerous dams on the lower Columbia and Snake Rivers. Even so, much bear food remains, with the fruit and forb-based dietary economy of north-central Idaho essentially intact.

The current distributions of major bear foods together with diets documented for grizzly bears in nearby ecosystems provide ample basis for anticipating what grizzlies would likely eat in different parts of central and north-central Idaho, ranging from a dominance of fruit and forbs to the north, to greater contributions of elk and whitebark pine seeds to the south—with salmon and trout of possible importance in between.

Given the large sizes of adult chinook salmon, steelhead trout, and even bull trout—all often >4 kg—fishing by grizzly bears could probably be sustained in headwaters of the Clearwater and Salmon Rivers by even modest spawning runs—which could, in turn, result in salmonids playing a significant role in the diets of grizzly bears in central and north-central Idaho.

There are clearly ample foods for grizzly bears on the Nez Perce-Clearwater National Forests, including potentially substantial amounts of meat from either salmonids or elk throughout the bears' active season. During summer and fall, distributions of key foods will likely attract grizzlies to comparatively secure habitat, much of it in designated Wilderness Areas, whereas during spring productive habitats will probably attract grizzlies to lower elevations where conflicts with humans will be likely. Other conflicts could arise over foreseeable impacts of grizzly bear predation on iconic elk populations that some people see as existing primarily to provide a harvestable surplus for humans to kill.

Security and Coexistence Infrastructure

Because of inattention to conflict prevention by state wildlife and federal land managers, current conditions on the Nez Perce-Clearwater Forests are ripe for grizzly bear-human conflicts over unsecured garbage and food; conflicts over livestock depredations; conflicts with big game hunters; and mortalities caused by black bear hunters mistaking a grizzly for a black bear. All of this promises to leave managers scrambling to deal with grizzly bear mortalities arising from foreseeable conflicts.

Disregard for the best available science together with inexplicable variation in security standards among ecosystems complicate any assessment of whether conditions on the Nez Perce-Clearwater National Forests provide adequate security for grizzly bears—which is further complicated by being nested within the larger issue of what's needed at a broader scale to insure population viability. But these sorts of complications do not debar an evaluation of landscape conditions and useful comparisons with other ecosystems.

There is an imperative to reduce road access on the Nez Perce-Clearwater National Forests, not only because median levels of habitat security for grizzly bears are subpar, but also because measures to prevent conflicts are inadequate and likelihood of poaching and other illegal killing is comparatively high. In other words, heightened odds of prospectively lethal confrontions between humans and grizzly bears increases the need to reduce levels of contact through restrictive management of road access.

Fragmentation

Natural colonization of north-central Idaho by grizzly bears will clearly depend on successful immigration of grizzly bears from the Selkirk, Cabinet-Yaak, and Northern Continental Divide Ecosystems. However, this on-going process will predictably proceed at a slow pace because of hazards created by I-90 to the north and human settlements in the Bitterroot Valley to the east. As much as natural colonization will depend on creation of *in situ* conditions that foster survival of newly-arrived grizzlies, it will also depend on making I-90 and the Bitterroot Valley more permeable to migrants. Fortunately, there is no shortage of knowledge and experience about how to do this, whether related to highway crossing structures or human-grizzly bear coexistence.

The Future

Dramatic increases in temperatures together with diminished snowpacks and substantial summer-time drying will predictably lead to deteriorating hydrologic regimes and increasingly frequent wildfires throughout most of Idaho. These and other environmental changes will almost certainly translate into foreseeable impacts on foods that are currently important to grizzly bears in Idaho's potential suitable habitat.

Emerging patterns in the Yellowstone and Northern Continental Divide Ecosystems foreshadow a future in which additional vegetal foods are lost and grizzly bears switch to alternate high-quality foods that catalyze local changes in distribution—a future in which meat from terrestrial sources plays a prominent dietary role, as it likely did at lower elevations in Idaho during the late Pleistocene and early to middle Holocene. If this future comes to pass, it will put human-bear relations increasingly to the test, especially when there are conflicts with livestock producers subject to depredation losses or hunters jealous of their preprogatives to kill harvestable elk.

Relations with humans will continue to dictate whether grizzly bears survive and thrive in the northern U.S. Rocky Mountains, including in the wildlands of Idaho. Yet relations with people have become increasingly typified by volatile dynamics at the juncture of human population increases, socio-economic change, political conflict, and unstable attitudes. The future of grizzlies will likely depend on whether human resentments and population increases are offset by the preservation of wild places and continued emergence of benevolent attitudes towards large carnivores.

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The Grizzly Bear Promised Land

Past, Present & Future of Grizzly Bears in the Bitterroot, Clearwater, Salmon & Selway Country

Report GBRP-2021-1
2021

The Grizzly Bear Recovery Project

P.O. Box 2406,
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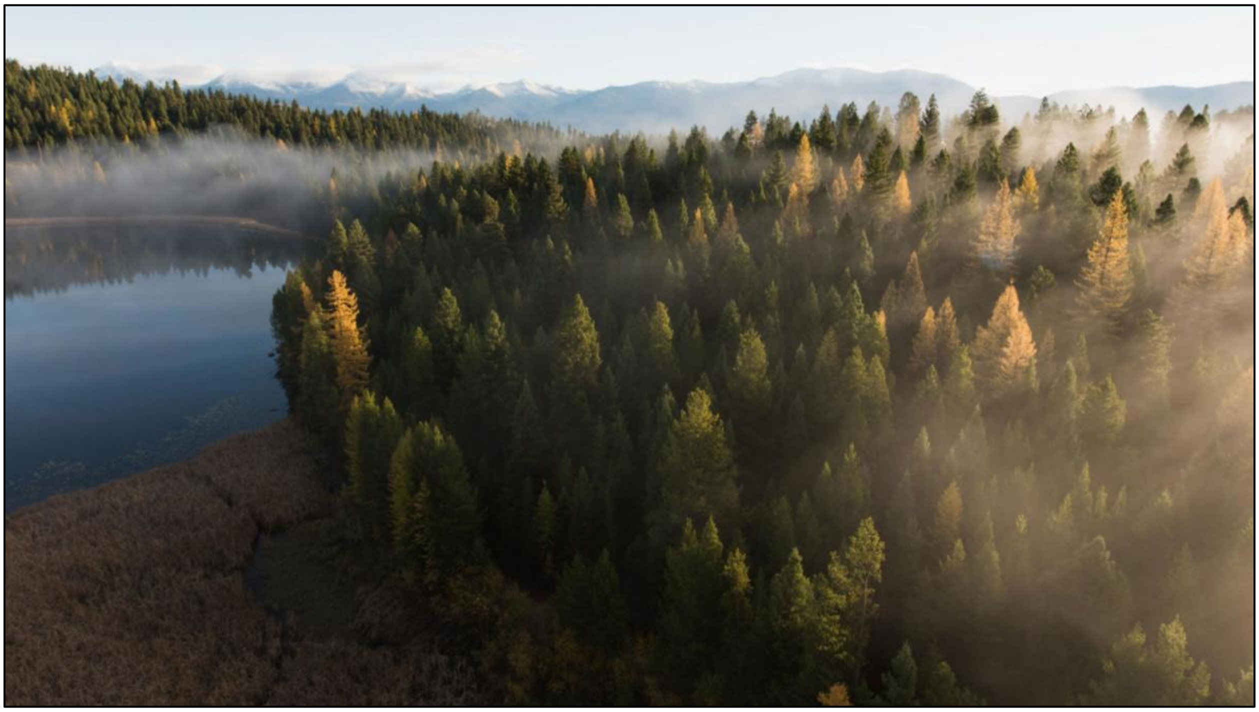
Natural Debate - Do Forests Grow Better With Our Help or Without

https://e360.yale.edu/features/natural-debate-do-forests-grow-better-with-our-help-or-without



The Tuppers Lake area in western Montana. STEVEN GNAM

24sep20 by FRED PEARCE / YaleEnvironment360

Nations around the world are pledging to plant billions of trees to grow new forests. But a new study shows that the potential for natural forest regrowth to absorb carbon from the atmosphere and fight climate change is far greater than has previously been estimated.

When Susan Cook-Patton was doing a post-doc in forest restoration at the Smithsonian Environmental Research Center in Maryland seven years ago, she says she helped plant 20,000 trees along Chesapeake Bay. It was a salutary lesson. "The ones that grew best were mostly ones we didn't plant," she remembers. "They just grew naturally on the ground we had set aside for planting. Lots popped up all around. It was a good reminder that nature knows what it is doing."

What is true for Chesapeake Bay is probably true in many other places, says Cook-Patton, now at The Nature Conservancy. Sometimes, we just need to give nature room to grow back naturally. Her conclusion follows a new global study that finds the potential for natural forest regrowth to absorb atmospheric carbon and fight climate change has been seriously underestimated.

Tree planting is all the rage right now. This year's World Economic Forum in Davos, Switzerland, called for the world to plant a trillion trees. In one of its few actions to address climate concerns, the U.S. administration — with support from businesses and nonprofits such as

American Forests — last month promised to contribute close to a billion of them — 855 million, to be precise — across an estimated 2.8 million acres.

The European Union this year promised 3 billion more trees as part of a Green Deal; and existing worldwide pledges under the 2011 Bonn Challenge and the 2015 Paris Climate Accord set targets to restore more than 850 million acres of forests, mostly through planting. That is an area slightly larger than India, and provides room for roughly a quarter-trillion trees.

The study found that natural regeneration can capture more carbon more quickly and securely than tree plantations.

Planting is widely seen as a vital "nature-based solution" to climate change — a way of moderating climate change in the next three decades as the world works to achieve a zero-carbon economy. But there is pushback.

Nobody condemns trees. But some critics argue that an aggressive drive to achieve planting targets will provide environmental cover for land grabs to blanket hundreds of millions of acres with monoculture plantations of a handful of fast-growing and often non-native commercial species such as acacia, eucalyptus, and pine. Others ask: Why plant at all, when we can often simply leave the land for nearby forests to seed and recolonize? Nature knows what to grow, and does it best.

Cook-Patton's new study, published in *Nature* and co-authored by researchers from 17 academic and environmental organizations, says estimates of the rate of carbon accumulation by natural forest regrowth, endorsed last year by the UN's Intergovernmental Panel on Climate Change, are on average 32 percent too low, a figures that rises to 53 percent for tropical forests.

The study is the most detailed attempt yet to map where forests could grow back naturally, and to assess the potential of those forests to accumulate carbon. "We looked at almost 11,000 measurements of carbon uptake from regrowing forests, measured in around 250 studies around the world," Cook-Patton told *Yale Environment 360*.

New vegetation grows amid burnt trees in the Amazon in the state of Para, Brazil. ANTONIO SCORZA/AFP VIA GETTY IMAGES

She found that current carbon accumulation rates vary by a factor of a hundred, depending on climate, soils, altitude, and terrain. This is much greater than previously assessed. "Even within countries there were huge differences." But overall, besides being better for biodiversity, the study showed, natural regeneration can capture more carbon more quickly and more securely than plantations.

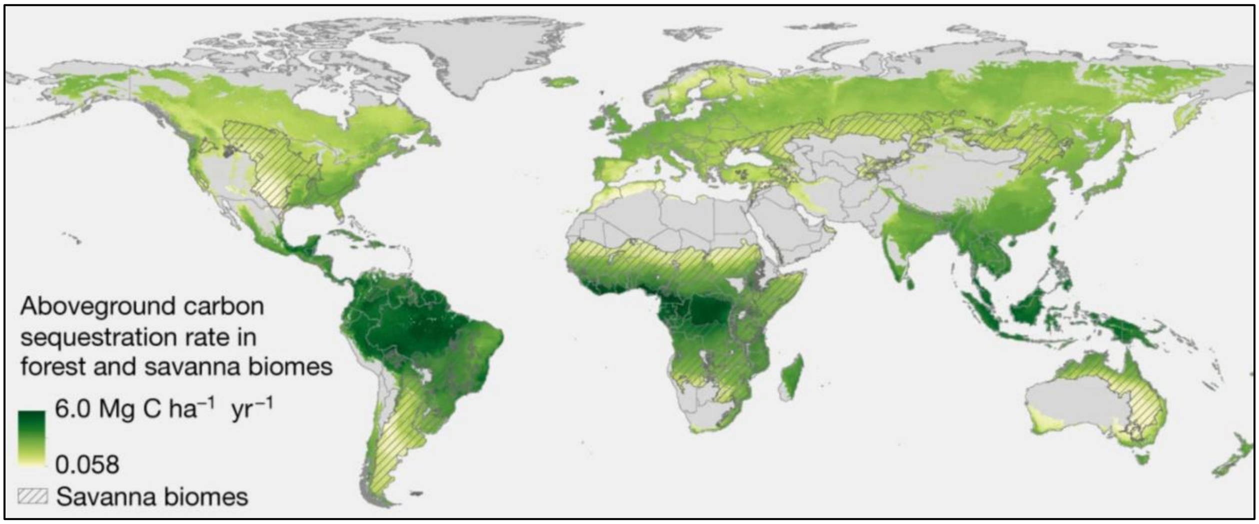
Will climate change upend projections of future forest growth? Read more.

Cook-Patton agrees that as climate change gathers pace in the coming decades, rates of carbon accumulation will change. But while some forests will grow more slowly or even die, others will probably grow faster due to the fertilization effect of more carbon dioxide in the air, an existing phenomenon sometimes called global greening.

The study identified up to 1.67 billion acres that could be set aside to allow trees to regrow. This excludes land under cultivation or built on, along with existing valuable ecosystems such as grasslands and boreal regions, where the warming effects of dark forest canopy outweigh the cooling benefits of carbon take-up.

Combining the mapping and carbon accumulation data, Cook-Patton estimates that natural forest regrowth could capture in biomass and soils 73 billion tons of carbon between now and 2050. That is equal to around seven years of current industrial emissions, making it "the single largest natural climate solution."

Cook-Patton said the study's local estimates of carbon accumulation fill an important data gap. Many countries intent on growing forests to store carbon have data for what can be achieved by planting, but lack equivalent data for natural regeneration. "I kept getting emails from people asking me what carbon they would get from [natural] reforesting projects," she says. "I had to keep saying: 'It depends.' Now we have data that allow people to estimate what happens if you put up a fence and let forest regrow."



Aboveground carbon accumulation rates, in metric tons of carbon per hectare per year, in naturally regrowing forests in forest and savanna biomes. COOK-PATTON ET AL., NATURE 2020

The new local estimates also allow comparisons between the potential of natural regrowth and planting. "I think planting has its place, for instance where soils are degraded and trees won't grow," she said. "But I do think natural regrowth is hugely under-appreciated."

The great thing about natural restoration of forests is that it often requires nothing more than human inaction. Nature is constantly at work restoring forests piecemeal and often unseen on the edges of fields, on abandoned pastures, in scrubby bush, and wherever forests lie degraded or former forest land is abandoned.

But because it requires no policy initiatives, investments, or oversight, data on its extent is badly lacking. Satellites such as Landsat are good at identifying deforestation, which is sudden and visible; but the extent of subsequent recovery is slower, harder to spot, and rarely assessed. Headline grabbing statistics on the loss of the world's forests generally ignore it.

In a rare study, Philip Curtis of the University of Arkansas recently attempted to get around the problem by devising a model that could predict from satellite imagery what had caused the deforestation, and hence the potential for forest recovery. He found that only about a quarter of lost forests are permanently taken over for human activities such as buildings, infrastructure, or farming. The remaining three-quarters suffered from forest fires, shifting cultivation, temporary grazing, or logging, and at least had the potential for natural recovery.

Another study published this year found that such recovery was widespread and rapid even in an epicenter of deforestation such as the Amazon. When Yunxia Wang of the University of Leeds in England analyzed recently-released Brazilian data from the Amazon, she found that 72 percent of the forest being burned by ranchers to create new cattle pasture is not pristine forest, as widely assumed, but is actually recent regrowth. The forest had been cleared, converted to cattle pasture and then abandoned, whereupon the forest returned so fast that it was typically only six years before it was cleared again. Such was the confusion caused by this rapid forest turnover that regular land-use assessments frequently wrongly categorized this new growth as degraded old-growth forest.

"Actively reintroducing native plants will still be a better option in highly degraded sites," says one scientist.

Wang noted that if Brazil's President, Jair Bolsonaro, wanted to fulfill a promise made by his predecessor Dilma Rousseff at the 2015 Paris climate summit to restore 30 million acres of forest by 2030, then he need not plant at all. He could just allow regrowth to proceed in the Amazon without further clearing.

Brazil's other great forest, the Atlantic forest, is already on that path, recovering slowly after more than a century of clearance for coffee and cattle. The government has an Atlantic Forest Restoration Pact that subsidizes landowners to replant, often with trees intended to supply the paper industry. Yet Camila Rezende of the Federal University of Rio de Janeiro says most of the forest regrowth is not from planting but from "spontaneous" regrowth, as forest remnants colonize neighboring abandoned farmland. She estimates that some 6.7 million acres of Atlantic Forest has naturally regenerated in this way since 1996. It now makes up about a tenth of the forest.

Much the same has been happening in Europe, where forest cover is now up to 43 percent, often from naturally recolonizing farmland rather than planting. Italy, for instance, has grown its forest cover by a 2.5 million acres. In the former Communist nations of central Europe, 16 percent of farmland in the Carpathian Mountains was abandoned in the 1990s, much of it reclaimed by the region's famed beech forests. Across Russia, an area of former farmland about twice the size of Spain has been recolonized by forests. Irina Kurganova of the Russian Academy of Sciences calls this retreat of the plow "the most widespread and abrupt land-use change in the 20th century in the Northern Hemisphere."

The United States has also seen natural forests regenerate as arable farmland has declined by almost a fifth in the past 30 years. "The entire eastern United States was deforested 200 years ago," says Karen Holl of the University of California, Santa Cruz. "Much of that has come back without actively planting trees." According to the U.S. Forest Service, over the past three decades the country's regrowing forests have soaked up about 11 percent of national greenhouse gas emissions.

A worker plants Sitka spruce saplings at a reforestation project in Doddington, England in 2018. DAN KITWOOD/GETTY IMAGES

With nature on the march, a major concern is whether a push for planting might grab land for plantations that natural forests might otherwise recolonize. The result would be less wildlife, less amenity for humans, and often less carbon stored.

Ecologists have traditionally dismissed the ecological gains from natural restoration of what is often called "secondary" forest. Such regrowth is often regarded as ephemeral, rarely sought out by wildlife, and prone to being cleared again. This has led many to regard planting to mimic natural forests as preferable.

Thomas Crowther, co-author of a widely-publicized study last year calling for a "global restoration" of a trillion trees to soak up carbon dioxide, emphasizes that, while nature could do the job in places, "people need to help out by spreading seeds and planting saplings."

But a reappraisal is going on. J. Leighton Reid, director of Restoration Ecology at Virginia Tech, who recently warned against bias in studies comparing natural regeneration with planting, nonetheless told *e360*, "Natural regeneration is an excellent restoration strategy for many landscapes, but actively reintroducing native plants will still be a better option in highly degraded sites and in places where invasive species dominate."

Others make the case that most of the time, natural restoration of secondary forests is a better option than planting. In her book, *Second Growth*, Robin Chazdon, a forest ecologist formerly at the University of Connecticut, says that secondary forests "continue to be misunderstood, understudied, and unappreciated for what they really are — young self-organizing forest ecosystems that are undergoing construction."

Yes, she agrees, they are work in progress. But they generally recover "remarkably fast." Recent research shows that regrowing tropical forests recover 80 percent of their species richness within 20 years, and frequently 100 percent within 50 years. That seems to be better than what human foresters achieve when trying to replant forest ecosystems.

Tree planting can worsen outcomes for everything from the number of bird and insect species to canopy cover.

A review of more than 100 tropical forest restoration projects by Renato Crouzeilles of the International Institute for Sustainability in Rio de Janeiro, with Chazdon as a co-author, found that success rates were higher for secondary forests allowed to regenerate naturally than for those subjected to the "active restoration" techniques of foresters. In other words, planting can often worsen outcomes for everything from the number of bird, insect, and plant species, to measures of canopy cover, tree density, and forest structure. Nature knows best.

Now, Cook-Patton has extended the reappraisal to the carbon-accumulating potential of natural forest regeneration. It too may often be superior.

This scientific rethink requires a policy rethink, says Holl. "Business leaders and politicians have jumped on the tree-planting bandwagon, and numerous nonprofit organizations and governments worldwide have started initiatives to plant billions or even trillions of trees for a host of social, ecological, and aesthetic reasons".

She concedes that on some damaged lands, "we will need to plant trees, but that should be the last option, since it is the most expensive and often is not successful."

Why green pledges will not create the natural forests we need. Read more.

Planting a trillion trees over the next three decades would be a huge logistical challenge. A trillion is a big number. That target would require a thousand new trees in the ground every second, and then for all of them to survive and grow. Once the cost of nurseries, soil preparation, seeding, and thinning are accounted for, says Crouzeilles, it would cost hundreds of billions of dollars. If natural forest growth is cheaper and better, does that make sense?

Exhibit 15

Proposed Grizzly Bear Management Units on the Lolo, Bitterroot and Select Portions of the Beaverhead-Deerlodge National Forests, Montana, USA

Paul Sieracki
Geospatial Analyst/Wildlife Biologist
&
Mike Bader
Independent Wildlife Consultant

Photo: Sam Parks

WildEarth GUARDIANS A FORCE FOR NATURE

Flathead-Lolo-Bitterroot Citizen Task Force

Friends of the Bitterroot

January, 2022

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BMU concept and initial identification, project supervision, report preparation and layout: MB;
BMU digitation via ArcGIS: PS; Data curation: MB/PS; and
Final BMU development: PS/MB.

Author Acknowledgments

The maps and supporting report were produced under contract with funds provided by WildEarth Guardians, the Flathead-Lolo-Bitterroot Citizen Task Force and Friends of the Bitterroot. Any mistakes in interpretation or assumptions are ours alone.

Photo: Sam Parks

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Introduction

The long-term survival of grizzly bears (*Ursus arctos*) in the northern Rockies is dependent on connecting isolated populations with areas of protected habitats between the designated Grizzly Bear Recovery Areas (Allendorf et al. 2019). As grizzly bears reoccupy native habitat in the Northern Rockies there is a need to update National Forest management plans and consultations with the U.S. Fish and Wildlife Service. For example, the Lolo and Bitterroot National Forests in Montana intend to begin long-term Forest Plan Revisions within the next two years and the Lolo has re-initiated formal Endangered Species Act Section 7 consultation on its existing Forest Plan. The Nez Perce-Clearwater National Forests in Idaho have a draft Plan revision.

In order to assess the existing baseline situation, proposed Bear Management Units (BMUs) were identified on the Lolo and Bitterroot National Forests in areas outside the Recovery Areas which have high value for connectivity and facilitating natural immigration into the Bitterroot ecosystem. Areas of the Beaverhead-Deerlodge National Forest that are part of the Sapphire-Pintlar connectivity area and contiguous with the Lolo and Bitterroot National Forests were also mapped. This information will have future use for calculating baselines for roads, secure core, habitat productivity, denning habitat and other resources.

Methods

BMU Size— The bounds of Bear Management Units within the project area were delineated based on several factors. Within Grizzly Bear Recovery Areas in the northern Rockies, female grizzly bear life ranges are from 300-600km^2 in the Selkirk Mountains (Wakkinen and Kasworm 1997; Almack 1986), approximately 600km^2 in the Cabinet-Yaak (Kasworm and Servheen 1995; Kasworm et al. 2021) and nearly 900km^2 in the Yellowstone Recovery Area (Blanchard and Knight 1991). As a general rule of thumb, bear density and life ranges are inversely related to precipitation with xeric habitats having the largest ranges with lower density. Bear densities are also lower in areas with less secure core habitat due to higher mortality risk.

Simply dividing the landscape into 600km^2 polygons would be arbitrary and not make biological sense as watersheds vary in size and current delineations of BMUs in the NCDE, Cabinet-Yaak and Selkirk Recovery Areas are of variable size. Therefore, the range of 300-900km^2 was used as a guide. In connectivity areas between Grizzly Bear Recovery Areas we anticipate that grizzly bears will at least initially have larger life ranges as they disperse into and explore new habitats before settling into a long-term home range. Movements of a male grizzly bear marked in the NCDE were detected in the East Fork of the Bitterroot 120 miles from the NCDE Recovery Area (USFWS 2021). We also used the presence of suitable denning habitats (Bader and Sieracki 2022) to guide design of BMUs.

BMU Bounds— The proposed BMUs consist of federal, state, and private lands with conservation easements. Larger parcels of private land, cities, towns and isolated parcels of public land were excluded. The management plan for the latter is focused on bear aware programs and co-existence strategies including securing of attractants such as garbage, chickens and bird-feeders.

BMUs were identified for two habitat types. One is for large core secure areas within and adjacent to the designated Recovery Areas. The other is for connective habitats straddling the hydrologic divides of mountain ranges which have smaller, spatially disjunct secure core habitats defined as areas at least 500m from open roads and at least 10km^2 (2500ac) in size (USFWS 2018).

BMUs have been identified and mapped for the Nez Perce-Clearwater National Forests (Mattson 2021). To prevent overlap, in areas of the Bitterroot and Lolo National Forests adjacent to the Nez Perce-Clearwater National Forests, BMU boundaries are defined by the boundary between the Lolo, Bitterroot and Nez Perce-Clearwater National Forests.

In large secure core within and adjacent to Grizzly Bear Recovery Areas, BMUs go to the top of watershed divides. In connectivity habitats, with a few exceptions, BMU boundaries go over the top of watershed divides because most secure core habitats overlap these features and are the best routes for grizzly bears based on least-cost path analysis (Peck et al. 2017; Walker and Craighead 1997) and coincide with the upper elevations in the center of mountain ranges. Thus, BMUs in connectivity areas have spring riparian ranges on two sides while having suitable fall, denning and secure core habitats at higher elevations. Figure 1 illustrates this concept, showing the proposed Three Lakes BMU within the Ninemile Demographic Connectivity Area which contains spring habitats on the North and South edges of the BMU.

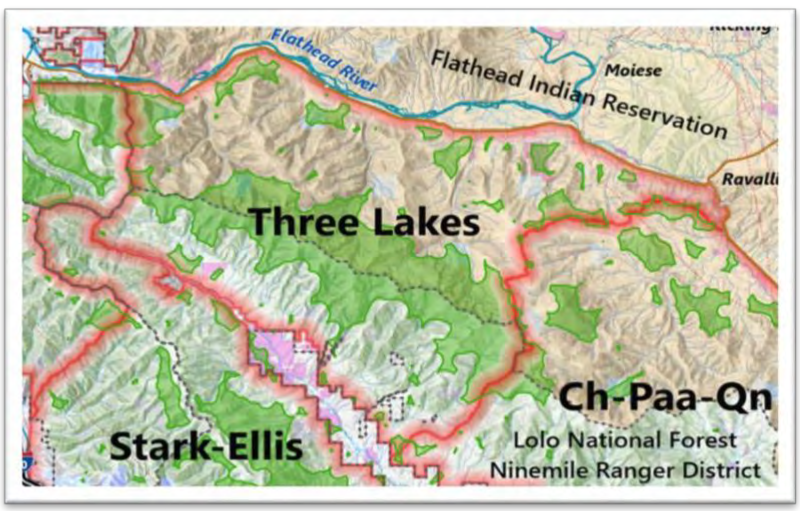

Figure 1. Three Lakes BMU with secure core (green) and lower elevation spring range along the Flathead River and Ninemile Creek.

Draft BMU boundaries were drawn by hand onto 3’ x 4’ U.S. Forest Service National Forest Maps. These were then digitized into electronic form using ArcGIS (ESRI 2021), and polygons were constructed from the maps. Constructing the GIS-based BMU boundary polygons involved tracing polygon edges of base layers. A general priority scheme was followed first tracing Hydrologic Unit boundaries from the USGS Watershed Database (in some cases we followed a ridge between Hydrologic Unit boundaries), then the Public Lands System (PLSS), and where practicable, administrative boundaries such as National Forest and Ranger District boundaries and conservation easements. In a few instances streams were followed in order to properly size the BMUs. Areas were then calculated for each BMU polygon.

BMU Naming— Provisional names were assigned to each BMU following the practice used in the NCDE, Cabinet-Yaak and Selkirk Grizzly Bear Recovery Areas where BMUs are named after well-known topographical features such as mountain peaks, rivers and streams.

Results

The map results are shown in Figures 3 and 4, and the spatial results are shown in Table 1. The mean size of the BMUs (n = 32) is 586km^2, which is approximate to the mid-point in the range of 300-900km^2 for female life ranges in Grizzly Bear Recovery Areas in the northern Rockies.

Figure 2. Sam Parks photo.

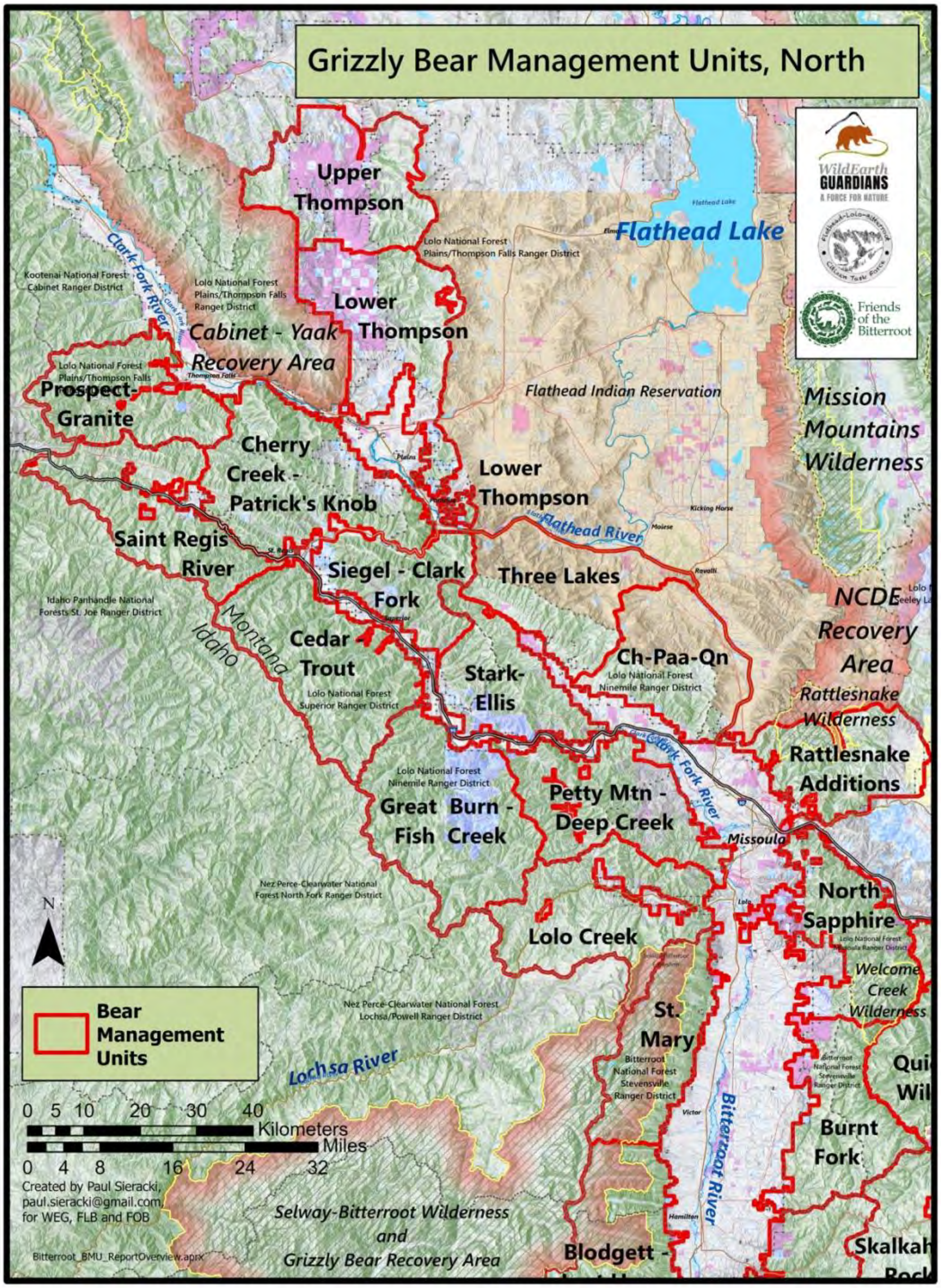

Figure 3. Proposed Bear Management Units, Lolo and Bitterroot National Forests.

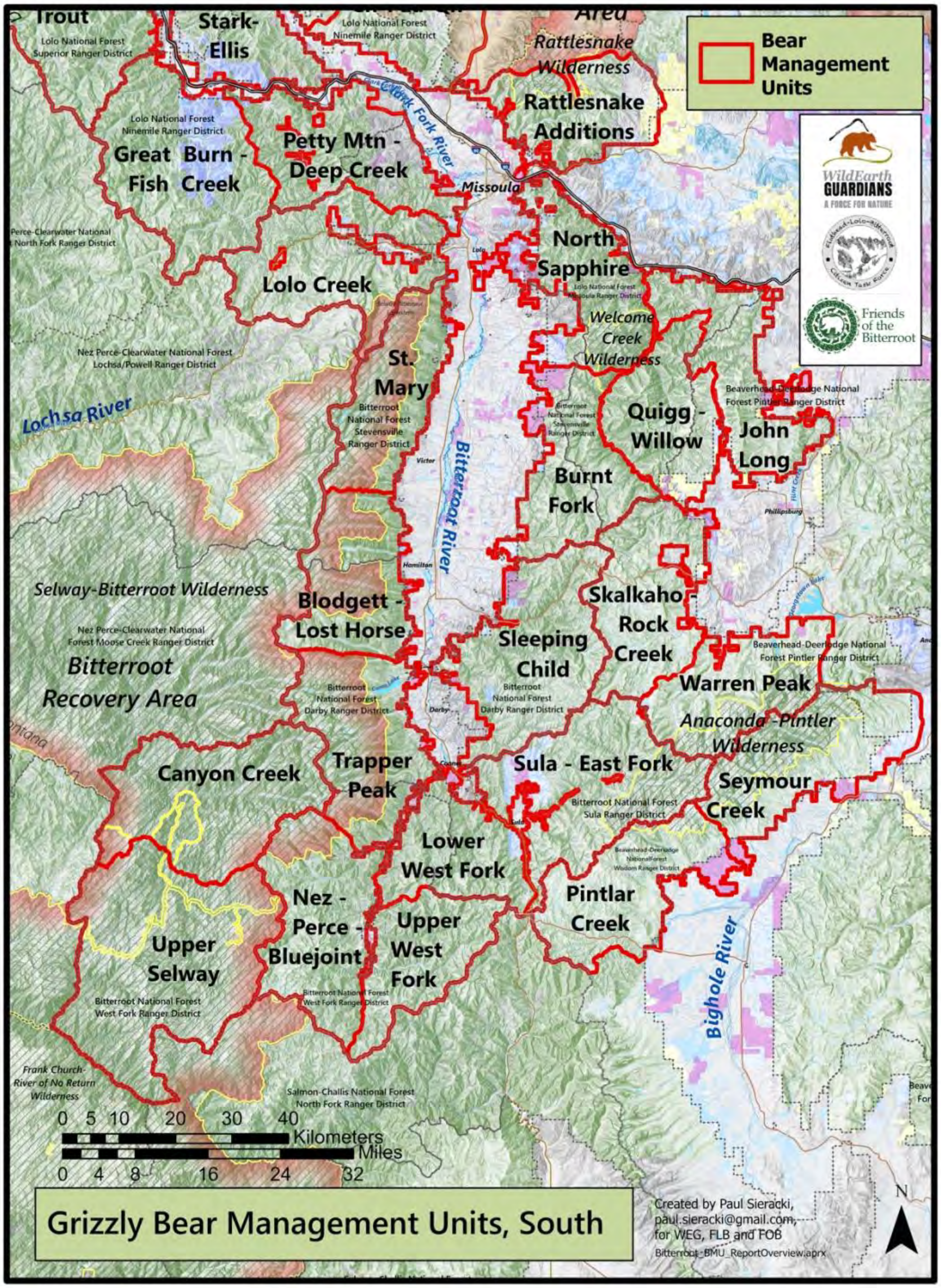

Figure 4. Proposed Grizzly Bear Management Units, Bitterroot, Beaverhead-Deerlodge and Lolo National Forests.

Table 1. Proposed Bear Management Units by Size and Management Agency.

Bear Management Unit	Acres	Square Miles	Square Kilometers	Hectares	Primary Management
Ch-Paa-Qn*	129,850	203	526	52,548	Lolo NF/FIR
Stark-Ellis*	104,927	164	425	42,462	Lolo NF
Three Lakes*	136,912	214	554	55,407	Lolo NF/FIR
Siegel-Clark Fork*	93,842	147	380	37,976	Lolo NF
Upper Thompson	151,197	236	612	61,187	Lolo NF/ Conservation Easements
Lower Thompson	170,139	266	689	68,853	Lolo NF/ MT State Lands
Cherry Creek - Patrick's Knob	184,884	289	748	74,820	Lolo NF
Saint Regis River	137,125	214	555	55,492	Lolo NF
Prospect-Granite	119,902	187	485	48,523	Lolo NF
Great Burn - Fish Creek	196,823	308	797	79,652	Lolo NF/MT State Lands
Cedar - Trout	174,636	273	707	70,673	Lolo NF
Petty Mtn - Deep Creek	137,642	215	557	55,702	Lolo NF
Lolo Creek	159,153	249	644	64,407	Lolo NF

Rattlesnake Additions	112,771	176	456	45,637	Lolo NF
St. Mary	118,312	185	479	47,879	Bitterroot NF
Blodgett - Lost Horse	125,825	197	509	50,920	Bitterroot NF
Trapper Peak	146,948	230	595	59,468	Bitterroot NF
Nez Perce - Bluejoint	153,695	240	622	62,198	Bitterroot NF
Upper Selway	280,173	438	1,134	113,382	Bitterroot NF
Canyon Creek	187,608	293	759	75,922	Bitterroot NF
Upper West Fork	102,672	160	416	41,550	Bitterroot NF
Lower West Fork	100,133	157	405	40,522	Bitterroot NF
Sula - East Fork	184,603	288	747	74,706	Bitterroot NF
Sleeping Child	170,433	266	690	68,972	Bitterroot NF
North Sapphire	134,370	210	544	54,378	Bitterroot NF
Burnt Fork	128,665	201	521	52,069	Bitterroot NF
John Long	123,936	194	502	50,155	Beaverhead-Deerlodge NF
Skalkaho - Rock Creek	136,026	213	551	55,048	Beaverhead-Deerlodge NF
Quigg - Willow	115,355	180	467	46,682	Lolo-Beaverhead-Deerlodge NFs
Warren Peak	123,422	193	500	49,947	Beaverhead-Deerlodge NF

Pintlar Creek	136,628	214	553	55,292	Beaverhead-Deerlodge NF
Seymour Creek	154,025	241	623	62,332	Beaverhead-Deerlodge NF
Totals: (n = 32)	**4,632,632**	**7241**	**18,752**	**1,874,581**	-
Range and Mean (n = 32)	**93,842-280,173** **$\bar{x}$ = 144,770**	**147-438** **$\bar{x}$ = 226**	**380-1,134** **$\bar{x}$ = 586**	**37,976-113,382** **$\bar{x}$ = 58,581**	-

*Ninemile Demographic Connectivity Area (designated in the Conservation Strategy for Grizzly Bears, USFWS 2018)

Discussion

It is advantageous for government management agencies, non-governmental organizations and academic institutions to agree on specific boundaries for BMUs. Having the same measurement units will aid land management planning, site-specific analyses, consultations and scientific research with results that can be interactive.

Moreover, identification of BMUs is a starting point for multi-resource evaluation of grizzly bear habitat outside of the Recovery Areas, which sets the stage for improved least-cost path analyses for female grizzly bears similar to Proctor et al. (2015). In addition to geographic area, each BMU can be assessed for total road and motorized route miles and densities, percent secure core habitat per BMU measured against the U.S. Forest Service (1995) definition of 68% and its spatial distribution as in Sieracki and Bader (2020), denning habitats (Bader and Sieracki 2022), spring ranges and so forth. These data can inform proposals for habitat protection and connectivity based on reductions in the road network, additional seasonal restrictions on motorized access and re-creation of additional secure core areas. This information would be particularly useful for grizzly bear recovery planning and National Forest Plan revisions, amendments and project-level analyses.

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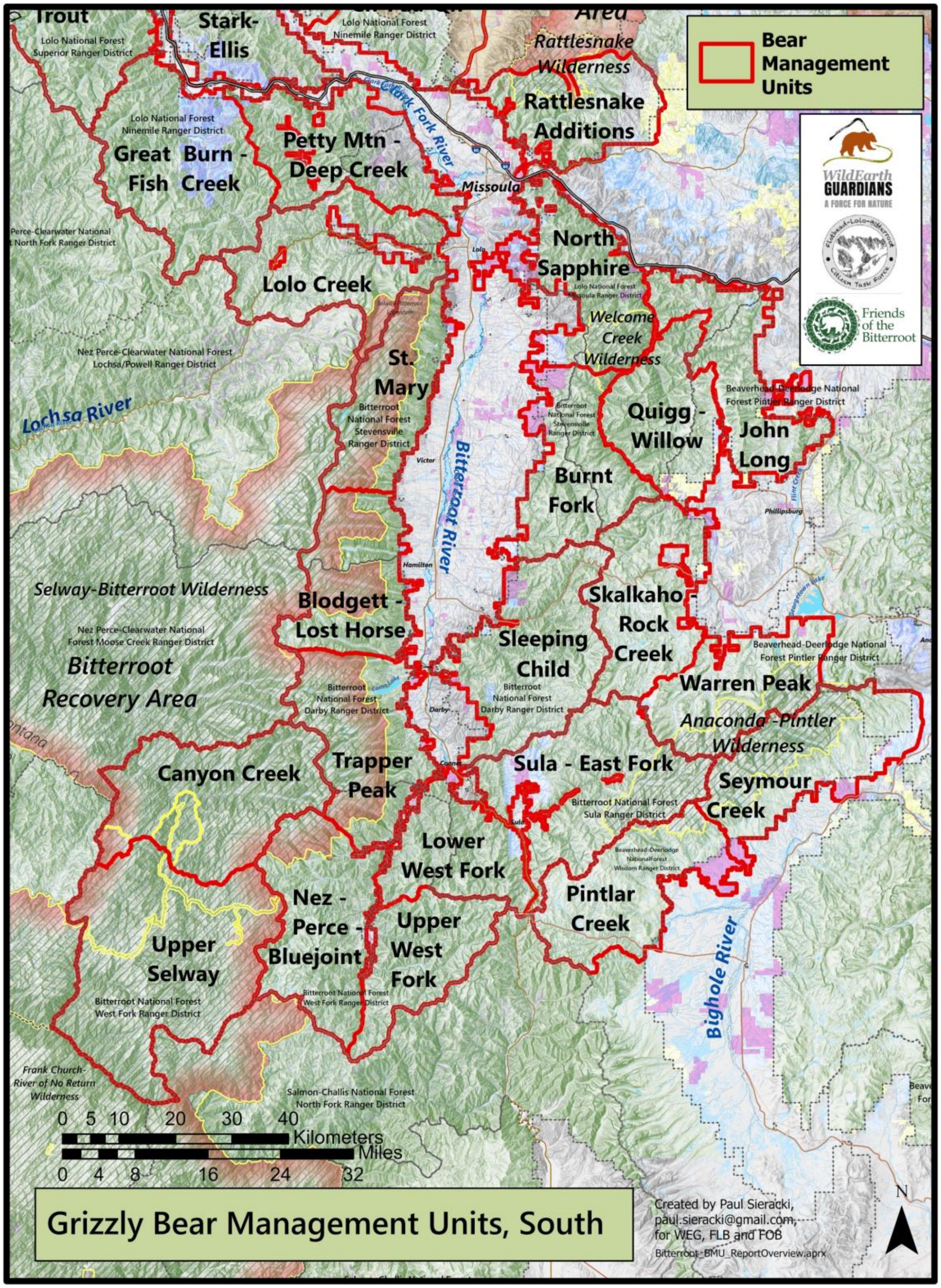
Exhibit 16 - Proposed Grizzly Bear BMUs, South Half



United States Department of the Interior
Fish and Wildlife Service
Montana Ecological Services Office
585 Shephard Way, Suite 1
Helena, Montana 59601-6287

In Reply Refer To:
File: M19 Lolo National Forest
Ecos # 2022-0007548 (Lolo Forest Plan)

March 10, 2023

Carolyn P. Upton, Forest Supervisor
Lolo National Forest
24 Fort Missoula Road
Missoula, Montana 59804

Dear Ms. Upton:

The U.S. Fish and Wildlife Service (Service) has reviewed the biological assessment regarding reinitiation of consultation on the effects of the Lolo National Forest (Forest) Plan (Forest Plan) on grizzly bears (*Ursus arctos horribilis*). The Forest analyzed the effects of the Forest Plan and made a determination of *may affect, likely to adversely affect* for federally listed grizzly bears. Reinitiation of consultation for other listed species was not necessary at this time.

The attached biological opinion addresses the effects of the Forest Plan on the listed grizzly bear and is based on information provided in the 2022 biological assessment and additional information received during the consultation process. The biological opinion was prepared in accordance with section 7 of the Endangered Species Act (Act) of 1973, as amended (16 U.S.C. 1531 et seq.).

Thank you for your continued assistance in the conservation of endangered, threatened, and proposed species. A complete project file of this consultation is on file at the Service's Montana Field Office. If you have questions or comments related to this consultation, please contact Katrina Dixon at katrina_dixon@fws.gov.

Sincerely,

for Adam Zerrenner
Office Supervisor

ENDANGERED SPECIES ACT SECTION 7 CONSULTATION

BIOLOGICAL OPINION

on the

Effects of the Lolo National Forest Plan
on Grizzly Bears

Agency:	U.S. Department of Agriculture Forest Service Lolo National Forest Missoula, Montana
Consultation Conducted by:	U.S. Fish and Wildlife Service Montana Field Office Helena, Montana
Date Issued:	March 10, 2023

Table of Contents

INTRODUCTION

This biological opinion was prepared by the U.S. Fish and Wildlife Service (Service) and analyzes the effects of the 1986 Forest Plan (Forest Plan) for the Lolo National Forest (Forest) on grizzly bears (*Ursus arctos horribilis*). As grizzly bear presence has expanded and they may be present Forest-wide, an area larger than previously consulted on, the Forest requested reinitiation of consultation in February of 2021 in order to analyze any potential additional effects of the Forest Plan on grizzly bear that were not previously consulted on. The Service received a draft biological assessment to review in August of 2021 and a final biological assessment on January 10, 2022. We continued to receive information regarding this consultation through March 8, 2023.

Section 7(b)(3)(A) of the Endangered Species Act of 1973, as amended (Act) requires that the Secretary of the Interior issue biological opinions on federal agency actions that may adversely affect listed species or critical habitat. Biological opinions determine if the action proposed by the action agency is likely to jeopardize the continued existence of listed species or destroy or adversely modify critical habitat. Section 7(b)(3)(A) of the Act also requires the Secretary to suggest reasonable and prudent alternatives to any action that is found likely to result in jeopardy or adverse modification of critical habitat, if any has been designated. If the Secretary determines "no jeopardy", then regulations implementing the Act (50 C.F.R. § 402.14) further require the Director to specify "reasonable and prudent measures" and "terms and conditions" necessary or appropriate to minimize the impact of any incidental take resulting from the action(s). This biological opinion addresses only impacts to federally listed species and does not address the overall environmental acceptability of the proposed action.

This consultation represents the first tier of a tiered consultation framework, with each subsequent project that may affect grizzly bears as analyzed within this programmatic biological opinion, as implemented under the Forest Plan, being the second tier of consultation. When applicable, some second tier consultations would reference back to this programmatic biological opinion to ensure that the effects of specific projects under consultation are commensurate with the effects anticipated in this biological opinion and incidental take statement.

Consultation History

Informal consultation on the Forest Plan began between the Forest and the Service in 2020. The Service received a draft biological assessment to review and comment on in August of 2021. We received the final biological assessment and request for consultation on the effects of the Forest Plan on January 10, 2022 (U.S. Forest Service 2022), which is incorporated here by reference. The Forest Plan has been through several consultation processes since 1986. Pages 7 through 10 of the biological assessment display a thorough history of consultation between the Forest and the Service (*Ibid.*). Further consultation continued through email, meetings, and phone conversations with Forest staff. We continued to receive information regarding this consultation through March 8, 2023.

Upon review of the biological assessment and additional information, the Service has prepared a new biological opinion for the Forest Plan that supersedes several previous biological opinions, as described below. The biological assessment, information in our files, and additional information and discussions throughout the informal and formal consultation process were used in the preparation of this biological opinion. A complete project file of this consultation is on file at our office.

DESCRIPTION OF THE PROPOSED ACTION

The proposed action is the ongoing implementation of the 1986 Forest Plan until such time as the Forest Plan is revised. The Forest anticipates beginning revision of the 1986 Forest Plan in 2023. The Forest expects to complete Forest Plan revision by 2026 at the earliest. This consultation and biological opinion on the ongoing implementation of the 1986 Forest Plan will be in effect until a biological opinion is completed for a revised Forest Plan and supersedes this biological opinion, up to 10 years.

The Forest Plan is the land use planning level guidance document for the Forest, providing direction for project and activity decision making and provides an integrated plan for land and resource management, which articulates desired conditions, goals, objectives, standards, guidelines, and suitability of lands. For more specific information on the Forest Plan, refer to the terrestrial biological assessment (U.S. Forest Service 2022). Existing management direction (forest-wide, by management area, and specific to the Cabinet-Yaak Ecosystem (CYE) and Northern Continental Divide Ecosystem (NCDE) recovery zones) that may affect grizzly bears on the Forest is listed in detail in Appendix 2 of the biological assessment. No Forest Plan direction specifically addresses the management of grizzly bears outside of the recovery zones, NCDE zone 1, and the Ninemile DCA. Broad Forest-wide goals, objectives, and standards in the Forest Plan that pertain to these areas and are aimed at conservation of threatened and endangered species displayed in the biological assessment (*Ibid*.).

The Forest Plan is considered a framework programmatic action. It does not authorize, fund, or carry out an action but provides direction for future actions that may be authorized, funded, or carried out by the Forest. Therefore, any action subsequently authorized, funded, or carried out under the Forest Plan, will be addressed in subsequent section 7 consultations, as appropriate. Types of activities subsequently authorized, funded, or carried out under the Forest Plan that may affect grizzly bears are described in the biological assessment prepared for the Forest Plan, which is hereby incorporated by reference (U.S. Forest Service 2022).

STATUS OF THE SPECIES

No critical habitat has been designated for grizzly bears. For information on the status of grizzly bears, including regulatory history, species description, life history, and status and distribution, refer to the Grizzly Bear Recovery Plan (U.S. Fish and Wildlife Service 1993), the grizzly bear 5-year status review (U.S. Fish and Wildlife Service 2021), the species status assessment (SSA) for grizzly bears (U.S. Fish and Wildlife Service 2022a), the grizzly bear recovery program 2021 annual report (U.S. Fish and Wildlife Service 2022b), the conservation strategy for the grizzly bear in the NCDE (NCDE subcommittee 2020), Grizzly bear demographics in the NCDE (Costello et al. 2016), NCDE grizzly bear population monitoring team 2021 annual report (Costello and Roberts 2022), the Greater Yellowstone Ecosystem (GYE) conservation strategy (U.S. Fish and Wildlife Service 2016), the Yellowstone Grizzly Bear Investigations 2021 (van Manen et al. 2022), the Cabinet-Yaak (CYE) Grizzly Bear Recovery Area 2021 Research and

Monitoring Progress Report (Kasworm et al. 2022a), Density, distribution, and genetic structure of grizzly bears in the Cabinet-Yaak Ecosystem (Kendall et al. 2016), and the Selkirk (SE) Mountains Grizzly Bear Recovery Area 2021 Research and Monitoring Progress Report (Kasworm et al. 2022b). These documents (referenced here), include the best available science regarding the status and distribution of grizzly bears and are incorporated by reference.

In summary of these documents cited above, grizzly bear populations within the lower 48 states currently exist primarily within and around four ecosystems (GYE, NCDE, CYE, and SE) that include portions of four States (Wyoming, Montana, Idaho, and Washington). Grizzly bear range has been expanding in these areas and multiple grizzly bear sightings have been confirmed in potential linkage areas between the existing ecosystems and also within the Bitterroot Ecosystem (BE); however, no known population occurs in the BE or between these ecosystems. No known population occurs in the North Cascades Ecosystem (NCE). While the range of grizzly bears in some ecosystems has significantly expanded since 1975, the overall range and distribution of grizzly bears in the lower-48 States remain below historical levels at approximately 6 percent of historical range (U.S. Fish and Wildlife Service 2022a). The estimated population size and distribution in both the GYE (1,063 individuals) and NCDE (1,138 individuals) have more than doubled since listing (van Manen et al 2022, Costello and Roberts 2022, U.S. Fish and Wildlife Service 2022a). All recovery criteria was met in both the GYE and NCDE for 2021 (U.S. Fish and Wildlife Service 2022b) and have all been met for at least the last 10 years, with some individual criteria being met even longer. The CYE and SE have also experienced positive population growth rates and increases in population sizes, with the CYE increasing with an annual growth rate of 1.9 percent and the SE increasing with an annual growth rate of 3.1 percent (Kasworm et al. 2022a, Kasworm et al. 2022b). The mortality criteria for the 2016 through 2021 period was met for the CYE but the number of unduplicated females with cubs and BMU distribution criteria have not been met (U.S. Fish and Wildlife Service 2022a, Kasworm et al. 2022a). For the period 2016 through 2021, the BMU distribution criteria was met for the SE but the number of unduplicated females with cubs and the total and female mortality criteria were not met (Kasworm et al. 2022b). Although no known population occurs within the BE, multiple verified sightings have occurred in linkage zones close to the BE recovery zone (U.S. Fish and Wildlife Service 2022a). The North Cascades is also currently unoccupied by a grizzly bear population (Ibid.). The SSA documents the results of a comprehensive review of the life history, ecology, threats, and viability for the grizzly bear and provides more detailed summaries and information for each ecosystem, as well as the listed entity of grizzly bears in the lower 48 states, including information incorporated from the documents referenced in the paragraph above, among many additional references (Ibid.).

Analysis of the Species Likely to be Affected

The biological assessment determined that implementation of the Forest Plan would likely adversely affect individual grizzly bears. Therefore, formal consultation with the Service was initiated and this biological opinion has been written to determine whether or not activities associated with this action are likely to jeopardize the continued existence of grizzly bears. Grizzly bears are listed as threatened under the Act. Critical habitat has not been designated for this species, therefore none would be affected by the proposed action.

ENVIRONMENTAL BASELINE

Under the provisions of section 7(a)(2), when considering the "effects of the action" on listed species, the Service is required to consider the environmental baseline. Regulations implementing the Act (50 C.F.R. § 402.02) define the environmental baseline as the condition of the listed species or its designated critical habitat in the action area, without the consequences to the listed species or designated critical habitat caused by the proposed action. The environmental baseline includes the past and present impacts of all federal, state, or private actions and other human activities in the action area, the anticipated impacts of all proposed federal projects in the action area that have already undergone formal or early section 7 consultation, and the impact of state or private actions which are contemporaneous with the consultation in progress. The consequences to listed species or designated critical habitat from ongoing agency activities or existing agency facilities that are not within the agency's discretion to modify are part of the environmental baseline.

Action area, as defined by the Act, is the entire area affected directly or indirectly by the federal action and not merely the immediate area involved in the action. For the purposes of this biological opinion, the action area for the analysis of effects of the Forest Plan includes the approximately 2,230,167 acres of Forest land within the administrative boundaries of the Forest. Although within the action area, the inholdings of ownerships other than the Forest are not included in the total acreages above and are not subject to Forest management. The Forest occurs within portions of Flathead, Granite, Lake, Lewis and Clark, Mineral, Missoula, Powell, Ravalli, and Sanders Counties and is managed as five ranger districts including the Missoula, Ninemile, Plains-Thompson Falls, Seeley Lake, and Superior Ranger Districts.

The Forest is influenced by both continental and maritime climates, resulting in a wide range of environmental gradients and diverse wildlife habitats. Elevations range from less than 2,400 feet on the Clark Fork River below Thompson Falls to Scapegoat Mountain at 9,202 feet. The Forest contains more than 100 named lakes, nearly 1,000 named streams, and five major rivers. Four wilderness areas are located at least partly on the Forest including the Rattlesnake, Welcome Creek, Scapegoat, and Selway-Bitterroot Wilderness Areas.

The Forest straddles three grizzly bear ecosystems: Cabinet-Yaak Ecosystem (CYE), Northern Continental Divide Ecosystem (NCDE), and Bitterroot Ecosystem (BE). In total, about 20 percent of the Forest lies within a grizzly bear recovery zone while about 80 percent of the Forest is outside of the recovery zones (Table 1). Areas within the CYE recovery zone are further delineated into bear management units (BMUs) and areas within the NCDE recovery zone are further delineated into subunits. Because a resident population of grizzly bears does not occur in the BE, no BMUs or subunits have been delineated for the BE recovery zone to date. The BMUs (CYE) and subunits (NCDE) are managed specifically for grizzly bears and approximate an average female home range size and are consistently used as analysis units for site-specific actions. A subset of acreage outside of the recovery zones occurs within areas identified as part of NCDE Zone 1 and the Ninemile demographic connectivity area (DCA) and have some level of grizzly bear management. Some lands in the CYE that occur outside of the recovery zone and meet certain recurring use criteria have been delineated as BORZ (bears outside of the recovery zone) and have some level of grizzly bear management. However, no areas on the Forest in the CYE have met the criteria for recurring use and therefore no BORZ areas have been delineated on the Forest.

The remaining portion of the Forest, which occurs outside of the recovery zones have been delineated into grizzly bear analysis units (GBAUs), which approximate an average female grizzly bear home range size and are used as static analysis units for site-specific actions in order to consistently analyze effects to grizzly bears over space and time. They do not represent actual grizzly bear home ranges or imply that occupancy or occurrence by grizzly bears is expected or required. GBAUs were delineated following watershed boundaries where possible and adjusted where necessary to minimize non-federal ownerships. The GBAUs encompass a total of 1,816,544 acres of the Forest (all of the lands on the Forest that are outside of grizzly bear recovery zones). GBAUs are delineated to provide a suite of seasonal habitats including some higher elevation, steeper terrain that could provide denning habitat, as well as more mesic, productive forest types and wet meadows that are likely to provide spring and fall food resources. Since the Forest continues to acquire land, the GBAU boundaries may need to be adjusted in the future to include those acquired lands that occur outside the GBAU boundaries.

Table 1. Acres of Forest land outside and within grizzly bear recovery zones (U.S. Forest Service 2022).

	Acres	**Percent**
Forest land within the CYE recovery zone	145,782	7%
Forest land within the NCDE recovery zone	269,822	12%
Forest land in NCDE Zone 1	173,099	8%
Forest land in the Ninemile DCA	256,229	11%
Forest land within the BE recovery zone	9,802	<1%
Remaining Forest land outside of the above areas	1,375,433	61%
Total	**2,230,167**	**100%**

Status of the Species within the Action Area

The only BMU within the CYE recovery zone that occurs on the Forest is BMU 22, which is also known as the Mt. Headley BMU but will be referred to as BMU 22 throughout this document. The Forest also has areas outside of the CYE recovery zone but none are considered as BORZ. Seven subunits occur within the NCDE recovery zone including the Monture, Mor-Dun, North Scapegoat, South Scapegoat, Mission, Rattlesnake, and Swan subunits. The Forest also has areas outside of the NCDE recovery zone, with some portions delineated within NCDE Zone 1 and the Ninemile DCA. Portions of the action area occur within the BE recovery zone where no BMUs or subunits have been delineated as well as areas outside of it. Refer to Table 1 above for the acreages of these areas. Grizzly bears may be present throughout most of the Forest with varying levels of occurrence ranging from a high likelihood in some areas, including residents, and a very low likelihood or transient use in others. The likelihood of grizzly bear presence is likely to increase over time as grizzly bear populations continue to increase and expand.

In some areas of the Forest either no grizzly bears have been verified or only male transients or dispersers have been verified. In these areas, where numbers of grizzly bears are likely low to very low to none, numbers are expected to increase relatively slowly over time. This is especially true for female grizzly bears. As described in Proctor et al. (2012), males move more frequently and over longer distances than females. Males have large home ranges and establish home ranges nearly three times further away from their mother’s home ranges than do female offspring. Females usually establish smaller home ranges than males that overlap with their mother's home range (Waser and Jones 1983; Schwartz et al. 2003). In doing so, they generally disperse over much shorter distances than male grizzly bears (McLellan and Hovey 2001; Proctor et al. 2004). Therefore, female dispersal is a multi-generational process where females must live year-round in an area, successfully reproduce, and offspring disperse into adjacent, unoccupied habitat. Thus, female grizzly bear presence in portions of the action area is likely to increase only slowly over time.

Factors Affecting Species Environment within the Action Area

This section identifies and describes key areas of the existing Forest Plan management that affect the grizzly bears' environment. These factors include access management, food and attractant management and developed sites, livestock management, vegetation and fire management, and energy and mineral development. Existing management related to these factors is summarized below. The biological assessment provides additional information on the existing condition related to the following factors and is incorporated by reference (U.S. Forest Service 2022). General impacts of these factors will be discussed in more detail in the '*Effects of the Action'* section below.

<u>Access Management</u>

Motorized access has long been recognized as a major factor affecting grizzly bears (see section below, '*General Effects of Roads on Grizzly Bears'*). Some portions of the action area are highly roaded while other portions are sparsely roaded or have no roads at all. With the exception of the subunits and BMUs within the recovery zones, we have previously analyzed portions of the action area using only linear motorized route density or an estimate of acres of low, moderate, or high levels of motorized route density. Providing linear route density or acreage of low, moderate, and high levels of motorized use gives an idea of the amount of roads in the action area, however it does not represent how these routes occur on the landscape. Although this information provides a useful threshold to describe human-caused effects to grizzly bears based on existing literature, motorized route density or acreage alone fails to consider how road placement affects habitat patch size (Proctor et al. 2019). For example, portions of the GBAUs may have high route densities (even within the GBAUs with lower overall linear route densities) while other portions of the GBAUs may have low route densities or even no motorized routes (even within the GBAUs with higher overall linear route densities). In other words, even in a GBAU with overall low route density, patches of high route density areas may be interspersed with patches of low route density or unroaded areas or in a GBAU with overall high route density, patches of low route density or unroaded areas may be interspersed with patches of high route density.

Secure habitat has been identified as one of the key issues related to effects of motorized access on grizzly bears and is important to the survival and reproductive success of grizzly bears. In a comprehensive review of research into the relationships between motorized access and grizzly bears, Proctor et al. (2018) cited research findings (e.g. Nielsen et al. 2004) indicating that distance to roads and location of roads in relation to certain habitats may be as or more important than road density in predicting impacts to bears. Proctor et al. (2018) also noted that the spatial arrangement of motorized routes and secure areas may be critically important in terms of the degree to which bears may be affected by motorized access. In other words, the key to limiting impacts of roads on bears is tied to availability, location, and distribution of secure habitat that is a function of not simply numeric density of motorized routes, but the spatial arrangement in which they occur.

While secure habitat is directly tied to and based on open and restricted motorized routes, it more adequately represents the potential effects to grizzly bears related to motorized access as it provides a more accurate indication of the spatial mix of motorized routes and secure habitat. For example, measurements of route density in situations of uniformly spaced roads, even at an otherwise acceptable route density, can provide very limited patches of secure habitat that are functionally useful for grizzly bears (Proctor et al. 2019). Similarly, large patches of important habitat may be available in areas with high road densities if roads are concentrated in specific areas. Accordingly, we have incorporated secure habitat into this analysis.

Several methods exist for defining secure habitat relative to distances from routes and/or other human disturbance. Although the concept and benefits of secure habitat has been well documented (Mace et al. 1996, Wakkinen and Kasworm 1997, Gibeau et al. 2001, Schwartz et al. 2010), science has not provided a clear definition of the specific metrics for defining secure habitat. The IGBC (IGBC 1998) reviewed four studies indicating a range of avoidance of roads in four disparate locations and recommended a distance of 500 meters (0.31 mile) from motorized routes as the minimum distance to define secure habitat. The 500 meter distance has become the most universal distance for delineating secure habitat.

Areas greater than 500 meters from motorized routes provide areas free of motorized access related disturbance and provide security for grizzly bears. Depending on the juxtaposition to other patches of secure habitat or other resources, even small patches of habitat more than 500 meters from motorized routes may provide valuable space for grizzly bears to avoid human disturbance, move between important food resources, and/or can be utilized for long-distance connectivity.

Within the portions of the action area that are within recovery zones, secure core is managed differently than secure habitat outside of the recovery zone. Therefore, it is important to distinguish the terminology associated with such habitat. Within the subunits of the NCDE recovery zone, areas more than 500 meters from an open or gated motorized route and greater than 2,500 acres in size are defined as ‘secure core’. Within the BMUs of the CYE recovery zone, areas more than 500 meters from an open or gated motorized route, with no minimum patch size, are also defined as ‘secure core’. Whereas, areas more than 500 meters from any drivable motorized route that are located outside of the recovery zones are defined as ‘secure habitat’. Further in this document, secure habitat outside of the recovery zones will be displayed showing both the total acreage of secure habitat, as well as the acreage of polygons larger than 2,500 acres. At the programmatic scale of this biological opinion on the Forest Plan, we will measure and track the total acreage of secure habitat within the GBAUs outside of the recovery zones.

Of the four occupied recovery zones, only the NCDE recovery zone has a minimum patch size requirement for secure core, which is 2,500 acres. This number relied on the observed patch size of unroaded habitat in the composite home range for seven adult females, with 83 percent of locations in the NCDE occurring within 7 polygons that exceeded 2,260 acres in size (U.S. Forest Service 2022). Conversely, Wakkinen and Kasworm (1997) reported that more than 97 percent of the use by successfully reproducing females in the CYE occurred in blocks greater than 1,280 acres in size. Smaller polygons, particularly those of less than 2 square miles, tended to be underused by grizzly bears in the study, although use still occurred in blocks as small as 141 acres. No minimum core area size was established for management in the CYE recovery zone due to the limitations of small sample size, although the authors suggested that if a minimum size occurs, it is likely between 1,280 and 5,120 acres. Larger areas of secure habitat are thought to be more valuable in providing for the habitat requirements of reproductive female bears. However, in areas with little availability of effective secure core/secure habitat, smaller patches may provide some value to bears, especially in providing habitat connectivity, although maybe not to the same value as larger patches (U.S. Fish and Wildlife Service 2016).

Management of motorized access is effective in minimizing the effects of motorized access on grizzly bears (Proctor 2019). All known National Forest System Roads (NFSR) and unauthorized roads on the Lolo National Forest are identified in GIS using the Forest Service Infrastructure (INFRA) database and roads atlas (U.S. Forest Service 2022). The INFRA database tracks general road information including route location, status, length, jurisdiction, design standard, travel condition, and maintenance level and is updated as additional information becomes available. Route status in INFRA denotes whether a road is a NFSR or an unauthorized road, both are defined below (*Ibid*.):

- National Forest System road: a forest road other than a road which has been authorized by a legally documented right-of-way held by a State, county, or other local public road authority.
- Unauthorized road and trail: a road or trail that is not a forest road or trail or a temporary road or trail and that is not included in a forest transportation atlas. Unauthorized roads are categorized into two types and recorded in the SYSTEM linear event in the INFRA Travel Routes database. The two types are:
    - Undetermined (UND): roads where long-term purpose and need has yet to be determined.
    - Not Needed (NOT): roads not needed for long-term management of national forest resources as determined through an appropriate planning process.

Undetermined roads on the Forest are commonly a result of old logging or mining roads constructed decades ago and are typically grown in with vegetation or have some type of road failure that would exclude motorized vehicle use. At times, old routes that have been on the landscape for decades are identified by Forest staff during routine field work. These routes were likely constructed to support logging and mining activities on the Forest in the early to mid-1900s. When identified, these routes are added to the Forest's INFRA database and attributed as "undetermined" until their long-term purpose and need are determined.

In more recent years, the Forest has acquired over 170,000 acres of non-Forest land that contained roads prior to Forest ownership. These acquired lands have resulted in the Forest adding many more miles of roads into INFRA. The motorized routes on acquired lands are not new routes as these routes likely existed on the acquired lands for years. Although the Forest does a basic roads assessment prior to acquiring lands, the Forest initially records all roads on acquired lands as "undetermined" in INFRA after acquisition and this remains the status until such time in the future when the Forest decides upon the long-term need of those roads. All undetermined roads are closed to public motorized use per the Forest's Motorized Vehicle Use Map. The Forest makes management decisions on these routes as projects are identified in the area of the acquired lands. As part of a Forest decision, undetermined roads can be added to the National Forest System or decommissioned. If an undetermined road is added to the system, then the Forest will decide on the maintenance level and closure status (open, closed, seasonally closed, or administrative) or decide to "store" the road. A stored road is closed to motorized vehicles, but it could be used in the future if it is needed. If an undetermined road is not needed for future use, the Forest will decommission the road. Any changes to a road's status are updated in INFRA. If a Forest decision includes the need for actions to physically add a closure device or decommission a road, INFRA is updated once those actions are contracted to be completed on the ground.

Thus, in most cases, undetermined routes have existed for many years (either on the Forest or on lands recently acquired by the Forest), and are part of the environmental baseline from which grizzly bears have been experiencing effects. Thus, while documenting undetermined routes offers a more accurate representation of the conditions on the ground, in many cases, it does not represent new effects to grizzly bears. Further, undetermined routes are often grown in with vegetation and are not accessible to motorized vehicles.

Like anywhere on the Forest, as new information becomes available, including undetermined routes not previously documented, the baseline will be adjusted accordingly to reflect these updates. These undetermined motorized routes, like other updates to the INFRA database, are used to update the grizzly bear secure habitat or motorized route metrics to reflect these changes and these changes will be shared with the Service, through reporting and/or project level consultation.

BE Recovery Zone

The Forest does not have any requirements to provide or manage for motorized access or secure core in the BE recovery zone. However, the portion of the BE recovery zone that occurs on the Forest is entirely within the Selway-Bitterroot Wilderness and it all functions as secure core. Thus, the portion of the Forest within the BE recovery zone is expected to provide habitat to support survival and reproduction of female grizzly bears that may occur there at some point over the life of the Forest Plan.

CYE Recovery Zone

Based on research by Wakkinen and Kasworm (1997), within the CYE recovery zone, research benchmarks for open motorized route density (OMRD), total motorized route density (TMRD), and secure core indicate that adverse effects to grizzly bears are likely to occur when OMRD exceeds 1 mile per square mile in more than 33 percent of the subunit, TMRD exceeds 2 miles per square mile in more than 26 percent of the subunit, and secure core is not at least 55 percent of the subunit during the non-denning period.

In 2011, the Lolo, Kootenai, and Idaho Panhandle Forest plans were amended with direction for motorized access management within the CYE and Selkirk Ecosystem (SE) recovery zones (2011 access amendments). The selected alternative established BMU-specific standards and provided the rationale for varying from the benchmark values. The portion of the CYE recovery zone that is on the Forest is within the BMU 22. For this BMU, the motorized access management standard is to maintain no more than 33 percent OMRD, no more than 35 percent

TMRD, and provide at least 55 percent secure core. TMRD was set higher than the research benchmark because the amount and pattern of private ownership precludes attaining 26 percent. At the time of the 2011 Access Amendment, none of these three access standards were met in BMU 22, which had 51 percent secure core, 38 percent OMRD, and 37 percent TMRD. These conditions were anticipated to cause adverse effects due to disturbance and displacement of individual grizzly bears that may be present in the BMU. This BMU is a major component of the Cabinet-Yaak to Bitterroot Linkage Zone identified by Servheen et al. (2001).

The Record of Decision for the 2011 access amendments estimated that full implementation of the actions needed to reach the prescribed standards of the selected alternative would take eight years from the date of the decision in 2011. On September 6, 2019, the Forest reported that the existing percent of secure core habitat in BMU 22 had been improved to 52.9 percent, and requested a three-year extension of the time-frame specified in the incidental take statement to reach 55 percent to allow for completion of the Forest's ongoing BMU 22 Compliance Project. On January 29, 2020, the Service amended their 2011 biological opinion to extend the incidental take statement to November 2022. On February 11, 2022, the Service received a letter from the Forest stating that the motorized route and secure core metrics described in the 2011 biological opinion and amended incidental take statement for the BMU 22 Compliance Project in BMU 22 have been met. Due to these recent changes in motorized access in BMU 22, the amount of secure core has increased to 55 percent while the OMRD has decreased to 32 percent and TMRD has decreased to 33 percent. Consequently, all three access amendment standards of the 2011 Access Amendment are currently met in BMU 22 and now represent the environmental baseline for the BMU related to motorized access management. Secure core and OMRD meet the research benchmarks where adverse effects are not expected. However, although the standard to have no more than 35 percent TMRD is met in BMU 22, it remains above the research benchmark of having no more than 26 percent TMRD. As such, it is likely that the environmental baseline in BMU 22 will continue to cause some level of displacement that may result in adverse effects to individual grizzly bears that may be present within the BMU.

In addition to meeting the standards associated with OMRD, TMRD, and secure core, other direction was provided under the 2011 access amendment. This direction is described in detail in Appendix 2 of the biological assessment, which is incorporated by reference (U.S. Forest Service 2022). Within this direction, standards were included related to administrative use in the recovery zone. Administrative use shall not exceed 60 vehicle round trips per active bear year (non-denning season of April 1 through November 30) per road, apportioned as follows: ≤18 round trips in spring (April 1 through June15); ≤23 round trips in summer (June 16 through September 15); and ≤19 round trips in fall (September 16 through November 30). If the number of trips exceeds 60 trips per active bear year in the Cabinet-Yaak ecosystem, then that road would be considered "open" for effects analysis and reporting purposes. Likewise, if the number of trips exceeds the allowable ecosystem-specific seasonal (spring, summer, and fall) vehicle round trips per road, then that road would be considered "open" for effects analysis and reporting purposes.

The 2011 access amendment direction also allows for some level of entering core area blocks for road decommissioning or stabilization activities. The effects of some scenarios were analyzed and no further section 7 consultation was required, including that the Forest Service may affect underlying core area (i.e., any core habitat that is affected by the subject road and its buffer) within a BMU once per 10-year time frame, and not to exceed 1 bear year for the sole purpose of completing road decommissioning/stabilization activities on existing closed or barriered roads in core area habitat. Subsequent needs to re-enter individual core areas within a BMU more frequently than once per decade for the purposes of road decommissioning shall be handled on a case-by-case basis through standard section 7 consultation procedures. Routine forest management may be proposed in a core area block after 10-years of core area benefit. However, BMUs must remain at or above the core standard. Therefore, potential losses to existing core must be compensated with in-kind replacement concurrently or prior to incurring the losses. Such in-kind replacement of core would be established within the affected BMU in accordance with the access management direction. Following management, core areas must subsequently be managed undisturbed for 10 years.

Parameters for establishing and managing core habitat in all BMUs were also provided as part of the direction. Once route closures to create core areas are established and effective, these core areas should remain in place for at least 10 years. Therefore, except for emergencies or other unforeseen circumstances requiring independent section 7 consultation, newly created core area shall not be entered via motorized access for at least 10 years after creation. As mentioned, other direction associated with the 2011 access amendment management direction can be found in Appendix 2 of the biological assessment (U.S. Forest Service 2022).

NCDE Recovery Zone

In 2018, the Forest amended their Forest Plan to incorporate management criteria from the NCDE grizzly bear conservation strategy (NCDE grizzly bear amendments). The intent of the NCDE grizzly bear conservation strategy and associated grizzly bear amendments to the Forest Plan is to ensure recovery is maintained post delisting. In general, the NCDE grizzly bear amendments stipulated that within the recovery zone (also referred to as the Primary conservation area or PCA) no net increase in OMRD and TMRD would occur above the 2011 motorized access baseline conditions and no net decrease in secure core would occur below the 2011 motorized access baseline conditions. Thus, over the life of the Forest Plan, the levels of OMRD, TMRD, and secure core in all subunits are to be maintained at the same (or better) level than the conditions as of December 31, 2011, at which time the NCDE grizzly bear population was stable to increasing. Some exceptions under certain conditions do exist, as detailed in the NCDE grizzly bear amendments and conservation strategy. For example, the NCDE grizzly bear amendments allow temporary effects to the 2011 baseline for temporary activities or projects. Temporary route construction and use would not affect the overall 2011 baseline measurement. Permanent changes in OMRD, TMRD, or secure core may occur due to improved data, unforeseen circumstances, natural events, or other reasonable considerations. Such changes may adjust the baseline values but will not be considered a violation of the motorized access management habitat objectives described in the NCDE grizzly bear conservation strategy (NCDE Subcommittee 2020) and will not require mitigation responses. Acceptable changes that may adjust baseline conditions, as well as a detailed list of application rules for motorized access on federal lands can be found in the 2020 NCDE grizzly bear conservation strategy (*Ibid.*) and summarized in the 2021 monitoring report (Ake 2022), which are incorporated by reference. The changes that have occurred under these exceptions to date along with the rationale for these changes can be found in the 2017, 2019, and 2021 biennial monitoring reports of the motorized access baselines that are produced for the NCDE subunits (Ake 2018, Ake 2020, and Ake 2022).

The existing motorized access conditions for the NCDE recovery zone portion of the action area are displayed in Table 2 by subunit and reflect the most recent information. These conditions represent the 2011 baseline conditions as updated. The 2021 biennial monitoring report of the 2021 motorized access baselines for the NCDE subunits was issued after completion of the biological assessment for the continued implementation of the Forest Plan. Accordingly, as some metrics were updated since that time, the metrics in Table 2 represent the most current information and may differ than some metrics displayed in the biological assessment. Rationale for those differences can be found in the 2021 monitoring report (Ake 2022). As all updates fall under the exceptions, the updated information does not violate the standard to maintain conditions as of December 2011 with allowable updates and the standard associated with the baseline motorized access conditions is being met.

Table 2. Existing OMRD, TMRD, and Secure Core within the NCDE recovery zone portion of the action area (Ake 2022).

Subunit[1]	OMRD[2]	TMRD[3]	Secure Core[4]
Monture	0 %	0 %	99 %
Mor-Dun	15 %	8 %	80 %
North Scapegoat	0 %	0 %	100 %
South Scapegoat	12 %	15 %	75 %
Mission*	25 %	50 %	37 %
Rattlesnake	6 %	13 %	85 %
Swan	31 %	20 %	53 %

[1]Subunits with an asterisk next to their name are less than 75 percent Forest ownership
[2]OMRD is the percent of the subunit with open motorized routed densities exceeding 1 mile per square mile
[3]TMRD is the percent of the subunit with total motorized routed densities exceeding 2 miles per square mile
[4]Secure core is the percent of the subunit functioning as secure core habitat in patches of at least 2,500 acres, excluding acreage of large lakes and small private lands.

Within the NCDE recovery zone, research benchmarks for OMRD, TMRD, and secure core describe that adverse effects to grizzly bears are likely to occur when OMRD exceeds 1 mile per square mile in more than 19 percent of the subunit, TMRD exceeds 2 miles per square mile in more than 19 percent of the subunit, and secure core is not at least 68 percent of the subunit during the non-denning period. This road-density threshold, first identified by Mace et al. (1996) has been roughly observed by other researchers in multiple study areas (summarized in Proctor et al. 2019) as being a density beyond which adverse effects to female grizzly bears can occur. Table 2 displays that all but two of the subunits (Mission and Swan) meet these conditions related to OMRD, TMRD and secure core. As all other subunits are better than the research benchmarks related to adverse effects for OMRD, TMRD, and Secure Core, the ongoing effects associated with the existing motorized access conditions within those subunits would be insignificant to grizzly bears. The Mission subunit is less than 75 percent Forest ownership and the lower amounts of secure core within the subunit are a result of motorized access on non-Forest land. The Swan subunit is long and narrow and does not contain as much wilderness and/or roadless as other subunits on the Lolo. In the Mission and Swan subunits where the research benchmarks are not achieved, it is anticipated that the environmental baseline may cause some level of displacement that may be adverse to individual grizzly bears in that area. The Forest previously completed a site-specific formal consultation on access management within the Swan subunit in 2011 and is discussed below. As a result of this consultation, in addition to overall OMRD, TMRD, and secure core, spring OMRD is also tracked for the Swan subunit and is currently at 22 percent OMRD.

Outside of the Recovery Zones

Recovery zones were established to identify areas necessary for the recovery of a species and are defined as the area in each grizzly bear ecosystem within which the population and habitat criteria for recovery are measured. Recovery zones are areas adequate for managing and promoting the recovery and survival of grizzly bear populations (U.S. Fish and Wildlife Service 1993). Areas within the recovery zones are managed to provide and conserve grizzly bear habitat. Some areas outside the recovery zones have some level of management as described above (i.e. NCDE zones 1 and 2, DCAs) but most areas outside the recovery zones are not managed for grizzly bears and do not have a need to track the same motorized access metrics as within the recovery zone. As such, the moving windows process is not used outside of the recovery zones and the information and knowledge associated with motorized access is not consistent with the information presented for the recovery zones. As described above, we have included an analysis of secure habitat for the areas outside of the recovery zone in order to more accurately portray the potential effects to grizzly bears than a simple linear route density.

NCDE zone 1 and the Ninemile DCA are described in the NCDE grizzly bear conservation strategy (NCDE Subcommittee 2020). In short, NCDE zone 1 is a buffer around the recovery zone (also known as the PCA). The NCDE recovery zone and NCDE zone 1 combined is the area within which NCDE population monitoring data are collected and mortality limits apply. The intent is for NCDE zone 1 to support continual occupancy by grizzly bears, although at a lower density than within the recovery zone. The portion of NCDE zone 1 on the Forest overlaps with six GBAUs including the Clearwater, Cottonwood, Gold, Middle Blackfoot, North Missoula, and Placid GBAUs. Within the southwest corner of NCDE zone 1 is the Ninemile DCA. The Ninemile DCA is intended to provide habitat that can be used by female grizzly bears with cubs and allow for grizzly bear movement to the BE recovery zone. The Ninemile DCA overlaps with four GBAUs including the Keystone, Mill North, Ninemile, and Trout East GBAUs.

Currently, in NCDE zone 1 on the Forest outside the Ninemile DCA, about 325 miles of Forest Service roads are legally open to public motorized use on about 289 square miles of Forest land, for an existing open route density of about 1.1 miles per square mile (U.S. Forest Service 2022 *in litt.*). Based on data presented by Boulanger and Stenhouse (2014), this existing density of roads open to public motorized use is expected to be compatible with bear occupancy and to support survival of females with dependent young sufficient for a stable to increasing population trend. Forest Plan standard NCDE-LNF Zone 1-STD-01 requires no net increase in the 2011 linear density of roads open to public motorized use during the non-denning season on National Forest System lands within NCDE zone 1 (other than the Ninemile DCA). In 2011, the linear open road density for NCDE zone 1, outside of Ninemile DCA, was 1.3 miles per square mile, thus standard NCDE-LNF Zone 1-STD-01 is being met. Secure habitat within the GBAUs that overlap NCDE zone 1 are displayed in Table 3 below. Most of the GBAUs within NCDE zone 1 outside of the Ninemile DCA provide secure habitat at a level substantially less than is likely needed to successfully support a female grizzly bear with cubs. It is likely that the baseline conditions within this area contributes some level of connectivity for bears traveling between recovery zones but is likely resulting in some level of displacement effects that are adverse to individual grizzly bears.

Within the Ninemile DCA, about 569 miles of Forest Service roads and 37 miles of Forest Service trails are legally open to public motorized use on about 400 square miles of Forest land, for an existing average motorized route density of 1.5 miles per square mile (U.S. Forest Service 2022 *in litt.*). This existing motorized route density is expected to be generally compatible with occupancy by and survival of female grizzly bears, including those with dependent young (Boulanger and Stenhouse 2014). Forest Plan standard NCDE-LNF Zone 1-STD-01 requires no net increase in the density of roads and trails open to public motorized use during the non-denning season on National Forest System lands within the Ninemile DCA. In 2011, the linear open route density for the Ninemile DCA, was 1.6 miles per square mile, thus standard NCDE-LNF Zone 1-STD-01 is being met. The environmental baseline with respect to motorized routes open to the public is expected to support habitat connectivity between the NCDE and the other recovery zones, which is the goal of the DCA. Secure habitat within the GBAUs that overlap the Ninemile DCA are displayed in Table 3 below. No Forest Plan standards are applicable to secure habitat in this area. The four GBAUs within the Ninemile DCA provide secure habitat at levels likely substantially less than is needed to successfully support a female grizzly bear with cubs. At the same time, the Keystone and Ninemile GBAUs are notable in that most of the secure habitat is in larger polygons more than 2,500 acres in size. It is likely that the baseline conditions within the Ninemile DCA contributes some level of connectivity for bears traveling between recovery zones but is likely resulting in some level of displacement effects that are adverse to some individual grizzly bears.

The Forest Plan does not require motorized access management in NCDE zones 2 and 3 or in areas outside of these designations nor is the Forest required to provide secure habitat in these areas. A very small portion of the Forest is located within NCDE zone 2 and none of the Forest is located within NCDE zone 3. The remainder of the action area outside of the recovery zones is also outside of the NCDE zones 1 and 2 designations. Reference figure 2 in Appendix 1 of the biological assessment for the various delineations of the action area (U.S. Forest Service 2022).

A Forest-wide analysis of the availability of secure habitat was completed to assess the amount and arrangement of secure habitat and its ability to support grizzly bears that may occupy or move through the areas outside of recovery zones. In the portions of the Forest outside of recovery zones, secure habitat was identified by buffering 500 meters from either side of all motorized routes in the Forest's database that may be drivable, irrespective of seasonal or yearlong restrictions, and includes known routes categorized as undetermined.[1] On Forest lands, routes known to be restricted with physical barriers (not gates), impassable routes, over-the-snow motorized routes/areas, and non-motorized trails can occur within secure habitat polygons and provide secure habitat. It is generally assumed that bermed roads are not in drivable condition, but when there is uncertainty of whether an effective barrier exists, roads were considered drivable and coded as such in the database. This methodology is similar to that used in the nearby NCDE recovery zone, but it acknowledges both that no standards limit administrative use of roads outside of the recovery zones and that available data are less complete in this portion of the Forest in terms of the types and locations of closure devices and the condition of the road prism beyond the barrier. It is important to note that although this approach may result in a

[1] This includes the undetermined routes referenced in the Soldier Butler litigation, *Alliance for the Wild Rockies v. Marten*, No. CV 20-156-M-DLC, 2021 WL 4551496 (D. Mont. Oct. 5, 2021), as well as undetermined routes throughout the Forest.

lower estimate of the existing amount of secure habitat in a GBAU, it assures that the impacts of motorized route use are not underestimated for the GBAU as a whole, giving the benefit of the doubt to the species (U.S. Fish and Wildlife Service 1998). Accordingly, the secure habitat amounts provided are useful mainly as a broad index of what may be available to grizzly bears that may use the action area outside of the recovery zone. The Forest is expected to update the secure habitat metrics as they update their access data during site-specific project planning in order to more accurately portray what is existing on the ground at the time of this consultation. Routes that were existing on the Forest but unmapped due to errors or lack of information may or may not affect the Forest's estimate of the existing amount of secure habitat, depending on the location of the roads. It is expected that this type of adjustment to the baseline would reflect better data and mapping rather than representing actual changes on the ground or result in additional effects to grizzly bears. As the access database is updated, the improved information will better reflect the existing conditions (that were already present and not new) related to secure habitat in the GBAUs.

In addition, since the Forest lacks inventory information and has no management authority over non-Forest lands, a 500 meter buffer was placed around Forest land in those areas where Forest land is adjacent to non-Forest land ownerships. Buffering Forest land 500 meters from non-Forest Service land ownerships is a conservative approach when considering effects to grizzly bears and will capture any unknown or undisclosed cumulative effects that may result from non-Forest actions on non-Forest land that occur adjacent to Forest lands. For example, actions on adjacent non-Forest land could affect secure habitat on adjacent Forest lands by having impacts within 500 meters of secure habitat. Accordingly, the Forest lands within 500 meters of lands not administered by the Forest may not provide secure habitat due to the potential effects associated with motorized access on adjacent non-federal lands. While it is possible that Forest land within 500 meters may provide secure habitat, information as to activity on non-Forest land is often unknown or not disclosed and the Forest lacks management authority over non-Forest lands. As such, the amount of secure habitat on Forest land adjacent to non-Forest land could change at any time without the Forest's knowledge or authority. Therefore, to be conservative when analyzing effects to grizzly bears, in order to not miss any potential effects associated with motorized access on non-Forest lands, Forest land within 500 meters of non-Forest land is buffered out of the secure habitat metric for the Forest. Because of the long life of the Forest Plan, it is not possible to know everything that may occur on non-Forest land and because the Forest has no control on non-Forest lands, this buffer accounts for any cumulative effects to grizzly bears that may have occurred from actions on non-Forest lands. In other words, any potential unknown effects associated with non-Forest lands have already been incorporated into this analysis ahead of time. For example, if motorized access were to increase on non-Forest land adjacent to Forest land, potentially affecting grizzly bears in the action area associated with disturbance and/or displacement, the effects of such are already considered into the metrics of secure habitat that are measured for Forest lands. Thus, we would not miss any effects to secure habitat on Forest lands over time, giving the benefit of the doubt to the species (U.S. Fish and Wildlife Service 1998). Using this conservative approach does not result in significant effects to the grizzly bear population.

The approximate existing amount of secure habitat within the GBAUs outside of the recovery zones is displayed in Table 3 by GBAU, rounded to the nearest whole number. Table 3 displays both the total amount of secure habitat in the GBAUs as well as the amount of secure habitat within blocks at least 2,500 acres in size. Patches of secure habitat greater than 2,500 acres may overlap one or more GABUs so the acres presented in the last column of Table 3 display the portion of those 2,500 acre patches of secure habitat that overlaps a given GBAU and may be less than 2,500 acres on its own but when combined with the habitat in the adjacent GBAU is 2,500 acres or more.

Table 3. Estimated existing secure habitat within the action area outside of the recovery zones (U.S. Forest Service 2022).

GBAU	GBAU Total Acres	Total Acres of Forest Lands in GBAU (percent of GBAU)	Total Acres of Secure Habitat with no minimum patch size (% of GBAU / % of Forest land in GBAU)	Acres of Secure Habitat that are part of patches greater than 2,500 acres (% of GBAU / % of Forest land in GBAU)
NCDE zone 1				
Clearwater	67,672	42,936 (63%)	1,791 (3% / 4%)	792 (1% / 2%)
Cottonwood	59,150	28,223 (48%)	3,123 (5% / 11%)	2,948 (5% / 10%)
Gold	56,700	31,990 (56%)	4,326 (8% / 14%)	3,517 (6% / 11%)
Middle Blackfoot	72,003	6,178 (9%)	140 (<1% / 2%)	0
North Missoula	60,485	52,617 (87%)	35,710 (59% / 68%)	35,575 (59% / 68%)
Placid	49,452	23,207 (47%)	800 (2% / 3%)	0
Ninemile DCA				
Keystone	78,844	57,233 (73%)	18,856 (24% / 33%)	15,340 (19% / 27%)
Mill North	45,962	39,489 (86%)	1,674 (4% / 4%)	251 (<1% / 1%)
Ninemile	118,325	99,597 (84%)	28,653 (24% / 29%)	25,786 (22% / 26%)
Trout East	96,830	59,911 (62%)	6,620 (7% / 11%)	948 (1% / 2%)
Outside of NCDE zone 1 and Ninemile DCA				
Dry Cold	54,727	47,742 (87%)	24,176 (44% / 51%)	19,514 (36% / 41%)
Dry Eddy	84,017	61,230 (73%)	25,172 (30% / 41%)	21,510 (26% / 35%)
Fish Creek	167,586	131,853 (79%)	100,527 (60% / 76%)	98,294 (59% / 75%)
Little Thompson	80,196	42,973 (54%)	4,665 (6% / 11%)	2,376 (3% / 6%)
Lower Rock	145,614	133,773 (92%)	75,014 (52% / 56%)	72,939 (50% / 55%)
Lynch Creek-Clark Fork	120,338	22,848 (19%)	2,919 (2% / 13%)	2,133 (2% / 9%)
Middle Thompson	54,977	31,463 (57%)	8,063 (15% / 26%)	5,535 (10% / 18%)
Mill South	69,834	28,669 (41%)	9,837 (14% / 34%)	9,299 (13% / 32%)
Miller	70,174	56,549 (81%)	2,255 (3% / 4%)	0
North Lolo	98,176	73,558 (75%)	11,667 (12% / 16%)	7,578 (8% / 10%)
Pats Knob	63,542	51,641 (81%)	17,808 (28% / 34%)	13,686 (22% / 27%)
Petty Creek	75,064	62,850 (84%)	15,683 (21% / 25%)	10,019 (13% / 16%)
Prospect	144,377	115,913 (80%)	29,671 (21% / 26%)	10,708 (7% / 9%)
St Regis North	107,509	94,354 (88%)	23,456 (22% / 25%)	15,499 (14% / 16%)
St Regis South	124,392	118,405 (95%)	27,282 (22% / 23%)	12,065 (10% / 10%)
South Lolo	82,455	73,547 (89%)	18,799 (23% / 26%)	15,903 (19% / 22%)
Trout West	140,809	123,039 (87%)	40,291 (29% / 33%)	39,259 (28% / 32%)
Upper Fishtrap	82,322	18,925 (23%)	1,178 (1% / 6%)	4 (<1% / <1%)
Upper Rock	73,711	73,095 (99%)	55,630 (75% / 76%)	55,324 (75% / 76%)
Upper Thompson	43,111	12,735 (30%)	1,886 (4% / 15%)	0

Motorized route densities outside the recovery zone are typically higher due to the varied ownerships, the long history of various human uses, and their proximity to human population centers, which are typically located away from large blocks of unroaded habitat such as wilderness. As such, the amount of secure habitat outside of the recovery zones is typically much lower than the amount within the recovery zones. As displayed in Table 3, the amount of secure habitat on Forest land varies greatly among GBAUs with a range from a low of 2 percent to a high of 76 percent. As previously mentioned, the amount of secure habitat also varies spatially within a GBAU, with higher amounts in some portions and lower amounts in others.

A cluster of three adjacent GBAUs located on the east side of the Lolo NF (Clearwater, Placid, and Middle Blackfoot) have a very small proportion of FS lands and consequently, these GBAUs have very low amounts of secure habitat on Forest lands. However, these GBAUs also contain a significant amount of land owned by The Nature Conservancy, which may provide additional secure habitat that is not recognized here.

Most of the GBAUs (25 of 30) provide less secure habitat than the roughly 50 to 70 percent reported for home ranges of female grizzly bears (Wakkinen and Kasworm 1997, Mace and Manley 1996, review in Proctor et al. 2020). It is likely that the five GBAUs with more than 50 percent secure habitat (North Missoula, Dry Cold, Fish Creek, Lower Rock, and Upper Rock) may be able to support female grizzly bears to successfully live, reproduce, and raise young, while the other GBAUs may not have the amount of secure habitat needed to support female grizzly bears. However, other land ownerships within these GBAUs may bolster the amount of secure habitat to the levels needed to establish and maintain regular home ranges. It is likely that existing motorized access conditions within most of the GBAUs on the Forest may be resulting in some level of ongoing significant displacement effects to grizzly bears, depending on site-specific information such as location and grizzly bear presence. However, some females are able to adapt and have proven that they are able to successfully reproduce and raise young in areas with high route densities and associated low amounts of secure habitat. If grizzly bears are not present, especially female grizzly bears, then no significant effects would be expected until such time that females began using the area.

Monitoring efforts to assess closure effectiveness on the Forest are focused in the NCDE and CYE recovery zones because of their importance for grizzly bear recovery. For the CYE recovery zone (BMU 22), per the Forest Plan, as amended, 30 percent of the road closure devices (gates and barriers) will be monitored annually. No specific requirements are in the Forest Plan to monitor road closure effectiveness in the NCDE recovery zone, but monitoring does occur during the active bear season. Road closure monitoring in the NCDE recovery zone is more opportunistic and usually occurs while conducting other field work. Unauthorized use is determined by damage to or removal of the restriction device, and/or by vegetation and ground disturbance that indicate wheeled motorized vehicle use.

Overall, road closures and gates have been found to be effective at restricting motorized vehicle use, but instances occur where vehicles illegally use restricted routes despite the presence of a sign, gate, or barrier. The CYE and NCDE recovery zones have similar closure effectiveness challenges. Recent road closure monitoring has discovered incidents where a gate has been compromised, gate lock has been cut off, or evidence of a motorcycle has gone around a gate. These types of road closure issues are repaired or augmented to deter use and are revisited to assess whether barrier repairs or barriers are effective. These repairs have not always resolved issues and continued efforts are sometimes needed to deter use of closed roads.

Roads that are not on the Motorized Vehicle Use Map (MVUM) for the Forest are closed to all public motorized use during the non-denning season. A private entity's non-compliance with the Forest's access management is an illegal activity. While illegal use of the Forest (action area) via motorized access in areas unauthorized for such use may occur within the action area, such illegal use is not considered a Forest action. The term "action" for Section 7 consultation is defined in the Consultation Handbook (U.S. Fish and Wildlife Service, National Marine Fisheries Service 1998) as: all activities or programs of any kind *authorized, funded, and/or carried out*, in whole or in part, by Federal agencies in the United States or upon the high seas (emphasis added). These and any other illegal activities are not the result of a federal action and therefore not analyzed under effects of the action, but their effects and influence are considered for describing the environmental baseline as they may have resulted in past cumulative effects. We have considered the effects of such illegal motorized access on grizzly bears to the best of our ability despite the uncertainty associated with illegal motorized access as described below.

Illegal motorized access could occur anywhere on the Forest. The Forest, including Forest staff and law enforcement, monitors road closures for violations and enforces closures to the extent practicable given the resources available. Recent road closure monitoring has discovered incidents where a gate has been compromised, gate lock has been cut off, or evidence of a motorcycle has gone around a gate. The Forest remedies the situation through repair or replacement as soon as possible after being made aware of the violation. These types of road closure issues are repaired or augmented to deter use and are revisited to assess whether barrier repairs or barriers are effective. These repairs have not always resolved issues and continued efforts are sometimes needed to deter use of closed roads. In a review of past warnings and citations issued by Forest law enforcement to drivers operating a motorized vehicle inconsistent with the MVUM, about ten warnings or citations have been issued each year over the past ten years, although it is unlikely these warnings or citations account for all of the motor vehicle issues nor all motor vehicle violations on the Forest.

The illegal motorized access situations on the Forest are typical of what would be expected for a National Forest in Montana. The Forest and Service both recognize that illegal use is always possible and that the Forest handles these situations by making repairs as soon as possible, to discourage recurring violations. Even with ongoing efforts, some individuals may continue to break the law and illegally access parts of the Forest via motorized vehicles. The Forest's efforts as described minimize areas of chronic and recurring illegal motorized use to the extent possible. Given the Forest's efforts to curtail illegal motorized access and the ongoing monitoring and maintenance of closures, the level of illegal motorized access of within the action area (the Forest) is expected to be minimal.

While illegal motorized access on the Forest has the potential to affect individual grizzly bears, the amount, location, duration, and timing of effects resulting from such illegal use is not typically known. The probability of long-term illegal motorized access and probability of illegal motorized access coinciding with the presence of grizzly bears is anticipated to be low but is unknown. As such, the potential consequences to grizzly bears are uncertain. Nonetheless, any disturbance effects associated with illegal motorized access is expected to be spatially disparate and temporary and is not likely to collectively cause an adverse effect because most Forest users follow travel regulations and when illegal motorized access is observed or becomes apparent the Forest corrects the situation as soon as they are able.

Moreover, when the Forest implements road restrictions, they typically (but not always (e.g. signage)) use closure devices or methods recognized by the IGBC (IGBC 1998) as effective to restrict motorized access. Accordingly, the intent of using these IGBC recognized closure devices is to implement a closure device that is meant to be effective and it is not the intent or purpose of the Forest to implement closure devices recognized by the IGBC that are meant to be ineffective. While, at any given time, a Forest user could illegally breach a closure device recognized by the IGBC as an effective method in restricting motorized access, that is not the intent of the Forest's action.

If grizzly bears are in the vicinity of illegal motorized access, such illegal use would most likely result in short-term, temporary disturbance effects to grizzly bears as opposed to long-term displacement effects because once they become aware of the issue the Forest corrects the situation as soon as they are able. As such, while the effects of illegal motorized access are considered in the baseline for the proposed action, a change to the metrics used by the Forest to assess the baseline motorized access conditions that are under the authority of the Forest would not occur as such use was temporary and was not authorized, carried out, or funded by the Forest. The timing for corrections may vary depending on seasonal and/or weather conditions and the type of correction needed (for example corrections may range from replacing a broken lock to replacing a broken gate or fixing a barrier, to redesigning and/or constructing a new barrier).

For the area outside recovery zones, secure habitat was delineated using a conservative approach by buffering all drivable motorized routes, regardless of route status (including undetermined routes). Because all routes are considered the same (whether open or restricted) for calculating secure habitat for grizzly bears, illegal motorized use of restricted routes does not affect secure habitat. Secure habitat could only be affected by illegal motorized access with off-road use or use of reclaimed/obliterated or bermed roads (which are no longer considered roads for the purposes of calculating grizzly bear secure habitat or motorized route miles/densities) that occurs within secure habitat. Any effects are expected to be short-term and temporary and would not affect the Forest's motorized access metrics for secure habitat unless the Forest makes a decision to authorize motorized use, thus resulting in long-term effects to secure habitat. Such effects would be analyzed during a site-specific project consultation as applicable.

While disturbance effects to grizzly bears may occur as a result of illegal motorized access on the Forest, it is the Service's opinion that such effects are reasonably uncertain. Information as to the length, duration, amount of illegal use, type of use, and location, among other conditions, is and will continue to be unknown. Accordingly, the Service and the Forest are not able to fully calculate the extent of such effects to individual grizzly bears. However, it is our opinion that the effects of any illegal motorized access on the grizzly bear populations are likely low as evidenced by: (1) the NCDE grizzly bear population status, including an increasing number of grizzly bears, an expansion of the distribution of grizzly bears, and an estimated positive population trend and (2) the CYE population trend changing from declining to slightly increasing, with 14 years of an improving trend since 2006, and improved genetic diversity. Because illegal motorized use is not considered a federal action, any effects associated with illegal motorized access are not exempted under this biological opinion.

The action area includes several designations, such as congressionally-designated wilderness areas and inventoried roadless areas (IRAs), which limit or restrict human activities including motorized travel. These areas provide some level of habitat security for grizzly bears by prohibiting or largely restricting motorized and mechanized travel and by limiting other activities such as timber harvest, development of recreation sites, and others. Four wilderness areas are located at least partly on the Forest, including the Rattlesnake, Welcome Creek, Scapegoat, and Selway-Bitterroot Wilderness Areas, as well as numerous IRAs. Approximately 41 percent of the Forest is within wilderness and IRAs. Table 4 displays the amount of designated wilderness and IRAs both inside and outside of the recovery zone.

Table 4. Acres of wilderness areas and inventoried roadless areas on the Forest (U.S Forest Service 2022).

Area of the Forest	Total Acres	Wilderness acres	Inventoried Roadless Area (IRA) acres	Wilderness plus IRA acres (percent)
CYE recovery zone	145,782	0	67,305	67,305 (45%)
NCDE recovery zone	269,822	94,433	127,979	222,412 (82%)
BE recovery zone	9,802	9,784	36	9,820 (100%)
NCDE zone 1 and Ninemile DCA	429,328	15,403	54,390	69,793 (16%)
Forest land that outside of the recovery zones, NCDE zone 1, and Ninemile DCA	1,375,433	28,262	506,227	534,489 (39%)
Totals	**2,230,167**	**147,882**	**755,937**	**903,819 (41%)**

Winter Motorized Use

The Over-Snow Vehicle Use Map (OSVUM) provides the areas and routes allowed for over-snow vehicle use on the Forest. About 550 miles of over-snow vehicle routes occur on the Forest, which include trails or roads that function as over-snow vehicle trails during the winter months. The Seeley Lake Ranger District is a snowmobile destination area and about half of the over-snow vehicle routes on the Forest occur on the Seeley Lake Ranger District. The Missoula and Superior Ranger Districts host the majority of the remaining half of the over-snow vehicle use routes on the Forest.

Over-snow vehicles are authorized to travel off of designated routes to travel cross-country in specific areas on the Forest. Cross-country travel with over-snow vehicles is allowed on about 66 percent of the Forest, either all winter or seasonally. However, over-snow vehicles can be limited where they can travel given natural conditions like topography and snow depth. The remaining 34 percent of the Forest, which includes wilderness and other sensitive areas, does not authorize over-snow vehicle use.

About 52 percent of the BE, CYE, and NCDE recovery zones and 16 percent of the NCDE zone 1/Ninemile DCA are closed year-round to all over the snow vehicles. A small percentage (<1 percent) within the recovery zone and NCDE zone 1/Ninemile DCA have seasonal restrictions for over snow vehicle use. About 34 percent of the portion of the Forest outside the recovery zones and NCDE zone 1/Ninemile DCA has year-round over-snow vehicle closures while about 3 percent of this area has seasonal over-snow vehicle closures.

As mentioned, the Seeley Lake Ranger District is a snowmobile destination area. Groomed over-snow vehicle routes and play areas are mainly concentrated outside the NCDE recovery zone. Several management areas (MAs) prohibit snowmobile use across large portions of the Seeley Lake Ranger District (MAs 10, 11 and 12). Spring road closures are in place around Colt Creek, Morrell Falls, Richmond Peak, and Clearwater Lake to specifically protect grizzly bears from over-snow vehicle use and other motorized disturbance during the non-denning period from April 1 to June 30. The Missoula and Superior Ranger Districts have many miles of trails and roads for over-snow vehicle recreation, in addition to areas where over-snow vehicles may travel off the roads and trails, such as Lolo Creek, Mineral Peak, Shoofly Meadow, and Twin Creeks. Trails and roads that allow over-snow vehicle use are less common on the Ninemile and Plains/Thompson Falls Districts. All over-snow vehicle use on the Forest is limited by the Forest's Over Snow Vehicle Use Map.

Despite the Forest covering a large area of grizzly bear habitat, the only known denning occurs within the NCDE. Grizzly bear denning has not been recorded in the portion of the BE or CYE portions of the Forest. Grizzly bears do den in the CYE to the north of the Forest but not currently within the portion located on the Forest (BMU22).

As the grizzly bear population continues to grow and expand, grizzly bears could den within areas not previously known to have active grizzly bear denning. Grizzly bears are quite variable in their selection of denning habitat and structures (Schwartz et al. 2003). Grizzly bears usually dig dens on steep slopes where wind and topography cause an accumulation of deep snow and where the snow is unlikely to melt during warm periods. In addition, grizzly bears are more likely to den in areas with greater canopy cover and at elevations above 6,371 feet (>1,942 meters) (Mace and Waller 1997). Grizzly bears within the CYE also appear to dig dens on steeper slopes and at elevations where snow is likely to persist during the denning period but grizzly bears in the Cabinet Mountains may choose den sites starting at a lower elevation since grizzly bear dens have been recorded above 5,740 feet (about 1,750 meters) in elevation (Kasworm et al. 2022a).

Denning habitat was spatially modeled in 2015 for the NCDE since grizzly bears were denning within the ecosystem. The analysis used the best available information at the time by using unpublished grizzly bear den site data collected by Richard Mace. The model included aspect, slope class, minimum elevation, and habitat classification of den sites. The NCDE was split into zones to refine the model for local differences. For this modeling effort, the localized modeled areas included the Swan Valley, Mission-South-end, and Wilderness Zones, which overlap the portions of the Forest.

Denning habitat on the remaining portion of the Forest uses a simplified approach. To estimate denning habitat on the remaining portion of the Forest (outside the NCDE), a basic GIS exercise was completed using available data such as slope, canopy cover, and elevation as a proxy to where denning habitat could occur outside of the NCDE. Given a lack of known den sites on the Forest outside of the NCDE, this approach likely overestimates denning habitat outside the NCDE because it is a simplified approach and is not a model that incorporates finer details such as localized den site characteristics. However, this analysis, although an overestimate of the amount of denning habitat, can provide an estimate of where denning habitat may occur. This denning habitat estimate will likely be updated as research becomes available.

Within the NCDE recovery zone, the standard NCDE-STD-AR-08 caps the amount of area available to motorized over-snow travel in modeled denning habitat during the den emergence period. No net increase in the percentage of area or miles of routes designated for motorized over-snow vehicle use is to occur on Forest lands in the NCDE recovery zone during the den emergence time period.

Over-snow vehicle use can occur on the Forest from December 1 to March 15, March 31, April 15 or April 30 depending on the location. In addition, some areas on the Forest do not have a closed season. As such, the Forest does have some areas where over-snow vehicle use may occur during the grizzly bear den emergence period. The Forest estimated the acres of overlap between denning habitat and over-snow vehicle use.

About 33 miles of over-snow vehicle use trails and/or roads pass through possible denning habitat, with about 29 of these miles open to over-snow vehicle use during the den emergence period. The NCDE recovery zone, NCDE zone 1, and the Ninemile DCA have about 24 miles open to over-snow vehicle use within possible denning habitat during the den emergence period. No trails for over-snow vehicle use are identified in the OSVUM for the CYE. No over-snow vehicle use trails or roads occur within the BE. The remaining 5 miles of over-snow vehicle use trails within possible denning habitat (currently not known to be used for denning) during the den emergence period occur in the outlying areas of the Forest (areas outside the NCDE, CYE, and BE recovery zones, NCDE zone 1, and the Ninemile DCA). It is important to note that a lack of snow can shorten the snowmobiling season regardless of the OSVUM season dates. About 206,000 acres of cross-country over-snow vehicle use on the Forest could occur within grizzly bear denning habitat during the denning period, with about 205,100 of these acres open to cross-country over-snow vehicle use during the den emergence period. About 58,200 acres of denning habitat within the NCDE recovery zone, NCDE zone 1, and the Ninemile DCA and about 22,800 acres within the CYE Recovery Zone in BMU 22 (currently not known to be used for denning) overlap over-snow vehicle use during the den emergence period. The portion of the BE Recovery Zone on the Forest is entirely within an area closed to over-snow vehicle use, thus no acres of over-snow vehicle use overlaps potential denning habitat. Within the areas outside the NCDE, CYE, and BE recovery zones, NCDE zone 1, and the Ninemile DCA, about 124,100 acres are open to cross-country over-snow vehicle use during the den emergence period (currently not known to be used for denning). However, from a qualitative review, not all of these acres of cross-country over-snow vehicle use are available for snowmobiling due to either the ruggedness of the terrain or other logistical limitations. In addition, some areas may not be available to over-snow vehicle use after March 31st due to a lack of snow, particularly on the Plains/Thompson Falls Ranger District where conditions are largely drier and at lower elevation. Effects to grizzly bear associated with winter motorized use may vary from none to insignificant to significant effects, dependent on site-specific information. In limited circumstances, where denning habitat overlaps over-snow vehicle use during the den emergence period over-snow use, we conservatively estimate some level of potential for significant effects to occur. These effects are further described in the effects section below.

Aircraft use

The use of aircraft, including helicopters, has occurred on the Forest for several reasons but have primarily been related to prescribed burning and tree harvest, although aircraft may be used for reconnaissance and for emergency actions such as during wildland fire suppression. The use of equipment that produces noise during project implementation may be used over possibly days to weeks in an area. The combination of equipment noise and human presence likely result in some level of disturbance effects to any grizzly bears that may be in the area during the time of aircraft activity. Effects from such disturbance may range from none, to insignificant, to adverse depending on location and duration and type of activity, among other things.

The NCDE grizzly bear conservation strategy (NCDE Subcommittee 2020) identifies and provides management guidance for several factors that influence grizzly bears including potential disturbance and displacement from habitat. The NCDE grizzly bear conservation strategy identifies the potential for disturbance by recurring low-elevation (<500m) helicopter flights.

Food and Attractant Management and Site Development

On National Forest System lands, requirements for proper storage of food, garbage, or other attractants are established and enforced through issuance of special orders. The portions of the Forest within the NCDE and CYE recovery zones began issuing food/attractant storage orders in the mid to late 1980s, and subsequently have updated and expanded the spatial extents of those orders. The Forest has had a forest-wide food/wildlife attractant storage special order in place since 2011. Under the most recent food storage order (Regional order R1-2023-02, February 2023), food, carcasses, and attractants must be stored in a bear-resistant container or stored in a bear-resistant manner if they are unattended.

Forest plan standard NCDE-STD-WL-02 requires that a food/wildlife attractant storage special order be in place on Forest lands within the NCDE PCA (recovery zone), NCDE zone 1 (including the Ninemile DCA), and NCDE zone 2. The Regional food/attractant storage order applies Forest-wide and covers these areas (and more) and complies with this standard. The food/attractant storage order is an important conservation action that has reduced the potential for human-bear conflicts and mortality risk.

Developed recreation sites are sites or facilities with features that are intended to accommodate public use and recreation, such as campgrounds, rental cabins, summer homes, trailheads, lodges, ski areas, fire lookouts, visitor centers, and others. Developed sites on public lands are associated with frequent and/or prolonged human use that may include continuous or frequent presence of food and attractants. To aid in trash and food storage, the Forest has installed several bear resistant trash containers and bear resistant food storage boxes across the Forest, mostly located in campgrounds. Whether a location has a bear resistant food container or trash container or not, visitors are responsible for ensuring attractants are stored properly according to the forest-wide food/attractant storage order.

The locations of existing developed recreation sites on the Forest are shown in figure 3 in Appendix 1 of the biological assessment (U.S. Forest Service 2022). No developed recreation sites occur on the Forest within the BE recovery zone.

No specific Forest plan direction pertains to developed recreation sites within BMU 22 within the CYE recovery zone. As of June 2021, five developed day-use only sites and five developed overnight use sites occur on the Forest within BMU 22.

Within the NCDE recovery zone, standard NCDE-STD-AR-05 limits any increase in the number and capacity of developed recreation sites that are designed and managed for overnight use by the public during the non-denning season to one increase per decade per bear management unit. Guideline NCDE-GDL-AR-03 states that if the number or capacity of day-use or overnight developed recreation sites is increased, the project should include one or more measures to reduce the risk of grizzly bear-human conflicts in that bear management unit. Such measures could include but are not limited to additional public information and education, providing backcountry food-hanging poles or bear-resistant food or garbage storage devices, project design criteria that would limit capacity increases to those needed for public health and safety, and increasing law enforcement and patrols. A total of three developed sites with overnight use, 17 sites with day-use only, and five administrative sites occur on the Forest within the NCDE recovery zone.

No Forest Plan direction is specific to coordinating developed recreation sites with grizzly bear conservation in the portions of the Forest outside of the recovery zones. As of June 2021, a total of 27 recreation residences, 56 recreation sites with overnight use, 83 day-use only recreation sites, and 52 administrative sites occur on the Forest outside of the recovery zones.

There is no history of recurring conflicts at developed recreation sites on the Forest. No mortalities on the Forest are known or suspected to be associated with food conditioning or unsecured attractants at developed recreation sites. Given the small number of existing developed recreation sites that provide overnight use, food/attractant storage orders and policies that are in place, and Forest Plan direction that discourages expansion of developed recreation sites, the existing environmental baseline with regard to developed recreation on the Forest may cause disturbance of individual bears but is unlikely to rise to the level of adverse effects by causing habitat displacement or food-conditioning of grizzly bears.

Dispersed recreational opportunities as well as non-motorized (e.g. hiking, horseback, mountain biking) recreation also occur throughout the Forest. Dispersed recreation consists of those activities that take place outside of developed recreation areas. Dispersed sites generally do not have fees associated with them and have little or no facilities such as toilets, tables, or garbage collection. Types of dispersed activities that occur on the Forest include, but are not limited to, camping, hiking, fishing, skiing, hunting, gathering huckleberries, horseback riding, river use, and snowmobiling.

Dispersed recreation occurs across much of the Forest, but typically occurs in close proximity to motorized routes. However, opportunities exist for non-motorized cross country (e.g. hiking or horseback) dispersed recreation, especially for game hunting purposes where people may access areas not commonly visited by people. In other words, much of the dispersed recreation that occurs on the Forest is occurring in close proximity to motorized routes and if it occurs away from motorized routes the use is typically non-motorized. As such, the existing environmental baseline with regard to dispersed recreation on the Forest may cause disturbance of individual bears but is unlikely to rise to the level of adverse effects by causing habitat displacement or food-conditioning of grizzly bears.

Livestock Management

The Forest has 11 active grazing allotments: two within the recovery zones (1 NCDE, 1 CYE), two within NCDE zone 1 and the Ninemile DCA (one in each), and seven outside of the recovery zones, NCDE zone 1, and the Ninemile DCA. None of these allotments are for domestic sheep or other small livestock. These active cattle allotments encompass 80,878 acres, or 3.6 percent of the Forest. Table 5 displays these allotments by areas of the Forest, inside and outside of the recovery zones.

Table 5. Active livestock grazing allotments on the Forest (U.S. Forest Service 2022).

	Number of active cattle allotments	Acres of active cattle allotments	Number of domestic sheep allotments
BE recovery zone	0	0	0
CYE recovery zone	1	78	0
NCDE recovery zone	1	220	0
NCDE Zone 1	1	1,984	0
Ninemile DCA	1	6,830	0
Remainder of Forest	7	71,766	0
Totals	**11**	**80,878**	**0**

Over the life of the Forest Plan, the number of grazing allotments has substantially decreased. In 1986, the Final EIS for the Lolo Forest Plan disclosed that there were 128 range allotments, 14 of which were for wilderness pack stock with the remainder for non-wilderness grazing. About 60 percent of the allotments were active and about 40 percent were inactive at that time. Forest Plan direction indicates for each Management Area whether or not livestock grazing will be permitted. Additional guidance for Range Practices is provided for MA-12 Wilderness, MA-14 riparian, and MA-20 grizzly bear habitat, which is primarily aimed at avoiding overutilization of forage in areas where cattle naturally tend to congregate.

No known incidents of grizzly bear mortality or grizzly bear-human conflict have occurred on the Forest as the result of livestock grazing-related management subsequent to the listing of the grizzly bear as Threatened in 1975. Permits for grazing by saddle and pack animals are granted primarily in support of outfitter and guide operations or Forest administrative use in wilderness areas. No history of conflicts between grizzly bears and horses/mules due to depredation or forage competition occurs on the Forest.

Honeybees, classified as livestock in Montana (MCA 15–24–921), can attract grizzly bears. While some apiaries occur on private land, none occur on the Forest. Forest Plan standard NCDE-STD-SFP-01 requires special-use permits for apiaries (beehives) located on Forest lands to incorporate measures, including electric fencing to reduce the risk of grizzly bear-human conflicts as specified in the food/wildlife attractant storage special order. Effects associated with livestock management are expected to be insignificant and are further described in the effects section below.

Vegetation and Fire Management

The existing environmental baseline is characterized by a forested matrix with early successional stages created by vegetation management and wildfires. The current environmental baseline provides a variety of bear foods while maintaining a mosaic of food and cover. The Forest Plan established a forest-wide objective to "provide for the maintenance of a diverse mosaic of vegetational development, well distributed across the Forest to ensure ecological integrity". Vegetation treatment, including prescribed fire, is encouraged to improve habitat for various wildlife species and groups. Harvesting has been used within the action area as a tool used to achieve a variety of resource objectives, including but not limited to lowering fuels and fire risk; establishing desired tree species; improving tree growth; reducing impacts of insects or disease; contributing wood products to the local economy; improving wildlife habitat; and salvaging the economic value of trees killed by fire or other factors.

All of the Forest land within the BE recovery zone is designated as Wilderness, where natural processes generally predominate without human intervention. The Forest Plan does not have specific direction to coordinate vegetation management with grizzly bear conservation in the CYE recovery zones or outside of the recovery zones. Vegetation management within the NCDE recovery zone includes desired conditions and guidelines that address considerations for the timing of activities to reduce the risk of disturbance/displacement, encouraging bear foods and retaining cover, and cessation of activities if needed to resolve a grizzly bear-human conflict situation. Standards for maintaining hiding cover to benefit big game and other species also benefit grizzly bears. Vegetation management must also adhere to other grizzly bear related guidance, including standards regarding motorized route density and food storage orders.

Under the Forest Plan, approximately 1,239,000 acres (about 56 percent of the action area) are identified as suitable for timber production. Timber production is the purposeful growing, tending, harvesting, and regeneration of rotational crops of trees to be cut into logs, bolts, or other round sections for industrial or consumer use. For purposes of Forest planning, timber production does not include production of fuelwood or harvest from unsuitable lands. The 1986 Forest Plan, recognizing the need to protect soil and water resources and other multiple uses, projected that the average annual harvest would be 133 MMBF during the 2001-2030 time period (U.S. Forest Service 2022).

A 2000-2001 Forest Plan Monitoring Report that provided a comparison of projected versus actual annual average acres treated during 1987 through 2001 by various silvicultural activities displayed that much less regeneration harvest (clearcut, seed tree and shelterwood) actually occurred than had been projected and more commercial thinning occurred than had been projected, during that time period. An annual average of the following occurred during that time period: 1,876 acres of clearcut and seed tree harvest, 726 acres of shelterwood harvest, 319 acres of overstory removal, 215 acres of selection harvest, 887 acres of sanitation and salvage harvest, 434 acres of commercial thinning, and 861 acres of timber stand improvement. The 2020 Forest Plan Monitoring Report also summarized timber program accomplishments for the period 2018 to 2020. The average acres of regeneration and intermediate harvests over the three-year period was 5,562 acres, a substantial increase compared to the earlier time period, yet still well below the Forest Plan projection. In addition, the Forest reported that an average of 5,980 acres of mechanical fuels treatments not related to timber harvest were completed from 2018 to 2020.

The biological assessment used the available reports to provide information on silvicultural actions, which have a large gap between reporting years. Given the gap in monitoring reports, the Forest provided the following additional information to the Service, which was pulled from the Forest's database of record for their vegetation accomplishments (FACTS). The acres presented in the 2000-2001 and 2020 Forest monitoring reports represented those acres of vegetation actions that went into contract for those fiscal years and not when the actions were completed on-the-ground. Typically, there is a delay between when a contract is executed, and the action occurs on the ground. Sometimes the delay could be years. In these circumstances, the reported acres of executed contract acres could be larger than what is accomplished on the ground for that fiscal year.

To provide a more accurate estimate of silviculture actions completed each year, the following information from the Forest represents those acres of silviculture actions completed on-the-ground. Due to how the data was compiled, the results are not necessarily comparable to those acres presented in the 2000-2001 and 2020 Forest monitoring reports. Over the past 10 years, the Forest has completed various silvicultural actions that can be divided into commercial (regeneration and intermediate harvest) and non-commercial actions. On average, across the past 10 years (2012-2021), the Forest has completed about 1,200 acres of regeneration harvest, 900 acres of intermediate harvest, and 1,500 acres of non-commercial harvest per year. However, the acres of silvicultural actions have steadily increased over the last 10 years, especially over the most recent 3 years.

Wildfire has a strong influence on the age distribution and spatial arrangement of Forest vegetation. The Forest typically experiences wildfire on an annual basis. Based on available GIS data, the Forest had 550 wildfires burning about 344,972 acres over the past 5 years (2017-2021). Wildfires ranged in size from less than 1 acre to several thousands of acres in size, such as in 2017 where wildfires burned about 228,000 acres. The size and severity of wildfires is expected to continue to increase due to climate change.

While most fires start naturally and are not federal actions, prescribed fires, burnouts, or backburns may be lit by fire crews during a wildfire incident as an import tool to protect values at risk. Prescribed fire operations are conducted under conditions such that ignition would be completed when fire behavior is expected to be minimal (time of day, relative humidity, etc.). Prescribed fire ignitions are implemented in a manner that focuses on reducing fuels prior to the wildfire reaching those areas in an attempt to reduce the spread and intensity of the wildfire.

The following information provides a brief summary of general wildfire suppression actions that may be used during a wildfire. The additional information received during consultation provides a detailed description of fire suppression actions. Wildfire suppression generally involves a designated incident command post, which houses all fire support services including daily briefings, support component tents, fire crew sleeping areas, food service facilities, and parking. Occasionally firefighter support is needed far from the original incident command post (ICP) and spike camps are established. Suppression actions include the use of hand line, machine line, drop points, and shaded fuel breaks. These vary in size depending on the fire and fire conditions. Water sources are also used for suppression actions and include aircraft dip sites and draft sites from which water trucks and portable pumps draw water. Fire retardant and water enhancers are also used when fires pose a direct threat to public safety. These are delivered by helicopter and airplanes directly to leading fire edges to reduce burn intensity or to vegetation immediately ahead of the advancing edge to reduce available fuels. Explosives are occasionally used by fire crews to remotely fall snags or create fireline in areas that would be too hazardous to be done directly by hand. Traffic on existing roads in and around fires tends to increase with the degree of road use varying by fire size and duration. Roads can also be affected by heavy equipment traffic and log skidding. Immediately after a fire, interdisciplinary Burned Area Emergency Response (BAER) teams are used to review burned landscapes to assess the need for emergency stabilization treatments to minimize threats and degradation to values at risk. Actions that may occur under BAER often include stabilizing roads and trails by replacing or repairing drainage structures and repairing trail and road surfaces. Seeding or other techniques to stabilize soils may also occur under BAER.

Effects to grizzly bears associated with vegetation and fire management range from minimal disturbance to significant displacement depending on the site specific circumstances such as location, duration, habitat affected, and motorized access conditions, among other activities. These effects are further described in the effects section below.

Energy and Mineral Exploration and Development

The production of oil and natural gas on federal lands is conducted through a leasing process under the Federal Onshore Oil and Gas Leasing Reform Act of 1987 (PL 100–203). Mineral development refers to surface and underground hardrock mining and coal production, which is regulated by permits on National Forest System lands under the Mining Act of 1872, as amended through PL 103–66. The Mineral Materials Act of 1947, as amended through PL 96–470, provides for the sale or public giveaway of certain minerals such as sand or gravel.

The potential for oil and gas resources on the Forest is considered to be low. No gas or oil exploration or development is occurring on the Forest at this time, thus no ongoing effects are occurring. Two active gold mines and one quartz crystal mine are located on the Forest. All three mines are located in the area outside the NCDE recovery zone, NCDE zone 1, Ninemile DCA, CYE recovery zone, and BE recovery zone. Each of these mines has less than 1/2 acre of surface disturbance.

The Forest-wide Standard 41 requires: "Before oil and gas lease stipulation recommendations are made, site specific analysis of environmental effects will be made. Stipulations, which are based upon the 1982 Environmental Analysis for Oil and Gas of Non-wilderness Lands on the Forest, will be recommended in accordance with management area direction in Chapter III. In some instances, the stipulations will include a provision for 'no surface occupancy.' The lessee or designated operator has the right to explore for and extract oil/gas from his/her lease in accordance with the stipulations attached to the lease." Thus, the magnitude of effects from leasable or locatable minerals exploration and development would be limited by provisions of the Forest plan. Any such proposals would be subject to additional site-specific analysis. Project development and mitigation plans would be designed to avoid, minimize, or compensate for any adverse effects associated with the mining proposal.

Additional forest plan desired conditions, standards, and guidelines specific to the NCDE recovery zone, NCDE Zone 1, and the Ninemile DCA, are designed to avoid, minimize, and/or mitigate impacts to grizzly bears or their habitat, subject to valid existing rights. For example, the standards address cessation of activities if needed to resolve a grizzly bear-human conflict, proper handling of food and garbage, possible timing restrictions on seismic and/or ground-disturbing activities, and a requirement for a no surface occupancy stipulation on any new leases.

Effects to grizzly bears associated with energy and mineral exploration and development range from minimal disturbance to significant displacement depending on the site specific circumstances such as location, duration, habitat affected, and motorized access conditions, among other activities. These effects are further described in the effects section below.

Connectivity

Dispersal between disjunct populations can play an important role in the persistence of a species by increasing genetic diversity, facilitating colonization and recolonization of unoccupied habitats, and augmenting the numbers of small populations (Mattson and Merrill 2002). Proctor et al. (2012) used genetic data from 3,134 grizzly bears along with radio telemetry location data from 792 grizzly bears across western Canada and northern United States to assess large-scale movement patterns and genetic connectivity among bear populations. In the northern, more remote portion of their distribution in Canada, grizzly bear populations were found to be well connected, with movement, dispersal, and gene flow influenced by distance and natural topographic features (e.g., icefields), as would be expected. In contrast, in the southeastern part of their distribution, rates of movement and genetic interchange were impaired. Population fragmentation in these areas was associated with human settlements, highways, and human-caused mortality.

Young female grizzly bears usually establish home ranges that overlap with their mother's (Blanchard and Knight 1991). McLellan and Hovey (2001) measured the distances between the home range center of a mother and those of her dispersed offspring (30 offspring, 12 females and 18 males) over 20 years. They reported that females dispersed, on average, 5.9 miles from their maternal home range, whereas males dispersed 17.9 miles. Using genetic analysis of 711 grizzly bears in southwestern Canada, Proctor et al. (2004) estimated that females, on average, dispersed 8.6 miles from the center of the natal home range; males, on average, dispersed 25 miles from a natal or maternal home range. Proctor et al. (2012) found that male grizzly bears generally move more frequently and over longer distances than females. The estimated maximum dispersal distances were about 47 miles for a female and 104 miles for a male (Ibid.). The distance between the known distributions of the NCDE and GYE, and from the NCDE distribution to the BE are approaching or within the dispersal range of male bears.

A goal of the recovery plan for the CYE is to attain a population of approximately 100 animals (U.S. Fish and Wildlife Service 1993). Because of the small size of this recovery zone, achieving and maintaining the population goal will require connectivity with other grizzly bear populations to maintain genetic health over time. Kasworm et al. (2022a) summarized data on movements of bears into and out of the Cabinet-Yaak recovery zone. A pilot program tested the feasibility of population augmentation by releasing four subadult female bears with no history of conflicts with humans from southeast British Columbia into the Cabinet Mountains during 1990 to 1994. Success of the augmentation pilot program prompted additional augmentation, with ten female bears and eight male bears moved from the Flathead River to the Cabinet Mountains during 2005 to 2021. Four of these individuals were killed during their first year and one was killed after 16 years. Eight of the bears left the target area for augmentation, but three returned and one was recaptured and brought back. Five individuals (3 females and 2 males) are known to have contributed to reproduction. The augmentation effort appears to be the primary reason grizzly bears have persisted and are increasing in numbers in the Cabinet Mountains (Kendall et al. 2016, Kasworm et al. 2022a).

During the period 1983 to 2021, 41 grizzly bears were identified as immigrants or emigrants to or from the CYE. Twenty-seven individuals (24 males and 3 females) are known to have moved into the CYE from adjacent populations including the North Purcells (17), NCDE (5), and South Selkirks (7). Of these, 11 were killed, removed, or emigrated out of the CYE prior to any known gene flow. Gene flow has been documented through reproduction by 4 immigrants from the North Purcells producing 14 offspring in the CYE (Kasworm et al. 2022a).

These observations suggest that movement between grizzly bear populations is possible under the conditions of the environmental baseline. The NCDE appears to be capable of serving as a source population for the CYE, based on its large, increasing population size and its expanding distribution (NCDE Subcommittee 2020), although only a few bears have moved from the NCDE to the Cabinet-Yaak to date. Some large roadless land areas occur immediately south of BMU 22 that may help facilitate connectivity between the Cabinet-Yaak and the Bitterroot recovery zones in the future.

The assessment of genetic health of the CYE provided in the SSA (U.S. Fish and Wildlife Service 2022a) is predicated on the management goal of the CYE entity being one population. Previously, prior to 2012, no movement was seen between the Yaak and the Cabinets. However, recent monitoring of grizzly bear movements have shown events toward reconnecting the Cabinets and Yaak portions with male grizzly bears being documented in this area in several instances over the last 10 years (Kasworm et al. 2022a). Though gene flow has not been detected, the SSA attempts to conservatively assess the genetic health of the CYE based on the Cabinets portion of this population and this lack of demonstrated gene flow (U.S. Fish and Wildlife Service 2022a). While genetic issues may be a concern for the small CYE population in the longer term, demographic concerns currently outweigh those genetic concerns. Movement from other populations into the Yaak portion of the CYE recovery zone and the continued augmentation from the NCDE reduce the level of concern associated with the small population size. While isolation of the CYE remains a concern, recent data indicate increasing movements by males and females and subsequent reproduction, resulting in limited but increasing population connectivity, particularly in the Yaak portion of the CYE (*Ibid.*).

The NCDE, SE, and CYE populations could serve as a source of grizzly bears for the unoccupied BE. It would require movement of both male and female grizzly bears to establish a population in the BE. Females disperse less often and for shorter distances than males, thus occupancy by female bears is likely to take much longer to achieve than occupancy by male bears. The distribution of grizzly bears in northwestern Montana has been expanding and the environmental baseline conditions on the Forest appear to be compatible with supporting movement of grizzly bears from the CYE or NCDE recovery zones to the BE recovery zone.

It is estimated that periodic immigration (one to two male migrants every 10 years) would be sufficient to provide for genetic connectivity of the greater Yellowstone ecosystem (GYE) (Miller and Waits 2003). The NCDE appears to be more than capable of serving as a source population for other grizzly bear populations, including the GYE, based on its large, increasing population size and its expanding distribution (NCDE Subcommittee 2020). Several potential linkage areas have been identified that could facilitate the natural movement of grizzly bears into the GYE (Servheen et al. 2001). Peck et al. (2017) used GPS telemetry data from 173 male grizzly bears in the NCDE and the GYE and a new analysis method (randomized shortest path algorithm and step selection function models) to identify possible routes for male-mediated gene flow. These models depicted numerous potential paths from the NCDE to the GYE. The more likely pathways to connect the NCDE and GYE grizzly bear populations are through the Tobacco Root/Boulder Ranges, the Flint Creek/Garnet Ranges, or the Bridger/Big Belt Ranges. The Sapphire Mountains were predicted to have at least a low potential for movement under all models. The predicted paths were corroborated by the locations of confirmed observations of 21 grizzly bears located 4.8 miles or more outside the two occupied ranges. The closest proximity is about 66 miles, between the Boulder and Madison Mountain ranges. The authors concluded that the probability of successful natural dispersal from the NCDE into the GYE remains low, due to the distance between the current occupied ranges and large intervening areas of inter-mountain valleys encompassing human settlements, highways, and agriculture.

Forest-wide goal 7, "For threatened and endangered species occurring on the Forest, including the grizzly bear, gray wolf, peregrine falcon, and bald eagle, manage to contribute to the recovery of each species to non-threatened status" and desired condition NCDE-DC-WL-02, "Within the NCDE primary conservation area and zone 1 (including the Ninemile demographic connectivity area), grizzly bear habitat on NFS lands contributes to sustaining the recovery of the grizzly bear population in the NCDE and contributes to connectivity with neighboring grizzly bear recovery zones" will encourage management actions that do not impair and may enhance habitat connectivity and genetic exchange between recovery zones. Secure habitat provides an important component to habitat connectivity. While the Forest Plan does not have standards requiring management of secure habitat outside the recovery zones, certain Forest Plan management areas limit or restrict construction of motorized routes, as previously described. The NCDE grizzly bear population has been increasing in numbers and expanding its range, and the NCDE grizzly bear conservation strategy and associated NCDE grizzly bear amendment standards and guidelines are aimed at maintaining or increasing the population. We anticipate that under continued implementation of the Forest Plan, the NCDE population will be capable of serving as a source population for other recovery zones where the bear population is smaller or absent.

Climate Change

In SSA, the Service examined climate change and potential effects on grizzly bears (U.S. Fish and Wildlife Service 2022a). The most likely ways in which climate change may potentially affect grizzly bears are: a reduction in snowpack levels, shifts in the denning season, shifts in the abundance and distribution of some natural food sources, and changes in fire regimes due to summer drought. The potential positive and negative effects would likely be variable and are difficult to predict.

Reduced snowpack or a shorter winter season possibly may improve over-winter survival of bears, assuming that sufficient bear foods are available later in the fall and earlier in the spring (Ibid.). However, a shorter denning period could increase the potential for spring and fall encounters between grizzly bears and hunters and/or recreationists, which in turn would increase the risk of mortality to grizzly bears (Servheen and Cross 2010).

Temporal and spatial shifts in food sources available to grizzly bears may occur and have been documented (U.S. Fish and Wildlife Service 2022a). The extent and rate to which individual plant species or plant communities are impacted by climate change is not possible to predict with any level of confidence (Fagre et al. 2003, Walther et al. 2002). However, there is general consensus that grizzly bears are flexible enough in their dietary needs that they are not and will not be impacted directly by changes in food sources due to climate change (Servheen and Cross 2010). It is anticipated that grizzly bears will be able to adapt to future potential changes in food availability because of the flexibility in their diets and the large range of foods available due to the varying climate, topography, and vegetative conditions within the ecosystems, which provide a variety of habitats and foods for grizzly bears to consume (U.S. Fish and Wildlife Service 2022a). For example, grizzly bears will eat almost anything available including vegetation, living or dead mammals or fish, insects, and human garbage (Ibid.).

Whitebark pine, a potential food source for grizzly bears (particularly in the GYE), is a species in decline across its range and has been recently listed as a threatened species under the ESA. As a result of widespread mortality of whitebark pine from blister rust, whitebark pine has been functionally extinct as a resource for grizzly bears in the NCDE for the past 40 years (Ibid.). Whitebark pine is not considered as a food resource for grizzly bears in the CYE (Ibid.). Therefore, the overall decline in whitebark pine throughout its range is not expected to result in effects to grizzly bears that use the action area. They have adapted and/or continue to use other food resources and both populations have experienced an increase in their numbers over the same time whitebark pine has been in decline.

Fire frequency and severity may increase as a result of climate change. Increases in fire frequency could result in improvements to grizzly bear forage, with low to moderate severity fires being most beneficial (U.S. Fish and Wildlife Service 2022a). Wildfires that convert mature forest to early successional condition alter the availability of grizzly bear foods and cover, potentially changing how bears use the landscape in the short-term. However, decreases in forest cover could benefit grizzly bears by increasing the production of shrubs, berries, and root crops in the years following fires, provided that appropriate hiding cover remains available.

Grizzly bears are habitat generalists and opportunistic omnivores, which may make them less susceptible to changes in plant communities than some other species of wildlife. We expect that grizzly bears would adapt to future changes in habitat and food sources caused by climate change. Because of the plasticity in their diets, it is expected they will be able to switch foods according to which foods are most nutritious and available (Ibid.). The continuing effects of climate change appear to be unlikely to reduce the ability of the Forest to support a population of grizzly bears and the movement of grizzly bears between recovery zones. As conservation plans and strategies as well as mortality limits are in place, the SSA expected that negative effects of climate change on grizzly bears will be limited. The SSA (Ibid.), incorporated by reference, has further information on the effects to grizzly bears associated with climate change.

Other forest management actions that are part of the baseline

In addition to the main programs and activities discussed above, other federally authorized activities occur on the Forest that could potentially affect grizzly bears. Activities such as road and trail maintenance, noxious weed control, maintenance and use of communication towers and other utilities, and gathering of firewood and other miscellaneous forest products may occur on an annual or infrequent interval. These types of activities are typically of low intensity and short duration. They may cause local disturbance to individual grizzly bears that are in the immediate vicinity.

These various past and present activities are ongoing and are part of the current baseline habitat conditions experienced by grizzly bears. It is important to note that these authorized activities were occurring during the period when research showed that the NCDE and CYE grizzly bear populations were stable to increasing in numbers and distribution. These activities are evaluated site-specifically during project analysis.

Existing Projects and Consultations

Several projects and consultations are ongoing on the Forest and are likely to continue after the completion of this biological opinion. Consultation with the Service has been completed for these actions, thus the actions are included in the environmental baseline as some of the effects associated with the existing consultations are likely to continue. Some consultations will be superseded by this biological opinion while others will continue to remain valid. This biological opinion on the continued implementation of the Forest Plan will supersede four biological opinions that are associated with the existing Forest Plan, including the 2004 biological opinion on the Forest Plan and associated 2012 amended incidental take statement, the 2011 biological opinion on the final access management strategy for the Swan subunit in the NCDE, the 2011 biological opinion on the access amendment to the Forest Plan for the CYE, and the 2017 biological opinion on the NCDE grizzly bear amendments. These projects and consultations are summarized below.

2004 Biological Opinion and 2012 Amended Incidental Take Statement on the Forest Plan

In 2004, the Service and Forest consulted on the effects of continued implementation of the Forest Plan on grizzly bears. The consultation applied to areas on the Forest that were situated within the NCDE recovery zone and some areas outside of the designated NCDE recovery zone that were included in the recognized distribution area for grizzly bears as of the 2004 consultation. In 2012, as grizzly bears continued to expand and based on new information on the status of grizzly bears, the Service issued an amended incidental take statement associated with the 2004 biological opinion that continued to apply to the areas of the Forest within the NCDE recovery zone and some areas outside of the NCDE recovery zone, which included some expanded areas of distribution over the 2004 conditions but not the entire Forest. Three program areas were the focus of the 2004 biological opinion: access management, food and attractant storage, and livestock grazing. Since this 2023 biological opinion is also analyzing the effects of the continued implementation of the Forest Plan on grizzly bears, but further expanding the analysis to the entire Forest, the 2004 biological opinion and 2012 amended incidental take statement (U.S. Fish and Wildlife Service 2004, 2012) are superseded by this 2023 biological opinion on the continued implementation of the Forest Plan.

Related to motorized access management, the effects to grizzly bears were previously analyzed (2004, 2012) using only an estimate of acres of low, moderate, or high levels of motorized route density. As explained above, providing the acreage of low, moderate, and high levels of motorized use gives an idea of the amount of roads in the action area, however it does not represent how these routes occur on the landscape. Secure habitat has been identified as one of the key issues related to effects of motorized access on grizzly bears and is important to the survival and reproductive success of grizzly bears. While secure habitat is directly tied to and based on open and restricted motorized routes, it more adequately represents the potential effects to grizzly bears related to motorized access as it provides a more accurate indication of the spatial mix of motorized routes and secure habitat. As such, we have incorporated secure habitat into the analysis for this 2023 biological opinion, which is different than how we analyzed effects in 2004 and 2012. In addition, we previously issued an amended incidental take statement in 2012 that limited the amount of new permanent road construction to 7.14 miles of road. In order to better represent the effects to grizzly bears from motorized access, this 2023 biological opinion and incidental take statement will analyze how new and temporary route construction affects secure habitat rather than providing a limit to the amount linear miles of road construction (see effects section and incidental take statement below).

2011 Biological Opinion on the Final Access Management Strategy for the NCDE Swan Subunit

The 2011 consultation on the final access management strategy for the Swan subunit analyzed the effects of reaching and maintaining the subunit at an OMRD of 22 percent during the spring and 31 percent during the fall, a TMRD of 17 percent, and a secure core of 55 percent. The Forest had met these conditions in 2011. Since the final access management strategy for the Swan subunit would maintain OMRD and secure core conditions that are worse than the research benchmarks for the NCDE, high open road densities, along with lower amounts of secure core, would continue to occur within the subunit indefinitely. Therefore, the access management strategy for the Swan subunit would likely result in adverse effects to some individual grizzly bears that may attempt to live in the Swan subunit and the 2011 biological opinion and incidental take statement on the final access management strategy for the Swan subunit was issued. While the Swan Subunit has met the Final Access Management Strategy for the Swan Subunit, the metrics have changed since consultation. The changes are partly a result of projects improving the OMRD, TMRD, and secure core and partly a result of updating the baseline conditions. As allowed under the NCDE grizzly bear amendments, updates to the baseline conditions occurred when better information became available (such as improved mapping accuracy) and when the Forest acquired land. All of the updates are documented in the NCDE Biennial Reports and are allowable updates to the baseline. The current conditions (2021) are documented in Table 2 above. Rationale for changes in the metrics can be found in the 2021 monitoring report (Ake 2022). As all updates fall under the exceptions, the updated information does not violate the standard to maintain conditions as of December 2011 with allowable updates and the standard associated with the baseline motorized access conditions is being met. In addition, some level of temporary road construction was also considered in the 2011 biological opinion. The effects of temporary road construction were subsequently addressed in the consultation on the 2018 NCDE grizzly bear amendments (for which the biological opinion is also being superseded as described below). Since the Forest has previously met the conditions under the final access management strategy for the Swan subunit and continued access management for the Swan subunit will be managed under the continued implementation of the Forest Plan, including the NCDE grizzly bear amendments, the biological opinion on the effects of the final access management strategy for the Swan subunit (U.S. Fish and Wildlife Service 2011a) is no longer relevant and is superseded by this 2023 biological opinion on the continued implementation of the Forest Plan.

2011 Biological Opinion of the Motorized Access Direction for the CYE Portion of the Forest

In 2011, the Lolo, Kootenai, and Idaho Panhandle Forest plans were amended with direction for motorized access management within the CYE and Selkirk Ecosystem (SE) recovery zones (2011 access amendment). Based on research by Wakkinen and Kasworm (1997), within the CYE recovery zone, research benchmarks for OMRD, TMRD, and secure core describe that adverse effects to grizzly bears are likely to occur when OMRD exceeds 1 mile per square mile in more than 33 percent of the subunit, TMRD exceeds 2 miles per square mile in more than 26 percent of the subunit, and secure core is not at least 55 percent of the subunit during the non-denning period.

The Forest's BMU-specific standards for the only BMU (BMU 22) on the Forest are to maintain no more than 33 percent OMRD, no more than 35 percent TMRD, and provide at least 55 percent secure core. TMRD was set higher than the research benchmark because the amount and pattern of private ownership precludes attaining 26 percent. In January 2020, the Service amended the 2011 biological opinion to extend incidental take coverage for the Forest's portion of the CYE recovery zone through November 2022, or the date of completion of ongoing actions bringing the Forest into compliance with the access standards, whichever occurred first. Since consultation in 2011 on the access amendment and the amendment issued in 2020, as of February 2022, the Forest has brought BMU 22 into compliance with these standards. While BMU 22 meets the standards for OMRD, TMRD, and secure core, the standard for TMRD remains above the research benchmark of having no more than 26 percent TMRD. As such, it is likely that the existing motorized access conditions in BMU 22, specifically TMRD, will continue to cause some level of disturbance and displacement that may result in adverse effects to individual grizzly bears that may be present within the BMU. The effects of such are analyzed in the baseline section above as well as the effects section below. In addition to standards associated with OMRD, TMRD, and secure core, other direction was also provided under the 2011 access management direction regarding secure core and administrative use. For more specific details see the baseline section above for the CYE recovery zone, effects section below, as well as Appendix 2 of the biological assessment (U.S. Forest Service 2022). As the 2011 access management standards were amended to the Forest Plan and we are including the effects of such in this 2023 biological opinion, the portion of the biological opinion on the effects of the 2011 access amendment related to the Lolo National Forest, including the 2020 amended biological opinion, (U.S. Fish and Wildlife Service 2011b, 2020) are superseded by this 2023 biological opinion on the continued implementation of the Forest Plan.

2017 Biological Opinion on the NCDE Grizzly Bear Amendments

In 2018, the Forest Plan was amended to incorporate management criteria from the NCDE grizzly bear conservation strategy (NCDE grizzly bear amendments). In general, the NCDE grizzly bear amendments incorporated management criteria regarding motorized access management, over-snow travel, developed sites, livestock grazing, vegetation management activities, mining and oil and gas exploration and development. Information and analysis associated with the NCDE grizzly bear amendments are described in the various sections above and below rather than in this section as an existing project as it is current Forest Plan direction. The direction under the NCDE grizzly bear amendments is also fully detailed in Appendix 2 of the biological assessment (U.S. Forest Service 2022). As the measures under the NCDE grizzly bear amendments were amended to the Forest Plan and we are including the effects of such in this 2023 biological opinion, the portions of the 2017 consultation on the NCDE grizzly bear amendments applicable to the Lolo National Forest (U.S. Fish and Wildlife Service 2017) are superseded by this 2023 biological opinion on the continued implementation of the Forest Plan.

Table 6. Ongoing Projects with Completed Section 7 Consultation.

Project Name	Ranger District	Work Completed on the Ground
Sawmill-Petty Project	Ninemile Ranger District	No on the ground work has started
Center Horse TAP	Seeley Lake Ranger District	No on the ground work has started
Rice Ridge Salvage	Seeley Lake Ranger District	Work has been completed except for pile burning and landing rehabilitation
Liberty Fire Salvage	Seeley Lake Ranger District	Work has been completed except for landing rehabilitation
Cruzane Mountain Project	Superior Ranger District	No on the ground work has started
D7 Access Requests	Superior Ranger District	No on the ground work has started
A-BLT	Plains/Thompson Falls Ranger District	No on the ground work has started
BMU 22 Compliance	Plains/Thompson Falls Ranger District	Motorized route work in progress
Thorne Fire Salvage	Plains/Thompson Falls Ranger District	No on the ground work has started
Sorrel Springs	Ninemile Ranger District	No on the ground work has started
Fryxel Access Request	Plains/Thompson Falls Ranger District	No on the ground work has started
Jam Cracker	Superior Ranger District	Thinning
12 Tamarack	Superior Ranger District	Thinning
Cedar Thom	Superior Ranger District	Thinning
Swamp Eddy	Plains/Thompson Falls Ranger District	Thinning
Fish Trap	Plains/Thompson Falls Ranger District	Thinning
Forestwide Integrated Weed Management Analysis	All Ranger Districts	Continuation of weed management
Lookout Pass Ski Area Expansion	Superior Ranger District	Maintenance of facilities and ski area

Table 6 above lists other site-specific ongoing projects that have completed section 7 consultation. Only projects that have completed section 7 consultation are considered as part of the baseline. The biological assessment provided information for other projects that are within the consultation process but since consultation has not been completed they were presented for tracking purposes only and are not considered as part of the baseline condition. While all projects for which consultation has been completed are considered as part of the baseline conditions, only the effects of the projects or portions of projects that have been completed or are currently occurring on-the-ground are reflected in the existing, baseline condition and/or metrics displayed above.

EFFECTS OF THE ACTION

Under section 7(a)(2) of the Act, "effects of the action" are all consequences to listed species or critical habitat that are caused by the proposed action, including the consequences of other activities that are caused by the proposed action. A consequence is caused by the proposed action if it would not occur but for the proposed action and it is reasonably certain to occur. Effects of the action may occur later in time and may include consequences occurring outside the immediate area involved in the action (50 C.F.R. § 402.02). The effects discussed below are the result of implementing the proposed action.

Motorized Access

General Effects of Motorized Access on Grizzly Bears

This section provides a general discussion of direct and indirect effects of motorized access management on grizzly bears as affected by motorized route densities. Research has confirmed adverse impacts of roads on grizzly bears (IGBC 1987, Mace et al. 1996, Mace et al. 1999, Proctor et al. 2018, Proctor et al. 2019). Negative impacts associated with roads and high road densities influence habitat use patterns of individual grizzly bears as well as the population. Proctor et al. (2019) found that motorized access affects grizzly bears at the individual level by affecting habitat use, home-range selection and the ability to move across the landscape. The same study concluded that effects of motorized access on individual bears also results in effects at the population level due to habitat fragmentation, and decreased survival and reproductive rates.

Displacement and security. Many grizzly bears under-use or avoid otherwise preferred habitats that are frequented by people. Not all avoidance results in significant impacts to grizzly bears. However, if road densities, and associated secure habitat, reach a level that such under-use of preferred habitat represents modification of normal grizzly bear behavior, grizzly bears may experience significant impacts. Negative association with motorized routes arises from the grizzly bears' response to vehicles, vehicle noise and other human-related noise around roads, human scent along roads, and hunting and shooting along or from roads. Grizzly bears that experience such negative consequences learn to avoid the disturbance and annoyance generated by motorized routes. Some may not change this resultant avoidance behavior for long periods after road closures. While occasional human-related vehicle noise can result in annoying some grizzly bears to the extent that they continue to avoid roaded habitat, other grizzly bears are able to adjust their behavior rather than avoid the habitat (such as using the habitat at night).

All factors contributing to direct links between roads and displacement from habitat have not been quantified. The level of road-use by people is likely an important factor in assessing the potential displacement caused by any motorized route. Grizzly bears were consistently displaced from roads and habitat surrounding roads, often despite relatively low levels of human use (Mattson et al. 1987, McLellan and Shackleton 1988, Aune and Kasworm 1989, Kasworm and Manley 1990, Mace and Manley 1993, Mace et al.1996).

In Montana, Aune and Stivers (1982) reported that grizzly bears avoided roads and adjacent corridors even when the area contained preferred habitat for breeding, feeding, shelter, and reproduction. McLellan and Shackleton (1988) found that grizzly bears used areas near roads less than expected in southeastern British Columbia and estimated that 8.7 percent of the total area was rendered incompatible for grizzly bear use because of roads. In Montana, Mace and Manley (1993) reported use of habitat by all sex and age classes of grizzly bears was less than expected in habitats where total road densities exceeded 2 miles per square mile. Twenty-two percent of the South Fork Study area exceeded 2 miles per square mile. Adult grizzly bears used habitats less than expected when open motorized access density exceeded 1 mile per square mile. Further, female grizzly bears in the South Fork Study area tended to use habitat more than 0.5 mile from roads or trails greater than expected. As traffic levels on roads increased, grizzly bear use of adjacent habitat decreased (Mace et al. 1996). In Yellowstone, Mattson et al. (1992) reported wary grizzly bears avoided areas within 2 kilometers (1.2 miles) of major roads and 4 kilometers (2.4 miles) of major developments or town sites.

Avoidance behavior is often strongest in adult grizzly bears, with males selecting for high quality habitats and absence of humans (Gibeau et al. 2002). Males that were found using high quality habitat near roads, did so during the night where hiding cover was available (ibid). However, adult females were more likely to avoid humans altogether, rather than seek out the highest quality habitats that may be near roads. Mueller et al. (2004) reported all age and sex classes used habitats closer to high-use roads and development during the human inactive period. All bears in the study showed a considerably greater avoidance of high-use roads and development during periods of high human activity. They did show however, that regardless of the time of day, subadult bears were found closer to high-use roads than adult bears. Gibeau et al. (2002) also demonstrated that subadults were almost always closer to human activity than adults. Boulanger and Stenhouse (2014) found that subadult grizzly bears were most vulnerable to road-based mortality.

Mace et al. (1996) and other researchers have used 500 meters as the zone of influence around roads. Waller and Servheen (2005) also demonstrated avoidance of areas within 500 meters of U.S. Highway 2. Benn and Herrero (2002) set zones of influence of 500 meters and 200 meters around roads and trails, respectively. They reported that all 95 human-caused grizzly bear mortalities with known locations that occurred in Banff and Yoho National Parks between 1971 and 1998 occurred within these zones of influence along roads and trails or around human settlements. Gibeau and Stevens (2005) documented bears further from roads when distant from high quality habitat, indicating avoidance behavior.

Research suggests that grizzly bears benefit from road closures aimed at minimizing traffic on roads within important seasonal habitat, especially in low elevation habitats during the spring (Proctor et al. 2019, McLellan 2015, Mace et al. 1999). Proctor et al. (2019) described management of motorized access as most beneficial in areas where roads occur in high quality habitat, especially within and adjacent to linkage areas between population units. McLellan (2015) found that the location of motorized routes relative to bear food sources was important and recommended that managers attempt to maintain or enhance high-energy foods while reducing human access into specific areas where and when those foods are abundant (seasonal habitat). When roads are located in important habitats such as riparian zones, snowchutes, and shrub fields, habitat loss through avoidance behavior can be significant. Mace et al. (1996) found that most of the roads within grizzly bear seasonal ranges were either closed to vehicles or used infrequently by humans. Some grizzly bears avoided areas with a high total road density even when the roads were closed to public travel. If human-related disturbances such as high levels of road use continue in preferred habitats for extended periods of time, grizzly bear use of the area may be significantly limited, particularly use by female grizzly bears and/or their dependent offspring. In the Swan Mountain study (Mace et al. 1996), female grizzly bear home range selection of unroaded cover types was greatest and as road densities increased, selection declined. Zager (1980) reported the underuse of areas near roads by females with cubs. Aune and Kasworm (1989) found that female cubs generally established their home range within or overlapping with their mother's home range, whereas males generally dispersed from their mother's home range. Long-term displacement from a portion of her home range may result in long-term under-use of that area by female grizzly bears. Because cubs may have limited potential to learn to use the area, learned avoidance behavior could persist for more than one generation of grizzly bears before grizzly bears again utilize habitat associated with closed roads. Thus, displacement from preferred habitats may significantly modify normal female grizzly bear behavioral patterns.

Conversely, grizzly bears can become habituated to human activity and show a high level of tolerance especially if the location and nature of human use are predictable and do not result in overtly negative impacts for grizzly bears (Mattson 1993). In Glacier National Park, Jope (1985) suggested grizzly bears in parks habituate to high human use and showed less displacement, even in open habitats. Yonge (2001) found that grizzly bears near Cooke City, Montana, were willing to consistently forage in very close proximity to high levels of human use if cover was sufficient and energetically efficient feeding opportunities were present. Both Mattson (1993) and Yonge (2001) postulated that areas with higher levels of human activity might have a positive effect for bears by serving as a kind of refugia for weaker population cohorts (subadults and females with cubs) seeking to avoid intra-specific competition (adult males). However, Mattson qualified this observation by adding that the beneficial effects vary as to whether hunting is allowed, and how closely the human population is regulated. Further, food conditioned grizzly bears were much more likely to be killed by humans.

Both Yonge (2001) and Mattson (1993) indicated that increases in human use levels can be deleterious if some human activities are unregulated, such as use of firearms, presence of attractants, nature and duration of human uses. Conversely, a level of coexistence between humans and grizzly bears can be achieved if such activities are controlled. Near Cooke City, Montana, the New World Mine reclamation project had minimal effects on grizzly bears, in part because reclamation activities were temporally and spatially predictable and people associated with the work were carefully regulated against carrying firearms or having attractants available to grizzly bears (Tyers, unpublished 2006). In the Swan Valley of Montana, raw location data from a small number of collared grizzly bears show nocturnal use of highly roaded habitat (C. Servheen, U.S. Fish and Wildlife Service, pers. comm. 2005). The Swan Valley data have not been statistically analyzed and the study was not designed to determine the impact of roads on bears, sample size is very small, and perhaps most importantly, mortality rates for these grizzly bears are not yet known. However, these data indicate that some grizzly bears can apparently habituate to relatively high levels of human activity.

It appears that some bears have adapted to the types of habitat and relatively low levels of security near human developments as compared to more remote areas. In particular, Ruby (2014) found that bears that used areas near roads and human development did so when human use was low, such as at night, and that bears rested less in these areas than in areas away from roads and human development. Northrup et al. (2012) looked at various levels of road use (low, medium and high) and found that during the day bears avoided crossing roads of all use levels, however the higher the use level the more likely avoidance occurred. Low volume routes were crossed during both day and night hours. In fact, at night, bears selected to cross low traffic volume roads at greater frequency than random.

Specific causes or factors involved in the selection or preferences for certain home ranges by grizzly bears are not well understood. Mace and Manley (1993) found that grizzly bear home ranges in the South Fork Study area included remote areas in high elevations. South Fork Study grizzly bear habitat-use data, road density analyses of the South Fork Study area, previous studies and CEM analysis (U.S. Forest Service 1994, Mace et al. 1999) suggested that low-elevation habitats were not freely available to grizzly bears because of high road densities and associated human use in these areas. High road densities in low-elevation habitats may result in avoidance of or displacement from important spring seasonal habitat for some grizzly bears. High road densities in and of themselves do not result in mortality but a mortality risk may occur for those individuals that venture into and attempt to exploit resources contained in these low-elevation areas.

Male grizzly bears typically have larger home ranges than females, and males, subadults, and transient grizzly bears are more mobile and do not have the same energetic needs as adult females. Transient individuals are highly mobile and not restricted to finding food and shelter within a home range. Thus, while displacement from habitat along roads may affect behavioral patterns such as feeding or sheltering of all grizzly bears, we do not anticipate such effects would cause harm or significant impairment to these behavioral patterns of transient, subadult, or male grizzly bears. Where road densities are high enough to result in significant displacement effects, non-lethal impairment to behavioral patterns of adult female grizzly bears and/or their dependent offspring may occur. However, some adult females have proven that they are able to successfully reproduce and raise young in BMUs, subunits, or areas outside of the recovery zone that exceed research benchmarks for adverse effects to grizzly bears (Kasworm et al. 2022a, Costello and Roberts 2021).

Secure Core/secure habitat. Ideal grizzly bear habitat provides some areas isolated from high levels of human impact. Studies have shown that female grizzly bears selected for, and survived better in, areas with greater secure habitat (Proctor et al. 2019). Analysis in the South Fork Study area (Mace and Manley 1993, Mace et al. 1996) indicated the importance of unroaded habitat, especially for females with cubs. Mace and Manley (1993) reported adult females used habitat further than 0.5 mile from roads or trails more than expected; 21 percent of the composite home range had no trails or roads and 46 percent was unroaded (greater than 0.5 mile from a road). Substantive blocks of unroaded habitat were components of all adult female home ranges.

Of the adult female locations within unroaded polygons, 83 percent occurred within 7 polygons that exceeded 2,260 acres in size (*Ibid*.). Based on grizzly bear habitat use data from the Yellowstone ecosystem, secure habitat and road densities outside of secure habitat were important predictors of grizzly bear survival (Schwartz et al. 2010).

The IGBC Taskforce (IGBC 1994, 1998) recognized the importance of secure areas to grizzly bears. The Taskforce defined "core areas" within the recovery zones as those areas with no motorized use of roads and trails (during the non-denning period) or high intensity, non-motorized use, providing some level of secure habitat for grizzly bears. Motorized use, such as snowmobiling or that associated with timber harvest, could occur within core areas during the denning (winter) period. The Taskforce recommended the establishment of core areas in all subunits within the recovery zones. Core areas within recovery zones should be a minimum of 0.31 mile (about 500 meters) from any open road or motorized trail, with the size and connectivity of core area patches being established by recovery zone, depending on ecosystem-specific habitat conditions. Once established and effective, core areas should remain intact on the landscape for at least 10 years (*Ibid*.). In the South Fork Study area of the NCDE, approximately 68 percent of the adult female composite home range was core area (U.S. Forest Service in litt. 1994, K. Ake, U.S. Forest Service, pers. comm. 2005).

Habituation to Human Attractants. Continued exposure to human presence, activity, noise, and other elements can result in habituation, which is essentially the loss of a grizzly bear's natural wariness of humans. High route densities and associated increases in human access into grizzly bear habitat can lead to the habituation of grizzly bears to humans. Habituation in turn increases the potential for conflicts between people and grizzly bears. Habituated grizzly bears may obtain human food or garbage and become involved in nuisance bear incidents, and/or threaten human life or property. Such grizzly bears generally experience higher mortality rates as they may eventually be removed from the population through management actions. Habituated grizzly bears are also more vulnerable to illegal killing because of their increased exposure to people. In the Yellowstone region, humans killed habituated grizzly bears over three times as often as non-habituated grizzly bears (Mattson et al. 1992).

Subadult grizzly bears are more often vulnerable to habituation and illegal killing or they conflict with people and are removed through management action. Subadult grizzly bears frequently traverse long distances or unknown territory, increasing the likelihood of encountering roads, human residences or other developments where human food or other attractants are available, increasing the potential for habituation and/or conflicts with people. In the Yellowstone ecosystem, roads impacted individual age and sex classes of grizzly bears differently. Subadults and females with young were most often located near roads, perhaps displaced into roaded, marginal habitat by dominant grizzly bears (Mattson et al. 1987, Mattson et al. 1992).

While management actions of grizzly bears due to human food habituation do occur, such actions are infrequent to none on many areas of federally administered lands as a result of the many food storage orders that are in place. On Forest Service administered lands, grizzly bear mortalities more often resulted from mistaken identity during legal hunting season, illegal or malicious killing, or automobile and train collisions (K. Ake 2011 *in litt.*).

Grizzly Bear Mortality. While grizzly bear mortality may occur as a result of collisions with motorized vehicles, such mortality is more likely to occur on motorized routes where motorized use occurs at high speed as opposed to Forest roads. Aside from grizzly bears killed by vehicle collision, the specific relationship between roads and the mortality risk to grizzly bears is difficult to quantify. The level of human use of roads is one of several factors influencing the mortality risk associated with any road. Research supports the premise that forest roads facilitate human access into grizzly bear habitat, which can directly or indirectly increase the risk of mortality to grizzly bears (Proctor et al. 2019, Mattson et al. 1992, McLellan and Shackleton 1988, Mace et al. 1987, Dood et al. 1986).

The presence of Forest roads alone does not necessarily result in direct mortality of grizzly bears, but the proximity of the roads to human population centers, resulting in high numbers of people using roads, and dispersed recreation in habitat around roads can pose considerable risks to grizzly bears. Social values and attitudes also contribute to the level of mortality risk to grizzly bears. Access management can be instrumental to reducing mortality risk to grizzly bears by managing the present and anticipated future road use-levels resulting from the increasing human population in western Montana. Potential grizzly bear mortality near roads is typically the result of intentional (self-defense, defense of life, poaching, etc.) or unintentional (mistaken identity) mortality. Whether illegal or not, these type of mortalities are not part of the Forest's proposed action and are not the focus of this biological opinion. Thus, any effects are not exempted under this biological opinion. Similar to illegal access of motorized routes, effects to grizzly bears related to mortality are reasonably uncertain. It is unknown as to when and where such mortality may occur. As such, the Service and the Forest are not able to calculate the extent of effects to individual grizzly bears. However, while such mortality may occur at times, effects of these intentional and unintentional grizzly bear mortalities are likely low as evidenced by the grizzly bear population status, including an increasing number of grizzly bears, an expansion of the distribution of grizzly bears, and an estimated positive population trend.

General effects of Winter Motorized Use on Grizzly Bears

Available information regarding the effects of snowmobiles on grizzly bears is generally anecdotal, such as grizzly bear responses to various stimuli other than snowmobiles collected during research. Such reports typically lack information related to the timing of disturbance, type of den, winter conditions or other important factors necessary to assess the significance of disturbance to grizzly bears, if any. Some information collected on black bears or other ursids may have some relevance, but even the data on these species is incidental and largely theoretical.

In the fall of 2000, the science and resource management staff of the Biological Resources Management Division of the National Park Service and the Rocky Mountains Cooperative Ecosystem Studies Unit at the University of Montana organized an expert workshop to summarize the state-of-science on monitoring the effects of snowmobiles on wildlife in national parks and surrounding lands. Graves and Reams (2001) edited the output of this expert workshop for protocols to monitor snowmobile effects on wildlife. The group concluded that the evidence was inadequate to predict impacts on grizzly bears, but the *possible* effects were identified: den abandonment, loss of young, increased energetic costs while bears were in dens or displaced away from suitable habitat if outside dens, death, and learned displacement from suitable habitat resulting from exposure to disturbance (Graves and Reams 2001). Impacts to emergent bears were identified as a higher concern than impacts to denning bears.

Typical high-use snowmobile areas and potential den sites have a limited likelihood of substantive overlap. Grizzly bears generally den in either timbered habitat or very steep slopes, including the slopes of open basins. Most of the heavy snowmobile use occurs on trails, roads, or open basins and meadows. Although some snowmobile riders use steep open basins for "high marking", in which case the potential for direct overlap between denning habitat and steep open slopes favored for "high marking" by snowmobiles may occur. However, most denning habitat, except for "high-marking" areas, is less favorable for snowmobile use and as such the chance of adverse overlap between grizzly bear den sites and snowmobile traffic is reduced.

Snow is an excellent sound barrier (Blix and Lentfer 1992) and impacts to denning bears would likely be less in deep snow conditions than in shallow snow conditions. It is likely that hibernating bears exposed to meaningless noise, with no negative consequences to the bear, habituate to this type of disturbance (Knight and Gutzweiler 1995). Reynolds et al. (1986) found that some bears, on occasion, appear to respond to noise or disturbance near the den site by waking up and moving around the den. On rare occasions, bears may abandon a den due to some disturbance (Reynolds et al. 1976, Swenson et al. 1997). However, den abandonment attributed to snowmobiles has not been documented.

The noise and human activity related to snowmobile use would likely impact grizzly bears most during the early and late denning period, or when snow levels are low and the snowmobile activity is near the den site. However, the early and late denning periods are times when snow conditions are least conducive to snowmobile activity. If disturbance occurred early during the denning season, a bear would likely have other denning habitat available. Grizzly bears are unlikely to abandon their dens very late into the winter due to the high energetic and fitness costs of doing so (Linnell et al. 2000). Theoretically, as the costs of abandoning a den and re-locating to another den increase, grizzly bears should be expected to tolerate greater levels of activity without abandonment.

Disturbance from snowmobiles is likely most consequential shortly before or after den emergence of a female with cubs. Most emerging bears move immediately to a known, reliable spring food source, such as a big game winter range (Reinhart and Tyers 1999). Females with cubs have high energetic needs, and cubs have limited mobility for several weeks after leaving the den, therefore they remain in the den site area for several weeks after emergence from dens (Haroldson et al. 2002; Mace and Waller 1997). Researchers involved in the 2000 workshop assessing snowmobile impacts (Graves and Reams 2001) indicated higher concerns with emergent females with cubs as they are likely the most sensitive to disturbance (Haroldson et al. 2002). Disturbance levels that cause a female to prematurely leave the den in spring or move from the den area could impair the fitness of the female and safety of the cubs. If cubs attempt to follow their mother, they would likely experience decreased fitness and the family group may be pushed to less suitable habitat. A disturbance would have to be severe for a sow to abandon her cubs (Linnell et al. 2000). In the judgment of the Service, snowmobile-related impacts on post-den emergence females with cubs are more likely to impart serious consequences than any potential impacts to denning grizzly bears.

Changing snow conditions in spring may help reduce the probability grizzly bears being impacted by snowmobiles. At the time of emergence, snow conditions are changing rapidly. The same conditions that help lead to bear emergence (e.g., water infiltrating the den) (Schoen et al. 1987; Craighead and Craighead 1972) lead to poor quality snow for snowmobiling. At that time, snow is melting at lower elevations, making access to higher elevations more difficult for snowmobilers. In general, female grizzly bears with cubs emerge later in the season, when these snow and melt conditions are even more prevalent. Individual circumstances of access and allowable seasons are important variables to analyzing effects of snowmobiles to grizzly bears.

Effects of Motorized Access in the Action Area (non-winter)

The action area occurs both inside and outside of the NCDE and CYE grizzly bear recovery zones, in areas where grizzly bears may be present. Tables 2 and 3 above display the existing OMRD, TMRD, and secure core for the subunits within the NCDE recovery zone and secure habitat for the GBAUs outside of the recovery zones, respectively, within the action area. In addition, BMU 22 in the CYE recovery zone has 32 percent OMRD, 33 percent TMRD, and 55 percent secure core.

The use of motorized wheeled vehicles off of existing designated roads and trails is not permitted on the Forest. The Forest's MVUM shows the routes that are designated open for motor vehicle use, what type or class of vehicles are allowed on each route, and seasons or times of the year the use is allowed. Users are responsible for ensuring they are on a route designated for the motor vehicle being used. The MVUM is updated annually and is available to the public in print and on the Forest's web site.

The existing access conditions were determined using the best available information. The metrics described here represent the existing access condition as reviewed, although the Service recognizes that improved information may be documented and mapping and calculation errors can occur. As the access database is updated, the improved information will better reflect the existing conditions related to motorized access. If the Forest finds that it has new information or has made a mapping or calculation error in describing the existing condition and corrects the metrics, the Service does not expect any additional effects to grizzly bears related to those corrections because no actual changes occurred on-the-ground. The intent of this analysis is to capture the existing motorized access conditions and the potential effects to grizzly bears, including potential ongoing effects that may not be represented in the metrics described above due to potential errors or unknown information. If however, changes in the metrics occur due to Forest actions on-the-ground, site-specific analyses would need to occur to determine the potential effects.

Portions of the action area have high levels of motorized access while other portions have low levels of motorized access or no motorized access at all. The existing motorized access conditions within the Monture, Mor-Dun, North Scapegoat, South Scapegoat, and Rattlesnake subunits in the NCDE recovery zone are not expected to result in ongoing significant effects to grizzly bears. As explained above, the existing motorized access conditions within BMU 22 in the CYE recovery zone and the Mission and Swan subunits in the NCDE recovery zone are likely resulting in some level of ongoing significant effects to grizzly bears. While the standards set for BMU 22 are met, the metric for TMRD is worse than the research benchmark for when adverse effects are expected. TMRD was set higher than the research benchmark in BMU 22 because the amount and pattern of private ownership precludes attaining 26 percent. The Mission subunit is less than 75 percent Forest ownership and the lower amounts of secure core within the subunit are a result of motorized access on non-Forest land. The Swan subunit is long and narrow and does not contain as much wilderness and/or roadless as other subunits on the

Forest. The portion of the action area outside of the recovery zones includes areas designated as NCDE zone 1, which includes the Ninemile DCA, and NCDE zone 2 as well as areas outside of these designations. Outside of the recovery zone, the estimated amount of secure habitat ranges from a low of 2 percent of Forest land in the Middle Blackfoot GBAU to a high of 76 percent of Forest land in both the Fish Creek and Upper Rock GBAUs. Of all 30 GBAUs delineated on the Forest, six have less than 10 percent secure habitat on Forest land, seven have between 11 and 20 percent secure habitat on Forest land, seven have between 21 and 30 percent secure habitat on Forest land, four have between 31 and 40 percent secure habitat on Forest land, one has between 41 and 50 percent secure habitat on Forest land, two have between 51 and 60 percent secure habitat on Forest land, and three have greater than 60 percent secure habitat on Forest land. It is likely that portions of most of the GBAUs have existing motorized access conditions that may be resulting in ongoing significant effects to grizzly bears if or when female grizzly bears are present.

BE

No criteria or requirements have been established for secure core in the BE recovery zone. Since the entire portion of the BE recovery zone that occurs on the Forest is within the Selway-Bitterroot Wilderness, and no motorized routes occur within this portion of the BE recovery zone, it will continue to function as secure core for the foreseeable future. Other land ownership parcels are located adjacent to this portion of the BE recovery zone, however these parcels have no record of motorized routes and the closest known motorized route is greater than two miles from the portion of the BE recovery zone on the Forest. Like other land ownerships, adjacent National Forests could build a motorized route adjacent to this portion of the recovery zone, but it is unlikely given the ruggedness of the topography and the associated costs. Since no motorized access occurs on the Forest's portion of the BE recovery zone, motorized access will not result in any effects in that portion of the action area.

CYE

As we are analyzing the effects of motorized access management in the CYE, specifically BMU 22, within this consultation on the continued implementation of the Forest Plan, the 2011 consultation on the access management direction for the portion of the Forest in the CYE recovery zone will be superseded with this 2023 biological opinion. While the direction is the same as consulted on in 2011, we are including the effects in this document in order to consolidate the amount of ongoing biological opinions and capture all effects of the Forest Plan direction in one consultation using the current best available information.

The Forest Plan standard for BMU 22 is to provide no more than 33 percent OMRD, no more than 35 percent TMRD, and at least 55 percent secure core. TMRD was set higher than the research benchmark because the amount and pattern of private ownership precludes attaining 26 percent. With continued implementation of the Forest Plan, these existing conditions in BMU 22 are expected to be maintained. The higher TMRD may result in some level of adverse effects associated with displacement of individual female grizzly bears that may be present in the BMU. Although motorized access conditions in BMU 22 could have adverse effects to female grizzly bears, such effects are unlikely at this time as BMU 22 supports few if any grizzly bears and is not known to be occupied by any female grizzly bears at this time. However, female grizzly bears may begin to use BMU 22 during the life of the Forest Plan and if and when they do, they may be displaced from key habitats and under certain conditions they may be displaced to levels that impair their normal ability to readily find food resources needed to sustain fitness necessary for breeding and producing cubs, and/or find shelter.

Standards for secure core were set individually for each BMU in consideration of unique biological factors such as habitat quality, seasonal habitat needs, sightings of family groups, records of human caused mortality, and adjacency to BMUs having females with young, as well as other non-biological factors such as presence of highways, private land inholdings, and access to popular recreation areas. Secure core areas strive to contain the full range of seasonal habitats that are available in the BMU and are fixed in place for a minimum of 10 years. In CYE BMUs not meeting their specific standard, which recently was the case for BMU 22 (met the standards in 2022), projects affecting secure core must result in increased core post-project. Once route closures to create core areas are established and effective, these core areas should remain in place for at least 10 years. Therefore, except for emergencies or other unforeseen circumstances requiring independent section 7 consultation, newly created core area shall not be entered for at least 10 years after creation. Once the secure core standard is achieved and in place for 10 years, routine forest management may be proposed in a core area block. However, BMUs must remain at or above the core standard. Consequently, potential losses to existing core must be compensated with in-kind replacement concurrently or prior to incurring the losses. New core areas must subsequently be managed undisturbed for 10 years. Such changes would be subject to further section 7 consultation for the site-specific project.

Permanent route construction within the CYE recovery zone is limited by standards. Since BMU 22 has standards to meet for OMRD, TMRD, and secure core, in order to construct permanent routes in these areas, other roads would likely need to be decommissioned depending on location and other site-specific details.

Forest Plan direction allows the Forest to temporarily affect underlying core area (i.e., any core habitat that is affected by the subject road and its buffer) within a BMU once per 10-year time frame, and not to exceed 1 bear year, for the sole purpose of completing road decommissioning/stabilization activities on existing closed or barriered roads in core area habitat. Subsequent needs to re-enter individual core areas within a BMU more frequently than once per decade for the purposes of road decommissioning shall be handled on a case-by-case basis. The effects of additional entries would be analyzed pursuant to such project level consultation. Pending the outcome of each analysis, additional measures to minimize potential effects to grizzly bears may be required. Temporary administrative use shall not exceed 60 vehicle round trips per active bear year per road, apportioned as follows: ≤18 round trips in spring (April 1 through June15); ≤23 round trips in summer (June 16 through September 15); and ≤19 round trips in fall (September 16 through November 30). If the number of trips exceeds 60 trips per active bear year in the Cabinet-Yaak ecosystem, then that road would be considered "open" for analysis and reporting purposes. Likewise, if the number of trips exceeds the allowable ecosystem-specific seasonal (spring, summer, and fall) vehicle round trips per road, then that road would be considered "open" for analysis and reporting purposes.

Depending on the location, timing, and duration, the allowance of temporary changes in access conditions within the CYE recovery zone may result in some level of effects, including the potential for adverse effects to grizzly bears through increased displacement. Such effects would depend on the potential temporary effects to the access metrics. While temporary effects to motorized access conditions may occur, the extent of area on the Forest that could be affected is limited due to the limitations of the Forest Plan direction in the CYE recovery zone. Any potential adverse effects may be ameliorated by high quality habitat that is available in a large undisturbed area in the center of the BMU (Cube Iron/Silcox proposed wilderness and roadless areas north to Benson and Lone Tree peaks).

NCDE

The existing motorized access conditions throughout the NCDE portion of the action area, including areas within and outside of the recovery zone, may result in some level of ongoing effects, including some adverse effects, which may continue during the life of the Forest Plan. Additional motorized access associated with site-specific project activities may add to these effects.

As we are analyzing the effects of motorized access management in the NCDE recovery zone, as well as NCDE zones 1 and 2, within this consultation on the continued implementation of the Forest Plan, the 2017 consultation on the NCDE grizzly bear amendments to incorporate habitat management direction for the portion of the Forest within the NCDE recovery zone and NCDE zones 1 and 2, will be superseded with this 2023 biological opinion. While the direction is the same as consulted on in 2017, we are including the effects in this document in order to consolidate the amount of ongoing biological opinions and capture all effects of the Forest Plan direction in one consultation using the current best available information.

Recovery Zone

In 2018, the Forest Plan was amended to incorporate habitat management direction for the NCDE recovery zone. Within this habitat management direction, many standards require meeting or being better than the 2011 baseline conditions. The general approach of the 2020 NCDE grizzly bear conservation strategy is to maintain the habitat conditions that existed during 2011 because this is the initial period when the NCDE grizzly bear population was determined to be stable to increasing (NCDE Subcommittee 2020). A key assumption is that the measured levels of selected conditions and management activity that existed in 2011 did not prevent the growth and expansion of the NCDE grizzly bear population and thus, those conditions and management actions could continue at the same levels (Ibid.). This is often referred to as the 2011 baseline conditions. The 2011 baseline for the NCDE is defined as conditions as of December 31, 2011, as modified by changes in numbers that were evaluated and found to be acceptable through the Endangered Species Act Section 7 consultation with Service while the grizzly bear was listed as Threatened. The baseline can also be updated to reflect changes allowed under the application rules, such as those caused by ownership changes or improved data (Ibid.). The information presented in Table 2 above displays the updated 2011 motorized access conditions and incorporates any errors, incomplete data, or changes made via section 7 consultation.

The Forest Plan desired condition NCDE-DC-AR-01 states that secure core will be provided at levels that contribute to recovery of the NCDE grizzly bear population. Within the grizzly bear subunits within the NCDE recovery zone, standard NCDE-STD-AR-02 requires no net increase in the 2011 baseline conditions for OMRD and TMRD and no net decrease from the 2011 baseline in the amount of secure core on Forest lands during the non-denning season. Thus, over the life of the Forest Plan, the levels of OMRD, TMRD, and secure core in all subunits will be maintained at the same (or better) level than the conditions as of December 31, 2011, at which time the NCDE grizzly bear population was stable to increasing. As mentioned, some exceptions do apply and minimal updates have occurred under specific rationale. Refer to the environmental baseline section above for further information on the 2011 baseline conditions, which includes any updates to these conditions as well as the rationale for the updates. As all updates fall under the exceptions, this standard is being met.

As mentioned previously, the research benchmarks of 19 percent OMRD of more than 1 mile per square mile, 19 percent TMRD of more than 2 mile per square mile, and less than 68 percent secure core are used to determine when adverse effects may occur within the subunits of the NCDE (also referred to as 19/19/68). Except for the Mission and Swan subunits, all other subunits meet or are better than the research benchmark for OMRD, TMRD, and secure core. Most subunits on the Forest have very low levels of OMRD and TMRD and a very high level of secure core. Due to land ownership patterns, shape, and other specific circumstances the Mission and Swan subunits provide substantially less secure core than the other five subunits within the NCDE recovery zone. The Mission subunit is unique in that it has less than 75 percent federal ownership and therefore historically had a rule set of “no net loss” of secure core on federal lands in the subunit. The existing motorized access conditions in the Swan and Mission subunits are likely resulting in some level of ongoing adverse effects to grizzly bears associated with the displacement of grizzly bears from seasonally important feeding sites.

In 2011, the Forest reinitiated consultation for the access management strategy for the Swan subunit due to noncompliance with portions of the 1996 incidental take statement. In recognition of its unique characteristics, the requirements were modified to no more than 17 percent TMRD; no more than 31 percent OMRD, with no more than 22 percent OMRD during the spring; and at least 55 percent security core (U.S. Fish and Wildlife Service 2011). The Forest had met these conditions in 2011. While the Swan Subunit has met the Final Access Management Strategy for the Swan Subunit, the metrics have changed since consultation. The changes are partly a result of projects improving the OMRD, TMRD, and secure core and partly a result of updating the baseline conditions. As allowed under the NCDE grizzly bear amendments, updates to the baseline conditions occurred when better information became available (such as improved mapping accuracy) and when the Forest acquired land. All of the updates are documented in the NCDE Biennial Reports and are allowable updates to the baseline. The current conditions (2021) are documented in Table 2 above. Rationale for changes in the metrics can be found in the 2021 monitoring report (Ake 2022). As all updates fall under the exceptions, the updated information does not violate the standard to maintain conditions as of December 2011 with allowable updates and the standard associated with the baseline motorized access conditions is being met. Since the final access management strategy for the Swan subunit would maintain OMRD and secure core conditions that are worse than the research benchmarks for the NCDE, high open road densities, along with lower amounts of secure core, would continue to occur within the subunit indefinitely. Therefore, the access management strategy for the Swan subunit would likely result in adverse effects to some individual grizzly bears that may attempt to live in the Swan subunit and the 2011 biological opinion and incidental take statement on the final access management strategy for the Swan subunit was issued. In addition, some level of temporary road construction was also considered in the 2011 biological opinion. The effects of temporary road construction were subsequently addressed in the consultation on the 2018 NCDE grizzly bear amendments (for which the biological opinion is also being superseded as described above). The effects of temporary route construction are analyzed below. As the Forest has previously met the conditions under the final access management strategy for the Swan subunit and continued motorized access management for the Swan subunit will be managed under the continued implementation of the Forest Plan, including the NCDE grizzly bear amendments, we are analyzing the effects of motorized access in the Swan subunit within this consultation on the continued implementation of the Forest Plan. As such, the biological opinion on the effects of the final access management strategy for the Swan subunit (U.S. Fish and Wildlife Service 2011a) is no longer relevant and is superseded by this 2023 biological opinion on the continued implementation of the Forest Plan.

Forest Plan Standard NCDE-STD-AR-03 allows for temporary increases in OMRD and TMRD for projects, not to exceed a 5 percent temporary increase in OMRD and not to exceed a 3 percent temporary increase in TMRD, both calculated over a 10-year running average. NCDE-STD-AR-03 also allows temporary changes in secure core during project activities with a limit of 2 percent temporary decrease in secure core calculated over a 10-year running average. NCDE-STD-AR-04 specifies that temporary public motorized use of restricted roads is not authorized within secure core. Temporary road construction and/or use within the recovery zone would be managed via these standards and would be expected to meet these standards.

The Monture, North Scapegoat, South Scapegoat, and Rattlesnake Subunits all encompass significant amounts of designated Wilderness and will remain above the research benchmark of 19/19/68 even if the temporary effects to OMRD, TMRD and secure core occur under projects having temporary effects associated with NCDE-STD-AR-03. These subunits are likely to continue to support the survival and reproduction of female grizzly bears, with no adverse effects anticipated associated with the temporary changes allowed under NCDE-STD-AR-03.

The Mor-Dun subunit currently meets the research benchmark values for OMRD, TMRD, and secure core. TMRD and secure core would remain above the research benchmark of 19 percent and 68 percent, respectively, even with temporary effects associated with NCDE-STD-AR-03. However, OMRD may temporarily increase above the benchmark if increases allowed under standard NCDE-STD-AR-03 are invoked to allow for project activities in the Mor-Dun subunit, potentially resulting in some level of short-term adverse effects associated with displacement of grizzly bears in this subunit, which may result in the under-use of suitable habitat by individual female grizzly bears and/or their dependent offspring, which may disrupt normal breeding (or more specifically, cub rearing) or feeding patterns. The amount of disturbance would depend on site-specific actions and conditions.

Temporary effects for projects allowed under NCDE-STD-AR-03 within the Mission and Swan subunits could result in temporary increases in OMRD and/or TMRD and/or temporary decreases in secure core that further exceed (worse than) the benchmarks. Since some level of ongoing adverse effects are likely already occurring as a result of the existing, baseline motorized access conditions in these subunits, use of the temporary increases allowed under NCDE-STD-AR-03 may result in additional adverse effects to grizzly bears that may be using the action area. The short-term, temporary increases allowed under NCDE-STD-AR-03 may result in additional under-use of suitable habitat by individual female grizzly bears and/or their dependent offspring, which may disrupt normal breeding (or more specifically, cub rearing) or feeding patterns. The amount of displacement would vary, depending on site-specific conditions (i.e. whether the area is providing secure habitat or is adjacent to other roads) and actions (i.e.

duration of use and/or length of road segment). Given the more favorable habitat conditions on the rest of the Forest within the NCDE recovery zone along with much of the remainder of the NCDE recovery zone and the improved status of the NCDE grizzly bear population, it is unlikely that measurable negative effects to the overall NCDE population would occur as a result of NCDE-STD-AR-03.

Guidelines are also provided to minimize the potential effects of temporary project implementation within the recovery zone. Temporary project implementation within the recovery zone should not exceed 5 years (NCDE-GDL-AR-01). Further, guideline NCDE-GDL-AR-02 states that secure core should be restored to pre-project levels within one year of completion of a project. Although projects meeting these guidelines may result in some adverse effects to grizzly bears as a result of displacement from preferred habitat, they would provide limits on the amount and duration of the displacement so that bears are not permanently displaced by human activities. While the Forest may deviate from guidelines with an approved exception, it is not known at this time what exceptions may be used. Thus, these guidelines, as written, will be used for the effects analysis. If these guidelines are not met for any given site-specific action, site-specific consultation may be necessary depending on the site-specific information and effects.

Forest Plan standard NCDE-STD-AR-01 allows administrative use of roads that are closed to public motorized use within the recovery zone, provided that doing so does not exceed either 6 trips (3 round trips) per week or 1 thirty-day unlimited use period during the non-denning season. Exceptions to this standard are allowed for emergency situations. Roads and trails closed to public motorized use remain available without limitations to Forest Service personnel for administrative purposes including wildfire suppression, search and rescue, medical emergencies, permit administration, data collection, noxious weed treatments, general management, and other activities. The effects of administrative use of roads on grizzly bears is likely similar to temporary roads in terms of disturbance and displacement described above and may either be insignificant or adverse depending on site-specific location and duration of use. NCDE-STD-AR-04 would allow temporary use of restricted roads for motorized use by the public for special purposes such as firewood gathering. The standard also indicates that motorized public use in these areas will not last longer than 30 days during one non-denning season, and will only occur outside the spring and fall bear hunting seasons. Further, public motorized use would not be permitted within secure core. Thus, the amount and duration of disturbance associated with this use would be limited and would likely be insignificant.

Depending on the location, timing, and duration, the allowance of temporary changes in motorized access conditions within the NCDE recovery zone may result in some level of effects. These effects could be insignificant associated with low levels of disturbance or could include the potential for adverse effects to grizzly bears through increased displacement associated with longer-term use. Such effects would depend on the existing motorized access conditions of the project subunit and the potential temporary changes to the access metrics. While temporary effects to motorized access conditions may occur, the extent of area on the Forest that could be affected is limited due to the limitations of the Forest Plan direction in the NCDE recovery zone. Any potential adverse effects may be ameliorated by high quality habitat that is available within the subunits.

Outside of Recovery Zones

Recovery zones were established to identify areas necessary for the recovery of a species and are defined as the area in each grizzly bear ecosystem within which the population and habitat criteria for recovery are measured. Recovery zones are areas adequate for managing and promoting the recovery and survival of grizzly bear populations (U.S. Fish and Wildlife Service 1993). Areas within the recovery zones are managed to provide and conserve grizzly bear habitat. Some areas outside the recovery zones have some level of management as described above (i.e. NCDE zones 1 and 2) but most areas outside the recovery zones are not managed for grizzly bears and do not have a need to track the same motorized access metrics as within the recovery zone. As such, the moving windows process is not used outside of the recovery zones and the information and knowledge associated with motorized access is not consistent with the information presented for the recovery zones. In order to analyze the effects of motorized access outside of the recovery zones, as described in the baseline section above, we have incorporated secure habitat into this analysis. Secure habitat has been identified as one of the key issues related to effects of motorized access on grizzly bears and is important to the survival and reproductive success of grizzly bears. As secure habitat is directly tied to and based on open and restricted motorized routes and provides a more accurate indication of the spatial mix of motorized routes and secure habitat, it more adequately represents the potential effects to grizzly bears related to motorized access than a simple linear route density.

The grizzly bear SSA (U.S. Fish and Wildlife Service 2022a) recommends that consideration be given to motorized access management to facilitate natural recolonization between the BE and other recovery zones. This is partially addressed by Forest Plan management direction for the Ninemile DCA (addressed further below) that establishes a desired condition to provide habitat that can be used by female bears and allow for movement of bears between ecosystems (NCDE-LNF Zone 1-DC-01). In the area that lies between the NCDE recovery zone and the Ninemile DCA, a desired condition encourages consolidation of Forest lands and conservation easements with willing landowners (NCDE-LNF Zone 1-DC-02).

Under NCDE-LNF Zone 1-STD-01, a net increase above the 2011 baseline density of roads (NCDE zone 1) and roads and trails (Ninemile DCA) open to public motorized use during the non-denning season would be precluded on Forest lands in NCDE zone 1, including the Ninemile DCA. Since the 2011 baseline associated with open linear route density must be maintained, in order to construct new permanent open roads in these areas (not related to the limited allowable circumstances described below), other open roads would likely need to be restricted and closed to the public. While open linear route density within NCDE zone 1 would be maintained, the standard does not apply to secure habitat and such a change could result in effects to secure habitat. Access management within these areas would be monitored and compared with the 2011 baseline motorized access conditions, as described in the NCDE grizzly bear conservation strategy. Several situations may not apply to maintaining the 2011 baseline and could result in a change to road density in NCDE zone 1 such as: acquiring or exchanging land; compliance with federal law; motorized use related to mining activities; grizzly bear-human conflicts, resource damage, or human safety concerns; emergency situations; and temporary roads for the development, construction, or staging of a project or event that has a finite lifespan. Effects associated with any of these situations would be evaluated in a site-specific analysis, as appropriate.

Currently, on the Forest in NCDE Zone 1 and outside the Ninemile DCA, about 325 miles of Forest Service roads are legally open to public motorized use on about 289 square miles of Forest land, for an existing open road density of about 1.1 miles per square mile (U.S. Forest Service 2022 *in litt*.). In 2011, the linear open road density for NCDE zone 1, outside of Ninemile DCA, was 1.3 miles per square mile, thus standard NCDE-LNF Zone 1-STD-01 is being met. Based on data presented by Boulanger and Stenhouse (2014), this existing density of roads open to public motorized use is expected to be compatible with bear occupancy and to support survival of females with dependent young sufficient for a stable to increasing population trend. The existing conditions are expected to remain the same (or be better) over the remaining life of the Forest Plan (U.S. Forest Service 2022). NCDE zone 1, excluding the Ninemile DCA, overlaps with six GBAUs including the Clearwater, Cottonwood, Gold, Middle Blackfoot, North Missoula, and Placid GBAUs. The percent of secure habitat on Forest land among these six GBAUs range from 2 percent to 68 percent. However, all but the North Missoula GBAU, which is 68 percent secure habitat, have less than 15 percent secure habitat and ongoing adverse effects associated with displacement of some individual female grizzly bears may occur during the life of the plan.

On the southwest corner of NCDE zone 1 is the Ninemile DCA. The Ninemile DCA is intended to provide habitat that can be used by female grizzly bears with cubs and allow for grizzly bear movement to the BE recovery zone. Within the Ninemile DCA, about 569 miles of Forest roads and 37 miles of Forest trails are legally open to public motorized use on about 400 square miles of Forest land, for an existing average motorized route density of 1.5 miles per square mile (U.S. Forest Service 2022 *in litt.*). Forest Plan standard NCDE-LNF Zone 1-STD-01 requires no net increase from the 2011 density of motorized routes (roads and trails) open to public motorized use during the non-denning season on Forest lands within the Ninemile DCA. In 2011, the linear open route density for the Ninemile DCA was 1.6 miles per square mile, thus standard NCDE-LNF Zone 1-STD-01 is being met. This existing motorized route density is expected to be generally compatible with occupancy by and survival of female grizzly bears, including those with dependent young (Boulanger and Stenhouse 2014). The environmental baseline and continued conditions with respect to motorized routes open to the public are expected to support habitat connectivity between the NCDE and the other recovery zones, which is the goal of the demographic connectivity area (NCDE Subcommittee 2020). With the standard in place, the existing conditions are expected to remain the same (or be better) over the remaining life of the Forest Plan. The Ninemile DCA overlaps with four GBAUs including the Keystone, Mill North, Ninemile, and Trout East GBAUs. The percent of secure habitat on Forest land among these four GBAUs range from 4 percent to 33 percent and ongoing adverse effects associated with displacement of some individual female grizzly bears may occur during the life of the plan.

The intent is for NCDE zone 1, including the Ninemile DCA, is to support continual occupancy by grizzly bears, although at a lower density than within the recovery zone. With the current motorized access conditions, along with the standard NCDE-LNF Zone 1-STD-01, continual occupancy by grizzly bears is expected, although with some low level of adverse effects likely occurring to some individual female grizzly bears.

Twenty GBAUs have been delineated in the area of the Forest outside of the recovery zones, NCDE zone 1, and Ninemile DCA. The percent of secure habitat on Forest land among these GBAUs ranges from 4 percent to 76 percent. Less than 10 percent of Forest land is within secure habitat in two GBAUs, between 10 and 20 percent of Forest land is within secure habitat in four GBAUs, between 20 and 30 percent of Forest land is within secure habitat in six GBAUs, between 30 and 40 percent of Forest land is within secure habitat in three GBAUs, between 40 and 50 percent of Forest land is within secure habitat in one GBAU, between 50 and 60 percent of Forest land is within secure habitat in two GBAUs, no GBAUs have between 60 and 70 percent of Forest land within secure habitat, and over 70 percent of Forest land is within secure habitat in two GBAUs. Table 3 above displays secure habitat within the GBAUs outside of the recovery zones.

When looking at all 30 GBAUs (within and outside of NCDE zone 1 and Ninemile DCA), the majority of existing secure habitat on the Forest (73%) is located in existing Wilderness and Inventoried Roadless Areas (IRA), while the remaining 27% of secure habitat occurs in other Forest MAs that limit road development. For example, the North Missoula GBAU has a large proportion of secure habitat outside of wilderness and IRAs (41%), but in this case, much of the secure habitat occurs within the National Recreation Area (MA 28) where road building is unlikely. A cluster of three adjacent GBAUs located on the east side of the Forest (Clearwater, Middle Blackfoot and Placid, all located in NCDE Zone 1) have very low amounts of secure habitat on Forest lands but contain a significant amount of land owned by The Nature Conservancy. Lands purchased by The Nature Conservancy from Plum Creek Timber Company are gradually being transferred into the public domain, creating continuous areas of publicly owned land. Over time, it is reasonable to expect that these GBAUs will be recognized as providing a greater proportion of secure habitat than they do currently; however, this effects analysis does not rely on that information as it would be associated with a future federal action subject to future site-specific consultation as necessary.

The Miller GBAU, located at the north end of the Sapphire Range, provides secure habitat between the North Missoula GBAU (Rattlesnake Wilderness) and Lower Rock GBAU (Welcome Creek Wilderness). However, the Miller GBAU has a very low level of secure habitat (4%) that is composed of several smaller patches under 2,500 acres in size. The relatively small patches of secure habitat scattered throughout the Miller GBAU are not ideal for bear movements and could impede bear movements primarily between Middle Blackfoot and North Missoula, and Lower Rock and Upper Rock Creek GBAUs, potentially affecting the larger scale connectivity among the NCDE, Bitterroot, or Greater Yellowstone recovery zones.

In addition, MA 6 (Research Natural Areas) and MA 19 (winter range, no timber) limit road building, which reduces the potential for reductions of secure habitat for GBAUs where those MAs occur. Although the elk summer habitat (MA 26) and grizzly bear habitat MAs (MA20 and MA 20a) don’t preclude road construction, they do limit or restrict roads.

An analysis of the availability of secure habitat on Forest land was completed to assess the ability to support grizzly bears that may occupy or move through areas of the Forest outside of the recovery zones. The Forest Plan does not have requirements to provide secure habitat outside of the recovery zones. As previously stated, in order to be conservative in favor of the grizzly bear when analyzing effects of motorized access, all existing, drivable routes are buffered when delineating secure habitat outside of the recovery zone, regardless of whether they are legally open or restricted to public travel and includes legally restricted routes that may not have a barrier such as a berm or gate restricting them (i.e. it is restricted or closed via MVUM and/or sign). It is generally assumed that bermed roads are not in drivable condition, but when there is uncertainty of whether effective berms or barriers exist, roads were considered drivable and coded as such in the database. The purpose of making these assumptions is only for analyzing effects to grizzly bears and does not change the management direction on the Forest. These assumptions are appropriate and necessary so as to not miss any potential effects to grizzly bears and give the benefit of the doubt to the species (U.S. Fish and Wildlife Service 1998). This methodology acknowledges both that the Forest does not have standards limiting administrative use of roads outside of the recovery zones and that available data are less complete in this portion of the Forest in terms of the types and locations of existing closure devices and the condition of the road prism beyond the barrier. It is important to note that although this approach may result in a lower estimate of the existing amount of secure habitat, it assures that the impacts of motorized route use are not underestimated as a whole.

In addition, since the Forest lacks inventory information and has no management authority over non-Forest lands, a 500 meter buffer was placed around Forest land in those areas where Forest land is adjacent to non-Forest land ownerships. Buffering Forest land 500 meters from non-Forest Service land ownerships is a conservative approach when considering effects to grizzly bears and will capture any unknown or undisclosed cumulative effects that may result from non-Forest actions on non-Forest land that occur adjacent to Forest lands. For example, actions on adjacent non-Forest land could affect secure habitat on adjacent Forest lands by having impacts within 500 meters of secure habitat. Accordingly, the Forest lands within 500 meters of lands not administered by the Forest may not provide secure habitat due to the potential effects associated with motorized access on adjacent non-federal lands. While it is possible that Forest land within 500 meters may provide secure habitat, information as to activity on non-Forest land is often unknown or not disclosed and the Forest lacks management authority over non-Forest lands. As such, the amount of secure habitat on Forest land adjacent to non-Forest land could change at any time without the Forest's knowledge or authority. Therefore, to be conservative when analyzing effects to grizzly bears, in order to not miss any potential effects associated with motorized access on non-Forest lands, Forest land within 500 meters of non-Forest land is buffered out of the secure habitat metric for the Forest. Because of the long life of the Forest Plan, it is not possible to know everything that may occur on non-Forest land and because the Forest has no control on non-Forest lands, this buffer accounts for any cumulative effects to grizzly bears that may have occurred from actions on non-Forest lands. In other words, any potential unknown effects associated with non-Forest lands have already been incorporated into this analysis ahead of time. For example, if motorized access were to increase on non-Forest land adjacent to Forest land, potentially affecting grizzly bears in the action area associated with disturbance and/or displacement, the effects of such are already considered into the metrics of secure habitat that are measured for Forest lands. Thus, we would not miss any effects to secure habitat on Forest lands over time, giving the benefit of the doubt to the species (U.S. Fish and Wildlife Service 1998). Using this conservative approach does not result in significant effects to the grizzly bear population.

Accordingly, the secure habitat amounts provided are useful as a broad index of what may be available to grizzly bears that may use the action area outside of the recovery zone and a metric to track over time. The Forest is expected to update the secure habitat metrics for Forest land as they update their access data during site-specific project planning in order to more accurately portray what was existing on the ground at the time of this consultation. Routes that were existing on the Forest but unmapped due to errors or lack of information may or may not affect the Forest's estimate of the existing amount of secure habitat, depending on the location of the roads. It is expected that this type of adjustment to the baseline would reflect better data and mapping rather than representing actual changes on the ground. As the access database is updated, the improved information will better reflect the existing conditions related to secure habitat in the GBAUs.

Given the lack of Forest Plan direction requiring specific levels of secure habitat in the areas outside of the recovery zones, it is possible that projects may permanently reduce secure habitat or more likely, temporarily reduce the effectiveness of the existing secure habitat. However, reductions and/or effects to secure habitat will be limited in most GBAUs by Forest Plan MA allocations that limit or preclude road construction. Given the variation in individual projects, the potential effects of permanent and temporary route construction and use on secure habitat depend entirely on the location of the new route and the existing secure habitat polygons. For example, permanent and/or temporary routes could be constructed completely outside of secure habitat and outside of the 500 meter buffer in close proximity to existing routes and would have no effect on secure habitat. Other circumstances may include temporary or permanent route construction and use within 500 meters of secure habitat but not directly within secure habitat, affecting the edge of secure habitat. Finally, sometimes temporary or permanent roads are built directly within secure habitat; thus affecting or potentially splitting a secure habitat polygon. Depending on the circumstances of the new roads as described above, the new roads may or may not affect secure habitat and potential effects to grizzly bears would range from insignificant to adverse.

While not specifically proposed under the Forest Plan, permanent route construction and use in the area outside of the recovery zones may occur, typically associated with a site-specific project. Permanent motorized route construction within NCDE zone 1 and the Ninemile DCA is limited by standards. Under NCDE-LNF Zone 1-STD-01, a net increase above the 2011 baseline density of roads (NCDE zone 1) and roads and trails (Ninemile DCA) open to public motorized use during the non-denning season would be precluded on Forest lands in NCDE zone 1, which includes the Ninemile DCA. However, while open linear route density within NCDE zone 1 would be maintained, permanent motorized routes that are restricted from the public could be constructed and have the potential to affect secure habitat or open motorized routes could be decommissioned and new permanent motorized routes could be constructed within secure habitat, thus reducing secure habitat but maintaining the linear motorized route density.

Permanent routes may be used during the short-term for a project and then restricted with a barrier with the potential for future administrative use or may be used for the long-term and receive a substantive amount of use if kept in an open status. Upon analyzing several large projects on the Forest, the Forest expects that some future projects will have at least a small permanent increase in roads, which may affect a small amount of secure habitat depending on site-specific decisions and information. As nothing is specifically proposed, for the purposes of this consultation, the information provided by the Forest was used and the effects of a very small permanent decrease of 1 percent of the secure habitat within any given GBAU outside of the recovery zones associated with the construction and use of permanent motorized routes will be analyzed. For future site-specific projects with permanent route construction that may affect more than 1 percent of a given GBAU, which is allowed but difficult to analyze programmatically, the effects of such will be analyzed during the site-specific project consultation as they would not fall under the level of effects analyzed here.

Vegetation or other management actions often require the construction and use of temporary routes or temporary use of restricted routes for motorized access. While not specifically proposed under the Forest Plan, temporary route construction and use, and temporary use of restricted routes may occur on a project by project basis. Temporary routes built for resource extraction such as timber harvest or mining may be short-term in duration of use or may remain on the landscape for several years and receive a substantive amount of use. To aid in estimating the amount of secure habitat that may be affected in the future, the Forest evaluated the effects to secure habitat from 4 recently planned projects that occur within 6 GBAUs (Table 15 in the biological assessment). Sawmill Petty and A-BLT previously calculated and analyzed the effects to secure habitat by GBAU. The Westside Bypass Wildfire Resiliency and Redd Bull previously calculated and analyzed secure habitat by analysis area (GBAUs were not delineated at that time) and were adjusted here to present the data by GBAU. The effects to secure habitat resulting from these recent projects ranged from 92 acres to 871 acres in a GBAU, with the percent of secure habitat affected ranging from nearly 1 percent to 5.5 percent in the short term. Over the longer term, after project completion, the amount of secure habitat affected by these projects will return to pre-project levels.

Using this information, and for the purposes of this consultation, the Forest estimated that the construction and use of temporary project routes or temporary use of restricted routes would temporarily decrease the effectiveness of secure habitat by no more than 5 percent in any given GBAU at any given period of time. Like the Sawmill Petty Project, projects may span more than one GBAU and for those projects, a project would not affect secure habitat by more than 5 percent in each of the GBAUs.

Depending on the site-specific project information (size, location, duration, etc.), effects associated with permanent and/or temporary route construction and use, or temporary use of restricted routes could range from minor disturbance and insignificant effects to displacement of grizzly bears that may result in adverse effects to individual female grizzly bears. The effects of displacement and under-use of habitat related to motorized access (including the existing motorized access conditions, the potential permanent and/or temporary route construction and use, and temporary use of restricted routes) are tempered by local resource availability, resource condition, seasonal use, and the number of grizzly bears using an area. Currently, the number of grizzly bears using the Forest varies, with use ranging from higher use in the NCDE recovery zone and NCDE zone 1 to very low or none in BMU 22 of the CYE recovery zone and portions of other areas outside of the recovery zones and NCDE zone 1. Depending on site-specific information on the presence of grizzly bears and location of secure habitat within the GBAUs, adverse effects from existing low amounts of secure habitat in some portions of the action area, permanent decreases in secure habitat, or temporary effects to secure habitat may result in the displacement of individual grizzly bears, the avoidance of suitable habitat, and/or the reduction of habitat to an unsuitable condition; potentially significantly affecting individual female grizzly bears and/or their dependent offspring. Under-use of habitat in proximity to roads by grizzly bears does not necessarily preclude use or form a barrier to dispersal and movement across the landscape.

At this time, within some portions of the GBAUs in the action area (the Forest), grizzly bears have not been verified. In addition, in some areas where transient males have been verified, no female grizzly bears have been verified. While we do not expect effects at this time for these scenarios, the existing, baseline motorized access conditions may result in some level of ongoing adverse effects to individual female grizzly bears and/or their dependent offspring if and when they occur in these areas at some point in the future. Numbers of grizzly bears in areas further away from grizzly bear populations are expected to increase slowly over time. This is especially true for female grizzly bears. As mentioned earlier, Proctor et al. (2012) found males move more frequently and over longer distances than females. Males have large home ranges and establish home ranges nearly three times further away from their mother's home ranges than do female offspring. Females usually establish smaller home ranges than males that overlap with their mother's home range (Waser and Jones 1983; Schwartz et al. 2003). In doing so, they generally disperse over much shorter distances than male grizzly bears (McLellan and Hovey 2001; Proctor et al. 2004). Therefore, female dispersal is a multi-generational process where females must live year-round in an area, successfully reproduce, and their independent offspring disperse into adjacent, unoccupied habitat. Thus, female grizzly bear presence in some portions of the action area is likely to increase slowly, if and when population pressure grows. The earliest detections of grizzly bears from the NCDE found in the intervening area between the NCDE and the YBGE were male, and males make up most of the known occurrences in this region (Mace and Roberts 2012). Multiple confirmed individuals have occurred in the area immediately surrounding the BE recovery zone since 2007; all of the known sex but one were male (U.S. Fish and Wildlife Service 2022a, J. Fortin-Noreus, U.S. Fish and Wildlife Service, pers. comm. 2023). While multiple verified sightings of unknown sex also occurred from 2017 to 2020, only one female grizzly bear has been documented in the BE (Ibid.). That female was a subadult from the NCDE found in the Bitterroot Valley (within 5 km of the recovery zone boundary). The bears was pre-emptively relocated to near the Welcome Creek Wilderness to avoid conflict. After the relocation the bear journeyed back north of I-90 to den (Ibid.). Until numbers substantially increase, grizzly bears now occupying or moving into these areas in the near future would not likely face significant competition for habitat and resources from other grizzly bears and displacement from quality habitat is not as likely to result in adverse effects to individuals as they are likely to have options to move to other areas to find resources.

Male grizzly bears have larger home ranges than females, and males and subadults are independent, more mobile and do not have the same energetic needs as adult females. While displacement may affect behavioral patterns of males and subadults, such as feeding or sheltering, we do not anticipate such effects to be significant to subadult or male grizzly bears. Displacement from quality habitat has more significant impacts on adult female grizzly bears than males or subadults because adult females have higher energetic needs to sustain fitness prior to and during gestation and lactation and when rearing. As such, adult females can less afford the additional energy expended to find high quality foods and shelter if displaced, especially during the early spring or late summer to fall hyperphagia season. During some years, due to poor climatic conditions and resulting food scarcity and/or high levels of forest management activity or recreational activity, displacement effects from areas with high road densities could be more frequent and intense.

Depending on the site specific information regarding the existing motorized access conditions, permanent route construction and use, temporary route construction and use, and temporary use of restricted routes, the Service anticipates that some level of adverse effects to female grizzly bears and/or their dependent offspring with home ranges impacted by such routes may occur in some situations during the life of the Forest Plan. Some adult females may be displaced from key habitats and under certain conditions they may be displaced to levels that impair their normal ability to readily find food resources needed to sustain fitness necessary for breeding and producing cubs, and find shelter. We do not expect that all existing routes, new permanent and/or temporary routes and use, or temporary use of restricted routes would have adverse impacts on female grizzly bears and/or their dependent offspring, or that all female grizzly bears and/or their dependent offspring would be adversely affected by these conditions. Some adult females have proven that they are able to successfully reproduce and raise young in BMUs or subunits that are worse than the research benchmarks (Kasworm et al. 2022a, Costello and Roberts 2021). The level of effects would depend on such things as grizzly bear use in the action area, location of the road, length of the road, timing of use, the frequency and intensity of use, and the duration the road would be on the landscape, in relation to those factors listed above for effects of roads. Not all temporary routes would likely to be constructed at once. Some of the routes would be consolidated in project areas and be constructed and used at the same time, which would concentrate effects on grizzly bears into a smaller area. Other roads would be separated by space and time across the Forest, which may affect more individual grizzly bears, but have less intense effects. However, if under-use of key feeding and sheltering habitat by female grizzly bears is significant, they may fail to obtain the necessary resources to breed, successfully reproduce, and/or successfully raise dependent offspring.

For the GBAUs lacking grizzly bear use, especially female grizzly bear use, we do not expect adverse effects associated with motorized access at this time. Until such time that female grizzly bears begin to use these GBAUs, the existing motorized access conditions are not likely resulting in adverse effects to grizzly bears. We conservatively include the potential for adverse effects in these areas due to the long time-frame that the Forest Plan will be effective, during which some females may begin to use these GBAUs and experience adverse effects from the ongoing motorized access conditions and low amounts of secure habitat and/or temporary roads or temporary use of restricted roads.

In sum, ongoing effects from existing motorized access conditions and new effects from permanent route construction and use, temporary route construction and use, and/or the temporary use of restricted routes may affect grizzly bears. These affects may be insignificant in some situations or adverse in others. Adverse effects may significantly impact an adult female grizzly bears' ability to find food resources, breed and raise young, and find adequate shelter at some time over the life of the Forest Plan. Not all actions related to access under the Forest Plan will result in adverse effects. We anticipate that the ongoing adverse effects from existing motorized access conditions and new effects from permanent and/or temporary route construction and use, and temporary use of restricted routes would affect only few adult females and/or their dependent offspring over the life of the Forest Plan. Further, we do not expect that all adult females and/or their dependent offspring that are exposed to disturbances related to motorized access conditions and low amounts of secure habitat would suffer significant displacement effects, nor would the effects persist throughout an individual female's life span as some females are able to adapt and have proven that they are able to successfully reproduce and raise young in areas with high route densities and associated low amounts of secure habitat. We expect that effects would vary substantially depending upon the wariness of the individual bear, the size of and habitat quality within her home range, the number of other grizzly bears using the particular area, climate conditions, annual food resources, and the nature, intensity and duration of human activity during any particular year. All of these are factors that may affect options available to adult females if displaced. Further, conditions the following year may be considerably different.

Winter Motorized Use

The primary concerns with winter over-snow vehicle use (snowmobile) with respect to grizzly bears are the potential effects associated with denning, den emergence, and spring habitat. Summer and fall habitats are not at issue since over-snow vehicle use would not overlap with these seasons. Winter recreation primarily occurs during the grizzly bear denning season. Information on winter motorized over-snow travel on the Forest is displayed in the baseline section above and will not change as a result of this consultation on continued implementation of the Forest Plan. Thus, the amount and timing of winter motorized use would remain the same under the Forest Plan as the existing, baseline condition.

The grizzly bear SSA stated that there is no evidence to indicate that current levels of recreation are limiting grizzly bear populations (U.S. Fish and Wildlife Service 2022a). Although sample sizes are small, there is no evidence from research to date that indicates existing winter motorized activities have adverse effects on denning grizzly bears. To be conservative for the grizzly bear, we cautiously anticipate some level of adverse effects associated with the overlap of over-snow vehicle use with the den emergence of female grizzly bears with offspring.

As stated above, the OSVUM displays about 550 miles of over-snow vehicle routes on the Forest. About half of the over-snow vehicle routes occur on the Seeley Lake Ranger District and the majority of the remaining half of the over-snow vehicle use routes occur on the Missoula and Superior Ranger Districts. Cross-country travel with over-snow vehicles is allowed on about 66 percent of the Forest, either all winter or seasonally.

The remaining 34 percent of the Forest does not authorize over-snow vehicle use which includes wilderness and other sensitive areas. About 52 percent of the BE, CYE, and NCDE recovery zones and 16 percent of the NCDE zone 1/Ninemile DCA are closed year-round to all over the snow vehicles. A small percentage (<1 percent) within the recovery zone and NCDE zone 1/Ninemile DCA have seasonal restrictions for over snow vehicle use. About 34 percent of the portion of the Forest outside the recovery zones and NCDE zone 1/Ninemile DCA has year-round over-snow vehicle closures while about 3 percent of this area has seasonal over-snow vehicle closures. The baseline section above described in more detail the existing and ongoing conditions associated with over-snow vehicle use.

Despite the Forest covering a large area of grizzly bear habitat, the only known denning habitat occurs within the NCDE. Grizzly bear denning has not been recorded in the portion of the BE or CYE portions of the Forest. Grizzly bears do den in the CYE to the north of the Forest but not currently within the portion located on the Forest (BMU 22). As the bear population continues to grow and expand, grizzly bears could den within areas not previously known to have active grizzly bear denning. Grizzly bears are quite variable in their selection of denning habitat and structures (Schwartz et al. 2003). Grizzly bears usually dig dens on steep slopes where wind and topography cause an accumulation of deep snow and where the snow is unlikely to melt during warm periods. In addition, grizzly bears are more likely to den in areas with greater canopy cover and at elevations above 6,371 feet (>1,942 meters) (Mace and Waller 1997).

Late season over-snow vehicle use is not restricted in all portions of the action area and in some portions of the action area winter motorized use would extend beyond the April 1 grizzly bear spring emergence period. In the NCDE recovery zone within modeled grizzly bear denning habitat, Forest Plan standard NCDE-STD-AR-08 allows no net increase in the percentage of area or miles of routes designated for motorized over-snow vehicle use on Forest lands during the den emergence time period. Outside of the NCDE recovery zone, the Forest Plan does not restrict motorized over-snow vehicle use during the den emergence period outside the areas with year-round closure as shown on the OSVUM.

Over-snow vehicle use can occur on the Forest from December 1 to March 15, March 31, April 15 or April 30 depending on the location. In addition, some areas on the Forest do not have a closed season. As such, the Forest does have some areas where over-snow vehicle use may occur during the den emergence period. The Forest estimated the acres of overlap between denning habitat and over-snow vehicle use (U.S. Forest Service 2022).

For those areas where winter motorized use does not occur beyond March 31, effects would be insignificant. The effects of winter motorized use beyond March 31 in those areas that overlap denning habitat are discussed below in the denning habitat, den emergence, and spring habitat sections.

Denning Habitat

As discussed in the 'general effects of snowmobiles on grizzly bears' section above, the potential for disturbance to denning grizzly bears does exist but is probably low due to the low probability of a direct encounter of a snowmobile to a den and even in that unlikely case, the excellent insulative properties of snow to mitigate the noise. It is more likely that impacts to denning grizzly bears, if they were to occur, would occur upon den emergence as discussed below. Therefore, although some grizzly bears may be affected during the denning season, the Service believes that the magnitude of impacts during this time would not reach levels that would injure grizzly bears, or be expected to appreciably reduce the reproduction, numbers or distribution of grizzly bears.

Den Emergence

To review, female grizzly bears begin emerging from their dens about April 1, with males typically beginning to emerge about 2 weeks earlier (Mace and Waller 1997). Grizzly bears typically spend a few days to a few weeks at or near the den before moving to other locations to begin feeding. During this time the grizzly bears have been observed to be lethargic and approachable. After leaving the den site grizzly bears usually move to lower elevation habitats such as riparian areas and avalanche chutes for much of their foraging during spring (Ibid.). Based on the behavior of grizzly bears in response to motorized use of roads in Mace and Waller's (1997) study, snowmobile activity after den emergence dates could disturb and/or displace grizzly bears. The greatest probability of interactions at or near dens would obviously be expected where modeled denning habitat overlaps with open snowmobile areas and the influence zones around roads or routes. As discussed in more detail below (under *spring habitat*), once grizzly bears move away from den sites and toward spring habitats, there will be very little potential for conflict with snowmobiles.

Snow conditions within portions of the action area are often suitable for over-snow vehicle use well beyond April 1, the date grizzly bears generally begin emerging from their dens. This is true especially in the higher elevations within the recovery zone. However, under the existing Forest Plan, areas with extended winter motorized use seasons (after April 1) do occur. Therefore, the potential exists for interactions between snowmobiles and grizzly bears that have recently emerged from their dens.

As previously mentioned, about 29 miles are open to over-snow vehicle use during the den emergence period (about 24 miles within the NCDE recovery zone, NCDE zone 1, and the Ninemile DCA and 5 miles outside of this area). No trails for over-snow vehicle use are identified in the OSVUM for the CYE and no over-snow vehicle use trails or roads are used within the BE. About 205,100 acres of denning habitat are open to cross-country over-snow vehicle use during the den emergence period. About 58,200 acres occur within the NCDE recovery zone, NCDE zone 1, and the Ninemile DCA, about 22,800 acres occur within the CYE Recovery Zone in BMU 22, and about 124,100 acres occur within areas outside the NCDE, CYE, and BE recovery zones, NCDE zone 1, and the Ninemile DCA. The portion of the BE Recovery Zone on the Forest is entirely within an area closed to over-snow vehicle use, thus no acres of over-snow vehicle use overlaps potential denning habitat. While these acres are open during the den emergence period, from a qualitative review, not all of these acres of cross-country over-snow vehicle use are available for such due to either the ruggedness of the terrain or logistical limitations (e.g., fuel). In addition, some areas may not be available to over-snow vehicle use after March 31st due to a lack of snow, particularly on the Plains/Thompson Falls Ranger District where it is largely drier and lower elevation. Finally, not all of these acres are currently supporting denning grizzly bears but the potential for grizzly bears to den in these areas over the life of the Forest Plan does exist.

Disturbance from over-snow vehicle use is likely most consequential shortly before or after den emergence, particularly to females with offspring. Females with cubs have high energetic needs in the spring, and cubs have limited ability to travel for several weeks after emergence from the den. Disturbance levels that cause a female to prematurely leave the den in spring or move from the den area could impair the fitness of the female and safety of the cubs. If cubs attempt to follow their mother, they may experience some level of decreased fitness and the family group may be pushed to less suitable habitat. Thus, significant disturbance during this time may reach levels that would injure grizzly bears, specifically adult females and/or their dependent offspring. Based on naturally earlier den emergence of male bears and females without young and their independence and mobility, the Service does not anticipate the effects of disturbance caused by over-snow vehicle use to be adverse to male grizzly bears or female grizzly bears without offspsring.

Spring Habitat

Upon emergence from their dens in the spring, grizzly bears typically move to lower elevations where their dietary needs may be met. Typical spring food sources include early greening herbaceous vegetation in low elevations, riparian areas, and in melted-out avalanche chutes. Grizzly bears also feed on dead ungulates from winter kill on winter ranges and in some locations grizzly bears prey on elk calves (usually available after June 1).

The potential for disturbance or displacement of grizzly bears from spring feeding habitat in the action area is influenced by the variability in snowpack and the rate of spring melt. Although over-snow vehicle use would be permitted after March 31 in some areas, spring over-snow vehicle use areas and spring grizzly bear habitat are almost mutually exclusive in that the areas that would be suitable for spring over-snow vehicle use (i.e. more snowpack) would not typically overlap with spring grizzly bear habitats (i.e. less snowpack). Therefore, the Service does not expect impacts to spring habitat and foraging grizzly bears related to winter motorized use to be significant.

Aircraft use

The use of aircraft, including helicopters, has occurred and is likely to continue to occur on the Forest associated with several activities. Helicopters can be used for tree harvest; however this activity has been decreasing on the Forest. Aircraft is also used for prescribed burning, aerial herbicide application, reconnaissance, and emergency actions such as during wildland fire suppression. The duration of use of aircraft that produces noise during project implementation may be as little as a day to several days to weeks or months or more in an area.

The NCDE grizzly bear conservation strategy (NCDE Subcommittee 2020) and guidance to the effects of helicopters on grizzly bears (Montana/Northern Idaho Level 1 Terrestrial Biologists Team 2009) identify the potential for disturbance by recurring low-elevation (<500m) helicopter flights. These documents also identify and provide management guidance for several factors that influence grizzly bears including potential disturbance and displacement from habitat. Low flying aircraft can also disturb bears, especially when the flights are recurring. The use of low flying aircraft would likely be limited to basic reconnaissance, wildland fire suppression, prescribed burning, herbicide treatment, and tree harvest. However, not including flight take-off and landing, it would be rare for reconnaissance flights to fly below 500 meters above the ground. The majority of the anticipated recurring flights below 500 meters may include a portion of the flights during wildland fire suppression, but more commonly would be during the use of a helicopter for prescribed burning, herbicide treatment, and/or tree harvest. During the use of aircraft equipment, people may be present on-the-ground, adding to the level of disturbance. The disturbance associated with equipment noise and/or human presence may result in any grizzly bears present in the area to move away, at least a short distance, while the work is on-going. With the exception of recurring long-term aircraft use, grizzly bears would likely return soon after the work has been completed and disturbance has stopped. Any potential for project-specific effects associated with aircraft use will be analyzed during site-specific consultation.

Non-motorized recreation

Non-motorized activities such as mountain biking, horseback riding, and hiking will occur throughout the action area. Dispersed recreation including the use of non-motorized trails may cause disturbance of grizzly bears to varying degrees. However, grizzly bear mortality related to non-motorized recreation is rare and population-level impacts have not been documented (Jope 1985, Kasworm and Manley 1990, Mace and Waller 1996, White et al. 1999).

In most situations, impacts associated with non-motorized use would likely be short-term and would range from no response from a grizzly bear to a grizzly bear temporary fleeing the area. Grizzly bears may adapt to consistent, predictable activity and may notice the activity but not flee from it (Jope 1985, Mattson 2019). This reaction is more likely to occur on trails with regular use. On non-motorized trails that receive low amounts of human use, human activity may result in a grizzly bear temporarily fleeing from the disturbance, expending extra amounts of energy (McClellan and Shackleton 1989, Mattson 2019).

Non-motorized trail uses (hiking, horseback riding, mountain biking) inherently have some risk of facilitating grizzly bear-human conflicts via sudden surprise encounters, depending on whether the bear flees or charges. Interactions with recreationists may disrupt bear's access to important food resources such as insect aggregation sites and huckleberry fields. However, except in the rare cases where a human-bear encounter leads to bear mortality, it is unlikely that the impacts of dispersed recreation would rise to the level of an adverse effect. In Alberta, Canada, Herrero and Higgins (2003) found small parties of 1 to 3 people were injured by grizzly bears more often than larger groups, with attacks by bears on humans occurring disproportionately more frequently in national parks. Most attacks by grizzly bears involved sudden encounters at close range where the bear is attacking defensively rather than predatory (Ibid.). Human activities that were occurring prior to the bear attacks mostly included hiking, hunting, and working, with hiking being the most common activity. Due to varying skill levels and speed of travel of mountain bikers, they are less likely to travel in close groups and maintain verbal contact with other riders, resulting in minimizing the amount of noise and reducing the potential for early detection and avoidance by grizzly bears. Thus, mountain biking may elicit greater flight response from grizzly bears than other non-motorized use due to the higher potential for sudden encounters (Quinn and Chernoff 2010, Mattson 2019, Servheen et al. 2017).

Often, grizzly bears disturbed by non-motorized use will exhibit increased nocturnal activity and decreased daytime activity when non-motorized use is most likely to occur (Mattson 2019). While grizzly bears may experience varying degrees of disturbance effects as a result of non-motorized recreation, due to the amount of human use and the type of activities on the Forest along with the lack of documented conflicts related to such, we expect effects will be insignificant as grizzly bears will likely adapt to such use or change its use patterns. Grizzly bears are habitat generalists and would be able to shift their use to low disturbance areas within their home ranges during activity. Such impacts are not likely to significantly affect an individual grizzly bear's ability to breed or find food or shelter.

We do not anticipate adverse impacts to grizzly bears as a result of the Forest Plan for non-motorized use during the winter. Due to the nature of activity, timing (grizzly bears are denning), duration, etc. we expect any disturbance effects to be minimal, if any effects occur at all. Even during the den emergence period, disturbance associated with non-motorized activity is not expected to reach a level that would displace grizzly bears and result in adverse effects, as described in the paragraph above.

Food and Attractant Storage and Site Development

This section focuses on analysis and discussion of the direct and indirect effects to grizzly bears related to food and attractant storage issues and site development. Also refer to the '*Habituation to Human Attractants*' subsection in the '*General Effects of Roads on Grizzly Bears'* section for further discussion on habituation.

General Effects of Food and Attractant Storage and Habituation

Improperly stored food, garbage, and/or livestock or pet foods can lure grizzly bears to areas near people and pose a significant risk of habituating bears to human presence and/or conditioning grizzly bears to seek out anthropogenic foods and attractants. Food conditioned grizzly bears enter unsecured garbage receptacles, sheds, and other buildings in search of a reward. Accessibility to human related attractants and conditioning to those rewards can lead to management removal of grizzly bears and additionally, mortality of grizzly bears by people defending their life and property.

Incidence of property damage or conflicts associated with human-related foods is inversely proportional to the availability of high quality grizzly bear foods found in the wild; during periods of poor natural food production incidences of human-grizzly bear conflicts typically increase. When poor seasonal bear foods exist in part of or through the entire non-denning season in the GYE and NCDE, the incidences of bears causing property damage and obtaining anthropogenic foods increased significantly over average or good years (Gunther et al. 2004, Manley 2005). The conflict relationship is magnified when the availability of late season natural foods such as whitebark pine seeds is insufficient to meet the high energy requirements during hyperphagia (Mattson et al. 1992).

Numerous studies in the NCDE elucidate the importance of late-season frugivory by grizzly bears, especially selection for globe huckleberries (*Vaccinium globulare*; Martinka and Kendall 1986, Weaver et al. 1990). Berry failure due to drought or destruction of plants by fire would force grizzly bears to range more widely than in normal periods of seasonal availability (Blanchard and Knight 1991). Therefore, grizzly bears face an increased risk of encounters with humans and ultimately human-caused mortality during the autumn season. Grizzly bears in some areas that avoided trails with human activity during part of the year changed this avoidance behavior when a favored berry resource came into season (Donelon 2004). Although grizzly bears still had a low tolerance for trails with high human activity, the tendency to approach areas of human activity when nutritional and energy needs are high could put individual bears at an increased risk of immediate conflict or condition them to the presence of people, which could lead to conflicts later in time.

Effects of Habituation and Developed Sites in the Action Area

Developed recreation sites are sites or facilities with features that are intended to accommodate public use and recreation, such as campgrounds, rental cabins, summer homes, trailheads, lodges, ski areas, fire lookouts, visitor centers, and others. In addition to disturbance effects described above, developed sites on public lands are associated with frequent and/or prolonged human use that may include continuous or frequent presence of food and attractants.

As of June 2021, five developed day-use only sites and five developed overnight use sites occur on the Forest within BMU 22. A total of three developed sites with overnight use, 17 sites with day-use only, and five administrative sites occur on the Forest within the NCDE recovery zone. No developed recreation sites occur on the Forest within the BE recovery zone. As of June 2021, a total of 27 recreation residences, 56 recreation sites with overnight use, 83 day-use only recreation sites, and 52 administrative sites occur on the Forest outside of the recovery zones. The locations of existing developed recreation sites on the Forest are shown in figure 3 in Appendix 1 of the biological assessment (U.S. Forest Service 2022).

No specific Forest plan direction pertains to developed recreation sites within BMU 22 within the CYE recovery zone. Within the NCDE recovery zone, standard NCDE-STD-AR-05 limits any increase in the number and capacity of developed recreation sites that are designed and managed for overnight use by the public during the non-denning season to one increase per decade per bear management unit. Guideline NCDE-GDL-AR-03 states that if the number or capacity of day-use or overnight developed recreation sites is increased, the project should include one or more measures to reduce the risk of grizzly bear-human conflicts in that bear management unit. Such measures could include but are not limited to additional public information and education, providing backcountry food-hanging poles or bear-resistant food or garbage storage devices, project design criteria that would limit capacity increases to those needed for public health and safety, and increasing law enforcement and patrols. No Forest Plan direction is specific to coordinating developed recreation sites with grizzly bear conservation in the portions of the Forest outside of the recovery zones.

Dispersed recreational opportunities, as well as non-motorized (e.g. hiking, horseback, mountain biking) recreation, also occur throughout the Forest and are largely composed of dispersed camping along trails and roads. Dispersed recreation consists of those activities that take place outside of developed recreation areas. Dispersed sites generally do not have fees associated with them and have little or no facilities such as toilets, tables, or garbage collection. Dispersed recreation is often intermittent or temporary where humans are not in any one location for long periods of time. Types of dispersed activities that occur on the Forest include, but are not limited to, camping, hiking, fishing, skiing, hunting, gathering huckleberries, horseback riding, river use, and snowmobiling.

Dispersed recreation occurs across much of the Forest, but typically occurs in close proximity to roads. However, opportunities for non-motorized cross country (e.g. hiking or horseback) dispersed recreation, especially for game hunting purposes where people may access areas not commonly visited by people. Outside of the CYE and NCDE recovery zones, grizzly bear density, and therefore the potential for bear-human encounters, is relatively low.

Habituation and food conditioning of grizzly bears is a concern. Habituated grizzly bears may learn to seek out developed and dispersed sites for food rewards. On Forest lands, requirements for proper storage of food, garbage, or other attractants are established and enforced through issuance of special orders. The food and attractant storage order is an important conservation action that has reduced the potential for human-bear conflicts and mortality risk. To aid in trash and food storage, the Forest has installed several bear resistant trash containers and bear resistant food storage boxes across the Forest, mostly located in campgrounds. Whether a location has a bear resistant food container or trash container or not, visitors are responsible for ensuring attractants are stored properly according to the forest-wide food/attractant storage order.

Since 2011, the Forest has had a Forest-wide food/attractant storage order. The current applicable food storage order is the Regional order R1-2023-02, which was updated in February of 2023. This Regional food/wildlife attractant storage order applies Forest-wide and is in effect annually from March 1 to December 31 through calendar year 2028. Under the food/wildlife attractant storage order: (1) during daytime hours, all attractants, including human, pet, and livestock food (except baled or cubed hay without additives) and garbage shall be stored in a bear-resistant manner when not being attended and (2) during nighttime hours, all attractants, including human, pet, and livestock food (except baled or cubed hay without additives) and garbage shall be stored in a bear-resistant manner unless it is in immediate control, being prepared for eating, being eaten, being transported, or being prepared for storage, as defined in the order. Reference the order for further requirements and definitions. In addition to the Regional order R1-2023-02, Forest Plan standard NCDE-STD-WL-02 requires that a food/wildlife attractant storage special order be in place on Forest lands within the NCDE PCA (recovery zone), NCDE zone 1 (including the Ninemile demographic connectivity area), and NCDE zone 2. The Forest Service's Regional food/attractant storage order covers the entire Forest (and more) and thus, complies with this standard. Although the Regional order expires after 5 years, we reasonably expect (based on past history) that additional food and attractant storage orders that apply Forest-wide will continue to be issued, reissued, or extended for the life of the Forest Plan. It is unlikely that a food and attractant storage order would not be in effect at any given time during the life of the Forest Plan. However, if at any given time a food and attractant storage order is not in effect during the life of the Forest Plan, additional effects to grizzly bears may result that have not been previously analyzed and reinitiation of consultation on the Forest Plan may be necessary.

There is no history of recurring conflicts at developed recreation sites on the Forest. No mortalities on the Forest are known or suspected to be associated with food conditioning or unsecured attractants at developed or dispersed recreation sites. Given the small number of existing developed recreation sites that provide overnight use, food/attractant storage orders and policies that are in place, and Forest Plan direction that discourages expansion of developed recreation sites, the effects of continued implementation of the Forest Plan with regard to developed and dispersed recreation on the Forest may cause disturbance of individual bears but is unlikely to rise to the level of adverse effects by causing habitat displacement or food-conditioning of grizzly bears.

With proper food and attractant storage under the Forest Plan, the potential of attracting grizzly bears would be reduced and the potential for grizzly bear-human conflicts would be minimized. Based on the previous history of no grizzly bear mortalities related to food or other attractants, along with measures taken to continue to manage food and attractants and to minimize the potential for grizzly bear-human conflicts (i.e. food and attractant storage orders Forest-wide), the effects of habituation and resulting grizzly bear-human conflicts are expected to be discountable.

Livestock Grazing

General Effects of Livestock Grazing

Effects of livestock grazing on grizzly bears are generally related to depredations of livestock by grizzly bears, disposal of livestock carcasses, storage of human food and stock feed, and grizzly bear habituation, food conditioning, and mortality risk associated with these activities. Depredating bears may become food conditioned resulting in management actions that remove bears from the population. Livestock can include a variety of animals such as (but not limited to) cattle, horses, mules, sheep, goats, and chickens.

Being an opportunistic feeder, any individual grizzly bear can learn to exploit livestock as an available food source just as easily as they habituate to other human food sources (Johnson and Griffel 1982). Livestock depredations tend to occur independent of natural grizzly bear food availability (Gunther et al. 2004, Gunther et al. 2012). Grizzly bears have demonstrated the ability to learn livestock depredation behavior. Thus, an assumption can be made that once a grizzly bear has preyed on livestock, it becomes more likely to repeat that behavior, however that is not always the case. Grizzly bears that kill livestock include a range of ages and both sexes (Johnson and Griffel 1982).

The adverse effects of domestic sheep grazing on grizzly bears are well documented (Knight and Judd 1983, Johnson and Griffel 1982). Sheep grazing in occupied grizzly bear habitat poses substantive risks to grizzly bears since in many areas grizzly bears kill sheep much more readily than other livestock and because sheep are often closely tended by herders typically armed and protective of their flock. In one study in the Yellowstone grizzly bear ecosystem, of 24 grizzly bears known to use livestock allotments, 10 were known to kill livestock (Knight and Judd 1983). Of these bears, seven killed sheep, five of which were trapped and fitted with radio transmitters. All but one radio-collared grizzly bear cub that had the opportunity to kill sheep did so. Grizzly bear depredation of domestic cattle is also well documented. Some grizzly bears coexist with livestock and never prey on them (Knight and Judd 1983). As with sheep, grizzly bear predation on cattle may result in the affected bears seeking out domestic livestock to supplement their diet. This in turn will likely cause an increased potential for bear-human conflicts.

Knight and Judd (1983) reported several differences between cattle and sheep conflicts with grizzly bears. They found that all radio-collared grizzly bears known to have come in close contact with sheep killed sheep, but most grizzly bears that encountered cattle did not make kills. They also found that all known cattle kills were carried out by adult bears 7 years or older, while both adults and subadults from 1 year to 13 years old killed sheep. Grizzly bears that killed sheep, usually took multiple sheep over several days. However, in each instance when the sheep were moved out of the area the predation ended (Johnson and Griffel 1982).

The resulting change in feeding behavior from natural foods to livestock often results in an adverse effect to individual grizzly bears because of the potential to relocate or remove the offending grizzly bear. The adverse effect of altered behavioral patterns does not, itself, cause injury to the involved grizzly bear. However, some grizzly bears become chronic depredators that actively seek livestock as prey. These grizzly bears are more likely to be the subject of grizzly bear-livestock or grizzly bear-human conflicts that may lead to their relocation or removal from the wild population through agency control actions.

In addition to livestock depredation, some grizzly bears can become food conditioned to human garbage or livestock feed if allotments are left unclean. Livestock carcasses can also attract grizzly bears similar to other animal carcasses. The presence of livestock carcasses in grizzly bear habitat may alter grizzly bears' behavior by attracting bears to these carcasses and away from other natural food sources as the opportunity allows. Grizzly bears have a strong tendency to return to a carcass for two or more feedings (Johnson and Griffel 1982). This change in habitat use and behavior has the potential to make affected grizzly bears more susceptible to conflicts with humans and particularly livestock riders/herders/permittees. Grizzly bears that become food conditioned also have a higher probability of being removed by agency personnel. Such potential effects can be minimized through implementation of food storage orders and carcass management programs. Proper food storage and treatment, movement or disposal of livestock carcasses can reduce the potential attractants for grizzly bears. Complete cattle carcass removal from allotments is not always possible due to the large and remote areas grazed by livestock, the size of the carcasses in non-motorized areas, and the difficulty in locating all carcasses over such vast areas, or locating them in a timely manner. In addition, Anderson et al. (2002) noted, "While carcass removal may reduce the concentration of bears in an area, it may not prevent bears from developing depredatory tendencies or repel depredating bears from grazing areas."

Effects of Livestock Grazing in the Action Area

The Forest has 11 active grazing allotments: two within the recovery zones (1 NCDE, 1 CYE), two within NCDE zone 1 and the Ninemile DCA (one in each), and seven outside of the recovery zones, NCDE zone 1, and the Ninemile DCA. None of these allotments are for domestic sheep or other small livestock. These active cattle allotments encompass 80,878 acres, or 3.6 percent of the Forest. Table 5 above displays these allotments by areas of the Forest, inside and outside of the recovery zones. Continued implementation of the Forest Plan will not change the number and location of livestock allotments nor the number and type of animals allowed to graze on these allotments. Forest Plan direction indicates for each Management Area whether or not livestock grazing will be permitted. Additional guidance for Range Practices is provided for MA-12 Wilderness, MA-14 riparian, and MA-20 grizzly bear habitat, which is primarily aimed at avoiding overutilization of forage in areas where cattle naturally tend to congregate. Any future changes would be addressed through separate analyses.

Impacts to grizzly bears from livestock operations potentially include competition for preferred forage, displacement of bears due to livestock-related activity, and direct mortality due to control actions as a consequence of livestock depredation or learned use of bear attractants such as livestock carcasses and feed.

The Forest Plan provides management direction that would be used when annual operating plans are developed, when grazing permits are issued or re-issued, and when allotment management plans are revised or developed. The following are additional Forest Plan components related to livestock grazing management for the NCDE recovery zone and/or NCDE zone 1, including the Ninemile DCA, and are described fully in Appendix 2 of the biological assessment (U.S. Forest Service 2022): NCDE-STD-GRZ-01, NCDE-STD-GRZ-02, NCDE-STD-GRZ-03, NCDE-STD-GRZ-04, NCDE-STD-GRZ-05, NCDE-STD-GRZ-06, NCDE-GDL-GRZ-01, and NCDE-GDL-GRZ-02. In summary, these standards and guidelines incorporate requirements into new or reauthorized grazing permits that reduce the risk of grizzly bear-human conflict, require reporting of livestock carcasses within 24 hours of discovery followed by proper disposal of carcasses, prohibit increases in the number of sheep allotments or permitted animal unit months above the baseline, reduce the number of sheep allotments when opportunities arise (although, no sheep allotments occur on the Forest), prohibit increases in the number of active cattle grazing allotments (recovery zone), limit potential conflict associated with weed control via small livestock, and specify needed measures to protect key grizzly bear food production areas from conflicting and competing use by livestock. These standards and guidelines do not apply to the portions of the Forest outside of the NCDE recovery zone or NCDE zone 1.

No known incidents of grizzly bear mortality or grizzly bear-human conflict have occurred on the Forest as the result of livestock grazing-related management subsequent to the listing of the grizzly bear as Threatened in 1975. Permits for grazing by saddle and pack animals are granted primarily in support of outfitter and guide operations or Forest administrative use in wilderness areas. No evidence of conflicts between grizzly bears and horses/mules due to depredation or forage competition occurs.

Honeybees, classified as livestock in Montana (MCA 15–24–921), can attract grizzly bears. While some apiaries occur on private land, none occur on the Forest. Forest Plan standard NCDE-STD-SFP-01 requires special-use permits for apiaries (beehives) located on Forest lands to incorporate measures, including electric fencing to reduce the risk of grizzly bear-human conflicts as specified in the food/wildlife attractant storage special order.

No information indicates that the continued grazing of cattle on the Forest will increase impacts or the risk of human-caused mortality on grizzly bears. Forage competition or displacement are also unlikely given the small and declining number of cattle grazing allotments on the Forest (action area). Based on the information for livestock grazing in the action area (no sheep allotments, the small number of cattle allotments, the standards within the recovery zone and NCDE zone 1, and the very long history of no grizzly bear mortalities or grizzly bear-human conflicts associated with livestock), adverse impacts to grizzly bears related to livestock grazing on the Forest during the life of the Forest Plan are not likely.

Vegetation and Fire Management

General Effects of Vegetation and Fire Management

Vegetation and fire management, including activities such as commercial or noncommercial harvest, fire suppression, and fuels treatments (prescribed fire, mechanical treatment, and/or chemical treatment) may impact grizzly bears as a result of the potential for short-term disturbance. Such disturbance involves the presence of humans and often includes the use of motorized equipment. Harvest units are often located in close proximity to existing roads, thus many units may already be avoided by grizzly bears. Also, untreated habitat typically remains widely distributed within project area as well as an action area and would accommodate grizzly bear use during activity.

We expect that grizzly bears would likely leave an area on their own accord in advance of an approaching fire and therefore be out of the area associated with fire suppression activities. However, if suppression activities were to take place prior to an approaching fire, grizzly bears may still be in the vicinity of the suppression activities. Some effects from disturbance may be caused by the overall increase in human activity in a particular area. These activities may include increased vehicular traffic, aerial support and fire camps, any of which may affect a grizzly bear prior to their leaving the area. The possibility of a direct encounter with a grizzly bear by a person or group of people involved in fire management activities is remote. Disturbance effects to grizzly bears as a result of vegetation or fire management would likely be short-term and insignificant.

Longer-term effects related to vegetation management include impacts to grizzly bear cover and forage. A decrease in the amount of cover may result in different effects to grizzly bears and their habitat. If cover is limiting in the project area, either by the amount or distribution, vegetation management may result in negative impacts (Ruediger and Mealy 1978). Reduced cover may increase the visibility of grizzly bears, which may potentially increase their vulnerability to illegal human-caused mortality and/or contribute to movement from preferred habitats. However, if cover is not limited in an action area, timber harvesting may have either no effect or a positive effect in those situations where food abundance or distribution is improved. By removing or reducing overstory vegetation through harvesting, slashing, and/or burning, sunlight reaches the forest floor or clearing and grizzly bear food production may be increased (Ibid.). This includes foods such as berries and succulent forbs.

In a study on use of harvested stands, Waller (1992) found that use of these stands increased during the berry season, due to some harvested stands having high berry production. If food production or distribution is improved but human activity is not controlled after the completion of harvest activities, negative impacts on grizzly bears may occur due to an increase in the potential for conflicts between humans and grizzly bears (Ruediger and Mealey 1978). Waller (1992) found that of the harvested stands that he studied, those with the highest grizzly bear use had limited access for people due to closed gates and/or over-grown roads. Grizzly bears within his study area that used harvested stands were found at higher elevations and spent little time in lower elevation stands where harvest was most common. Waller attributed this to human use of those lower, more accessible harvested stands. Waller also found that grizzly bears avoided stands where the vegetation had not recovered enough to provide security cover and preferred to use stands that were 30 to 40 years post-harvest.

Zager (1980) found that differences of shrub responses depended on the type of treatment that occurred post-harvest. Among the key shrub grizzly bear foods on clearcut sites where slash was bulldozer-piled before burning, Zager found a consistent decline in canopy coverage when compared to old burns. This is likely due to the extreme heat created by burning slash piles which may kill rhizomes and root crowns and bulldozer use which may also destroy rhizomes and root crowns. In those areas where slash was either broadcast burned or not treated, key grizzly bear shrub foods were generally found throughout the sites, except on skid roads and other severely disturbed areas. On relatively mesic sites, globe huckleberry, mountain-ash and serviceberry generally increased in cover.

The use of wildland fire for resource benefit is typically allowed only where there is some degree of certainty that the fire would go out naturally or could be contained within predefined lines. These types of fires can result in short-term negative effects and/or long-term beneficial effects depending on the vegetation species and fire severity. Some foraging habitat and/or cover may be affected in the short-term. However, natural fire often stimulates the understory and/or increases the vegetative diversity (forbs, grasses, berry-producing shrubs) in high quality grizzly bear habitat, benefitting grizzly bears in the long-term.

Vegetation management activities that would occur during the grizzly bear denning season are not likely to impact grizzly bears. Snow is an excellent sound barrier (Blix and Lentfer 1992) and impacts to denning bears would likely be less in deep snow situations than in shallow snow conditions. It is likely that hibernating bears exposed to meaningless noise, with no negative consequences to the bear, habituate to this type of disturbance (Knight and Gutzweiler 1995).

Often, temporary roads are constructed and/or restricted roads are used in relation to vegetation and fire management activities. Effects from fire suppression activities may result from constructing firebreaks and/or machine lines. These actions may temporarily contribute to the effects related to motorized access or may result in effects to grizzly bears similar to effect of roads on grizzly bears. The impacts of roads are discussed above in the '*General Effects of*

Roads on Grizzly Bears' and the '*Effects of Motorized Access in the Action Area*' sections above. In addition, food and garbage storage at activity sites and camps may attract grizzly bears and contribute to risks. Such effects are also discussed above (see the '*Effects of Food and Attractant Storage and Habituation*' section above).

The use of aircraft, including helicopters, may also be used in vegetation and fire management activities, and in general reduce impacts to grizzly bears where they reduce or eliminate the need for new roads. Helicopter or other aircraft use may elicit a response in grizzly bears. Effects may range from a simple awareness, short-term disturbance or flight response, or displacement from an area (Montana/Northern Idaho Level 1 Terrestrial Biologist Team 2009). In timbered habitats, McLellan and Shackleton (1989) found that an overt avoidance or displacement response occurred with high intensity helicopter activity, such as carrying equipment within 200 meters of a grizzly bear. Helicopter use that is short in duration and low in frequency, would not likely result in significant affects to grizzly bears. Extended helicopter use with multiple passes could interfere with the normal behavior patterns of grizzly bears. However, when considering long-term habitat effects, helicopter use does not use or require roads and may not pose the same chronic displacement effects or mortality risks that roads-based operations do. Helicopter use is a temporary event, whereas roads can be features on the landscape long after a project is complete. Consequently, while short-term helicopter activities may impact grizzly bears, they do not impart the same chronic habitat effects as roads. If repeated, low altitude flights continue into multiple seasons, the effects upon grizzly bear behavior (i.e., avoidance and more than just temporary disturbance) may become more substantial.

The effects to grizzly bears of repeated, low altitude flight paths that follow open roads may be partially offset by the existing under-use of habitat in the immediate vicinity of the roads due to the "avoidance" by grizzly bears of habitat in close proximity to open roads. In many cases, the effects of helicopter use that occurs in roaded habitat would have insignificant effects to grizzly bears. However, helicopter use in areas that are not highly roaded could result in adverse effects to grizzly bears adapted to using more secure habitat. Thus, the effects of helicopter use on grizzly bears can vary considerably; as such, effects will be determined through an analysis of site-specific activities and conditions in the area.

Effects of Vegetation and Fire Management in the Action Area

The existing environmental baseline is characterized by a forested matrix with early successional stages created by vegetation management and wildfires. The current environmental baseline provides a variety of bear foods while maintaining a mosaic of food and cover. The Forest Plan established a forest-wide objective to "provide for the maintenance of a diverse mosaic of vegetational development, well distributed across the Forest to ensure ecological integrity". Vegetation treatment, including prescribed fire, is encouraged to improve habitat for various wildlife species and groups. Harvesting has been used within the action area as a tool used to achieve a variety of resource objectives, including but not limited to lowering fuels and fire risk; establishing desired tree species; improving tree growth; reducing impacts of insects or disease; contributing wood products to the local economy; improving wildlife habitat; and salvaging the economic value of trees killed by fire or other factors.

The Forest Plan components related to vegetation and fire management are described fully in Appendix 2 of the biological assessment (U.S. Forest Service 2022), which is incorporated by reference. All of the Forest land within the BE recovery zone is designated as Wilderness, where natural processes generally predominate without human intervention. The Forest Plan does not have specific direction to coordinate vegetation management with grizzly bear conservation in the CYE recovery zone or outside of the recovery zones. Vegetation management within the NCDE recovery zone includes desired conditions and guidelines that address considerations for the timing of activities to reduce the risk of disturbance/displacement, encouraging bear foods and retaining cover, and cessation of activities if needed to resolve a grizzly bear-human conflict situation. These plan components would sustain healthy, resilient plant communities on which grizzly bears depend for food and cover and would reduce the risk of disturbance to bears during or as a result of vegetation management activities, and to maintain or increase habitat and cover where possible. Vegetation management must also adhere to other grizzly bear related guidance, including standards regarding motorized route density and food storage orders.

Under the Forest Plan, approximately 1,239,000 acres (about 56 percent of the action area) are identified as suitable for timber production (the purposeful growing, tending, harvesting, and regeneration of rotational crops of trees to be cut into logs, bolts, or other round sections for industrial or consumer use, not including production of fuelwood or harvest from unsuitable lands). The 1986 Forest Plan, recognizing the need to protect soil and water resources and other multiple uses, projected that the average annual harvest would be 133 MMBF during the 2001-2030 time period (U.S. Forest Service 2022).

Looking at the past tree harvest levels completed on the ground (described in baseline section above) and the anticipated increase in capacity, regeneration harvest is likely to increase to about a total of 3,000 acres per year in about five years. This increase of regeneration harvest is not likely to jump in one year but rather a slow increase each year until reaching the 3,000 acres per year in the fifth year (U.S. Forest Service 2022, additional information). Intermediate harvest and non-commercial thinning are likely to remain about the ten year average.

About 845,500 acres or 38 percent of the action area are identified as unsuitable for timber production on the Forest. In addition, timber production is largely limited on about 181,500 acres of riparian areas or about 8 percent of the action area. Areas that are not suitable for timber production include wilderness areas, recommended wilderness areas, Rattlesnake Natural Area and Botanical Areas, and others. In addition, lands with marginal timber growth potential based on landscape or vegetation characteristics, areas with limited access, or areas with certain other management emphasis (e.g., big game winter range) are included in unsuitable lands for timber production. However, tree harvest could occur for other multiple use values and purposes in areas identified as unsuitable for timber production. Inventoried roadless areas make up about 22 percent of the Forest’s unsuitable land for timber production and like other areas identified as unsuitable land for timber production, the occasional need to cut and remove commercial size trees for other resource needs does occur. This is not a common practice on the Forest but when it does occur it is usually narrow in scope and limited to a small area.

Wildfire has a strong influence on the age distribution and spatial arrangement of Forest vegetation. While acres affected by wildfire will be highly variable, the size and severity of wildfires are expected to continue to increase due to climate change. The types of activities associated with wildfire suppression are described in the baseline section above.

Since decisions regarding management of wildfires are made using site-specific information as individual fires occur, a prediction on the number of acres of wildfire that may be managed for resource benefit was not made. Decisions on whether to manage a wildfire for resource benefit will include an analysis of the site-specific information such as location of a wildfire start, natural and human resources and values at risk, timing of fire occurrence, current and predicted weather, local and national resource availability, and other factors. Thus, it will be determined at the time of a wildfire event whether the appropriate action will be suppression or to manage the wildfire for resource benefit, or a combination of these options.

Based on our history of consultation on vegetation and fire management projects, information in our files, and the analysis under the '*General Effects of Vegetation Management*' section above, the effects of vegetation and wildfire management activities on grizzly bears can range from none if grizzly bears are not expected to be in the area (i.e. they have fled the area ahead of the fire) to minimal disturbance to displacement depending on the types of activities used. We do not anticipate that vegetation and fire management activities by themselves would result in effects to grizzly bears that would be significant and impact breeding, feeding or sheltering. The Forest will consider and analyze the potential effects to grizzly bears for future site-specific vegetation and/or fire management projects or emergency wildfire suppression actions during the site-specific project analysis process. Site-specific consultation with the Service will occur as necessary.

Grizzly bears are habitat generalists and would be able to shift their use to low disturbance areas within their home ranges during treatment activity. Thus, disturbance effects are expected to be minimal. Future proposed vegetation and fire management actions are expected to provide sufficient habitat for grizzly bears, such as connectivity, cover, forage, and denning habitat, among others. We expect that forest, grassland, shrubland, and riparian habitats would be managed to provide early, mid, and late successional vegetation stages. Based on decades of previous consultation, the effects to important habitat features such as connectivity, cover, forage, and/or denning are expected to be minor and insignificant and potentially beneficial. While proposed activities would likely open up patches of forested habitat and travel may be altered somewhat, areas of untreated forest typically remain and treatments are not expected to create barriers to movement or preclude travel. Linkage and habitat connectivity are not likely to be significantly affected.

With proper food and attractant storage (i.e. the Forest-wide food/attractant storage order), the potential of attracting grizzly bears into the treatment units would be reduced and the potential for conflicts between grizzly bears and personnel associated with the action would be minimized. With such measures taken to minimize the potential for grizzly bear-human conflicts, the effects of such conflicts are expected to be discountable.

Activities that occur along with vegetation and fire management actions, such as temporary road construction, restricted road use, or helicopter use, may result in additional effects to grizzly bears. Such effects could range from insignificant to significant depending on site-specific information. The effects of temporary roads are discussed in the '*Effects of Motorized Access in the Action Area*' sections above. General effects of helicopter use are discussed above in the '*General Effects of Vegetation Management*' section. Potential effects that may occur as a result of temporary road use, restricted road use, and/or helicopter use associated with vegetation management would be considered in a site-specific analysis. Some of those effects may tier to this programmatic consultation as described above.

In summary, with the exception of effects related access management or helicopter use, which may be adverse at times, we do not anticipate adverse effects to grizzly bears as a result of vegetation and/or fire management within the action area. Related motorized access and helicopter use may or may not result in adverse effects to grizzly bears and any effects would be considered in a site-specific analysis. Again, site-specific project analyses will occur to determine the potential effects of any proposed action. The effects on grizzly bears associated with fire suppression and/or wildfire for resource benefit would be analyzed after the suppression activities and/or wildland fire are complete, with emergency consultation occurring when appropriate.

Energy and Mineral Development

Effects of Energy and Mineral development in the Action Area

The production of oil and natural gas on federal lands is conducted through a leasing process under the Federal Onshore Oil and Gas Leasing Reform Act of 1987 (PL 100–203). Mineral development refers to surface and underground hardrock mining and coal production, which is regulated by permits on National Forest System lands under the Mining Act of 1872, as amended through PL 103–66. The Mineral Materials Act of 1947, as amended through PL 96–470, provides for the sale or public giveaway of certain minerals such as sand or gravel.

No gas or oil exploration or development is occurring on the Forest at this time. The potential for oil and gas resources on the Forest is considered to be low. The Forest-wide Standard 41 requires: “Before oil and gas lease stipulation recommendations are made, site specific analysis of environmental effects will be made. Stipulations, which are based upon the 1982 Environmental Analysis for Oil and Gas of Non-wilderness Lands on the Forest, will be recommended in accordance with management area direction in Chapter III. In some instances, the stipulations will include a provision for ‘no surface occupancy.’ The lessee or designated operator has the right to explore for and extract oil/gas from his/her lease in accordance with the stipulations attached to the lease.” Thus, the magnitude of effects from leasable or locatable minerals exploration and development would be limited by provisions of the Forest plan. Any such proposals would be subject to additional site-specific analysis. Project development and mitigation plans would be designed to avoid, minimize, or compensate for any adverse effects associated with the mining proposal (U.S. Forest Service 2022). Any future gas or oil developments would undergo a site-specific review and analysis of effects and site-specific consultation if applicable.

Two active gold mines and one quartz crystal mine are located on the Forest outside of the NCDE recovery zone, NCDE zone 1, Ninemile DCA, CYE recovery zone, and Bitterroot recovery zone. Each of these mines has less than 1/2 acre of surface disturbance. These are both likely to continue to operate in accordance with the Forest Plan and may cause disturbance to grizzly bears that are in the vicinity of the mines. Before any new mining operation could begin, the claimant would have to file a notice of intent and a plan of operations with the Forest Service. A plan of operations would trigger the NEPA process to evaluate environmental effects of the proposal and an analysis of effects and site-specific consultation for grizzly bears would occur if applicable.

Additional forest plan desired conditions, standards, and guidelines specific to the NCDE recovery zone, NCDE Zone 1, and the Ninemile DCA, are designed to avoid, minimize, and/or mitigate impacts to grizzly bears or their habitat, subject to valid existing rights. Standard NCDE-STD-MIN-08 requires no surface occupancy for any new leases for leasable minerals within the NCDE recovery zone. Several additional standards associated with mineral development, including standards NCDE-STD-MIN-01, 02, 03, 04, 05, 06, and 07 include measures to reduce, minimize, and/or mitigate potential impacts to grizzly bears in the recovery zone and NCDE zone 1. These standards are displayed in full in Appendix 2 of the biological assessment, which is incorporated by reference (U.S Forest Service 2022). Guidelines related to the management of energy and mineral development and grizzly bears that are also in place for the NCDE recovery zone and NCDE zone 1 are also displayed in Appendix 2 of the biological assessment. In summary, these standards and guidelines provide for modification or temporary cessation of activities if needed to resolve a grizzly bear-human conflict situation; mitigate impacts associated with land, vegetation, and water disturbance; provide food storage and sanitation requirements; provide timing requirements, mitigate impacts associated with motorized access, require safety training related to living and working in grizzly bear habitat; recommend avoidance of recurring helicopter use and establishing landing zones in important grizzly bear habitat, suggest use of noise-reduction technology; recommend maintaining wildlife cover to provide habitat connectivity; mitigate impacts to grizzly bear habitat; recommend carrying bear spray; and recommend use of existing gravel pits before construction of new pits.

Activities associated with energy and minerals exploration and development have the potential to impact individual grizzly bears. Many of the impacts are associated with motorized access and are discussed above in the '*General Effects of Roads on Grizzly Bears*' and the '*Effects of Motorized Access in the Action Area*' sections above. In addition, food and garbage storage at activity sites and camps may attract grizzly bears and contribute to risks. Such effects are also discussed above (see the '*Effects of Food and Attractant Storage and Habituation*' section above). Finally, general effects associated with helicopters are discussed above in the '*General Effects of Vegetation and Fire Management*' section above.

Given the small footprint and overall low level of mineral and energy development activity in the action area (the Forest) and the application of design features and measures intended to prevent or minimize effects to grizzly bears, any grizzly bears that occur in the vicinity of activity related to mineral and energy development activities would likely have options to move to more undisturbed, available habitat. If grizzly bears are using the area in the vicinity of a proposed activity related to mineral development, we would expect some level of short-term disturbance from areas of activity. With the exception of potential adverse effects associated with motorized access or helicopter use, the remaining effects associated with energy and/or mineral development are not likely to be adverse to grizzly bears and grizzly bear habitat conditions. Any additional effects not specifically addressed here would be addressed in a site-specific consultation if the site-specific action 'may affect' grizzly bears.

Connectivity

The Forest has goals and desired conditions that will encourage management actions that do not impair and may enhance habitat connectivity and genetic exchange between recovery zones. For example: Forest-wide goal 7 states "For threatened and endangered species occurring on the Forest, including the grizzly bear, gray wolf, peregrine falcon, and bald eagle, manage to contribute to the recovery of each species to non-threatened status" and desired condition NCDE-DC-WL-02 states "Within the NCDE primary conservation area and zone 1 (including the Ninemile demographic connectivity area), grizzly bear habitat on NFS lands contributes to sustaining the recovery of the grizzly bear population in the NCDE and contributes to connectivity with neighboring grizzly bear recovery zones." The NCDE grizzly bear population has been increasing in numbers and expanding its range, and the NCDE grizzly bear conservation strategy is aimed at maintaining or increasing the population. We anticipate that under continued implementation of the Forest Plan, the NCDE population will be capable of serving as a source population for other recovery zones where the bear population is smaller or absent. Secure habitat provides an important component to habitat connectivity. While no Forest Plan standards require management of secure habitat outside the recovery zones, certain management areas do limit or restrict construction of motorized routes, as previously described. Habitat conditions that provide for the movement of grizzly bears are not expected to change substantially in a manner that would impede grizzly bear movements over the remaining life of the Forest Plan. Continued implementation of the Forest Plan is likely to continue to maintain or improve habitat connectivity and demographic connectivity on the Forest between the NCDE, CYE, and/or BE recovery zones.

Effects Summary

A Federal action is a framework programmatic action if it approves a framework for the development of future action(s) that are authorized, funded, or carried out at a later time. The Forest Plan is a framework programmatic action, i.e. it provides direction for future actions that may be authorized, funded, and/or carried out by the Forest and it does not in itself mandate or approve future implementation of activities on the Forest. In this framework programmatic consultation on the Forest Plan, we describe the potential effects of the continued implementation of the Forest Plan using the best available information and made every effort to capture the majority of anticipated effects. It is not possible to account for all potential effects that may occur as a result of future actions that occur under the Forest Plan direction. Thus, it is important to note that any effects resulting from any site-specific action subsequently authorized, funded, or carried out under the Forest Plan that are not addressed in in this biological opinion will be subject to subsequent site-specific section 7 consultation as appropriate.

In reviewing the effects of the continued implementation of the Forest Plan on grizzly bears across the action area, the overwhelming majority of Forest management actions that may have the potential to adversely impact grizzly bears include motorized access. Effects related to motorized access management will vary depending on site-specific information. Not all actions related to motorized access that may be proposed under the Forest Plan will result in adverse effects. We do not anticipate adverse effects as a result of non-motorized recreation, food and attractant storage and site development, livestock grazing, vegetation and fire management, or energy and mineral development, except for the effects that may be associated with motorized access management, including potential helicopter use, which may be adverse at times depending on the site specific information.

As anticipated in the Recovery Plan, grizzly bears are expanding their range outside of the recovery zones. Grizzly bears outside of recovery zones probably experience a higher level of adverse impacts due to land management actions than grizzly bears inside the recovery zones. However, grizzly bears are able to live in habitat in the action area outside of the recovery zones. As grizzly bear numbers increase in the action area and expand their range, it is possible that the Forest will experience an increase in conflicts involving grizzly bears and human use. Nevertheless, we conclude that the Forest Plan contains measures that minimize the potential for adverse impacts to grizzly bears from Forest management activities within the action area.

Portions of the action area have high levels of motorized routes and low amounts of secure habitat while other portions have low levels of motorized routes or no motorized routes at all and high levels of secure habitat. Permanent and temporary route construction and use, and temporary use of restricted routes may also occur on a project by project basis. Permanent routes may be used during the short-term for a project and then restricted with a barrier with the potential for future administrative use or may be used for the long-term and receive a substantive amount of use if kept in an open status. Temporary use of newly constructed routes and use of restricted routes may be short-term in duration or may occur on the landscape for several years and receive a substantive amount of use.

Forest lands within BMU 22 in the CYE recovery zone recently met the access management standards for the BMU and are expected to remain as such through the duration of the Forest Plan. Permanent route construction within the CYE recovery zone is limited by standards. Since BMU 22 has standards to meet for OMRD, TMRD, and secure core, in order to construct permanent routes in these areas, other roads would likely need to be decommissioned depending on location and other site-specific details.

Within the CYE recovery zone, Forest Plan direction allows the Forest to temporarily affect underlying core area (i.e., any core habitat that is affected by the subject road and its buffer) within a BMU once per 10-year time frame, and not to exceed 1 bear year, for the sole purpose of completing road decommissioning/stabilization activities on existing closed or barriered roads in core area habitat. Subsequent needs to re-enter individual core areas within a BMU more frequently than once per decade for the purposes of road decommissioning would be analyzed on a case-by-case basis. Also within the CYE recovery zone, temporary administrative use of restricted routes shall not exceed 60 vehicle round trips per active bear year per road, apportioned as follows: ≤18 round trips in spring (April 1 through June15); ≤23 round trips in summer (June 16 through September 15); and ≤19 round trips in fall (September 16 through November 30). While temporary effects to motorized access conditions may occur, the extent of area on the Forest that could be affected is limited due to the limitations of the Forest Plan direction in the CYE recovery zone.

With a few exceptions, current motorized access conditions within the NCDE recovery zone and NCDE zone 1 are expected to be maintained under the Forest Plan. Forest lands within the NCDE recovery zone and NCDE zone 1 would be managed for no net increase above the 2011 baseline motorized access conditions, as updated. Secure habitat within the portion of the Forest outside of the recovery zones could change under the Forest Plan, with a potential decrease in the amount of secure habitat. However, as described above, the likelihood of a substantial decrease is low. If such changes were to occur within the action area, the effects related to displacement of grizzly bears may also increase.

Within the NCDE recovery zone, Forest Plan Standard NCDE-STD-AR-03 allows for temporary increases in OMRD and TMRD for projects, not to exceed a 5 percent temporary increase in OMRD and not to exceed a 3 percent temporary increase in TMRD, both calculated over a 10-year running average. NCDE-STD-AR-03 also allows temporary effects to secure core during project activities with a limit of 2 percent temporary decrease in secure core calculated over a 10-year running average. NCDE-STD-AR-04 specifies that temporary public motorized use of restricted roads is not authorized within secure core. Temporary road construction and/or use within the NCDE recovery zone would be managed via these standards and would be expected to meet these standards. Temporary project implementation within the NCDE recovery zone is not expected to exceed 5 years (NCDE-GDL-AR-01). Further, under guideline PCA-NCDE-GDL-02, pre-project conditions (i.e., OMRD, TMRD, secure core) would generally be restored within 1 year of project completion. While the Forest may deviate from guidelines with an approved exception, it is not known at this time what exceptions may be used. Thus, the guidelines, as written, will be used for the effects analysis. If the guidelines are not met for any given site-specific action, site-specific consultation may be necessary depending on the site-specific information and effects.

Outside of the recovery zones, for the purposes of this consultation, the Forest estimated that the construction and use of permanent routes would not permanently decrease the amount of secure habitat in any given GBAU by more than 1 percent over the life of the Forest Plan and that temporary project routes and/or temporary use of restricted routes would not temporarily decrease the effectiveness of secure habitat by more than 5 percent in any given GBAU at any given period of time. Projects may span more than one GBAU and for those projects, a project would not temporarily affect secure habitat by more than 5 percent in each of the GBAUs.

We do not expect all permanent or temporary routes (including use of newly constructed routes and/or use of restricted routes) to have adverse impacts on female grizzly bears and/or their dependent offspring, or that all female grizzly bears and/or their dependent offspring would be adversely affected by these routes. Some adult females have proven that they are able to successfully reproduce and raise young in BMUs, subunits, and outside of the recovery zones that exceed research benchmarks for adverse effects to grizzly bears (Kasworm et al. 2022a, Costello and Roberts 2022). However, if under-use of key feeding and sheltering habitat by female grizzly bears and/or their dependent offspring is significant, they may fail to obtain the necessary resources to breed and successfully reproduce. The level of effects would depend on such things as grizzly bear use in the action area, location of the road, (i.e. does it affect secure habitat), length of the road, the frequency and intensity of use, and the duration the road would be on the landscape, in relation to those factors listed above for effects of roads.

The effects of displacement and under-use of habitat related to the existing motorized access conditions, limited permanent route construction and use, temporary route construction and use, and temporary use of restricted routes are tempered by local resource availability, resource condition, seasonal use, and the number of grizzly bears using an area. Currently, the number of grizzly bears using the action area varies, with use ranging from higher use in the NCDE recovery zone and NCDE zone 1 to very low or none in BMU 22 of the CYE recovery zone and portions of other areas outside of the recovery zones and NCDE zone 1. For some areas of the Forest, grizzly bears numbers are very low to none and are expected to increase slowly over time. This is particularly true for female grizzly bears and presence of female grizzly bears within some portions of the action area (Forest) is likely to increase slowly. For the GBAUs lacking female grizzly bear use, until such time that female grizzly bears begin to use these GBAUs, the existing motorized access conditions, limited permanent routes, temporary routes, and temporary use of restricted roads are not likely to result in adverse effects to grizzly bears.

As such, while ongoing adverse effects from existing low amounts of secure habitat and high route densities in some portions of the action area may result in the displacement of individual grizzly bears, the avoidance of suitable habitat, and/or the reduction of habitat to an unsuitable condition, we anticipate that these adverse effects would affect only few adult females and/or their dependent offspring over the remaining life of the Forest Plan. We conservatively include the potential for adverse effects in areas lacking female grizzly bear use due to the long time-frame that the Forest Plan will be in effect, during which some females may begin to use these GBAUs and experience some level of adverse effects from the ongoing motorized access conditions and low amounts of secure habitat and/or permanent routes, temporary routes, or temporary use of restricted routes that affect secure habitat.

Because some adult females have proven that they are able to successfully reproduce and raise young in BMUs, subunits, and areas outside of the recovery zone that have less than optimal motorized access conditions and/or low amounts of secure habitat, we do not expect that all adult females exposed to motorized routes would suffer significant effects, nor would the effects persist throughout an individual female's life span. We expect that effects would vary substantially depending upon the wariness of the individual bear, the size of and habitat quality within their home range, the number of other grizzly bears using the particular area, climate conditions, annual food resources, and the nature, intensity and duration of human activity during any particular year. All of these are factors that may affect options available to adult females if displaced. Additionally, conditions the following year may be considerably different. Thus, not all female grizzly bears and/or their dependent offspring that may use the action area during the life of the Forest Plan will experience significant effects related to motorized access management. If or when female grizzly bears begin to use the portions of the action area with very low to no grizzly bear use currently, specific areas with higher motorized route densities may lead to the under-use of suitable habitat by grizzly bears and may significantly impact some grizzly bears' ability to find food resources, breed and raise young, and find shelter. However, grizzly bears moving into these portions of the action area may be able to tolerate the existing levels of motorized route densities or may be able to entirely avoid areas with roads in some GBAUs without significant effects to breeding and/or feeding due to less competition from other grizzly bears.

The Service anticipates that over-snow vehicle use (snowmobile) that may occur under the Forest Plan may incidentally result in some very low level of adverse effects to female grizzly bears with offspring during den emergence. Over-snow vehicle use would be restricted on large proportions of denning and spring habitat on the Forest and thousands of acres of denning and spring habitat would be legally unavailable to over-snow vehicle use in the broader area where grizzly bears may occur. Where grizzly bears and over-snow vehicle use do generally overlap, there is still some spatial separation. However, the potential of over-snow vehicle use adversely impacting an individual female grizzly bear with offspring cannot be eliminated.

The best information available indicates that snowmobile impacts to grizzly bears emerging from dens was a higher concern than impacts to denning bears (Graves and Ream 2001). The Service concludes that snowmobile-generated disturbance to grizzly bears in dens during the deep of winter is not likely to rise to the level causing significant impairment of breeding or sheltering to the point of injury or death. In spring, disturbance from snowmobiles to grizzly bears in dens may cause premature den emergence. Based on naturally earlier den emergence of male bears and females without young, their independence, and their mobility, the Service does not anticipate the effects of disturbance caused by snowmobiles would be adverse to male grizzly bears or female grizzly bears without cubs.

However, late season snowmobile use may cause a female grizzly bear with cubs to prematurely leave a den in the spring or cause a recently emerged female with cubs to be prematurely displaced from her den or den site, potentially resulting in decreased fitness of the adult female bear and/or decreased fitness or abandonment of her dependent offspring. If the dependent offspring attempt to follow their mother from a den site prior to their gaining some mobility, they may suffer from decreased fitness or death.

In total, about 29 miles and approximately 205,100 acres of denning habitat are open to over-snow vehicle use during the during the den emergence period beyond March 31. About 24 miles occur within the NCDE recovery zone, NCDE zone 1, and the Ninemile DCA and 5 miles occur outside of this area. No trails for over-snow vehicle use are identified in the OSVUM for the CYE and no over-snow vehicle use trails or roads are used within the BE. Of the 205,100 acres of denning habitat that are open to cross-country over-snow vehicle use during the den emergence period, about 58,200 acres occur in the NCDE recovery zone, NCDE zone 1, and the Ninemile DCA, about 22,800 acres occur within the CYE Recovery Zone in BMU22, and about 124,100 acres occur within the areas outside the NCDE, CYE, and BE recovery zones, NCDE zone 1, and the Ninemile DCA. The portion of the BE Recovery Zone on the Forest is entirely within an area closed to over-snow vehicle use, thus no acres of over-snow vehicle use overlaps potential denning habitat. While these acres are open during the den emergence period, from a qualitative review, not all of these acres of cross-country over-snow vehicle use are available for such due to either the ruggedness of the terrain or logistical limitations (e.g., fuel). In addition, some areas may not be available to over-snow vehicle use after March 31st due to a lack of snow, particularly on the Plains/Thompson Falls Ranger District where it is largely drier and lower elevation.

Although the Forest's management of grizzly bear habitat may result in direct and indirect adverse effects on individual grizzly bears, we do not anticipate that these effects will have appreciable negative impacts on the grizzly bear populations or the listed entity as a whole. Grizzly bears have been expanding their range into areas with higher than optimal (for grizzly bears) human use levels and mortalities and conflicts in the action area (the Forest) are rare to non-existent.

Much of the action area is located outside of the recovery zones. The Recovery Plan stated that grizzly bears living within the recovery zones are crucial to recovery goals and hence to delisting. Grizzly bears inside and outside of recovery zones are listed as threatened under the Act, but only lands inside the recovery zones are managed primarily for the recovery and survival of the grizzly bear as a species. In developing the recovery zones, all areas necessary for the conservation of the grizzly bear were included.

Even though much of the action area is outside of the recovery zones, the Forest has managed and will continue to manage the lands in such a way that has allowed grizzly bears to expand. Thus, although individual female grizzly bears may be adversely affected at times over the remaining life of the Forest Plan, we anticipate that grizzly bear numbers and use will continue to increase within the action area into the future.

CUMULATIVE EFFECTS

The implementing regulations for section 7 define cumulative effects as those effects of future state, tribal, local, or private actions that are reasonably certain to occur in the action area considered in this biological opinion. Future federal actions that are unrelated to the proposed action are not considered in this section because they require separate consultation pursuant to section 7 of the Act. As this biological opinion is at a programmatic scale for the entire Forest and due to the long duration of the Forest Plan, it is not possible to capture all cumulative effects that may occur during the life of the Forest Plan. The analysis below describes any known cumulative effects and provides a qualitative description of the types of potential cumulative effects we would expect during the life of the Forest Plan. While some actions and associated effects are not *certain* to occur, it is reasonable to assume they may occur at some point over the long life of the Forest Plan and this consultation considers the cumulative effects generally.

Due to the extremely large action area for the Forest Plan (the entire Forest), the long duration of the Forest Plan, and because information for non-federal entities is often incomplete or inaccurate, the cumulative effects analysis completed by the Forest was more of a qualitative approach. Below is a summary of potential effects based on the cumulative effects analysis provided by the Forest in the biological assessment, which is incorporated by reference (U.S. Forest Service 2022). This summary includes the best available information that the Forest and Service have and may not include all potential cumulative effects as non-federal entities may undertake additional actions not disclosed here. This qualitative approach is likely to capture the types of effects we would expect to occur even though we may not have site-specific information at this time. Any future site-specific cumulative effects will be analyzed during future site-specific project consultations.

The Montana Department of Natural Resources and Conservation (DNRC) administers 5.2 million acres of school trust lands throughout the state to achieve the mission of producing long-term income for the designated trust beneficiary (such as schools). The DNRC's state forest land management plan emphasizes intensively managing for healthy and biologically diverse forests to provide a reliable and sustained income. The state forest land management plan also directs the transportation system to be planned for the minimum number of road miles. The DNRC will only build roads that are needed for current and near-term management objectives, as consistent with the other resource management standards (U.S. Forest Service 2022).

The Clearwater State Forest is located within the action area, northeast of Missoula, Montana, and is approximately 18,076 acres in size. The DNRC also manages scattered small parcels in the vicinity of the Forest (action area). These include scattered parcels in the DNRC Plains, Missoula, and Clearwater units. In 2011, the DNRC developed a habitat conservation plan

(HCP) for the scattered parcels that is designed to minimize and mitigate impacts on five terrestrial and aquatic species, including the grizzly bear. The HCP provides guidance to ensure the long-term conservation needs of HCP species during timber harvest, road construction and use, and grazing activities over a 50-year period.

The DNRC lands may regularly see activities such as maintenance and use of roads, trails, and utilities; recreational activities such as hunting, hiking, mountain biking, camping, horseback riding, driving, motorcycle and ATV riding; and gathering of firewood and miscellaneous forest products. Based on past history and the current levels of visitors to the area, the activities listed above are expected to continue to occur, at minimum, at levels similar to the past but may increase in the future to meet public demand. These activities are expected to have local effects by altering habitat used by grizzly bears and disturbing and/or displacing grizzly bears. Whether such effects are adverse or significant would be dependent on site-specific conditions.

Human activities also increase the chance of conflict with bears and thus, the chance for grizzly bear mortality. DNRC has food storage requirements for their lands, which help to minimize the potential for grizzly bear-human conflicts. As a partner in the Blackfoot Challenge, the DNRC placed bear-resistant dumpsters at state land locations where bear-attractant conflicts have been known to occur. The DNRC provides all of its cabin lessees with the brochure "Living with Bears" that explains measures that should be taken to minimize human-bear conflicts. No DNRC employees or contractors have been involved in a human-grizzly bear conflict that resulted in a management action or death of a grizzly bear.

The goal of the commitments made for grizzly bears in the 2011 HCP is to support Federal conservation efforts by providing important seasonal habitat and limitations on activities affecting bears within those habitats. While cumulative effects may occur as a result of projects on DNRC lands, the HCP applies conservation commitments across a larger geographic area within DNRC's forested trust lands than previously and increases the level of conservation based on the importance of that habitat for bears (e.g., more commitments in recovery zones); minimizes disturbance and displacement of grizzly bears from human activities; provides for seasonal habitat use and security; and designs timber sales and applies silvicultural prescriptions to maintain important habitat features, including den sites, avalanche chutes, lush riparian zones, and locations that produce high volumes of forage.

Montana Fish, Wildlife and Parks (FWP) completed a grizzly bear management plan for western Montana in 2006 (Dood et al. 2006) and a grizzly bear management plan for southwestern Montana in 2013 (Montana FWP 2013). These plans establish goals and strategies to manage and enhance grizzly bear populations and to minimize the potential for grizzly bear-human conflicts. A long-term goal is to allow the populations in western and southwestern Montana to reconnect through the intervening, currently unoccupied habitats. Montana FWP is also very active in providing public information and education about conserving grizzly bears and their habitat. This includes bear management specialists, including one stationed nearby in Missoula, who provide information and assistance to landowners on appropriate ways to secure food and bear attractants and respond to reports of conflicts with bears. These specialist positions have a proven track record of success in informing the public, reducing the availability of attractants to bears on private and public lands, and resulting in a reduction of human-caused grizzly bear mortalities, thus benefiting grizzly bears overall.

Montana FWP Fish Creek and Blackfoot-Clearwater Wildlife Management Areas (WMAs) are adjacent to the action area. The primary management goal of both WMAs is to provide winter range for elk and compatible recreational opportunities for the public. For example, the Blackfoot-Clearwater Management Area offers antler shed gathering opportunity in the spring which typically draws many visitors into an area that may not experience much other human presence. Pack in/pack out is required for food and garbage at both WMAs, minimizing the potential for human-grizzly bear conflicts. While these efforts have helped to decrease human-grizzly bear conflicts and mortalities of grizzly bears, the potential for grizzly bear mortality (via removal) associated with food storage and habituation still exists on non-federal land.

Montana FWP regulates hunting for black bears and other wildlife species. Hunting of grizzly bears has not been allowed in Montana since 1991. A potential for grizzly bear mortality by hunters does exist as a result of mistaken bear identification or in self-defense, especially in proximity to the carcasses of harvested animals. FWP provides a variety of public information and education programs, including a mandatory black bear hunter testing and certification program, to help educate hunters in distinguishing the two species. Black bear hunting seasons have been shortened in recent years, reducing the potential for mistaken identity. While these efforts have helped to decrease legal and illegal shooting mortalities of grizzly bears, the potential for grizzly bear mortality associated with hunting still exists.

Private lands, including large blocks owned and managed by The Nature Conservancy (TNC), occur within and adjacent to the action area. The human population within northwest Montana, including the action area, has grown at a relatively high rate during the past few decades and growth is expected to continue. Such growth is expected to result in an increase of residential development of private lands within the action area which can result in habitat loss, habitat fragmentation, and increases in human-grizzly bear conflicts. Food and attractant storage issues on private land can create grizzly bear-human conflicts by providing attractants to grizzly bears. Once grizzly bears become habituated and/or associated with a grizzly bear-human conflict, they may be removed. Human population growth could also result in additional grizzly bear attractants and further increase the potential for grizzly bear-human conflicts. As more people use private land and adjoining federal land for homes, recreation or business, the challenge to accommodate those uses in ways that continue to protect the grizzly bear population increases. Private lands continue to account for a disproportionate number of conflicts and grizzly bear mortalities in Montana. These impacts are likely to intensify, although appropriate residential planning, outreach to landowners about how to avoid conflicts, tools such as bear-resistant containers and electric fencing, and assistance in resolving conflicts can help prevent or reduce these impacts.

In addition to conflicts, activities on private land can also be expected to have local effects by altering habitat used by grizzly bears and/or disturbing or displacing grizzly bears. Activities that are currently occurring and are expected to continue into the foreseeable future on non-federal lands include but are not limited to maintenance and use of roads, trails, and utilities; recreational activities such as hunting, hiking, mountain biking, camping, horseback riding, driving, motorcycle and ATV riding; livestock grazing, ranching, and farming; mineral development; and timber harvest, fuels management such as thinning and/or burning, fire management, and gathering of firewood and miscellaneous forest products. Whether such effects are adverse or significant would be dependent on site-specific conditions, with effects ranging from some level of insignificant disturbance to more significant effects such as displacement. Any motorized access associated with these activities may add to the ongoing significant effects already occurring associated with high motorized access conditions and low amounts of secure habitat. However, not all effects would be significant due to the higher amounts of human activity already occurring in some areas of non-federal land. Effects to grizzly bear habitat conditions such as forage, cover, and denning are expected to be insignificant and similar to the effects described for the proposed action above.

As grizzly bears are managed for recovery within the recovery zones, all land ownerships are considered when calculating motorized access metrics. Any cumulative motorized access effects that may occur as a result of activities on non-Forest lands would be captured in the metrics measured for the subunits (NCDE recovery zone) and/or BMU (CYE recovery zone). Management of grizzly bears outside of the recovery zones is different than within the recovery zones. The Forest often lacks inventory information on non-Forest lands outside of the recovery zones and the best available information regarding motorized access on non-Forest lands outside of the recovery zone is unable to capture all effects of motorized access resulting from non-Forest actions. As such, a 500 meter buffer was placed around Forest land in those areas where Forest land is adjacent to non-Forest land ownerships. Buffering Forest land 500 meters from non-Forest Service land ownerships is a conservative approach when considering effects to grizzly bears and will capture any unknown or undisclosed cumulative effects to grizzly bears that may result from non-Forest actions on non-Forest land that occur adjacent to Forest lands. For example, actions on adjacent non-Forest land could affect secure habitat on adjacent Forest lands, thus cumulatively affecting grizzly bears that use Forest land because areas within 500 meters of motorized access are not considered secure habitat. Accordingly, because it is very often unknown, Forest lands within 500 meters of lands not administered by the Forest may not provide secure habitat due to the potential cumulative effects associated with motorized access on adjacent non-federal lands. While it is possible that Forest land within 500 meters of non-Forest land may provide secure habitat, information as to activity on non-Forest land is often unknown or not disclosed. In addition, the Forest lacks management authority over non-Forest lands. As such, any secure habitat on Forest lands located adjacent to non-Forest land could be cumulatively affected at any time without the Forest’s knowledge or authority, as it is not required. Therefore, to be conservative when analyzing cumulative effects to grizzly bears, in order to not miss any potential cumulative effects, Forest land within 500 meters of non-Forest land is buffered out of the secure habitat metric for the Forest. Due to the unknown or lack of information on non-Forest land we are unable to measure secure habitat on these lands. We are not assuming that non-Forest lands are not secure, however, we do not have enough accurate information to determine whether or not secure habitat occurs. Because of the long life of the Forest Plan, it is not possible to know everything that may occur on non-Forest land, nor is it required that non-Forest ownership inform the Forest or the Service of everything that may occur. Due to this potential lack of knowledge and because the Forest has no management authority on non-Forest lands, incorporating this buffer is a conservative approach and accounts for any cumulative effects to grizzly bears from actions that may occur on non-Forest lands without the Forest’s knowledge. In other words, any potential unknown cumulative effects have already been incorporated into this analysis ahead of time. For example, if motorized access were to increase on non-Forest land adjacent to Forest land, cumulatively affecting grizzly bears in the action area associated with disturbance and/or displacement, the effects of such are already considered into the metrics of secure habitat that are measured for Forest lands. Accordingly, we would not miss any effects to secure habitat on Forest lands over time, giving the benefit of the doubt to the species (U.S. Fish and Wildlife Service 1998). Using this conservative approach does not result in significant effects to the grizzly bear populations within the action area.

As described in the baseline section above, any private entity's non-compliance with the Forest's access management is an illegal activity. Even with ongoing efforts by the Forest to deter illegal motorized access, some individuals may continue to break the law and illegally access parts of the Forest via motorized vehicles. Any such illegal motorized access is not considered a Forest (federal) action. While it may be reasonable to assume that some future illegal use of the Forest via motorized access in areas not authorized for such use may occur within the action area, it is not reasonably certain to occur in any specific given area. These, and any other illegal activities are not the result of a federal action and therefore not analyzed under effects of the action, but their influence is considered for potential cumulative effects (due to the entity's illegal actions being non-federal). We have considered the cumulative effects of such illegal motorized access on grizzly bears to the best of our ability despite the uncertainty associated with illegal motorized access.

While illegal use is not considered part of the federal action, the effects of many types of illegal actions are captured in the baseline and effects section above in that if a road is drivable, independent of whether it is legally closed (via MVUM, sign, gate), it is not considered as providing secure habitat. Therefore, in most instances of illegal motorized access, effects to secure habitat would not occur because the area being accessed is not providing secure habitat. How secure habitat is determined is described in detail in the baseline and effects sections above and displays a conservative approach to the analysis so as to not miss any potential effects to grizzly bears. Illegal motorized access may also occur in areas that are not considered drivable, potentially affecting secure habitat. No specific amount or location of illegal motorized access is reasonably certain to occur (as it is not supposed to occur in the first place), however if it does occur, cumulative effects to grizzly bears may occur as a result. The information as to the length, duration, amount of use, type of use, and location, among other conditions, is and will continue to be unknown until such time that illegal use is found to be occurring. The probability of long-term illegal motorized access and probability of illegal motorized access coinciding with the presence of grizzly bears is anticipated to be low but is unknown. As such, the potential consequences to grizzly bears are uncertain. Illegal motorized access is expected to be spatially disparate and temporary and is not likely to collectively cause an adverse effect because most users follow travel regulations and when illegal use is observed or when user-created roads become apparent the Forest corrects the situation as soon as they are able.

Despite the recent growth of the human population and the potential non-federal effects that have been occurring in the past and present, the grizzly bear population in the NCDE is increasing and expanding distribution and has more than doubled since listing (U.S. Fish and Wildlife Service 2022, Costello et al. 2016), while the population in the CYE is experiencing a positive population growth rates of 1.9 percent (Kasworm et al. 2022a). In addition, large federal land ownership (including Forest Service) and large blocks of wilderness within which human access is restricted by regulation and topography serve to reduce the impacts of non-federal actions associated with larger residential human populations on grizzly bears. While federal land management cannot entirely compensate for cumulative impacts on non-federal land, management on Forest Service lands as well as management under the Forest Plan would continue to provide habitat for grizzly bears. Cumulative effects are not likely to result in significant effects to the NCDE and CYE grizzly bear populations within the action area or the grizzly bear population as a whole.

CONCLUSION

Implementing regulations for section 7 (50 C.F.R. § 402) define "jeopardize the continued existence of" as to "engage in an action that reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of a listed species in the wild by reducing the reproduction, numbers, or distribution of that species." The Service's section 7 handbook explains that adverse effects on individuals of a species generally do not result in jeopardy determinations unless those effects, when added to the environmental baseline and cumulative effects, are likely to result in an appreciable reduction of the likelihood of both survival and recovery of a listed species in the wild by reducing the reproducing, numbers, or distribution of that species. Should the federal action result in a jeopardy and/or adverse modification conclusion, the Service may propose reasonable and prudent alternatives that the federal agency can take to avoid violation of section 7(a)(2).

We reviewed and considered: (1) the current status of grizzly bears, which evaluates the range-wide status of the listed entity of grizzly bears; (2) the environmental baseline for the action area, which evaluates the status of grizzly bears in the action area and the factors affecting the species environment within the action area; (3) the effects of the action, which includes all consequences to grizzly bears that are caused by the proposed action; and (4) the cumulative effects, which evaluates the effects of future non-federal activities on grizzly bears that are reasonably certain to occur in the action area. The effects of the action and cumulative effects are added to the environmental baseline and in light of the status of the grizzly bear, the Service formulates an opinion as to whether the action is likely to jeopardize the continued existence of grizzly bears by resulting in an appreciable reduction in the likelihood of both the survival and recovery of the listed entity of grizzly bears in the Coterminous United States.

After reviewing these components, it is the Service's biological opinion that the effects of the continued implementation of the Forest Plan on grizzly bears are not likely to jeopardize the continued existence of the listed entity of grizzly bear. No critical habitat has been designated for this species, therefore, none will be affected. Our conclusion is based on, but not limited to, the information presented in the biological assessment (U.S. Forest Service 2022), additional information received during this consultation process, information in our files, and informal discussions between the Service and the Forest.

Actions conducted under the Forest Plan may occasionally result in adverse effects to individual female grizzly bears and/or dependent offspring over the remaining life of the Forest Plan, particularly as a consequence of the potential disturbance and/or displacement related to motorized access management. Based on the best available scientific information reviewed in this consultation, such adverse effects will not negatively impact the recovery of the NCDE or CYE grizzly bear populations, nor the listed entity of grizzly bears as a whole. Further, we expect the Forest Plan direction will result in conditions that support continued grizzly bear use of the action area, especially in the NCDE recovery zone, NCDE zone 1, Ninemile DCA, and CYE recovery zone, as well as use of areas outside of these. Portions of the Forest further removed from the aforementioned areas are expected to continue to be used for dispersal or exploratory movements and potentially some home range establishment at some point in the future, albeit at densities lower than those in the recovery zones. Thus, it is our opinion that the continued implementation of the Forest Plan would not appreciably reduce the likelihood of both the survival and recovery of the listed entity of grizzly bears as a whole. Below we summarize key factors of our rationale for our no-jeopardy conclusion as detailed and analyzed in this biological opinion. These key factors include, but are not limited to, the following:

Factors related to the Forest Plan:

- In 1993, the Recovery Plan articulated the conservation needs for the recovery of grizzly bears. The Recovery Plan stated that recovery zones include areas large enough and of sufficient habitat quality to support recovered grizzly bear populations, and that although grizzly bears are expected to reside in areas outside the recovery zones, only habitat within the recovery zone is needed for management primarily for grizzly bears. The Forest Plan applies to areas both within and outside of the recovery zone.

- We do not anticipate adverse effects as a result of food and attractant storage and site development, livestock grazing, vegetation management and fire management, or energy and mineral development, except for the potential effects that may be associated with motorized access management or helicopter use.

- Effects related to winter and non-winter motorized access management, including helicopter use, will vary depending on site-specific information. Not all actions related to motorized access that may be allowed and/or proposed under the Forest Plan will result in adverse effects.

- Any effects associated with helicopter use will be analyzed during future site-specific consultations, as necessary.

- In general, the existing (baseline) motorized access conditions, potential permanent and/or temporary route construction and use, and/or temporary use of restricted routes may result in some level of adverse effects to individual female grizzly bears and/or their dependent offspring within the action area, where they may be present. We anticipate these effects to be non-lethal and do not anticipate adverse effects to male or transient grizzly bears that may use the action area.

- Within the NCDE recovery zone, the Monture, North Scapegoat, South Scapegoat, and Rattlesnake Subunits all encompass significant amounts of designated Wilderness and are and will remain better than the research benchmarks of 19/19/68, even if the temporary effects to OMRD, TMRD and secure core occur under projects having temporary effects associated with NCDE-STD-AR-03. These subunits are likely to continue to support the survival and reproduction of female grizzly bears, with no adverse effects anticipated associated with the temporary changes allowed under NCDE-STD-AR-03.

- Within the NCDE recovery zone, the Mor-Dun subunit currently meets the research benchmark values for OMRD, TMRD, and secure core. With temporary effects associated with NCDE-STD-AR-03, TMRD and secure core would remain better than the research benchmarks; however, OMRD may temporarily increase above the benchmark potentially resulting in some level of short-term adverse effects associated with displacement of grizzly bears in this subunit, which may result in the under-use of suitable habitat by individual female grizzly bears and/or their dependent offspring, which may disrupt normal breeding (or more specifically, cub rearing) or feeding patterns. The amount of disturbance or displacement would depend on site-specific actions and conditions.

- Within the NCDE recovery zone, the Mission and Swan subunits are currently worse than the research benchmarks for OMRD, TMRD, and secure core. Since some level of ongoing adverse effects are likely already occurring as a result of the existing, baseline motorized access conditions in these subunits, use of the temporary increases allowed under NCDE-STD-AR-03 could temporarily further degrade these conditions and may result in additional adverse effects to grizzly bears that may be using the action area. The short-term, temporary increases allowed under NCDE-STD-AR-03 may result in additional under-use of suitable habitat by individual female grizzly bears and/or their dependent offspring, which may disrupt normal breeding (or more specifically, cub rearing) or feeding patterns. The amount of displacement would vary, depending on site-specific conditions (i.e. whether the area is providing secure habitat or is adjacent to other roads) and actions (i.e. duration of use and/or length of road segment).

- Within the CYE recovery zone, temporary access to secure core area may occur within BMU 22 once per 10-year time-frame, not to exceed 1 bear year for the sole purpose of completing road decommissioning/stabilization activities. In addition, temporary administrative use is allowed under certain conditions. As BMU 22 may already be experiencing ongoing adverse effects associated with the existing motorized access conditions (if and when female grizzly bears are present), additional temporary, short-term adverse effects may occur on a project by project basis. Given the improving status of the CYE, it is unlikely this would result in measurable negative effects to the overall CYE population.

- Because some adult females have proven that they are able to successfully reproduce and raise young in BMUs, subunits, and areas outside of the recovery zone that have less than optimal motorized access conditions and/or low amounts of secure habitat, we do not expect that all adult females exposed to motorized routes would suffer significant effects, nor would the effects persist throughout an individual female's life span. While motorized routes in some portions of the action area may result in displacement of some female grizzly bears and/or their dependent offspring from key habitat at some time over the life of the Forest Plan, some grizzly bears are able to persist in areas with higher levels of human pressure, as documented by verified reports of females with offspring (indicating home range use and successful reproduction) in areas of high motorized access that exceed research benchmarks, including areas outside of the recovery zones. In other words, we do not expect the existing, baseline motorized access conditions in all portions of the action area to have ongoing adverse impacts on female grizzly bears and/or their dependent offspring. Nor do we expect all permanent and/or temporary routes or temporary use of restricted routes to have adverse effects on female grizzly bears and/or their dependent offspring. The level of effects would depend on such things as grizzly bear use in the action area, location and length of the road(s), the frequency and intensity of use of the road(s), and the duration that the road(s) would be on the landscape. Not all females would experience the same effects, thus, some may not be adversely affected as a result of motorized access management under the Forest Plan.

- As described above, while adverse effects from high motorized route densities and low amounts of secure habitat in some portions of the action area may result in the displacement of individual female grizzly bears and/or their dependent offspring, the avoidance of suitable habitat, and/or the reduction of habitat to an unsuitable condition, we anticipate that the adverse effects would affect only a few adult females and/or their dependent offspring over the remaining life of the Forest Plan.

- Motorized access conditions and management will not preclude grizzly bears from using the action area, nor will it form a barrier to dispersal and movement within or across the action area or between the action area and other parts of the grizzly bear ecosystems.

- Late-season over-snow vehicle use, past March 31, is allowed in portions of the action area. Where grizzly bear use and over-snow vehicle use do generally overlap, some level of spatial separation does exist, however, the potential of over-snow vehicle use adversely impacting an individual female grizzly bear with offspring cannot be eliminated during the grizzly bear den emergence period.

- In total, about 29 miles of over-snow vehicle routes and approximately 205,100 acres overlap grizzly bear denning habitat and are open to over-snow vehicle use during the during the den emergence period beyond March 31. About 24 miles occur within the NCDE recovery zone, NCDE zone 1, and the Ninemile DCA and 5 miles occur outside of this area. No trails for over-snow vehicle use are identified in the OSVUM for the CYE and no over-snow vehicle trails or roads are used within the BE. Of the 205,100 acres of denning habitat that are open to cross-country over-snow vehicle use during the den emergence period, about 58,200 acres occur in the NCDE recovery zone, NCDE zone 1, and the Ninemile DCA, about 22,800 acres occur within the CYE Recovery Zone in BMU22, and about 124,100 acres occur within the areas outside the NCDE, CYE, and BE recovery zones, NCDE zone 1, and the Ninemile DCA. The portion of the BE Recovery Zone on the Forest is entirely within an area closed to over-snow vehicle use, thus no acres of over-snow vehicle use overlaps potential denning habitat. Currently, grizzly bears are only known to den in the NCDE. Thus, some of the areas mentioned above do not currently have denning grizzly bears but due to the long-term nature of the Forest Plan such use could occur in the future.

- While many of these acres open to over-snow vehicle use during the den emergence period, from a qualitative review, not all of these acres of cross-country over-snow vehicle use are available for such use due to either the ruggedness of the terrain or logistical limitations (e.g., fuel). In addition, some areas may not be available to over-snow vehicle use after March 31st due to a lack of snow, particularly on the Plains/Thompson Falls Ranger District where it is largely drier and lower elevation.

- While some level of non-lethal adverse effects to individual grizzly bears may occur related to actions carried out under the Forest Plan, they are not expected to have a negative effect on the survival and recovery of the listed entity of grizzly bears.

- The Forest has managed and will continue to manage their lands in such a way that has allowed grizzly bears to expand in numbers and distribution. Thus, although individual grizzly bears may be adversely affected at times over the remaining life of the Forest Plan, we anticipate that grizzly bears use will continue to increase within the action area into the future.

Factors related to the NCDE grizzly bear population:

- Kendall et al. (2009) produced a final total NCDE grizzly bear population estimate of 765 grizzly bears for 2004 (Ibid.), more than double the recovery plan estimate for that year.

- Kendall et al. (2009) also indicated that in 2004 (http://www.nrmsc.usgs.gov):

    1. Female grizzly bears were present in all 23 BMUs.
    2. The number and distribution of female grizzly bears indicated good reproductive potential.
    3. The occupied range of NCDE grizzly bears now extends 2.6 million acres beyond the 1993 recovery zone.
    4. The genetic health of NCDE grizzly bears is good, with diversity approaching levels seen in undisturbed populations in Canada and Alaska.
    5. The genetic structure of the NCDE population suggests that population growth occurred between 1976 and 2004.
    6. Human development is just beginning to inhibit interbreeding between bears living north and south of the U.S. Highway 2 corridor, west of the Continental Divide.

- Montana Fish, Wildlife and Parks research conducted between 2004 and 2011 indicated an increasing trend in numbers of NCDE grizzly bears (Mace and Roberts 2012). Costello et al. (2016) calculated a growth rate of 2.3 percent for grizzly bears in the NCDE. For the 6-year period of 2016 through 2021, the estimated annual survival rate for independent females within the demographic monitoring area was 93 percent (Costello and Roberts 2022).

- Assuming previously observed vital rates from Costello et al. 2016, the projected population size of grizzly bears in the NCDE for the management period 2019–2023, is 1,068 for 2019 increasing to 1,092 in 2020, 1,114 in 2021, 1,138 in 2022, and 1,163 in 2023 (Costello and Roberts 2022).

- From 2016 through 2021, the average annual number of total reported and unreported (TRU) mortalities for independent females within the DMA was 15, below the maximum threshold of 25 and the average annual number of TRU for independent males was 23, falling below the maximum threshold of 30 (Costello and Roberts 2022).

- The NCDE grizzly bear population currently meets the demographic recovery criteria related to the number of BMUs occupied by family groups and the sustainable human-caused mortality levels for both total and female grizzly bears (U.S. Fish and Wildlife Service 2022b, Costello and Roberts 2022).

- The NCDE grizzly bear population is increasing, which explains the expansion of its range into areas outside the recovery zone. Female grizzly bears with young have been observed outside of the recovery zone, indicating that a number of females are able to find the resources needed to establish home ranges and survive and reproduce outside the recovery zone, despite the lack of specific habitat protections.

- Using verified grizzly bear locations, Costello et al. (2016) estimated that grizzly bears occupied an area of roughly 13.6 million acres, more than double the size of the recovery zone. The distribution of the NCDE grizzly bear population is estimated biannually. The estimated occupied range of the NCDE grizzly bear population during 2011 through 2020 was 67,652 square kilometers (16,717,173 acres), representing an increase of about 6 percent from the 2009-2018 estimate or an annual increase of about 3 percent (Costello and Roberts 2021).

- In part due to grizzly bear expansion into areas that had previously been unoccupied, the number of grizzly bear-human conflicts has generally increased. However, much of the recent grizzly bear mortality is primarily associated with conflicts arising from attractants on private lands rather than conflicts on public lands.

- Food Storage Orders are in effect throughout the NCDE recovery zone and several areas outside of the recovery zone on National Forest lands and Glacier National Park. These agencies have been successful at managing attractants on federal lands under the food storage orders.

- Montana Fish, Wildlife and Parks' bear specialist program is expected to continue to work with the public to reduce risks to grizzly bears on private and public lands. In cooperation with other agencies, this program has made notable strides toward an informed public and reduced the availability of attractants to grizzly bears on private and public lands.

- The NCDE encompasses 5.7 million acres, of which 1.7 million acres is wilderness and 962,000 acres is Glacier National Park, which contains highest quality grizzly bear habitat. Considering these lands only, nearly half of the NCDE is essentially roadless or free of motorized use (47 percent). Further, the Flathead National Forest, which makes up 40 percent of the NCDE recovery zone, currently contributes approximately 1.5 million acres of additional grizzly bear secure core area. The four other National Forests in the NCDE also provide additional substantial secure core areas.

- The majority of the NCDE is managed by the National Forest and National Park Service, whose access management outside of wilderness areas or otherwise protected area is directly based on IGBC Guidelines. The current access management conditions on Federal lands across the ecosystem have contributed towards the recovery of grizzly bears in the NCDE.

Factors related to the CYE Recovery Zone:

- The CYE is a smaller ecosystem that is still slowly recovering from being close to historical extirpation, particularly in the Cabinets portion of the ecosystem. The CYE has low resiliency due to low numbers of grizzly bears, low fecundity, moderate inter-ecosystem connectivity, low genetic diversity, and moderate amounts of large, intact blocks of land.

- Based on known fates of radio-collared individuals and reproductive outputs, it is estimated that the population of grizzly bears in the CYE is currently increasing, with an annual growth rate of 1.9 percent between 1983 and 2021 (Kasworm et al. 2022a). This is a significant improvement from earlier trend calculations that indicated the population was declining, and now represents 15 years of an improving trend since 2006 (Kasworm et al. 2022a).

- A CYE population estimate derived from mark and recapture efforts estimated the U.S. population in 2012 at 48 to 50 individuals (Kendall et al. 2016). Using all methods (capture, collared bears, DNA, photos, credible observations), Kasworm et al. (2022a) detected a minimum of 45 individual grizzly bears alive in the CYE at some point during 2020, 18 grizzly bears in the Cabinets and 29 in the Yaak. Some of these detected individuals have died.

- A reasonable population estimate for the CYE, using the mid-point of 49 grizzly bears from Kendall et al. (2016) and rate of increase of 1.9 percent, is about 60 to 65 grizzly bears (Ibid.).

- Augmentation of grizzly bears from the NCDE into the CYE has been ongoing. Recent data suggests that the number of grizzly bears in the Cabinet portion of the CYE has increased (Kendall et al. 2016; Kasworm et al. 2022a), almost exclusively through the augmentation program and reproduction from those individuals (Kasworm et al. 2022a).

- While the current population estimate of about 60 to 65 grizzly bears in the CYE remains below the goal of a minimum population of 100 bears (U.S. Fish and Wildlife Service 1993), the population trend for the CYE has changed from declining to slightly increasing and successful augmentation and natural immigration has led to improved genetic diversity (Kasworm et al. 2022a).

- The probability that the CYE population is stable or increasing is 70 percent (Kasworm et al. 2022a). Improved adult and subadult female survival rates resulted in an improving population trend estimate since 2006 (Ibid.). We expect that over time, if the population trend and adult female survival rates remain high and continue to increase in the CYE and existing conservation measures are maintained, the population in this ecosystem will likely expand. Expanding population size will result in increased resiliency of the population to stressors, ensuring greater viability of the CYE population. Resiliency is expected to increase in the next 30 to 45-year timeframe (U.S. Fish and Wildlife Service 2022a).

- Maintaining or increasing current levels of genetic diversity in the CYE would help ensure genetic concerns do not become a threat in the future. Recent data indicate increasing movements by males and females and subsequent reproduction, resulting in limited, but increasing population connectivity, particularly in the Yaak portion of the CYE." (U.S. Fish and Wildlife Service 2022a).

- The recovery plan established a goal of zero human-caused mortality for the CYE until the minimum population reached approximately 100 bears. However, it also stated "In reality, this goal may not be realized because human bear conflicts are likely to occur at some level within the ecosystem." Therefore, even if the goal of zero mortality is not met, it is important to evaluate the recovery criteria (applicable to the recovery zone) to determine if progress towards recovery is occurring. Refer to the recovery plan for explicit recovery criteria (U.S. Fish and Wildlife Service 1993).

- For the period 2016 through 2021, demographic recovery criteria associated with unduplicated females and occupied BMUs have not been met in the CYE, but progress is being made towards meeting the criteria (Kasworm et al. 2022a). Occupancy and reproduction are slow processes that rely on multiple factors. Managing mortality is a key factor in assuring opportunities for female grizzly bears to expand their range and reproduce.

- For the period 2016 through 2021, demographic recovery criteria associated with total known, human-caused mortality and known, female human-caused mortality have been met. Using the minimum estimated population size (41), the total mortality limit is 1.6 bears per year and the female mortality limit is 0.5 female bears per year. The average annual human-caused mortality for 2016 through 2021 was 1 bear per year and 0.5 females per year. The mortality levels for total bears as well as female bears were less than or equal to the calculated mortality limits for 2016 through 2021 (Ibid.).

- Genetic connectivity between the CYE and other grizzly bear populations is important. Recent data indicate increasing movements by males and females and subsequent reproduction, resulting in limited, but increasing population connectivity, particularly in the Yaak portion of the CYE." (U.S. Fish and Wildlife Service 2022a)

- The Cabinet-Yaak recovery zone encompasses approximately 1.6 million acres (6,705 square kilometers), of which 44 percent are protected as designated wilderness or inventoried roadless areas. Blocks of contiguous habitat extend into Canada.

- Nearly 98 percent of the recovery zone is federally-managed land, including portions of the Kootenai, Idaho Panhandle, and Lolo National Forests, whose access management outside of wilderness areas or otherwise protected areas is directly based on IGBC Guidelines with the intent to improve conditions for grizzly bears.

- The Kootenai National Forest's access management standards that provide for large, intact blocks of land, are an example of the many current conservation measures in place in the CYE that was included in the future scenario analysis in the SSA (U.S. Fish and Wildlife Service 2022a).

- The Kootenai River bisects the CYE approximately in half, with the Cabinet Mountains to the south and the Yaak River drainage to the north, and may have limited movement between the two (Kasworm et al. 2022a). While movement was believed to be minimal, several movements into the Cabinet Mountains from the Yaak River and Selkirks have occurred since 2012 (Ibid.). Due to the short distance between these two populations, full connectivity remains a management goal and evidence to date suggests progress towards that goal.

- The Tobacco BORZ and Salish DCA provide an opportunity for connectivity between the CYE and NCDE. Female grizzly bears with young have been observed in the Tobacco BORZ, indicating that some of females are able to find the resources needed to establish home ranges and survive and reproduce outside the recovery zone.

- A Food Storage Order is in effect throughout the CYE recovery zone and BORZ. Managing attractants on federal lands under the current food storage order has been successful.

- Montana Fish, Wildlife and Parks' bear specialist program and the Bear Ranger program in the CYE are expected to continue to work with the public to reduce risks to grizzly bears on private and public lands. In cooperation with other agencies, these programs have made notable strides toward an informed public and reduced the availability of attractants to grizzly bears on private and public lands.

The conclusion is focused on the NCDE and CYE because the remainder of the action area is within the BE where no known grizzly bear population occurs within or outside of the defined BE recovery zone. Because no female grizzly bears have been documented in the BE recovery zone, the BE is currently considered unoccupied as per the definition of a population of grizzly bears (two or more reproductive females or one female reproducing during two separate years) (U.S. Fish and Wildlife Service 2022a). While no individual grizzly bears have been documented within the BE recovery zone, solitary grizzly bears have been documented immediately surrounding it (Ibid.). Since the entire portion of the BE recovery zone that occurs on the Forest is within the Selway-Bitterroot Wilderness no adverse effects are expected associated with any of the activities conducted under the Forest Plan. No motorized routes occur within this portion of the BE recovery zone and it will continue to function as secure habitat for the foreseeable future.

Recovery zones were established to identify areas necessary for the recovery of a species and are defined as the area in each grizzly bear ecosystem within which the population and habitat criteria for recovery are measured. Recovery zones are areas adequate for managing and promoting the recovery and survival of grizzly bear populations (U.S. Fish and Wildlife Service 1993). Areas within the recovery zones are managed to provide and conserve grizzly bear habitat. The recovery zones contain large portions of wilderness and in some cases national park lands, which are protected from the influence of many types of human uses occurring on lands elsewhere. Multiple use lands are managed with grizzly bear recovery as a primary factor. As anticipated in the Recovery Plan, grizzly bear populations have responded to these conditions; the recovery plan strategy has been successful and has resulted in growth of the grizzly bear populations. Based on the best available information, grizzly bears are slightly increasing, with expanding distribution and low mortality rates in some ecosystems (CYE, SE) and are robust, have stabilized, and have reached or are nearing recovery in other recovery zones (YGBE, NCDE). In addition, the grizzly bears have been expanding and continue to expand their existing range outside of the recovery zones, as evidenced by the verified records of grizzly bears in many portions of the action area including some recently verified occurrences in the BE. Such expansion will increase opportunities for expanding population size and increased genetic connectivity between the ecosystems.

Grizzly bears outside the recovery zones probably experience a higher level of adverse impacts due to human development and management of land than do grizzly bears inside. As anticipated in the recovery plan, we expect more grizzly bears will inhabit the Forest in the future. We expect grizzly bears will occur outside of the recovery zones at lower densities than within the recovery zones as a result of suboptimal habitat conditions, which include higher motorized route densities, fewer areas of secure habitat, and more human presence. In our recent 5-Year Review, the Service states that the "effects of stressors in the areas between ecosystems would only impact individual bears and could not have any impacts at the level of a population or the entire entity" (U.S. Fish and Wildlife Service 2021).

Despite the growth of the human population and the increase in the number of grizzly bear-human conflicts and grizzly bear mortalities, the preponderance of evidence suggests an increasing number of grizzly bears in the NCDE recovery zone: a total population estimate of 1,114 grizzly bears for 2021 (U.S. Fish and Wildlife Service 2022), an estimated positive population trend of 2.3 percent annually (U.S. Fish and Wildlife Service 2022, Costello et al. 2016), and the current distribution of grizzly bears (U.S. Fish and Wildlife Service 2022, Costello and Roberts 2022, Costello et al. 2016.). Based on the best available information, the Service concludes that the status of the NCDE grizzly bear population is robust and is at or near recovery. In addition, the population trend for the CYE has changed from declining to slightly increasing and successful augmentation and natural immigration has led to improved genetic diversity (Kasworm et al. 2022a). It is estimated that the population of grizzly bears in the CYE is currently increasing, with an annual growth rate of 1.9 percent between 1983 and 2020 (Ibid.). Improved adult and subadult female survival rates have resulted in a significant improvement from earlier trend calculations that indicated the population was declining, and now represents an improving population trend estimate since 2006 (Ibid.). The probability that the CYE population is stable or increasing is 70 percent (Ibid.). We expect that over time, if the population trend and adult female survival rates remain high and continue to increase in the CYE and existing conservation measures are maintained, the population in this ecosystem will likely expand, increasing the resiliency of the population to stressors and ensuring greater viability of the CYE population. Resiliency is expected to increase in the next 30 to 45-year timeframe (U.S. Fish and Wildlife Service 2022a).

While the Forest Plan direction may result in some low level of non-lethal adverse effects to some of the individual female grizzly bears and/or their dependent offspring using the action area, considering the large size of the CYE and NCDE recovery zones, favorable land management within the recovery zones, the robust status of the NCDE grizzly bear population, the increasing population of the CYE, and the improved survival of grizzly bears in the CYE, adverse effects on grizzly bears as a result of implementing the Forest Plan would not have negative effects on the status of the NCDE and CYE grizzly bear populations. The management of grizzly bears within the recovery zones favors the needs of grizzly bears; these results signal successful federal land management related to grizzly bear recovery under the strategy detailed in the 1993 Recovery Plan. Therefore, we conclude that the continued implementation of the Forest Plan is not likely to reduce the numbers, distribution, or reproduction of grizzly bears in the action area and consequently in the listed lower 48 states listed entity.

We do not expect any effects to individual grizzly bears that do not have all or a portion of a home range within the action area (the Forest). We do not expect the Forest Plan to have any negative effects to individual grizzly bears or to grizzly bear populations outside of the NCDE, CYE, or BE. In other words, we do not expect the Forest Plan to negatively affect grizzly bears within or connectivity with the surrounding grizzly bear ecosystems (Yellowstone) nor the ecosystems further away (North Cascades, Selkirks). Because the Forest Plan would not reduce the reproduction, numbers, or distribution of grizzly bears throughout the NCDE, CYE, and BE, the Forest Plan would not have negative impacts at the level of the entire listed entity (the lower 48 states). Thus, we conclude that the Forest Plan is not likely to reduce the numbers, distribution, or reproduction of grizzly bears across their listed range. When considering this, along with the status of the overall grizzly bear population in the lower 48 states, we conclude that the level of adverse effects is not reasonably expected to reduce appreciably the likelihood of both the survival and recovery of the listed entity of grizzly bears as a whole. Accordingly, it is the Service's biological opinion that the effects of the Forest Plan on grizzly bears are not likely to jeopardize the continued existence of the listed entity of grizzly bears.

INCIDENTAL TAKE STATEMENT

Section 9 of the Act, and Federal regulations pursuant to section 4(d) of the Act, prohibit the take of endangered and threatened species, respectively without special exemption. *Take* is defined as harass, harm, pursue, hunt, shoot, wound, kill, trap, capture or collect, or to attempt to engage in any such conduct. *Harm* is further defined by the Service to include significant habitat modification or degradation that results in death or injury to listed species by significantly impairing behavioral patterns, including breeding, feeding, or sheltering. *Harass* is defined by the Service as an intentional or negligent act or omission that creates the likelihood of injury to listed wildlife by annoying it to such an extent as to significantly disrupt normal behavior patterns which include, but are not limited to, breeding, feeding or sheltering. *Incidental take* is defined as take that is incidental to, and not the purpose of, the carrying out of an otherwise lawful activity. Under the terms of section 7(b)(4) and section 7(o)(2), taking that is incidental to and not intended as part of the agency action is not considered to be prohibited taking under the Act provided that such taking is in compliance with this Incidental Take Statement.

The Forest Plan is a framework programmatic action, i.e. it provides direction for future actions that may be authorized, funded, and/or carried out by the Forest and it does not in itself mandate or approve future implementation of activities on the Forest. For the purposes of an incidental take statement, a Federal action is a framework programmatic action if it approves a framework for the development of future action(s) that are authorized, funded, or carried out at a later time, and any take of a listed species would not occur unless and until those future action(s) are authorized, funded, or carried out and subject to further section 7 consultation. 50 C.F.R. § 402.02. For a framework programmatic action, an incidental take statement may be provided but is not required at the programmatic level; any incidental take resulting from any action subsequently authorized, funded, or carried out under the program that is not addressed below will be addressed in subsequent section 7 consultation, as appropriate.

For some activities implemented under the Forest Plan, the level of detail available is insufficient to identify with particularity all possible circumstances that may possibly involve the incidental take of listed species. Given the lack of specificity and information regarding future effects of actions implemented under the Forest Plan, providing the amount or extent of take would be speculative and unlikely to provide an accurate and reliable trigger for reinitiation of consultation for some effects. Consequently, with the exception of incidental take related to grizzly bears as described below, other potential for incidental take that we are unable to anticipate at this time is deferred to future consultation on individual projects. Any incidental take resulting from subsequent actions that proceed under the Forest Plan will be subject to section 7 consultation, as appropriate. In addition, take that may occur due to illegal activities by private citizens within the action area is not exempted in this incidental take statement.

This 2023 biological opinion on the continued implementation of the Forest Plan has analyzed the effects to grizzly bears associated with the Forest Plan direction across the entire Forest and will supersede four biological opinions and incidental take statements that are associated with the existing Forest Plan, including the 2004 biological opinion on the Forest Plan and associated 2012 amended incidental take statement, the 2011 biological opinion and incidental take statement on the final access management strategy for the Swan subunit in the NCDE, the 2011 biological opinion and incidental take statement on the access amendment to the Forest Plan for the CYE, and the 2017 biological opinion and incidental take statement on the NCDE grizzly bear amendments. These previous consultations are summarized in the biological opinion above. While the direction under the Forest Plan did not change from the direction consulted on in these four biological opinions and associated incidental take statements, we are including the effects and any associated incidental take with those actions in this 2023 biological opinion and incidental take statement in order to consolidate the amount of ongoing biological opinions and capture all effects and incidental take associated with the continued implementation of the Forest Plan direction in one consultation using the current best available information and including the entire Forest as the action area.

The measures described below are non-discretionary and must be undertaken by the Forest so that they become binding conditions of any grant or permit issued, as appropriate, for the exemption in section 7(o)(2) to apply. The Forest has a continuing duty to regulate the activity that is covered by this incidental take statement. If the Forest (1) fails to assume and implement the terms and conditions or (2) fails to require an applicant to adhere to the terms and conditions of the incidental take statement through enforceable terms that are added to the permit or grant document, the protective coverage of section 7(o)(2) may lapse. To monitor the impact of incidental take, the Forest must report the progress of the action and its impact on the species to the Service as specified in the incidental take statement [50 C.F.R. § 402.14(i)(3)].

Amount or Extent of Take Anticipated

Motorized Access (non-winter)

Based on research detailed earlier in this biological opinion, the Service has defined harm of grizzly bears in terms of adverse habitat conditions caused by high motorized route densities, resulting in low amounts of secure habitat, which may displace individuals from key habitat to the extent that significant under-use of habitat by grizzly bears may occur. Using the best information on the effects of motorized access on grizzly bears, we conclude that existing high motorized route densities and associated low amounts of secure habitat in portions of the action area are likely to result in some level of adverse effects to some female grizzly bears and/or their dependent offspring at some point during the life of the Forest Plan, primarily those that attempt to establish and maintain home ranges within the action area. Future permanent and/or temporary route construction and use, and/or temporary use of restricted routes may add to or increase the likelihood of such adverse effects. These adverse effects may result from potential displacement of grizzly bears from essential habitat. Displacement may result in significant under-use of key habitat when high amounts of motorized access exist on the landscape. The Service maintains that such under-use of otherwise suitable habitat within a grizzly bear's home range may constitute incidental take of individual female grizzly bears and/or their dependent offspring through "harm" as a result of significant habitat alteration that impairs breeding, feeding, and/or sheltering.

Portions of the action area have high levels of motorized routes while other portions have low levels of motorized routes or no motorized routes at all. With the exception of the subunits and BMUs within the NCDE and CYE recovery zones respectively, we have previously analyzed portions of the action area using only linear motorized route density or an estimate of low, medium, or high levels of motorized use. Although providing the linear route density provides a useful threshold to describe human-caused effects to grizzly bears based on existing literature and gives an idea of the amount of roads in the action area, motorized route density or acreage alone fails to represent how these routes occur on the landscape and fails to consider how road placement affects habitat patch size (Proctor et al. 2019). For example, portions of the GBAUs may have high route densities (even within the GBAUs with lower overall linear route densities) while other portions of the GBAUs may have low route densities or even no motorized routes (even within the GBAUs with higher overall linear route densities). For instance, even in a GBAU with overall low road density, there may be patches of high road density interspersed with patches of low road density or even unroaded areas. Secure habitat has been identified as one of the key issues related to effects of motorized access on grizzly bears and is important to the survival and reproductive success of grizzly bears. While secure habitat is directly tied to motorized routes, it more adequately represents the potential effects to grizzly bears related to motorized access as it provides a more accurate indication of the spatial patterns of motorized and non-motorized areas. Consequently, changes to the amount of secure habitat is an appropriate measure of potential effects to grizzly bears related to motorized access. For example, measurements of route density in situations of uniformly spaced roads, even at an otherwise acceptable route density, can provide very limited patches of secure habitat that are functionally useful for grizzly bears (Proctor et al. 2019). Similarly, larger patches of secure habitat may be available in areas with high road densities if roads are concentrated in specific areas. In other words, the key to limiting impacts of roads on bears is tied to availability, location, and distribution of secure habitat that is a function of not simply numeric density of motorized routes, but the spatial arrangement in which they occur. Accordingly, we have incorporated secure habitat into this analysis and incidental take statement.

As previously stated, in order to be conservative in favor of the grizzly bear when analyzing effects of motorized access, all existing, drivable routes are buffered when delineating secure habitat outside of the recovery zone, regardless of whether they are legally open or restricted to public travel and includes legally restricted routes that may not have a barrier such as a berm or gate restricting them (i.e. it is restricted or closed via MVUM and/or sign). It is generally assumed that bermed roads are not in drivable condition, but when there is uncertainty of whether berm construction was completed, roads were considered drivable and coded as such in the database. The purpose of making these assumptions is only for analyzing effects to grizzly bears and does not change the management direction on the Forest. These assumptions are appropriate and necessary so as to not miss any potential effects to grizzly bears and give the benefit of the doubt to the species (U.S. Fish and Wildlife Service 1998). This methodology acknowledges both that the Forest does not have standards limiting administrative use of roads outside of the recovery zones and that available data are less complete in this portion of the Forest in terms of the types and locations of closure devices and the condition of the road prism beyond the barrier. It is important to note that although this approach may result in a lower estimate of the existing amount of secure habitat, it assures that the impacts of motorized route use are not underestimated as a whole.

In addition, since the Forest lacks inventory information and has no management authority over non-Forest lands, a 500 meter buffer was placed around Forest land in those areas where Forest land is adjacent to non-Forest land ownerships. Buffering Forest land 500 meters from non-Forest Service land ownerships is a conservative approach when considering effects to grizzly bears and will capture any unknown or undisclosed cumulative effects that may result from non-Forest actions on non-Forest land that occur adjacent to Forest lands. For example, actions on adjacent non-Forest land could affect secure habitat on adjacent Forest lands by having impacts within 500 meters of secure habitat. Accordingly, the Forest lands within 500 meters of lands not administered by the Forest may not provide secure habitat due to the potential effects associated with motorized access on adjacent non-federal lands. While it is possible that Forest land within 500 meters may provide secure habitat, information as to activity on non-Forest land is often unknown or not disclosed and the Forest lacks management authority over non-Forest lands. As such, the amount of secure habitat on Forest land adjacent to non-Forest land could change at any time without the Forest's knowledge or authority. Therefore, to be conservative when analyzing effects to grizzly bears, in order to not miss any potential effects associated with motorized access on non-Forest lands, Forest land within 500 meters of non-Forest land is buffered out of the secure habitat metric for the Forest. Because of the long life of the Forest Plan, it is not possible to know everything that may occur on non-Forest land and because the Forest has no control on non-Forest lands, this buffer accounts for any cumulative effects to grizzly bears that may have occurred from actions on non-Forest lands. In other words, any potential unknown effects associated with non-Forest lands have already been incorporated into this analysis ahead of time. For example, if motorized access were to increase on non-Forest land adjacent to Forest land, potentially affecting grizzly bears in the action area associated with disturbance and/or displacement, the effects of such are already considered into the metrics of secure habitat that are measured for Forest lands. Thus, we would not miss any effects to secure habitat on Forest lands over time, giving the benefit of the doubt to the species (U.S. Fish and Wildlife Service 1998). Using this conservative approach does not result in significant effects to the grizzly bear population.

The Forest is expected to update the secure habitat metrics as they update their access data during site-specific project planning in order to more accurately portray what is existing on the ground at the time of this consultation. Routes that were existing on the Forest but unmapped due to errors or lack of information may or may not affect the Forest's estimate of the existing amount of secure habitat, depending on the location of the roads. It is expected that this type of adjustment to the baseline would reflect better data and mapping rather than representing actual changes on the ground. As the access database is updated, the improved information will better reflect the existing conditions related to secure habitat in the GBAUs.

The existing motorized access conditions within the Monture, Mor-Dun, North Scapegoat, South Scapegoat, and Rattlesnake subunits in the NCDE recovery zone are not expected to result in significant effects or incidental take of grizzly bears. The existing motorized access conditions within the Mission and Swan subunits in the NCDE recovery zone and BMU 22 in the CYE recovery zone are likely resulting in some level of ongoing significant effects to and incidental take of individual female grizzly bears and/or their dependent young.

The portion of the action area outside of the recovery zones includes areas designated as NCDE zone 1, which includes the Ninemile DCA, and NCDE zone 2 as well as areas outside of these designations. Outside of the recovery zones, the estimated amount of secure habitat ranges from a low of 2 percent of Forest land in the Middle Blackfoot GBAU to a high of 76 percent of Forest land in both the Fish Creek and Upper Rock GBAUs. Of all 30 GBAUs delineated on the Forest, six have less than 10 percent secure habitat on Forest land, seven have between 11 and 20 percent secure habitat on Forest land, seven have between 21 and 30 percent secure habitat on Forest land, four have between 31 and 40 percent secure habitat on Forest land, one has between 41 and 50 percent secure habitat on Forest land, two have between 51 and 60 percent secure habitat on Forest land, and three have greater than 60 percent secure habitat on Forest land. It is likely that portions of most of the GBAUs have existing conditions that may be resulting in some level of ongoing significant effects to and incidental take of grizzly bears if or when female grizzly bears are present.

The effects of the existing motorized access conditions throughout the action area, including the NCDE and CYE recovery zones, NCDE zones 1 and 2, and areas outside of these designations result in some level of ongoing affects, including some adverse effects, that will continue during the life of the Forest Plan. Ongoing displacement of grizzly bears may be occurring due to the potentially significant under-use of key habitat by female grizzly bears and/or their dependent offspring and may constitute incidental take of grizzly bears through “harm” as a result of significant habitat alteration that impairs breeding, feeding and/or sheltering.

Given the lack of forest plan direction requiring specific levels of secure habitat in the areas outside of the recovery zones, NCDE zone 1, and the Ninemile DCA, it's possible that projects may permanently reduce secure habitat or more likely, temporarily reduce the effectiveness of the existing secure habitat. However, reductions and/or effects to secure habitat will be limited in most GBAUs by Forest Plan MA allocations that limit or preclude road construction. Given the variation in individual projects, the potential effects of permanent and temporary route construction and use on secure habitat depend entirely on the location of the new route and the existing secure habitat polygons. For example, permanent and/or temporary routes could be constructed completely outside of secure habitat and outside of the 500 meter buffer in close proximity to existing routes and would have no effect on secure habitat. Other circumstances may include temporary or permanent route construction and use within 500 meters of secure habitat but not directly within secure habitat, affecting the edge of secure habitat. Finally, sometimes temporary or permanent roads are built directly within secure habitat; thus affecting or potentially splitting a secure habitat polygon. Depending on the circumstances of the new roads as described above, the new roads may or may not affect secure habitat.

The construction and use of permanent and/or temporary routes and/or temporary use of restricted routes for motorized access may increase the likelihood of displacement of grizzly bears in or near a project area. While not specifically proposed under the Forest Plan, permanent and/or temporary route construction and use, and/or temporary use of restricted routes may occur on a project by project basis. Permanent routes may be used during the short-term for a project and then restricted with a barrier and placed in storage with the potential for future administrative use or may be used for the long-term and receive a substantive amount of use if kept in an open status. Temporary routes built or restricted routes temporarily used may be short-term in duration of use or may remain on the landscape for several years and receive a substantive amount of use. Depending on the site-specific project information (size, location, duration, etc.), effects associated with permanent and/or temporary route construction and use, or temporary use of restricted routes could range from minor disturbance and insignificant effects to displacement of grizzly bears that may result in adverse effects.

In sum, existing motorized access conditions in some areas and continued presence of these motorized routes under the Forest Plan, along with permanent and/or temporary route construction and use, and/or temporary use of restricted routes, may result in incidental take of some individual female grizzly bears and/or their dependent offspring attempting to establish or maintain home ranges in roaded areas at some point over the life of the Forest Plan. We anticipate that in a limited number of circumstances, site specific conditions would result in significant displacement of adult females and/or their dependent offspring from key seasonal habitat, impairing their ability to find adequate food resources, breed and raise young, and/or find shelter.

We do not anticipate any take of subadult or male grizzly bears. Male grizzly bears have larger home ranges than females, and males and subadults are more mobile and do not have the same energetic needs as adult females. We also do not anticipate take of grizzly bears that are transient (moving through areas outside of home range use). Such individuals are highly mobile and not restricted to finding food and shelter within a home range. Thus, while displacement may affect behavioral patterns such as feeding or sheltering, we do not anticipate such effects would cause injury to transient, subadult, or male grizzly bears.

As detailed in this biological opinion, we anticipate that existing motorized access conditions, permanent motorized route construction and use, temporary motorized route construction and use, and temporary use of restricted routes would affect only a very few adult females over the over the life of the Forest Plan because grizzly bears occur at low densities in the action area and numbers of females are expected to increase only slowly over time in much of the action area. Also, substantial increases in road densities are not expected. If subadult females move into portions of the action area further away from the recovery zone seeking to establish home ranges, they would be exposed to levels of roading that would factor into home range selection, and that level of roading is not likely to significantly increase. Therefore, the take we anticipate would be harm to only a very low number of female grizzly bears and/or their dependent offspring that may inhabit the action area now and into the future, over the life of the Forest Plan. We expect harm would be caused by significant under-use of key habitat in areas affected by high road densities to levels that result in decreased fitness and impaired reproductive potential. In other words, infrequently and in site-specific circumstances, an adult female grizzly bear wary of humans and human-generated disturbance may not breed at its potential frequency or may fail to complete gestation due to decreased fitness. As some adult females have proven that they are able to successfully reproduce and raise young in areas that have high motorized access conditions, we do not expect all adult female grizzly bears and/or their dependent offspring affected by less than optimal motorized access conditions to suffer impairment of breeding, feeding, and/or sheltering, nor would we expect any female to experience permanent effects (lasting more than one reproductive cycle) as they would likely adapt. Variables such as annual climate and resulting habitat and food resource conditions, the level of roading, and the number of grizzly bears using an area may change over time and are all factors influencing the displacement within a home range.

The effects of high route densities and associated low amounts of secure habitat on individual female grizzly bears and/or their dependent offspring are difficult to quantify in the short term and may be measurable only as long-term effects on the species' habitat and population levels. The amount of take is difficult to quantify for the following reasons:

1) The amount of take would depend on the number of adult female grizzly bears and/or their dependent offspring impacted by high road densities. We lack specific information on the precise number of adult female grizzly bears and/or their dependent offspring that have home ranges encompassing all or portions of the action area.
2) Individual grizzly bears would react differently to the disturbance. Because some adult females have proven that they are able to successfully reproduce and raise young in areas that are worse than research benchmarks associated with motorized access, not all adult female bears and/or their dependent offspring that are exposed to disturbances from high road densities would be adversely impacted to the point of take. Low numbers of grizzly bears would likely decrease intra-specific competition for habitat, allowing more options for individuals to move within home ranges in many cases.
3) Some individual female grizzly bears and/or their dependent offspring that initially may be sensitive to disturbances may adjust to the routine disturbances generated by human activity over time.

Therefore, determining the precise amount of take, as defined by impaired reproductive potential (as affected by feeding and sheltering), is difficult. The amount of take would be also difficult to detect for the following reasons:

1) Grizzly bears are not easily detected or observed in the wild.
2) Reproductive rates of female grizzly bears and/or their dependent offspring vary naturally due to environmental and physiological causes.
3) A reduction in "normal" reproductive success is not discernable in the wild.
4) The reasons a grizzly bear fails to breed and/or failure to complete gestation are not discernable in the wild.

According to Service regulations implementing the Act (50 C.F.R. § 402.14(i)(1)(i)) and as stated in the Endangered Species Consultation Handbook (March 1998) (Handbook), some detectable measure of effect should be provided, such as the relative occurrence of the species or a surrogate species in the local community, or amount of habitat used by the species, to serve as a measure for take. Take also may be expressed as a change in habitat characteristics affecting the species (Handbook, p 4-47 to 4-48). In instances where incidental take is difficult to quantify, the Service uses a surrogate measure of take. The number of grizzly bears that use the action area is unknown but grizzly bears have been documented. However, female grizzly bears have yet to be verified within some portions of the action area. The mechanism of female grizzly bear dispersal makes it likely that only relatively few female grizzly bears would occupy much of the action area during the life of the Forest Plan. Therefore, for reasons explained above, the

Service anticipates that incidental take of adult female grizzly bears and/or their dependent offspring would be very low and would occur only infrequently over the life of the Forest Plan in the form of harm related to the displacement effects of existing motorized access, permanent and/or temporary road construction and use, and temporary use of restricted roads. As incidental take associated with motorized access is difficult to quantify, we will express incidental take as a change in habitat characteristics and conditions affecting grizzly bears, specifically secure habitat.

We do not anticipate that motorized access in all portions of the action area would result in incidental take as some areas may have relatively high amounts of secure habitat. We anticipate that the likelihood of incidental take of females would be highest in those areas with lower amounts of secure habitat, if females occupy them. We also do not anticipate that all permanent and/or temporary routes constructed and used, or temporary use of restricted routes in the action area would result in incidental take. This would depend on such things as grizzly bear use of an action area, location and length of the temporary road, and the duration it would be on the landscape, as well as the potential for female grizzly bear occurrence.

Surrogate 1

We expect some level of incidental take associated with the ongoing effects of the existing motorized access conditions within the action area. Our **first surrogate measures of incidental take of grizzly bears** will be represented by the habitat conditions resulting from the existing motorized access conditions on the Forest that may continue to result in some level of incidental take over the life of the Forest Plan. Within the NCDE recovery zone, research benchmarks for OMRD, TMRD, and secure core describe that adverse effects to grizzly bears are likely to occur when OMRD exceeds 1 mile per square mile in more than 19 percent of the subunit, TMRD exceeds 2 miles per square mile in more than 19 percent of the subunit, and secure core is not at least 68 percent of the subunit during the non-denning period. This road-density threshold, first identified by Mace et al. (1996) has been roughly observed by other researchers in multiple study areas (summarized in Proctor et al. 2019) as being a density beyond which adverse effects to female grizzly bears can occur. Within the CYE recovery zone, based on research by Wakkinen and Kasworm (1997), research benchmarks for OMRD, TMRD, and secure core describe that adverse effects to grizzly bears are likely to occur when OMRD exceeds 1 mile per square mile in more than 33 percent of the subunit, TMRD exceeds 2 miles per square mile in more than 26 percent of the subunit, and secure core is not at least 55 percent of the subunit during the non-denning period.

As described above, the existing motorized access conditions within the Mission and Swan subunits in the NCDE recovery zone and BMU 22 in the CYE recovery zone are likely resulting in some level of ongoing significant effects to and incidental take of grizzly bears. The habitat conditions of OMRD, TMRD, and secure core will represent the incidental take associated with existing motorized access conditions within the recovery zones. Also described above, the majority of the GBAUs delineated outside of the recovery zones have existing motorized access conditions that are likely resulting in some level of ongoing significant effects to and incidental take of grizzly bears. The Forest does not measure OMRD or TMRD in areas outside of the recovery zones. Because secure habitat provides a more accurate indication of the spatial mix of motorized routes, it more adequately represents the potential effects related to open and restricted motorized access as opposed to a linear route density. Thus, the habitat conditions associated with the amount of secure habitat on the Forest will represent the incidental take associated with existing motorized access conditions within the GBAUs outside of the recovery zones. Tables 7 and 8 below display the **first surrogate measures of incidental take of grizzly bears** related to the ongoing effects associated with the existing motorized access conditions on the Forest.

Table 7. Existing motorized access conditions in the Mission and Swan Subunits of the NCDE recovery zone and BMU 22 of the CYE recovery zone

Subunit/BMU	OMRD	TMRD	Secure Core
Mission	25 %	50 %	37 %
Swan*	31 %	20 %	53 %
BMU 22	32 %	33%	55 %

*This includes an OMRD of 22 percent during the spring (as discussed above).

Table 8. Existing secure habitat within the action area outside of the NCDE recovery zone (U.S. Forest Service 2022).

GBAU	Estimated Percent of Forest Land Providing Secure Habitat
NCDE zone 1	
Clearwater	4 %
Cottonwood	11 %
Gold	14 %
Middle Blackfoot	2 %
North Missoula	68 %
Placid	3 %
Ninemile DCA	
Keystone	33 %
Mill North	4 %
Ninemile	29 %
Trout East	11 %
Outside of NCDE zone 1 and Ninemile DCA	
Dry Cold	51 %
Dry Eddy	41 %
Fish Creek	76 %
Little Thompson	11 %
Lower Rock	56 %
Lynch Creek-Clark Fork	13 %
Middle Thompson	26 %
Mill South	34 %
Miller	4 %
North Lolo	16 %
Pats Knob	34 %
Petty Creek	25 %
Prospect	26 %
St Regis North	25 %
St Regis South	23 %

South Lolo	26 %
Trout West	33 %
Upper Fishtrap	6 %
Upper Rock	76 %
Upper Thompson	15 %

The existing motorized access conditions were determined using the best available information. The Service recognizes that improved information may be documented and mapping and calculation errors can occur. If the Forest updates the motorized access metrics to better reflect existing conditions (no changes on the ground) or finds that it has new information or has made a mapping or calculation error in describing the existing condition and corrects the metrics, the Service does not expect any additional incidental take of grizzly bears related to those corrections because the changes would not reflect any actual changes on the ground. The intent of this incidental take statement is to capture the existing access conditions, including potential incidental take that may not be represented in the metrics described above due to potential errors or lack of information at the time of consultation. The Forest is expected to update the motorized access metrics as they update their motorized access data during site-specific project planning in order to more accurately portray what is on the ground at the time of this consultation.

As described in the biological opinion above and in surrogate measure 2 below, changes to secure habitat in the GBAUs may occur as a result of permanent route construction (affecting up to 1 percent of secure habitat in a given GBAU). Thus, secure habitat in the GBAUs represented in surrogate measure 1 above could decrease within any given GBAU by 1 percent and not exceed the amount of incidental take exempted. However, a site-specific consultation (likely a tiered consultation) will occur associated with such permanent construction. If the existing conditions become worse than what is displayed in Tables 7 and 8 above due to changes on the ground and no project-specific consultation occurred, then the level of incidental take we anticipate in our first surrogate measure of take would be exceeded and therefore the level of take exempted would be exceeded.

Surrogate 2

Permanent motorized route construction within the recovery zones is limited by standards. Since the NCDE subunits and CYE BMU 22 have standards to meet for OMRD, TMRD, and secure core, in order to construct permanent routes in many areas of the recovery zones, other roads would likely need to be decommissioned depending on location and other site-specific details in order to continue to meet the standards. In some portions of the recovery zones, permanent motorized route construction could occur and the subunit or BMU may continue to meet the standards. However, nothing specific has been proposed for analysis in this programmatic consultation on the Forest Plan. As such, potential effects related to permanent motorized route construction in the recovery zones was not analyzed in this biological opinion. Therefore, permanent motorized routes that would affect OMRD, TMRD, and secure core in the recovery zones are not considered in this incidental take statement.

Permanent motorized route construction within NCDE zone 1 and the Ninemile DCA are also limited by standards. Under NCDE-LNF Zone 1-STD-01, a net increase above the 2011 baseline density of roads (NCDE zone 1) and roads and trails (Ninemile DCA) open to public motorized use during the non-denning season would be precluded on Forest lands in NCDE zone 1, which includes the Ninemile DCA. However, while open linear route density within NCDE zone 1 would be maintained, permanent motorized routes that are restricted from the public could be constructed and have the potential to affect secure habitat or open motorized routes could be decommissioned and new permanent motorized routes could be constructed within secure habitat, thus reducing secure habitat but maintaining the linear motorized route density.

While not specifically proposed under the Forest Plan, permanent motorized route construction and use in the GBAUs outside of the recovery zones may occur, typically associated with a site-specific project. Permanent routes may be used during the short-term for a project and then restricted with a barrier with the potential for future administrative use or may be used for the long-term and receive a substantive amount of use if kept in an open status. Based on the information provided by the Forest, a very small amount of permanent decrease of secure core was estimated and analyzed for the GBAUs. For the purposes of this consultation and incidental take statement, an amount of no more than one percent of the secure habitat within any given GBAU would be affected associated with the construction and use of permanent motorized routes. In sum, this estimated amount of no more than a total of one percent of secure habitat in any given GBAU could be permanently decreased over the life of the Forest Plan represents our **second surrogate measure of incidental take of grizzly bears** that we anticipate in regards to motorized access. Permanent changes could affect our first surrogate measure of take if new permanent route construction and use results in a net decrease in the amount of secure habitat post-project. Thus, motorized access conditions represented in surrogate measure 1 above could decrease within any given GBAU by 1 percent and not exceed the amount of incidental take exempted.

For future site-specific projects with permanent route construction that may affect more than 1 percent of a given GBAU, the effects of such will be analyzed during the site-specific project consultation as they would not fall under the level of effects analyzed or incidental take provided here. If secure habitat within any given GBAU is permanently reduced by more than a total of 1 percent as a result of permanent route construction and use then the level of incidental take we anticipate in our second surrogate measure of take for the area outside of the recovery zones would be exceeded and therefore the level of take exempted would be exceeded associated with this incidental take statement. Additional incidental may be exempted during that site-specific consultation.

Surrogate 3

Vegetation or other management actions often require the construction and use of temporary routes or temporary use of restricted routes for motorized access. While not specifically proposed under the Forest Plan, temporary route construction and use, and temporary use of restricted routes may occur on a project by project basis. Temporary routes constructed may be short-term in duration of use or may remain on the landscape for several years and receive a substantive amount of use. If it is determined that the construction and use of temporary routes or temporary use of restricted routes for a specific action will not adversely affect grizzly bears then we would not expect any incidental take associated with that action and this incidental take statement would not apply. For those scenarios where temporary routes may result in adverse effects to grizzly bears, some level of incidental take of grizzly bears may occur as described below. As such, we do expect some level of incidental take associated with the construction and use of temporary routes and/or temporary use of restricted routes within the action area over the life of the Forest Plan. Our third surrogate measure of incidental take of grizzly bears will be represented by the habitat conditions resulting from temporary changes to the existing motorized access conditions on the Forest that may result in some level of additional incidental take over the life of the Forest Plan. Temporary changes do not affect our first surrogate measure of take as temporary use would not result in a net increase in the amount of permanent routes or a net decrease in secure habitat post-project. Thus, motorized access would return to the pre-project levels, lessening the effects on grizzly bears over time.

Within the NCDE recovery zone, Forest Plan Standard NCDE-STD-AR-03 allows for temporary increases in OMRD and TMRD for projects, not to exceed a 5 percent temporary increase in OMRD and not to exceed a 3 percent temporary increase in TMRD, both calculated over a 10-year running average. NCDE-STD-AR-03 also allows temporary changes in secure core during project activities with a limit of 2 percent temporary decrease in secure core calculated over a 10-year running average. NCDE-STD-AR-04 specifies that temporary public motorized use of restricted roads is not authorized within secure core. The Monture, North Scapegoat, South Scapegoat, and Rattlesnake Subunits will remain above the research benchmarks of 19/19/68 even if temporary effects to OMRD, TMRD and secure core occur under projects associated with NCDE-STD-AR-03 and will not result in adverse effects or incidental take. The Mor-Dun subunit currently meets the research benchmark values for OMRD, TMRD, and secure core. TMRD and secure core effectiveness would remain above the research benchmark of 19 percent and 68 percent, respectively, even with temporary effects associated with NCDE-STD-AR-03. However, OMRD may temporarily exceed the benchmarks if increases allowed under standard NCDE-STD-AR-03 are invoked to allow for project activities in the Mor-Dun subunit, potentially resulting in some level of short-term adverse effects and incidental take. Temporary effects for projects allowed under NCDE-STD-AR-03 within the Mission and Swan subunits could result in temporary increases in OMRD and/or TMRD and/or temporary decreases in the effectiveness of secure core that further exceed (are worse than) the benchmarks. Since some level of ongoing adverse effects are likely already occurring as a result of the existing, baseline motorized access conditions in these subunits, the temporary increases allowed under NCDE-STD-AR-03 may result in additional adverse effects and incidental take to grizzly bears that may be using these subunits.

Forest Plan standard NCDE-STD-AR-01 allows administrative use of roads that are closed to public motorized use within the recovery zone, provided that doing so does not exceed either 6 trips (3 round trips) per week or 1 thirty-day unlimited use period during the non-denning season. Exceptions to this standard are allowed for emergency situations. NCDE-STD-AR-04 would allow temporary use of restricted roads for motorized use by the public for special purposes such as firewood gathering. The standard also indicates that motorized public use in these areas will not last longer than 30 days during one non-denning season, and will only occur outside the spring and fall bear hunting seasons. Further, public motorized use would not be permitted within secure core.

Guidelines are also provided for the NCDE recovery zone to minimize the potential effects of temporary project implementation within the recovery zone. Temporary project implementation within the recovery zone should not exceed 5 years (NCDE-GDL-AR-01). Further, guideline NCDE-GDL-AR-02 states that secure core should be restored to pre-project levels within 1 year of completion of a project. Although projects meeting these guidelines may result in some adverse effects to grizzly bears as a result of displacement from preferred habitat, they would provide limits on the amount and duration of the disturbance so that bears are not permanently displaced by human activities. While the Forest may deviate from guidelines with an approved exception, it is not known at this time what exceptions may be used. Thus, these guidelines, as written, will be used as part of our surrogate measure of take. If these guidelines are not met for any given site-specific action, site-specific consultation may be necessary depending on the site-specific information and effects.

Within the CYE recovery zone, Forest Plan direction allows the Forest to temporarily affect underlying core area (i.e., any core habitat that is affected by the subject road and its buffer) within a BMU once per 10-year time frame, and not to exceed 1 bear year, for the sole purpose of completing road decommissioning/stabilization activities on existing closed or barriered roads in core area habitat. Subsequent needs to re-enter individual core areas within a BMU more frequently than once per decade for the purposes of road decommissioning shall be handled on a case-by-case basis. The effects of additional entries will be analyzed pursuant to such project level consultation. In addition, temporary administrative use shall not exceed 60 vehicle round trips per active bear year per road, apportioned as follows: ≤18 round trips in spring (April 1 through June15); ≤23 round trips in summer (June 16 through September 15); and ≤19 round trips in fall (September 16 through November 30). If the number of trips exceeds 60 trips per active bear year in the Cabinet-Yaak ecosystem, then that road would be considered "open" for analysis and reporting purposes. Likewise, if the number of trips exceeds the allowable ecosystem-specific seasonal (spring, summer, and fall) vehicle round trips per road, then that road would be considered "open" for analysis and reporting purposes. Since some level of ongoing adverse effects may already occurring as a result of the existing, baseline motorized access conditions in BMU 22, these temporary effects may result in additional adverse effects and incidental take to female grizzly bears and/or their dependent offspring that may be using the BMU.

Outside of the recovery zones, the Forest estimated that the construction and use of temporary routes and/or temporary use of restricted routes may temporarily decrease the effectiveness of secure habitat by no more than 5 percent in any individual GBAU at any given period of time. If projects span more than one GBAU, a project may not affect secure habitat by more than 5 percent in each of the GBAUs. Since some level of ongoing adverse effects are likely already occurring as a result of the existing, baseline motorized access conditions in most GBAUs on the Forest, temporary effects to secure habitat may result in additional adverse effects and incidental take to female grizzly bears and/or their dependent offspring that may be using the action area.

In sum, the estimated amounts of OMRD, TMRD, and/or secure core in the recovery zones or secure habitat outside the recovery zone affected by temporary route construction and use and/or temporary restricted route use represents our **third surrogate measure of incidental take of grizzly bears** that we anticipate in regards to motorized access.

- If projects within the NCDE recovery zone: temporarily result in more than 19 percent OMRD, 19 percent TMRD, and/or less than 68 percent secure core **and** temporarily increase OMRD by more than 5 percent, temporarily increase TMRD by more than 3 percent, or temporarily decrease secure core by more than 2 percent using a 10-year running average; result in administrative use on roads with public restrictions exceeding either 6 trips (3 round trips) per week or 1 thirty-day unlimited use period during the non-denning season; exceed 5 years; and/or access conditions (i.e., OMRD, TMRD, secure core) are not restored to pre-project conditions within 1 year of project completion then the level of incidental take we anticipate in our third surrogate measure of take for the NCDE recovery zone would be exceeded and therefore the level of take exempted would be exceeded.

- If the core area within BMU 22 in the CYE recovery zone is affected for completing road decommissioning/stabilization activities more than once per 10-year timeframe and/or exceeds 1 bear year, and/or temporary administrative use exceeds 60 vehicle round trips per active bear year per road, apportioned as follows: ≤18 round trips in spring (April 1 through June15); ≤23 round trips in summer (June 16 through September 15); and ≤19 round trips in fall (September 16 through November 30) then the level of incidental take we anticipate in our third surrogate measure of take for the CYE recovery zone would be exceeded and therefore the level of take exempted would be exceeded.
- If more than 5 percent of the secure habitat is affected in any individual GBAU outside of the recovery zones at any given time as a result of temporary route construction and use and/or temporary use of restricted routes then the level of incidental take we anticipate in our third surrogate measure of take for the area outside of the recovery zones would be exceeded and therefore the level of take exempted would be exceeded.

Winter Motorized Use

In addition to non-winter motorized access, the Service anticipates that over-snow vehicle use (snowmobile) that may occur under the Forest Plan may incidentally result in some very low level of take of female grizzly bears with offspring during den emergence. Over-snow vehicle use would be restricted on large proportions of denning and spring habitat on the Forest and thousands of acres of denning and spring habitat would be legally unavailable to over-snow vehicle use in the broader area where grizzly bears may occur. Where grizzly bears and over-snow vehicle use do generally overlap, there is still some spatial separation. However, the potential of over-snow vehicle use adversely impacting an individual female grizzly bear with offspring and resulting in some level of incidental take cannot be eliminated. The incidental take is expected to be in the form of harm or harassment to individual female grizzly bears and/or dependent offspring caused by premature den emergence or premature displacement from the den site area.

The best information available indicates that snowmobile impacts to grizzly bears emerging from dens was a higher concern than impacts to denning bears (Graves and Ream 2001). The Service concludes that snowmobile-generated disturbance to grizzly bears in dens during the deep of winter is not likely to rise to the level causing significant impairment of breeding or sheltering to the point of injury or death. In spring, disturbance from snowmobiles to grizzly bears in dens may cause premature den emergence. Based on naturally earlier den emergence of male bears and females without young, their independence and mobility, the Service does not anticipate the effects of disturbance caused by over-snow vehicle use would be adverse to male grizzly bears or female grizzly bears without cubs.

However, late season over-snow vehicle use may result in some level of incident take of female grizzly bears with offspring by causing a female grizzly bear with cubs to prematurely leave a den in the spring or cause a recently emerged female with cubs to be prematurely displaced from her den or den site, potentially resulting in decreased fitness of the adult female bear and/or decreased fitness or abandonment of her dependent offspring. If the dependent offspring attempt to follow their mother from a den site prior to their gaining some mobility, they may suffer from decreased fitness or death.

The incidental take of female grizzly bears or their cubs may be indicated by:
- a female grizzly bear's premature den emergence (earlier than documented for this ecosystem, based on gender, age and reproductive status) following exposure to over-snow vehicle use;
- the location of one or more cubs abandoned by their mother near or in a den in an area of over-snow vehicle use;
- the location of one or more cubs accompanying a female prior to the normal (earlier than documented for this ecosystem) den emergence period in an area of over-snow vehicle use; or
- a female bear that emerges in poor fitness in early spring (when other bears are in good condition) in an area of over-snow vehicle use.

However, the Service anticipates such incidental take of grizzly bears will be difficult to detect for the following reasons:
- grizzly bears are difficult to detect in the wild;
- grizzly bears are wide-ranging and their denning habitat is remote, largely wilderness and difficult to access;
- grizzly bear den sites cannot be precisely located over large portions of the denning habitat;
- grizzly bear den sites are often not re-used, so even known den sites cannot be monitored over time for indications of early abandonment, injury or mortality;
- close monitoring of den sites may actually increase the risk of abandonment;
- the resorption of or loss of fetuses, or loss of cubs born in inaccessible underground den sites cannot be quantified; and
- decreased fitness, loss of young, and premature den emergence may all be related to a variety of other factors; establishing a causal relationship between over-snow vehicle use and these effects would be difficult.

Discovery of an individual grizzly bear injury or mortality attributed to over-snow vehicle use is very unlikely. The exact number of grizzly bears in the population is unknown, den site locations are generally unknown, and the exact levels, frequency, and location of over-snow vehicle use is not known. The number of females with cubs, pregnant females, den emergence dates, and over-snow vehicle use varies each year due to a number of factors, including snow conditions. All of these variables are difficult to monitor or census. The Service concludes that the level of take of grizzly bears that would result from over-snow vehicle use would be very low based on the best available grizzly bear population information, the amount of protected and unprotected denning habitat available on the Forest, the characteristics of most grizzly bear den sites, expert opinion of grizzly bear researchers, and the best available information on grizzly bear denning.

As described above, some detectable measure of effect should be provided, such as the relative occurrence of the species or a surrogate species in the local community, or amount of habitat used by the species, to serve as a measure for take. Take also may be expressed as a change in habitat characteristics affecting the species. In instances where incidental take is difficult to quantify, the Service uses a surrogate measure of take. The number of grizzly bears that use the action area is unknown but grizzly bears have been documented. For reasons explained above, the Service anticipates that incidental take of adult female grizzly bears would be very low and would occur only infrequently over the life of the Forest Plan in the form of harm related to the effects of existing winter motorized use. As incidental take associated with winter motorized use is difficult to quantify, we will express incidental take as an amount of habitat used by grizzly bears that may be affected by winter motorized use, specifically grizzly bear denning habitat.

Surrogate 4

As described above, in instances where incidental take is difficult to quantify, the Service uses a surrogate measure of take. The surrogate measure for the number of grizzly bears harmed and/or harassed will be quantified using acres of potential grizzly bear denning habitat open to over-snow vehicle use beyond April 1.

Despite the Forest covering a large area of grizzly bear habitat, the only known denning habitat occurs within the NCDE. Grizzly bear denning has not been recorded in the portion of the BE or CYE portions of the Forest. Grizzly bears do den in the CYE to the north of the Forest but not currently within the portion located on the Forest (BMU22). As the bear population continues to grow and expand, grizzly bears could den within areas not previously known to have active grizzly bear denning. Although incidental take may not be occurring until such time a female with cubs dens in any given area, due to the long duration of the Forest Plan, we will address all areas of the Forest.

Snow conditions within portions of the action area are often suitable for over-snow vehicle use well beyond April 1, the date grizzly bears generally begin emerging from their dens. This is true especially in the higher elevations within the recovery zone. However, under the existing Forest Plan, areas with extended winter motorized use seasons (after April 1) do occur. Late season over-snow vehicle use is not restricted in all portions of the action area and in some portions of the action area winter motorized use would extend beyond the April 1 grizzly bear spring emergence period. Over-snow vehicle use can occur on the Forest from December 1 to March 15, March 31, April 15 or April 30 depending on the location. In addition, some areas on the Forest do not have a closed season. In the NCDE recovery zone within modeled grizzly bear denning habitat, Forest Plan standard NCDE-STD-AR-08 allows no net increase in the percentage of area or miles of routes designated for motorized over-snow vehicle use on Forest lands during the den emergence time period. Outside of the NCDE, the Forest Plan does not restrict motorized over-snow vehicle use during the den emergence period outside the areas with year-round closure as shown on the OSVUM. As such, the Forest does have some areas where over-snow vehicle use may occur during the den emergence period. The Forest estimated the acres of overlap between denning habitat and over-snow vehicle use.

In total, about 29 miles and approximately 205,100 acres of grizzly bear denning habitat are open to over-snow vehicle use during the during the den emergence period beyond March 31. About 24 miles occur within the NCDE recovery zone, NCDE zone 1, and the Ninemile DCA and 5 miles occur outside of this area. No trails for over-snow vehicle use are identified in the OSVUM for the CYE and no trails or roads for over-snow vehicle use are used within the BE. Of the 205,100 acres of denning habitat that are open to cross-country over-snow vehicle use during the den emergence period, about 58,200 acres occur in the NCDE recovery zone, NCDE zone 1, and the Ninemile DCA, about 22,800 acres occur within the CYE Recovery Zone in

BMU22, and about 124,100 acres occur within the areas outside the NCDE, CYE, and BE recovery zones, NCDE zone 1, and the Ninemile DCA. The portion of the BE Recovery Zone on the Forest is entirely within an area closed to over-snow vehicle use, thus no acres of over-snow vehicle use overlaps potential denning habitat. While these acres are open during the den emergence period, from a qualitative review, not all of these acres of cross-country over-snow vehicle use are available for such due to either the ruggedness of the terrain or logistical limitations (e.g., fuel). In addition, some drier and lower elevation areas may not be available to over-snow vehicle use after March 31st due to a lack of snow.

Thus, in total, approximately 29 miles and 205,100 acres of grizzly bear denning habitat overlap late season over-snow vehicle use beyond April 1. These acres of grizzly bear denning habitat represent the **fourth surrogate measure of the incidental take of grizzly bears** that we anticipate as a result of the Forest Plan. If the amount of grizzly bear denning habitat open to authorized over-snow vehicle use after April 1 exceeds the miles and acres provided in the fourth surrogate measure of take, then the level of incidental take we anticipate in our fourth surrogate measure of take would be exceeded and therefore the level of take exempted would be exceeded.

Summary

In summary, over the life of the Forest Plan, if the following scenarios occur then the level of incidental take we anticipate associated with motorized access would be exceeded and therefore the level of take exempted would be exceeded. Under CFR 402.16 (1), in any of these scenarios, reinitiation of consultation would be required unless the effects of such impacts are analyzed under a site-specific consultation:

1) Permanent increases in the existing motorized access conditions within the recovery zones occur over the amounts displayed in Table 7 in our first surrogate measure of take above and are not associated with a mapping or calculation error;
2) Permanent decreases of more than 1 percent of the secure habitat within the GBAUs occur over the amounts displayed in portions of Table 8 in our first surrogate measure of take above and described in our second surrogate measure of take above and are not associated with a mapping or calculation error;
3) Projects within the NCDE recovery zone result in temporary increases in OMRD by more than 5 percent, temporary increases in TMRD by more than 3 percent, or temporary decreases in secure core by more than 2 percent and result in a subunit having more than 19 percent OMRD, 19 percent TMRD, and/or less than 68 percent secure core; result in administrative use on roads with public restrictions exceeding either 6 trips (3 round trips) per week or 1 thirty-day unlimited use period during the non-denning season; exceed 5 years; and/or access conditions (i.e., OMRD, TMRD, secure core) are not restored to pre-project conditions within 1 year of project completion;
4) If the core area within BMU 22 in the CYE recovery zone is affected for completing road decommissioning/stabilization activities more than once per 10-year timeframe and/or exceeds 1 bear year, and/or temporary administrative use exceeds 60 vehicle round trips per active bear year per road, apportioned as follows: ≤18 round trips in spring (April 1 through June15); ≤23 round trips in summer (June 16 through September 15); and ≤19 round trips in fall (September 16 through November 30);
5) Temporary road construction and use and/or temporary restricted road use outside of the recovery zones impacts more than 5 percent of secure habitat in an individual GBAU at any given time; and/or

6) Authorized late season winter motorized use overlaps more than 29 miles and 205,100 acres of grizzly bear denning habitat overlap late season over-snow vehicle use beyond April 1.

In addition, as described in the effects section above, we don't expect adverse effects (and correspondingly we don't expect incidental take) related to human-grizzly bear conflicts associated with food and attractants at this time. However, as the Regional food and attractant storage order expires after 5 years, it is possible (although unlikely) that the Forest is without a food and attractant storage order at some point during the life of the Forest Plan. As previously stated, we reasonably expect (based on past history) that additional food and attractant storage orders that apply Forest-wide will continue to be issued, reissued, or extended for life of the Forest Plan. It is unlikely that a food and attractant storage order would not be in effect at any given time during the life of the Forest Plan. However, if at any given time, a food and attractant storage order is not in effect during the life of the Forest Plan, additional effects to grizzly bears may result that have not been previously analyzed and reinitiation of consultation on the Forest Plan may be necessary.

Effect of the take

In the accompanying biological opinion, the Service determined that this level of anticipated take is not likely to result in jeopardy to the species. The amount of incidental take described above is low. Much of the action area occurs outside of the recovery zones. As detailed in this opinion, and according to the 1993 recovery plan (U.S. Fish and Wildlife Service 1993), most lands outside of the recovery zones are not considered biologically essential to recovery of the species. Further, considering the grizzly bear recovery strategies and the size, status, and distribution of the NCDE and CYE grizzly bear populations, incidental take of grizzly bears in the action area would not affect the recovery of the listed entity of grizzly bears. The Forest Plan implements several measures that would sufficiently minimize impacts to grizzly bears.

Reasonable and Prudent Measures

Biological opinions provide reasonable and prudent measures that are expected to reduce the amount of incidental take. Reasonable and prudent measures are those measures necessary and appropriate to minimize incidental take resulting from proposed actions. Reasonable and prudent measures are nondiscretionary and must be implemented by the agency in order for the exemption in section 7(o)(2) to apply. The Service believes that the Forest Plan reduces the potential for and minimizes the effect of incidental take of grizzly bears. By managing for grizzly bears within the NCDE and CYE recovery zones and NCDE zone 1, including the Ninemile DCA (following standards in the NCDE grizzly bear amendment and CYE access management direction), the amount of incidental take of grizzly bears will be reduced. The following reasonable and prudent measures are appropriate to further minimize the impacts of incidental take of grizzly bears.

1. Reduce the potential for displacement of grizzly bears related to motorized access.

Terms and Conditions

In order to be exempt from the prohibitions of section 9 of the Act, the Forest must comply with the following terms and conditions that implement the reasonable and prudent measures described above and outline reporting and monitoring requirements. These terms and conditions are non-discretionary:

To implement Reasonable and Prudent Measure #1:

1. Within the Swan subunit in the NCDE, maintain OMRD during the spring (from April 1 through June 30) at 22 percent throughout the life of the Forest Plan. This is accomplished via the gated seasonal closure on the northern section of National Forest Service Route 4370. The closure extends from the junction with Highway 83 in T19NR16WS36 to the Clearwater Lake Trailhead in T19NR15WS19.

2. When implementing future road restriction decisions to restrict motorized access, the Forest shall use devices or methods recognized by the IGBC as effective closure devices and methods (IGBC 1998).

3. The Forest shall update the secure habitat data within the GBAUs outside of the recovery zones as they obtain new information and/or develop site-specific projects.

4. The duration for those actions associated with site-specific projects that result in temporary changes in the effectiveness of secure habitat within GBAUs outside of the recovery zones associated with site-specific temporary route construction and use, and/or temporary use of restricted routes shall be limited to the following: within NCDE zone 1 and the Ninemile DCA, new temporary routes that affect secure habitat shall not be on the landscape for more than 5 years from the start of construction and the temporary use of restricted routes that affect secure habitat should occur for more than 5 years; and within the area outside of NCDE zone 1 and the Ninemile DCA, new temporary routes that affect secure habitat shall not be on the landscape for more than 10 years from the start of construction and the temporary use of restricted routes that affect secure habitat should not occur for more than 10 years.

Reporting requirements

To demonstrate that the Forest Plan is adequately reducing the potential for and minimizing the effect of any incidental take that may result, the Forest shall complete a report with the information listed below and submit it to the Service's Montana Field Office biennially by June 1 for the preceding calendar year for the life of the Forest Plan. The report shall include:

1. In relation to the first and second surrogate measures of incidental take of grizzly bears and term and condition 3, provide an up-to-date record of the existing, ongoing access conditions including OMRD, TMRD, and secure core for the subunits within the recovery zone and secure habitat for the GBAUs outside of the recovery zone. Provide rationale for any changes that occur from the metrics displayed in the first and second surrogate measures of incidental take to differentiate if the changes are related to updates associated with no changes on the ground (based on new information, mapping or calculation errors, etc.) as described in the first surrogate

measure or updates associated with new permanent route construction as described in the second surrogate measure. In addition, report the existing conditions along with any updates to the baseline at the time of site-specific section 7 project consultations.

2. In relation to the third surrogate measure of incidental take of grizzly bears and term and condition 4, provide an up-to-date record of:

    a. the amount of OMRD, TMRD, and secure core affected by temporary projects and the duration of temporary project implementation within the recovery zones;
    b. the percent of secure habitat temporarily affected within the GBAUs outside the recovery zones from new temporary route construction and use, or temporary use of restricted routes and the duration that new temporary routes are on the landscape and/or the duration restricted routes were used for site-specific projects.

3. In relation to the fourth surrogate measure of incidental take of grizzly bears, provide an up-to-date record of any changes in the amount of grizzly bear denning habitat that overlaps late season over-snow vehicle use beyond April 1.

4. To gauge the validity of our assumptions that (1) illegal motorized access would most likely result in temporary effects to grizzly bears and (2) when illegal motorized access is observed or when user-created roads become apparent the Forest corrects the situation as soon as they are able, provide an up-to-date record of known illegal motorized access that occurred during the preceding two calendar years and how the Forest responded. Include information such as (but not limited to): the location of illegal motorized access, the type of barrier breached, how the barrier was breached, the date the Forest became aware of the illegal motorized access, how the Forest responded to the illegal motorized access, and the date the Forest carried out its response.

Closing Statement

The Service is unable to precisely quantify the number of grizzly bears that will be incidentally taken as a result of the Forest Plan. Therefore, we use surrogate measures for the amount of incidental take we anticipate based on habitat characteristics and/or conditions affecting grizzly bears, specifically secure habitat (non-winter motorized access) and denning habitat (winter motorized access). We use the existing levels of motorized access management, effects from permanent route construction in the GBAUs, and effects from temporary route construction and use, and temporary use of restricted routes as our first, second, and third surrogate measures of incidental take of grizzly bears related to motorized access management. We use the amount of grizzly bear denning habitat that overlaps late-season winter motorized use as our fourth surrogate measure of incidental take of grizzly bears.

Reasonable and prudent measures, with their implementing terms and conditions, are designed to minimize the impact of incidental take that might otherwise result from the proposed action. If, during the course of the action, the level of take occurring exceeds that anticipated in this incidental take statement, such incidental take represents new information requiring reinitiation of consultation and review of the incidental take statement. The Forest must immediately provide an explanation of the causes of the taking and review with the Service the need for possible modification of the reasonable and prudent measures.

CONSERVATION RECOMMENDATIONS

Sections 7(a)(1) of the Act directs federal agencies to use their authorities to further the purposes of the Act by carrying out conservation programs for the benefit of endangered and threatened species. Conservation recommendations are discretionary agency activities to minimize or avoid adverse effects of a proposed action on listed species or critical habitat, to help implement recovery plans or to develop information. The recommendations provided here relate only to the proposed action and do not necessarily represent complete fulfillment of the agency's section 7(a)(1) responsibility for the species.

1. Continue to manage access on the Forest to achieve lower route densities. By managing motorized access, several grizzly bear management objectives could be met including: (1) minimizing human interaction and potential grizzly bear mortality; (2) minimizing displacement from important habitats; (3) minimizing habituation to humans; and (4) providing relatively secure habitat where energetic requirements can be met (Interagency Grizzly Bear Committee 1998). Additionally, lower route densities would also benefit other wildlife and public resources.

2. Motorized access management is only one of several factors influencing grizzly bear habitat and grizzly bear security. The presence of attractants is a major factor leading to the food conditioning and habituation, and the eventual direct mortality or management removal of grizzly bears. The Service supports the Forest's continued efforts to manage food storage. Management of garbage, food and livestock feed storage, to prevent access to bears, benefits grizzly bears as well as black bears and other carnivores. Human/carnivore interactions would also be reduced, leading to a public safety benefit.

3. Grizzly bears concentrate in certain areas during specific time periods to take advantage of concentrated food sources or because the area provides a high seasonal food value due to diversity in vegetation and plant phenology (e.g., important spring for fall range). Where grizzly bear use is known or likely to occur and where practicable, delay disturbing activities during the spring in spring habitats to minimize displacement of grizzly bears.

REINITIATION NOTICE

This concludes consultation on the effects of the continued implementation of the Forest Plan on grizzly bears. As provided in 50 C.F.R. § 402.16, reinitiation of consultation is required and shall be requested by the federal agency or by the Service where discretionary federal involvement or control over the action has been retained or is authorized by law and: (1) if the amount or extent of taking specified in the incidental take statement is exceeded; (2) if new information reveals effects of the action that may affect listed species or critical habitat in a manner or to an extent not previously considered; (3) if the identified action is subsequently modified in a manner that causes an effect to the listed species or critical habitat that was not considered in the biological opinion or written concurrence; or (4) if a new species is listed or critical habitat designated that may be affected by the identified action.

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The Earth's Energy Budget, Climate Feedbacks and Climate Sensitivity

7

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Table of Contents

Executive Summary

This chapter assesses the present state of knowledge of Earth's energy budget: that is, the main flows of energy into and out of the Earth system, and how these energy flows govern the climate response to a radiative forcing. Changes in atmospheric composition and land use, like those caused by anthropogenic greenhouse gas emissions and emissions of aerosols and their precursors, affect climate through perturbations to Earth's top-of-atmosphere energy budget. The effective radiative forcings (ERFs) quantify these perturbations, including any consequent adjustment to the climate system (but excluding surface temperature response). How the climate system responds to a given forcing is determined by climate feedbacks associated with physical, biogeophysical and biogeochemical processes. These feedback processes are assessed, as are useful measures of global climate response, namely equilibrium climate sensitivity (ECS) and the transient climate response (TCR). This chapter also assesses emissions metrics, which are used to quantify how the climate response to the emissions of different greenhouse gases compares to the response to the emissions of carbon dioxide (CO_2). This chapter builds on the assessment of carbon cycle and aerosol processes from Chapters 5 and 6, respectively, to quantify non-CO_2 biogeochemical feedbacks and the ERF for aerosols. Other chapters in this Report use this chapter's assessment of ERF, ECS and TCR to help understand historical and future temperature changes (Chapters 3 and 4, respectively), the response to cumulative emissions and the remaining carbon budget (Chapter 5), emissions-based radiative forcing (Chapter 6) and sea level rise (Chapter 9). This chapter builds on findings from the IPCC Fifth Assessment Report (AR5), the Special Report on Global Warming of 1.5°C (SR1.5), the Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) and the Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas luxes in terrestrial ecosystems (SRCCL). *Very likely* ranges are presented unless otherwise indicated.

Earth's Energy Budget

Since AR5, the accumulation of energy in the Earth system, quantified by changes in the global energy inventory for all components of the climate system, has become established as a robust measure of the rate of global climate change on interannual-to-decadal time scales. Compared to changes in global surface air temperature (GSAT), the global energy inventory exhibits less variability, which can mask underlying climate trends. Compared to AR5, there is increased confidence in the quantification of changes in the global energy inventory due to improved observational records and closure of the sea level budget. Energy will continue to accumulate in the Earth system until at least the end of the 21st century, even under strong mitigation scenarios, and will primarily be observed through ocean warming and associated with continued sea level rise through thermal expansion (*high confidence*). {7.2.2, Box 7.2, Table 7.1, Cross-Chapter Box 9.1, Table 9.5, 9.2.2, 9.6.3}

The global energy inventory increased by 282 [177 to 387] Zettajoules (ZJ; 10^{21} Joules) for the period 1971–2006 and 152 [100 to 205] ZJ for the period 2006–2018. This corresponds to an Earth energy imbalance of 0.50 [0.32 to 0.69] W m^{-2} for the period 1971–2006, increasing to 0.79 [0.52 to 1.06] W m^{-2} for the period 2006–2018, expressed per unit area of Earth's surface. Ocean heat uptake is by far the largest contribution and accounts for 91% of the total energy change. Compared to AR5, the contribution from land heating has been revised upwards from about 3% to about 5%. Melting of ice and warming of the atmosphere account for about 3% and 1% of the total change respectively. More comprehensive analysis of inventory components and cross-validation of global heating rates from satellite and in situ observations lead to a strengthened assessment relative to AR5 (*high confidence*). {Box 7.2, 7.2.2, Table 7.1, 7.5.2.3}

Improved quantification of effective radiative forcing, the climate system radiative response, and the observed energy increase in the Earth system for the period 1971–2018 demonstrate improved closure of the global energy budget compared to AR5. Combining the *likely* range of ERF with the central estimate of radiative response gives an expected energy gain of 340 [47 to 662] ZJ. Combining the *likely* range of climate response with the central estimate of ERF gives an expected energy gain of 340 [147 to 527] ZJ. Both estimates are consistent with an independent observation-based assessment of the global energy increase of 284 [96 to 471] ZJ, (*very likely* range) expressed relative to the estimated 1850–1900 Earth energy imbalance (*high confidence*). {7.2.2, Box 7.2, 7.3.5, 7.5.2}

Since AR5, additional evidence for a widespread decline (or dimming) in solar radiation reaching the surface is found in the observational records between the 1950s and 1980s, with a partial recovery (brightening) at many observational sites thereafter (*high confidence*). These trends are neither a local phenomenon nor a measurement artefact (*high confidence*). Multi-decadal variation in anthropogenic aerosol emissions are thought to be a major contributor (*medium confidence*), but multi-decadal variability in cloudiness may also have played a role. The downward and upward thermal radiation at the surface has increased in recent decades, in line with increased greenhouse gas concentrations and associated surface and atmospheric warming and moistening (*medium confidence*). {7.2.2}

Effective Radiative Forcing

For carbon dioxide, methane, nitrous oxide and chlorofluorocarbons, there is now evidence to quantify the effect on ERF of tropospheric adjustments (e.g., from changes in atmospheric temperatures, clouds and water vapour). The assessed ERF for a doubling of carbon dioxide compared to 1750 levels (3.93 ± 0.47 W m^{-2}) is larger than in AR5. Effective radiative forcings (ERF), introduced in AR5, have been estimated for a larger number of agents and shown to be more closely related to the temperature response than the stratospheric-temperature adjusted radiative forcing. For carbon dioxide, the adjustments include the physiological effects on vegetation (*high confidence*). {7.3.2}

The total anthropogenic ERF over the industrial era (1750–2019) was 2.72 [1.96 to 3.48] W m^{-2}. This estimate has increased by 0.43 W m^{-2} compared to AR5 estimates for 1750–2011. This increase includes +0.34 W m^{-2} from increases in atmospheric concentrations of well-mixed greenhouse gases (including halogenated species) since 2011, +0.15 W m^{-2} from upwards revisions of their radiative efficiencies and +0.10 W m^{-2} from re-evaluation of the ozone and stratospheric water vapour ERF. The 0.59 W m^{-2} increase in ERF from greenhouse gases is partly offset by a better-constrained assessment of total aerosol ERF that is more strongly negative than in AR5, based on multiple lines of evidence (*high confidence*). Changes in surface reflectance from land-use change, deposition of light-absorbing particles on ice and snow, and contrails and aviation-induced cirrus have also contributed to the total anthropogenic ERF over the industrial era, with –0.20 [–0.30 to –0.10] W m^{-2} (*medium confidence*), +0.08 [0 to 0.18] W m^{-2} (*low confidence*) and +0.06 [0.02 to 0.10] W m^{-2} (*low confidence*), respectively. {7.3.2, 7.3.4, 7.3.5}

Anthropogenic emissions of greenhouse gases and their precursors contribute an ERF of 3.84 [3.46 to 4.22] W m^{-2} over the industrial era (1750–2019). Most of this total ERF, 3.32 [3.03 to 3.61] W m^{-2}, comes from the well-mixed greenhouse gases, with changes in ozone and stratospheric water vapour (from methane oxidation) contributing the remainder. The ERF of greenhouse gases is composed of 2.16 [1.90 to 2.41] W m^{-2} from carbon dioxide, 0.54 [0.43 to 0.65] W m^{-2} from methane, 0.41 [0.33 to 0.49] W m^{-2} from halogenated species, and 0.21 [0.18 to 0.24] W m^{-2} from nitrous oxide. The ERF for ozone is 0.47 [0.24 to 0.71] W m^{-2}. The estimate of ERF for ozone has increased since AR5 due to revised estimates of precursor emissions and better accounting for effects of tropospheric ozone precursors in the stratosphere. The estimated ERF for methane has slightly increased due to a combination of increases from improved spectroscopic treatments being somewhat offset by accounting for adjustments (*high confidence*). {7.3.2, 7.3.5}

Aerosols contribute an ERF of –1.3 [–2.0 to –0.6] W m^{-2} over the industrial era (1750–2014) (*medium confidence*). The ERF due to aerosol–cloud interactions (ERFaci) contributes most to the magnitude of the total aerosol ERF (*high confidence*) and is assessed to be –1.0 [–1.7 to –0.3] W m^{-2} (*medium confidence*), with the remainder due to aerosol–radiation interactions (ERFari), assessed to be –0.3 [–0.6 to 0.0] W m^{-2} (*medium confidence*). There has been an increase in the estimated magnitude but a reduction in the uncertainty of the total aerosol ERF relative to AR5, supported by a combination of increased process-understanding and progress in modelling and observational analyses. ERF estimates from these separate lines of evidence are now consistent with each other, in contrast to AR5, and support the assessment that it is *virtually certain* that the total aerosol ERF is negative. Compared to AR5, the assessed magnitude of ERFaci has increased, while the magnitude of ERFari has decreased. The total aerosol ERF over the period 1750–2019 is less certain than the headline statement assessment. It is also assessed to be smaller in magnitude at –1.1 [–1.7 to –0.4] W m^{-2}, primarily due to recent emissions changes (*medium confidence*). {7.3.3, 7.3.5, 2.2.6}

Climate Feedbacks and Sensitivity

The net effect of changes in clouds in response to global warming is to amplify human-induced warming, that is, the net cloud feedback is positive (*high confidence*). Compared to AR5, major advances in the understanding of cloud processes have increased the level of confidence and decreased the uncertainty range in the cloud feedback by about 50%. An assessment of the low-altitude cloud feedback over the subtropical oceans, which was previously the major source of uncertainty in the net cloud feedback, is improved owing to a combined use of climate model simulations, satellite observations, and explicit simulations of clouds, altogether leading to strong evidence that this type of cloud amplifies global warming. The net cloud feedback, obtained by summing the cloud feedbacks assessed for individual regimes, is 0.42 [–0.10 to +0.94] W m^{-2} °C^{-1}. A net negative cloud feedback is *very unlikely* (*high confidence*). {7.4.2, Figure 7.10, Table 7.10}

The combined effect of all known radiative feedbacks (physical, biogeophysical, and non-CO_2 biogeochemical) is to amplify the base climate response, also known as the Planck temperature response (*virtually certain*). Combining these feedbacks with the base climate response, the net feedback parameter based on process understanding is assessed to be –1.16 [–1.81 to –0.51] W m^{-2} °C^{-1}, which is slightly less negative than that inferred from the overall ECS assessment. The combined water-vapour and lapse-rate feedback makes the largest single contribution to global warming, whereas the cloud feedback remains the largest contribution to overall uncertainty. Due to the state-dependence of feedbacks, as evidenced from paleoclimate observations and from models, the net feedback parameter will increase (become less negative) as global temperature increases. Furthermore, on long time scales the ice-sheet feedback parameter is *very likely* positive, promoting additional warming on millennial time scales as ice sheets come into equilibrium with the forcing (*high confidence*). {7.4.2, 7.4.3, 7.5.7}

Radiative feedbacks, particularly from clouds, are expected to become less negative (more amplifying) on multi-decadal time scales as the *spatial pattern* of surface warming evolves, leading to an ECS that is higher than was inferred in AR5 based on warming over the instrumental record. This new understanding, along with updated estimates of historical temperature change, ERF, and Earth's energy imbalance, reconciles previously disparate ECS estimates (*high confidence*). However, there is currently insufficient evidence to quantify a *likely* range of the magnitude of future changes to current climate feedbacks. Warming over the instrumental record provides robust constraints on the lower end of the ECS range (*high confidence*), but owing to the possibility of future feedback changes it does not, on its own, constrain the upper end of the range, in contrast to what was reported in AR5. {7.4.4, 7.5.2, 7.5.3}

Based on multiple lines of evidence the best estimate of ECS is 3°C, the *likely* range is 2.5°C to 4°C, and the *very likely* range is 2°C to 5°C. It is *virtually certain* that ECS is larger than 1.5°C. Substantial advances since AR5 have been made in quantifying ECS based on feedback process understanding, the instrumental record, paleoclimates and emergent constraints. There is a high level of agreement among the different lines of evidence. All lines of evidence help rule out ECS values below 1.5°C, but currently it is not possible to rule out ECS values above 5°C. Therefore, the 5°C upper end of the *very likely* range is assessed to have *medium confidence* and the other bounds have *high confidence*. {7.5.5}

Based on process understanding, warming over the instrumental record, and emergent constraints, the best estimate of TCR is 1.8°C, the *likely* range is 1.4°C to 2.2°C and the *very likely* range is 1.2°C to 2.4°C (*high confidence*). {7.5.5}

On average, Coupled Model Intercomparison Project Phase 6 (CMIP6) models have higher mean ECS and TCR values than the Phase 5 (CMIP5) generation of models. They also have higher mean values and wider spreads than the assessed best estimates and *very likely* ranges within this Report. These higher ECS and TCR values can, in some models, be traced to changes in extra-tropical cloud feedbacks that have emerged from efforts to reduce biases in these clouds compared to satellite observations (*medium confidence*). The broader ECS and TCR ranges from CMIP6 also lead the models to project a range of future warming that is wider than the assessed warming range, which is based on multiple lines of evidence. However, some of the high-sensitivity CMIP6 models are less consistent with observed recent changes in global warming and with paleoclimate proxy data than models with ECS within the *very likely* range. Similarly, some of the low-sensitivity models are less consistent with the paleoclimate data. The CMIP models with the highest ECS and TCR values provide insights into low-likelihood, high-impact outcomes, which cannot be excluded based on currently available evidence (*high confidence*). {4.3.1, 4.3.4, 7.4.2, 7.5.6}

Climate Response

The total human-forced GSAT change from 1750 to 2019 is calculated to be 1.29 [0.99 to 1.65] °C. This calculation is an emulator-based estimate, constrained by the historic GSAT and ocean heat content changes from Chapter 2 and the ERF, ECS and TCR from this chapter. The calculated GSAT change is composed of a well-mixed greenhouse gas warming of 1.58 [1.17 to 2.17] °C (*high confidence*), a warming from ozone changes of 0.23 [0.11 to 0.39] °C (*high confidence*), a cooling of –0.50 [–0.22 to –0.96] °C from aerosol effects (*medium confidence*), and a –0.06 [–0.15 to +0.01] °C contribution from surface reflectance changes from land-use change and light-absorbing particles on ice and snow (*medium confidence*). Changes in solar and volcanic activity are assessed to have together contributed a small change of –0.02 [–0.06 to +0.02] °C since 1750 (*medium confidence*). {7.3.5}

Uncertainties regarding the true value of ECS and TCR are the dominant source of uncertainty in global temperature projections over the 21st century under moderate to high greenhouse gas emissions scenarios. For scenarios that reach net zero carbon dioxide emissions, the uncertainty in the ERF values of aerosol and other short-lived climate forcers contribute substantial uncertainty in projected temperature. Global ocean heat uptake is a smaller source of uncertainty in centennial-time scale surface warming (*high confidence*). {7.5.7}

The assessed historical and future ranges of GSAT change in this Report are shown to be internally consistent with the Report's assessment of key physical-climate indicators: greenhouse gas ERFs, ECS and TCR. When calibrated to match the assessed ranges within the assessment, physically based emulators can reproduce the best estimate of GSAT change over 1850–1900 to 1995–2014 to within 5% and the *very likely* range of this GSAT change to within 10%. Two physically based emulators match at least two-thirds of the Chapter 4-assessed projected GSAT changes to within these levels of precision. When used for multi-scenario experiments, calibrated physically based emulators can adequately reflect assessments regarding future GSAT from Earth system models and/or other lines of evidence (*high confidence*). {Cross-Chapter Box 7.1}

It is now well understood that the Arctic warms more quickly than the Antarctic due to differences in radiative feedbacks and ocean heat uptake between the poles, but that surface warming will eventually be amplified in both the Arctic and Antarctic (*high confidence*). The causes of this polar amplification are well understood, and the evidence is stronger than at the time of AR5, supported by better agreement between modelled and observed polar amplification during warm paleo time periods (*high confidence*). The Antarctic warms more slowly than the Arctic owing primarily to upwelling in the Southern Ocean, and even at equilibrium is expected to warm less than the Arctic. The rate of Arctic surface warming will continue to exceed the global average over this century (*high confidence*). There is also *high confidence* that Antarctic amplification will emerge as the Southern Ocean surface warms on centennial time scales, although only *low confidence* regarding whether this feature will emerge during the 21st century. {7.4.4}

The assessed global warming potentials (GWP) and global temperature-change potentials (GTP) for methane and nitrous oxide are slightly lower than in AR5 due to revised estimates of their lifetimes and updated estimates of their indirect chemical effects (*medium confidence*). The assessed metrics now also include the carbon cycle response for non-CO_2 gases. The carbon cycle estimate is lower than in AR5, but there is *high confidence* in the need for its inclusion and in the quantification methodology. Metrics for methane from fossil fuel sources account for the extra fossil CO_2 that these emissions contribute to the atmosphere and so have slightly higher emissions metric values than those from biogenic sources (*high confidence*). {7.6.1}

New emissions metric approaches such as GWP* and the combined-GTP (CGTP) are designed to relate emissions rates of short-lived gases to cumulative emissions of CO_2. These metric approaches are well suited to estimate the GSAT response from aggregated emissions of a range of gases over time, which can be done by scaling the cumulative CO_2 equivalent emissions calculated with these metrics by the transient climate response to cumulative emissions of CO_2. For a given multi-gas emissions pathway, the estimated contribution of emissions to surface warming is improved by using either these new metric approaches or by treating short- and long-lived GHG emissions pathways separately, as compared to approaches that aggregate emissions of GHGs using standard GWP or GTP emissions metrics. By contrast, if emissions are weighted by their 100-year GWP or GTP values, different multi-gas emissions pathways with the same aggregated CO_2 equivalent emissions rarely lead to the same estimated temperature outcome (*high confidence*). {7.6.1, Box 7.3}

The choice of emissions metric affects the quantification of net zero GHG emissions and therefore the resulting temperature outcome after net zero emissions are achieved. In general, achieving net zero CO_2 emissions and declining non-CO_2 radiative forcing would be sufficient to prevent additional human-caused warming. Reaching net zero GHG emissions as quantified by GWP-100 typically results in global temperatures that peak and then decline after net zero GHGs emissions are achieved, though this outcome depends on the relative sequencing of mitigation of short-lived and long-lived species. In contrast, reaching net zero GHG emissions when quantified using new emissions metrics such as CGTP or GWP* would lead to approximate temperature stabilization (*high confidence*). {7.6.2}

7.1 Introduction, Conceptual Framework, and Advances Since the Fifth Assessment Report

This chapter assesses the major physical processes that affect the evolution of Earth's energy budget and the associated changes in surface temperature and the broader climate system, integrating elements that were dealt with separately in previous reports.

The top-of-atmosphere (TOA) energy budget determines the net amount of energy entering or leaving the climate system. Its time variations can be monitored in three ways, using: (i) satellite observations of the radiative fluxes at the TOA; (ii) observations of the accumulation of energy in the climate system; and (iii) observations of surface energy fluxes. When the TOA energy budget is changed by a human or natural cause (a 'radiative forcing'), the climate system responds by warming or cooling (i.e., the system gains or loses energy). Understanding of changes in the Earth's energy flows helps understanding of the main physical processes driving climate change. It also provides a fundamental test of climate models and their projections.

This chapter principally builds on the IPCC Fifth Assessment Report (AR5; Boucher, 2012; Church et al., 2013; M. Collins et al., 2013; Flato et al., 2013; Hartmann et al., 2013; Myhre et al., 2013b; Rhein et al., 2013). It also builds on the subsequent IPCC Special Report on Global Warming of 1.5°C (SR1.5; IPCC, 2018), the Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC; IPCC, 2019a) and the Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCCL; IPCC, 2019b), as well as community-led assessments (e.g., Bellouin et al. (2020) covering aerosol radiative forcing and Sherwood et al. (2020) covering equilibrium climate sensitivity).

Throughout this chapter, global surface air temperature (GSAT) is used to quantify surface temperature change (Cross-Chapter Box 2.3 and Section 4.3.4). The total energy accumulation in the Earth system represents a metric of global change that is complementary to GSAT but shows considerably less variability on interannual-to-decadal time scales (Section 7.2.2). Research and new observations since AR5 have improved scientific confidence in the quantification of changes in the global energy inventory and corresponding estimates of Earth's energy imbalance (Section 7.2). Improved understanding of adjustments to radiative forcing and of aerosol–cloud interactions have led to revisions of forcing estimates (Section 7.3). New approaches to the quantification and treatment of feedbacks (Section 7.4) have improved the understanding of their nature and time-evolution, leading to a better understanding of how these feedbacks relate to equilibrium climate sensitivity (ECS). This has helped to reconcile disparate estimates of ECS from different lines of evidence (Section 7.5). Innovations in the use of emissions metrics have clarified the relationships between metric choice and temperature policy goals (Section 7.6), linking this chapter to WGIII which provides further information on metrics, their use, and policy goals beyond temperature. *Very likely* (5–95%) ranges are presented unless otherwise indicated. In particular, the addition of '(one standard deviation)' indicates that the range represents one standard deviation.

(a)

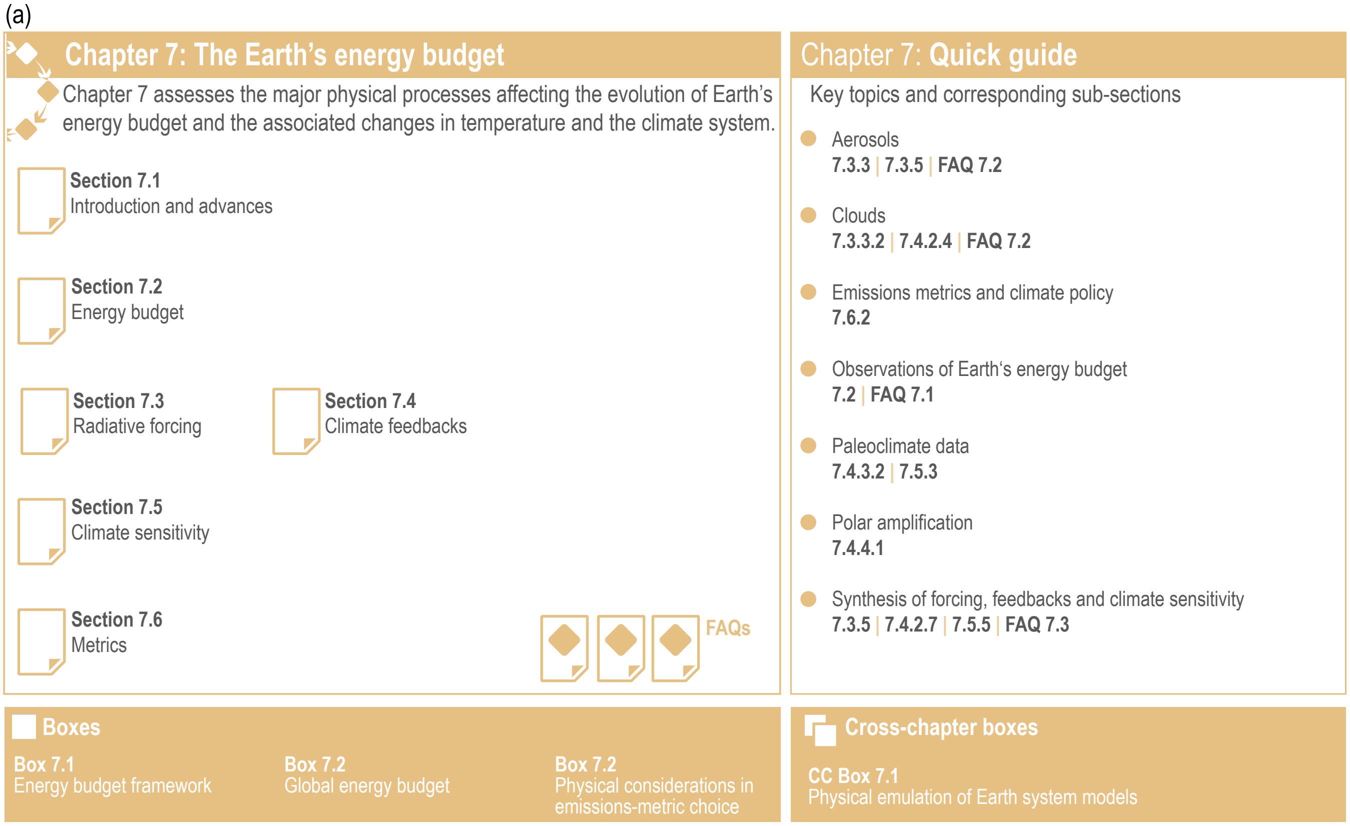


Figure 7.1 | Visual guide to Chapter 7. Panel **(a)** Overview of the chapter.

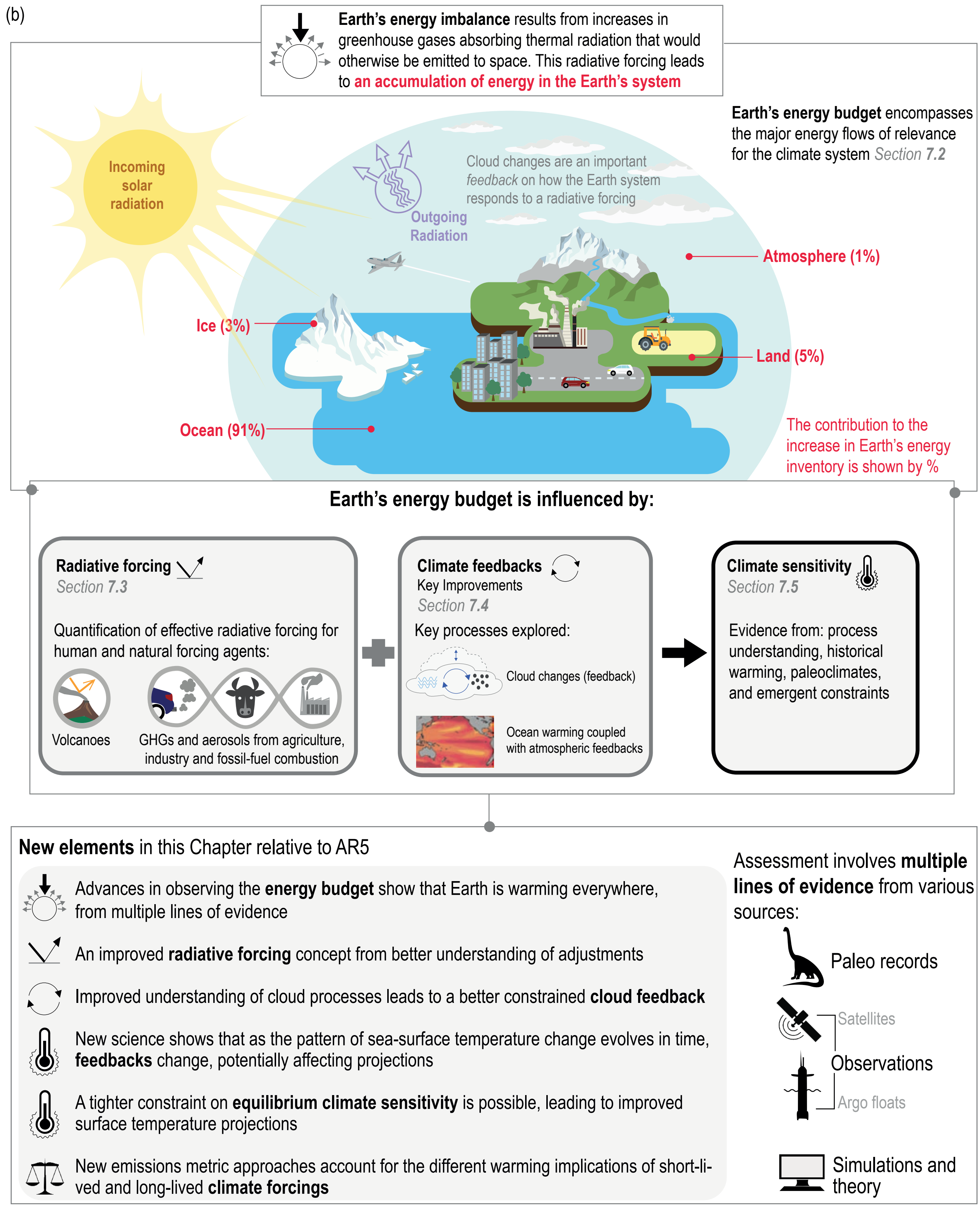


Figure 7.1 (continued): Panel **(b)** Visual abstract of the chapter, illustrating why the Earth's energy budget matters and how it relates to the underlying chapter assessment. The methods used to assess processes and key new findings relative to AR5 are highlighted. Upper schematic adapted from Von Schuckmann et al. (2020).

In Box 7.1 an energy budget framework is introduced, which forms the basis for the discussions and scientific assessment in the remainder of this chapter and across the Report. The framework reflects advances in the understanding of the Earth system response to climate forcing since the publication of AR5. A schematic of this framework and the key changes relative to the science reported in AR5 are provided in Figure 7.1.

A simple way to characterize the behaviour of multiple aspects of the climate system at once is to summarize them using global-scale metrics. This Report distinguishes between 'climate metrics' (e.g., ECS, TCR) and 'emissions metrics' (e.g., global warming potential, GWP, or global temperature-change potential, GTP), but this distinction is not definitive. Climate metrics are generally used to summarize aspects of the surface temperature response (Box 7.1). Emissions metrics are generally used to summarize the relative effects of emissions of different forcing agents, usually greenhouse gases (GHGs; Section 7.6). The climate metrics used in this report typically evaluate how the Earth system response varies with atmospheric gas concentration or change in radiative forcing. Emissions metrics evaluate how radiative forcing or a key climate variable (such as GSAT) is affected by the emissions of a certain amount of gas. Emissions-related metrics are sometimes used in mitigation policy decisions such as trading GHG reduction measures and life cycle analysis. Climate metrics are useful to gauge the range of future climate impacts for adaptation decisions under a given emissions pathway. Metrics such as the transient climate response to cumulative emissions of carbon dioxide (TCRE) are used in both adaptation and mitigation contexts: for gauging future global surface temperature change under specific emissions scenarios, and to estimate remaining carbon budgets that are used to inform mitigation policies (Section 5.5).

Given that TCR and ECS are metrics of GSAT response to a theoretical doubling of atmospheric CO_2 (Box 7.1), they do not directly correspond to the warming that would occur under realistic forcing scenarios that include time-varying CO_2 concentrations and non-CO_2 forcing agents (such as aerosols and land-use changes). It has been argued that TCR, as a metric of transient warming, is more policy-relevant than ECS (Frame et al., 2006; Schwartz, 2018). However, as detailed in Chapter 4, both established and recent results (Forster et al., 2013; Gregory et al., 2015; Marotzke and Forster, 2015; Grose et al., 2018; Marotzke, 2019) indicate that TCR and ECS help explain variation across climate models both over the historical period and across a range of concentration-driven future scenarios. In emission-driven scenarios the carbon cycle response is also important (Smith et al., 2019). The proportion of variation explained by ECS and TCR varies with scenario and the time period considered, but both past and future surface warming depend on these metrics (Section 7.5.7).

Regional changes in temperature, rainfall, and climate extremes have been found to correlate well with the forced changes in GSAT within Earth System Models (ESMs; Section 4.6.1; Giorgetta et al., 2013; Tebaldi and Arblaster, 2014; Seneviratne et al., 2016). While this so-called 'pattern scaling' has important limitations arising from, for instance, localized forcings, land-use changes, or internal climate variability (Deser et al., 2012; Luyssaert et al., 2014), changes in GSAT nonetheless explain a substantial fraction of inter-model differences in projections of regional climate changes over the 21st century (Tebaldi and Knutti, 2018). This Chapter's assessments of TCR and ECS thus provide constraints on future global and regional climate change (Chapters 4 and 11).

Box 7.1 | The Energy Budget Framework: Forcing and Response

The forcing and response energy budget framework provides a methodology to assess the effect of individual drivers of global surface temperature response, and to facilitate the understanding of the key phenomena that set the magnitude of this temperature response. The framework used here is developed from that adopted in previous IPCC reports (see Ramaswamy et al., 2019 for a discussion). **Effective Radiative Forcing (ERF)**, introduced in AR5 (Boucher et al., 2013; Myhre et al., 2013b) is more explicitly defined in this Report and is employed as the central definition of radiative forcing (Sherwood et al., 2015, Box 7.1, Figure 1a). The framework has also been extended to allow variations in feedbacks over different time scales and with changing climate state (Sections 7.4.3 and 7.4.4).

The global surface air temperature (GSAT) response to perturbations that give rise to an energy imbalance is traditionally approximated by the following linear energy budget equation, in which ΔN represents the change in the top-of-atmosphere (TOA) net energy flux, ΔF is an **effective radiative forcing** perturbation to the TOA net energy flux, α is the net **feedback parameter** and ΔT is the change in **GSAT**:

$$\Delta N = \Delta F + \alpha \Delta T \qquad \text{(Box 7.1, Equation 7.1)}$$

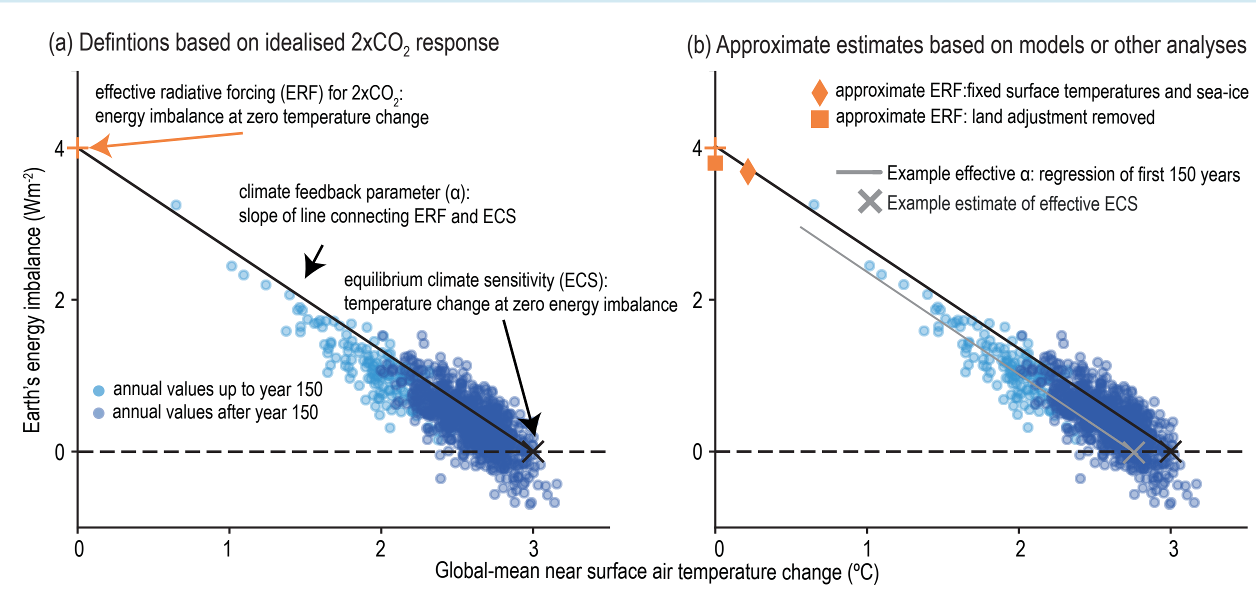
ERF is the TOA energy budget change resulting from the perturbation, excluding any radiative response related to a change in GSAT (i.e., $\Delta T = 0$). Climate feedbacks (α) represent those processes that change the TOA energy budget in response to a given ΔT.

The **effective radiative forcing, ERF** (ΔF; units: W m^{-2}) quantifies the change in the net TOA energy flux of the Earth system due to an imposed perturbation (e.g., changes in greenhouse gas or aerosol concentrations, in incoming solar radiation, or land-use change). ERF is expressed as a change in net downward radiative flux at the TOA following adjustments in both tropospheric and stratospheric temperatures, water vapour, clouds, and some surface properties, such as surface albedo from vegetation changes, that are uncoupled to

7

Box 7.1 (continued)

any GSAT change (Smith et al., 2018b). These adjustments affect the TOA energy balance and hence the ERF. They are generally assumed to be linear and additive (Section 7.3.1). Accounting for such processes gives an estimate of ERF that is more representative of the climate change response associated with forcing agents than stratospheric-temperature-adjusted radiative forcing (SARF) or the instantaneous radiative forcing (IRF; Section 7.3.1). Adjustments are processes that are independent of GSAT change, whereas feedbacks refer to processes caused by GSAT change. Although adjustments generally occur on time scales of hours to several months, and feedbacks respond to ocean surface temperature changes on time scales of a year or more, time scale is not used to separate the definitions. ERF has often been approximated as the TOA energy balance change due to an imposed perturbation in climate model simulations with sea surface temperature and sea-ice concentrations set to their pre-industrial climatological values (e.g., Forster et al., 2016). However, to match the adopted forcing–feedback framework, the small effects of any GSAT change from changes in land surface temperatures need to be removed from the TOA energy balance in such simulations to give an approximate measure of ERF (Box 7.1, Figure 1b and Section 7.3.1).



Box 7.1, Figure 1 | Schematics of the forcing–feedback framework adopted within the assessment, following Equation 7.1. The figure illustrates how the Earth's top-of-atmosphere (TOA) net energy flux might evolve for a hypothetical doubling of atmospheric CO_2 concentration above pre-industrial levels, where an initial positive energy imbalance (energy entering the Earth system, shown on the y-axis) is gradually restored towards equilibrium as the surface temperature warms (shown on the x-axis). **(a)** illustrates the definitions of effective radiative forcing (ERF) for the special case of a doubling of atmospheric CO_2 concentration, the feedback parameter and the equilibrium climate sensitivity (ECS). **(b)** illustrates how approximate estimates of these metrics are made within the chapter and how these approximations might relate to the exact definitions adopted in panel (a).

The **feedback parameter,** α (units: W m^{-2} °C^{-1}) quantifies the change in net energy flux at the TOA for a given change in GSAT. Many climate variables affect the TOA energy budget, and the feedback parameter can be decomposed, to first order, into a sum of terms

$$\alpha = \sum_x \frac{\partial N}{\partial x}\frac{dx}{d\mathrm{T}}$$

where x represents a variable of the Earth system that has a direct effect on the energy budget at the TOA. The sum of the feedback terms (i.e., α in Equation 7.1) governs Earth's equilibrium GSAT response to an imposed ERF. In previous assessments, α and the related ECS have been associated with a distinct set of physical processes (Planck response and changes in water vapour, lapse rate, surface albedo, and clouds; Charney et al., 1979). In this assessment, a more general definition of α and ECS is adopted such that they include additional Earth system processes that act across many time scales (e.g., changes in natural aerosol emissions or vegetation). Because, in our assessment, these additional processes sum to a near-zero value, including these additional processes does not change the assessed central value of ECS but does affect its assessed uncertainty range (Section 7.4.2). Note that there is no standardized notation or sign convention for the feedback parameter in the literature. Here the convention is used that the sum of all feedback terms (the net feedback parameter, α) is negative for a stable climate that radiates additional energy to space with a GSAT increase, with a more negative value of α corresponding to a stronger radiative response and thus a smaller GSAT change required to balance a change in ERF (Equation 7.1).

Box 7.1 (continued)

A change in process *x* amplifies the temperature response to a forcing when the associated feedback parameter α_x is positive (positive feedback) and dampens the temperature response when α_x is negative (negative feedback). New research since AR5 emphasizes how feedbacks can vary over different time scales (Section 7.4.4) and with climate state (Section 7.4.3), giving rise to the concept of an 'effective feedback parameter' that may be different from the equilibrium value of the feedback parameter governing ECS (Section 7.4.3).

The **equilibrium climate sensitivity, ECS** (units: °C), is defined as the equilibrium value of ΔT in response to a sustained doubling of atmospheric CO_2 concentration from a pre-industrial reference state. The value of ERF for this scenario is denoted by ΔF_{2xCO2}, giving ECS = $-\Delta F_{2xCO2}/\alpha$ from Equation 7.1 applied at equilibrium (Box 7.1, Figure 1a and Section 7.5). 'Equilibrium' refers to a steady state where ΔN averages to zero over a multi-century period. ECS is representative of the multi-century to millennial ΔT response to ΔF_{2xCO2}, and is based on a CO_2 concentration change so any feedbacks that affect the atmospheric concentration of CO_2 do not influence its value. As employed here, ECS also excludes the long-term response of the ice sheets (Section 7.4.2.6) which may take multiple millennia to reach equilibrium, but includes all other feedbacks. Due to a number of factors, studies rarely estimate ECS or α at equilibrium or under CO_2 forcing alone. Rather, they give an 'effective feedback parameter' (Section 7.4.1 and Box 7.1, Figure 1b) or an 'effective ECS' (Section 7.5.1 and Box 7.1, Figure 1b), which represent approximations to the true values of α or ECS. The 'effective ECS' represents the equilibrium value of ΔT in response to a sustained doubling of atmospheric CO_2 concentration that would occur assuming the 'effective feedback parameter' applied at that equilibrium state. For example, a feedback parameter can be estimated from the linear slope of ΔN against ΔT over a set number of years within ESM simulations of an abrupt doubling or quadrupling of atmospheric CO_2 (2×CO_2 or 4×CO_2, respectively), and the ECS can be estimated from the intersect of this regression line with $\Delta N = 0$ (Box 7.1, Figure 1b). To infer ECS from a given estimate of effective ECS necessitates that assumptions are made for how ERF varies with CO_2 concentration (Section 7.3.2) and how the slope of ΔN against ΔT relates to the slope of the straight line from ERF to ECS (Section 7.5 and Box 7.1, Figure 1b). Care has to be taken when comparing results across different lines of evidence to translate their estimates of the effective ECS into the ECS definition used here (Section 7.5.5).

The **transient climate response, TCR** (units: °C), is defined as the ΔT for the hypothetical scenario in which CO_2 increases at 1% yr^{-1} from a pre-industrial reference state to the time of a doubling of atmospheric CO_2 concentration (year 70; Section 7.5). TCR is based on a CO_2 concentration change, so any feedbacks that affect the atmospheric concentration of CO_2 do not influence its value. It is a measure of transient warming accounting for the strength of climate feedbacks and ocean heat uptake. The **transient climate response to cumulative emissions of carbon dioxide (TCRE)** is defined as the transient ΔT per 1000 Gt C of cumulative CO_2 emissions increase since the pre-industrial period. TCRE combines information on the airborne fraction of cumulative CO_2 emissions (the fraction of the total CO_2 emitted that remains in the atmosphere at the time of doubling, which is determined by carbon cycle processes) with information on the TCR. TCR is assessed in this chapter, whereas TCRE is assessed in Chapter 5 (Section 5.5).

7.2 Earth's Energy Budget and its Changes Through Time

Earth's energy budget encompasses the major energy flows of relevance for the climate system (Figure 7.2). Virtually all the energy that enters or leaves the climate system does so in the form of radiation at the TOA. The TOA energy budget is determined by the amount of incoming solar (shortwave) radiation and the outgoing radiation that is composed of reflected solar radiation and outgoing thermal (longwave) radiation emitted by the climate system. In a steady-state climate, the outgoing and incoming radiative components are essentially in balance in the long-term global mean, although there are still fluctuations around this balanced state that arise through internal climate variability (Brown et al., 2014; Palmer and McNeall, 2014). However, anthropogenic forcing has given rise to a persistent imbalance in the global mean TOA radiation budget that is often referred to as Earth's energy imbalance (e.g., Trenberth et al., 2014; von Schuckmann et al., 2016), which is a key element of the energy budget framework (*N*; Box 7.1, Equation 7.1) and an important metric of the rate of global climate change (Hansen et al., 2005a; von Schuckmann et al., 2020). In addition to the TOA energy fluxes, Earth's energy budget al.o includes the internal flows of energy within the climate system, which characterize the climate state. The surface energy budget consists of the net solar and thermal radiation as well as the non-radiative components such as sensible, latent and ground heat fluxes (Figure 7.2, upper panel). It is a key driver of the global water cycle, atmosphere and ocean dynamics, as well as a variety of surface processes.

7.2.1 Present-day Energy Budget

Figure 7.2 (upper panel) shows a schematic representation of Earth's energy budget for the early 21st century, including globally averaged estimates of the individual components (Wild et al., 2015). Clouds are important modulators of global energy fluxes. Thus, any perturbations in the cloud fields, such as forcing by aerosol–cloud interactions (Section 7.3) or through cloud feedbacks (Section 7.4) can have a strong influence on the energy distribution in the climate system. To illustrate the overall effects that clouds exert on energy fluxes, Figure 7.2 (lower panel) also shows the energy budget in the absence

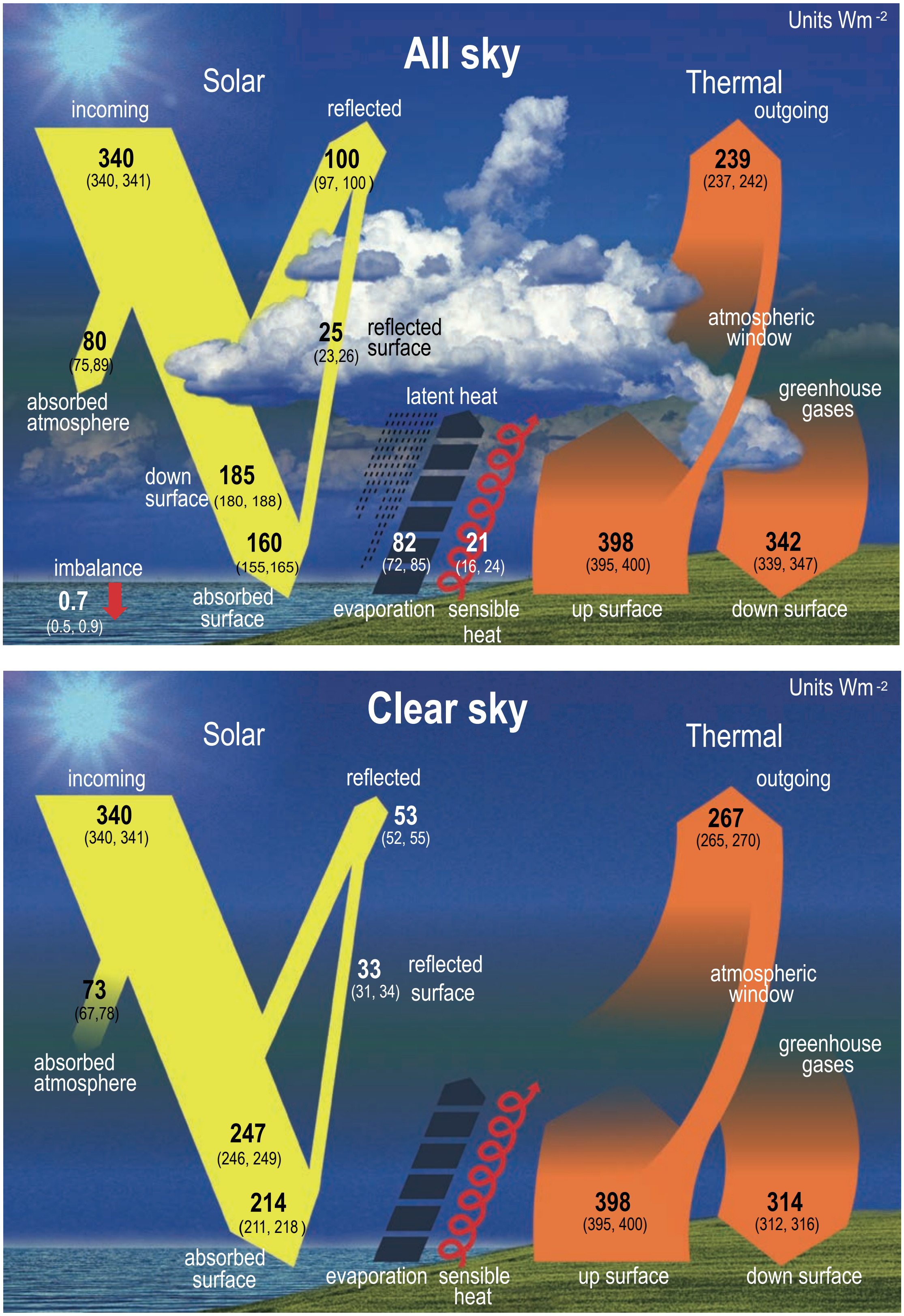


Figure 7.2 | Schematic representation of the global mean energy budget of the Earth (upper panel), and its equivalent without considerations of cloud effects (lower panel). Numbers indicate best estimates for the magnitudes of the globally averaged energy balance components in W m^{-2} together with their uncertainty ranges in parentheses (5–95% confidence range), representing climate conditions at the beginning of the 21st century. Note that the cloud-free energy budget shown in the lower panel is not the one that Earth would achieve in equilibrium when no clouds could form. It rather represents the global mean fluxes as determined solely by removing the clouds but otherwise retaining the entire atmospheric structure. This enables the quantification of the effects of clouds on the Earth energy budget and corresponds to the way clear-sky fluxes are calculated in climate models. Thus, the cloud-free energy budget is not closed and therefore the sensible and latent heat fluxes are not quantified in the lower panel. Figure adapted from Wild et al. (2015, 2019).

of clouds, with otherwise identical atmospheric and surface radiative properties. It has been derived by taking into account information contained in both in situ and satellite radiation measurements taken under cloud-free conditions (Wild et al., 2019). A comparison of the upper and lower panels in Figure 7.2 shows that without clouds, 47 W m^{-2} less solar radiation is reflected back to space globally (53 ± 2 W m^{-2} instead of 100 ± 2 W m^{-2}), while 28 W m^{-2} more thermal radiation is emitted to space (267 ± 3 W m^{-2} instead of 239 ± 3 W m^{-2}). As a result, there is a 20 W m^{-2} radiative imbalance at the TOA in the clear-sky energy budget (Figure 7.2, lower panel), suggesting that the Earth would warm substantially if there were no clouds.

The AR5 (Church et al., 2013; Hartmann et al., 2013; Myhre et al., 2013b) highlighted the progress that had been made in quantifying the TOA radiation budget following new satellite observations that became available in the early 21st century (Clouds and the Earth's Radiant Energy System, CERES; Solar Radiation and Climate Experiment, SORCE). Progress in the quantification of changes in incoming solar radiation at the TOA is discussed in Chapter 2 (Section 2.2). Since AR5, the CERES Energy Balance EBAF Ed4.0 product was released, which includes algorithm improvements and consistent input datasets throughout the record (Loeb et al., 2018b). However, the overall precision of these fluxes (uncertainty in global mean TOA flux of 1.7% (1.7 W m^{-2}) for reflected solar and 1.3% (3.0 W m^{-2}) for outgoing thermal radiation at the 90% confidence level) is not sufficient to quantify the Earth's energy imbalance in absolute terms. Therefore, the CERES EBAF reflected solar and emitted thermal TOA fluxes were adjusted, within the estimated uncertainties, to ensure that the net TOA flux for July 2005 to June 2015 was consistent with the estimated Earth's energy imbalance for the same period based on ocean heat content (OHC) measurements and energy uptake estimates for the land, cryosphere and atmosphere (Section 7.2.2.2; Johnson et al., 2016; Riser et al., 2016). ESMs typically show good agreement with global mean TOA fluxes from CERES-EBAF. However, as some ESMs are known to calibrate their TOA fluxes to CERES or similar data (Hourdin et al., 2017), this is not necessarily an indication of model accuracy, especially as ESMs show significant discrepancies on regional scales, often related to their representation of clouds (Trenberth and Fasullo, 2010; Donohoe and Battisti, 2012; Hwang and Frierson, 2013; J.-L.F. Li et al., 2013; Dolinar et al., 2015; Wild et al., 2015).

The radiation components of the surface energy budget are associated with substantially larger uncertainties than at the TOA, since they are less directly measured by passive satellite sensors and require retrieval algorithms and ancillary data for their estimation (Raschke et al., 2016; Kato et al., 2018; Huang et al., 2019). Confidence in the quantification of the global mean surface radiation components has increased recently, as independent estimates now converge to within a few W m^{-2} (Wild, 2017). Current best estimates for downward solar and thermal radiation at Earth's surface are approximately 185 W m^{-2} and 342 W m^{-2}, respectively (Figure 7.2). These estimates are based on complementary approaches that make use of satellite products from active and passive sensors (L'Ecuyer et al., 2015; Kato et al., 2018) and information from surface observations and Earth system models (ESMs; Wild et al., 2015). Inconsistencies in the quantification of the global mean energy and water budgets discussed in AR5 (Hartmann et al., 2013) have been reconciled within the (considerable) uncertainty ranges of their individual components (Wild et al., 2013, 2015; L'Ecuyer et al., 2015). However, on regional scales, the closure of the surface energy budgets remains a challenge with satellite-derived datasets (Loeb et al., 2014; L'Ecuyer et al., 2015; Kato et al., 2016). Nevertheless, attempts have been made to derive surface energy budgets over land and ocean (Wild et al., 2015), over the Arctic (Christensen et al., 2016b), and over individual continents and ocean basins (L'Ecuyer et al., 2015; Thomas et al., 2020). Since AR5, the quantification of the uncertainties in surface energy flux datasets has improved. Uncertainties in global monthly mean downward solar and thermal fluxes in the CERES-EBAF surface dataset are, respectively, 10 W m^{-2} and 8 W m^{-2} (converted to 5–95% ranges; Kato et al., 2018). The uncertainty in the surface fluxes for polar regions is larger than in other regions (Kato et al., 2018) due to the limited number of surface sites and larger uncertainty in surface observations (Previdi et al., 2015). The uncertainties in ocean mean latent and sensible heat fluxes are approximately 11 W m^{-2} and 5 W m^{-2} (converted to 5–95% ranges), respectively (L'Ecuyer et al., 2015). A recent review of the latent and sensible heat flux accuracies over the period 2000–2007 highlights significant differences between several gridded products over ocean, where root-mean-squared differences between the multi-product ensemble and data at more than 200 moorings reached up to 25 W m^{-2} for latent heat and 5 W m^{-2} for sensible heat (Bentamy et al., 2017). This uncertainty stems from the retrieval of flux-relevant meteorological variables, as well as from differences in the flux parametrizations (Yu, 2019). Estimating the uncertainty in sensible and latent heat fluxes over land is difficult because of the large temporal and spatial variability. The flux values over land computed with three global datasets vary by 10–20% (L'Ecuyer et al., 2015).

ESMs also show larger discrepancies in their surface energy fluxes than at the TOA due to weaker observational constraints, with a spread of typically 10–20 W m^{-2} in the global average, and an even greater spread at regional scales (J.-L.F. Li et al., 2013; Wild et al., 2013; Boeke and Taylor, 2016; Wild, 2017, 2020; C. Zhang et al., 2018). Differences in the land-averaged downward thermal and solar radiation in CMIP5 ESMs amount to more than 30 and 40 W m^{-2}, respectively (Wild et al., 2015). However, in the global multi-model mean, the magnitudes of the energy budget components of the CMIP6 ESMs generally show better agreement with reference estimates than previous model generations (Wild, 2020).

In summary, since AR5, the magnitudes of the global mean energy budget components have been quantified more accurately, not only at the TOA, but also at the Earth's surface, where independent estimates of the radiative components have converged (*high confidence*). Considerable uncertainties remain in regional surface energy budget estimates as well as their representation in climate models.

7.2.2 Changes in Earth's Energy Budget

7.2.2.1 Changes in Earth's Top-of-atmosphere Energy Budget

Since 2000, changes in top-of-atmosphere (TOA) energy fluxes can be tracked from space using CERES satellite observations (Figure 7.3). The variations in TOA energy fluxes reflect the influence of internal climate variability, particularly that of El Niño–Southern Oscillation

(ENSO), in addition to radiative forcing of the climate system and climate feedbacks (Allan et al., 2014; Loeb et al., 2018b). For example, globally, the reduction in both outgoing thermal and reflected solar radiation during La Niña conditions in 2008/2009 led to an energy gain for the climate system, whereas enhanced outgoing thermal and reflected solar radiation caused an energy loss during the El Niños of 2002/2003 and 2009/2010 (Figure 7.3; Loeb et al., 2018b). An ensemble of CMIP6 models is able to track the variability in global mean TOA fluxes observed by CERES, when driven with prescribed sea surface temperatures (SSTs) and sea ice concentrations (Figure 7.3; Loeb et al., 2020). Under cloud-free conditions, the CERES record shows a near zero trend in outgoing thermal radiation (Loeb et al., 2018b), which – combined with an increasing surface upwelling thermal flux – implies an increasing clear-sky greenhouse effect (Raghuraman et al., 2019). Conversely, clear-sky solar reflected TOA radiation in the CERES record covering March 2000 to September 2017 shows a decrease due to

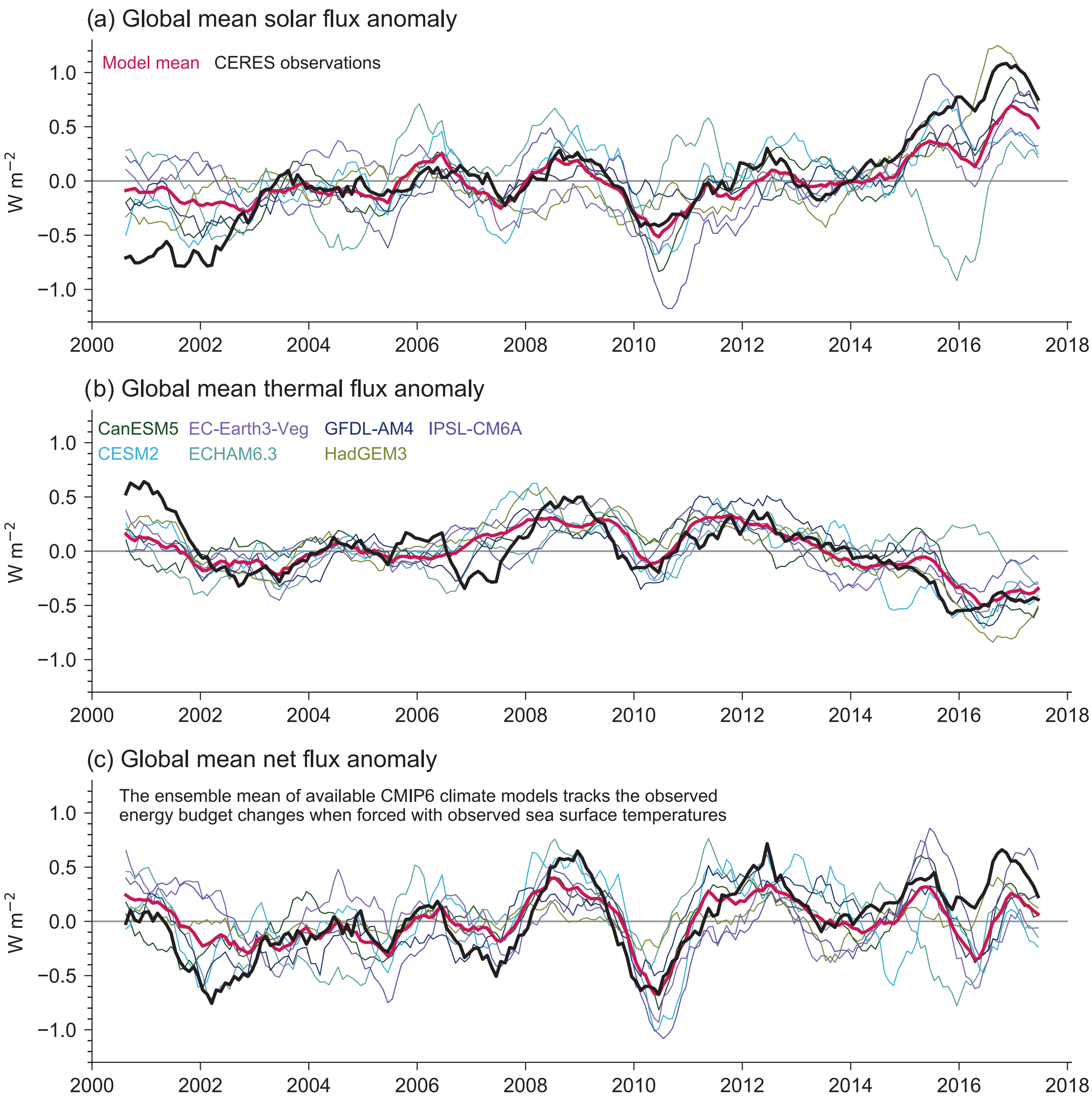


Figure 7.3 | Anomalies in global mean all-sky top-of-atmosphere (TOA) fluxes from CERES-EBAF Ed4.0 (solid black lines) and various CMIP6 climate models (coloured lines) in terms of (a) reflected solar, (b) emitted thermal and (c) net TOA fluxes. The multi-model means are additionally depicted as solid red lines. Model fluxes stem from simulations driven with prescribed sea surface temperatures (SSTs) and all known anthropogenic and natural forcings. Shown are anomalies of 12-month running means. All flux anomalies are defined as positive downwards, consistent with the sign convention used throughout this chapter. The correlations between the multi-model means (solid red lines) and the CERES records (solid black lines) for 12-month running means are: 0.85 for the global mean reflected solar; 0.73 for outgoing thermal radiation; and 0.81 for net TOA radiation. Figure adapted from Loeb et al. (2020). Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

reductions in aerosol optical depth in the Northern Hemisphere and sea ice fraction (Loeb et al., 2018a; Paulot et al., 2018).

An effort to reconstruct variations in net TOA fluxes back to 1985, based on a combination of satellite data, atmospheric reanalysis and high-resolution climate model simulations (Allan et al., 2014; Liu et al., 2020), exhibits strong interannual variability associated with the volcanic eruption of Mount Pinatubo in 1991 and the ENSO events before 2000. The same reconstruction suggests that Earth's energy imbalance increased by several tenths of a W m^{-2} between the periods 1985–1999 and 2000–2016, in agreement with the assessment of changes in the global energy inventory (Section 7.2.2.2, and Box 7.2, Figure 1). Comparisons of year-to-year variations in Earth's energy imbalance estimated from CERES and independent estimates based on ocean heat content change are significantly correlated with similar phase and magnitude (Johnson et al., 2016; Meyssignac et al., 2019), promoting confidence in both satellite and in situ-based estimates (Section 7.2.2.2).

In summary, variations in the energy exchange between Earth and space can be accurately tracked since the advent of improved observations since the year 2000 (*high confidence*), while reconstructions indicate that the Earth's energy imbalance was larger in the 2000s than in the 1985–1999 period (*high confidence*).

7.2.2.2 Changes in the Global Energy Inventory

The global energy inventory quantifies the integrated energy gain of the climate system associated with global ocean heat uptake, warming of the atmosphere, warming of the land, and melting of ice. Due to energy conservation, the rate of accumulation of energy in the Earth system (Section 7.1) is equivalent to the Earth energy imbalance (ΔN in Box 7.1, Equation 7.1). On annual and longer time scales, changes in the global energy inventory are dominated by changes in global ocean heat content (OHC; Rhein et al., 2013; Palmer and McNeall, 2014; Johnson et al., 2016). Thus, observational estimates and climate model simulations of OHC change are critical to the understanding of both past and future climate change (Sections 2.3.3.1, 3.5.1.3, 4.5.2.1 and 9.2.2.1).

Since AR5, both modelling and observation-based studies have established Earth's energy imbalance (characterized by OHC change) as a more robust metric of the rate of global climate change than GSAT on interannual-to-decadal time scales (Palmer and McNeall, 2014; von Schuckmann et al., 2016; Wijffels et al., 2016; Cheng et al., 2018; Allison et al., 2020). This is because GSAT is influenced by large unforced variations, for example linked to ENSO and Pacific Decadal Variability (Roberts et al., 2015; Yan et al., 2016; Cheng et al., 2018). Measuring OHC change more comprehensively over the full ocean depth results in a higher signal-to-noise ratio and a time series that increases steadily over time (Box 7.2, Figure 1; Allison et al., 2020). In addition, understanding of the potential effects of historical ocean sampling on estimated global ocean heating rates has improved (Durack et al., 2014; Good, 2017; Allison et al., 2019) and there are now more estimates of OHC change available that aim to mitigate the effect of limited observational sampling in the Southern Hemisphere (Lyman and Johnson, 2008; Cheng et al., 2017; Ishii et al., 2017).

The assessment of changes in the global energy inventory for the periods 1971–2018, 1993–2018 and 2006–2018 draws upon the latest observational time series and the assessments presented in other chapters of this report. The estimates of OHC change come directly from the assessment presented in Chapter 2 (Section 2.3.3.1). The assessment of land and atmospheric heating comes from von Schuckmann et al. (2020), based on the estimates of Cuesta-Valero et al. (2021) and Steiner et al. (2020), respectively. Heating of inland waters, including lakes, reservoirs and rivers, is estimated to account for <0.1% of the total energy change, and is therefore omitted from this assessment (Vanderkelen et al., 2020). The cryosphere contribution from the melting of grounded ice is based on the mass-loss assessments presented in Chapter 9, Section 9.4.1 (Greenland Ice Sheet), Section 9.4.2 (Antarctic Ice Sheet) and Section 9.5.1 (glaciers). Following AR5, the estimate of heating associated with loss of Arctic sea ice is based on a reanalysis (Schweiger et al., 2011), following the methods described by Slater et al. (2021). Chapter 9 (Section 9.3.2) finds no significant trend in Antarctic sea ice area over the observational record, so a zero contribution is assumed. Ice melt associated with the calving and thinning of floating ice shelves is based on the decadal rates presented in Slater et al. (2021). For all cryospheric components, mass loss is converted to heat input using a latent heat of fusion of 3.34×10^5 J Kg^{-1} $°C^{-1}$ with the second-order contributions from variations associated with ice type and warming of ice from sub-freezing temperatures disregarded, as in AR5. The net change in energy, quantified in Zettajoules (1 ZJ = 10^{21} Joules), is computed for each component as the difference between the first and last year of each period (Table 7.1). The uncertainties in the depth-interval contributions to OHC are summed to get the uncertainty in global OHC change. All other uncertainties are assumed to be independent and added in quadrature.

For the period 1971–2010, AR5 (Rhein et al., 2013) found an increase in the global energy inventory of 274 [196 to 351] ZJ with a 93% contribution from total OHC change, approximately 3% for both ice melt and land heating, and approximately 1% for warming of the atmosphere. For the same period, this Report finds an upwards revision of OHC change for the upper (<700 m depth) and deep (>700 m depth) ocean of approximately 8% and 20%, respectively, compared to AR5 and a modest increase in the estimated uncertainties associated with the ensemble approach of Palmer et al. (2021). The other substantive change compared to AR5 is the updated assessment of land heating, with values approximately double those assessed previously, based on a more comprehensive analysis of the available observations (von Schuckmann et al., 2020; Cuesta-Valero et al., 2021). The result of these changes is an assessed energy gain of 329 [224 to 434] ZJ for the period 1971–2010, which is consistent with AR5 within the estimated uncertainties, despite the systematic increase.

The assessed changes in the global energy inventory (Box 7.2, Figure 1, and Table 7.1) yields an average value for Earth's energy imbalance (N in Box 7.1, Equation 7.1) of 0.57 [0.43 to 0.72] W m^{-2} for the period 1971–2018, expressed relative to Earth's surface area (*high confidence*). The estimates for the periods 1993–2018 and 2006–2018 yield substantially larger values of 0.72 [0.55 to 0.89] W m^{-2} and 0.79 [0.52 to 1.06] W m^{-2}, respectively, consistent with the increased radiative forcing from GHGs (*high confidence*). For the

Table 7.1 | Contributions of the different components of the global energy inventory for the periods 1971–2018, 1993–2018 and 2006–2018 (Box 7.2 and Cross-Chapter Box 9.1). Energy changes are computed as the difference between annual mean values or year mid-points. The total heating rates correspond to Earth's energy imbalance and are expressed per unit area of Earth's surface.

Component	1971–2018		1993–2018		2006–2018	
	Energy Gain (ZJ)	%	Energy Gain (ZJ)	%	Energy Gain (ZJ)	%
Ocean	396.0 [285.7 to 506.2]	91.0	263.0 [194.1 to 331.9]	91.0	138.8 [86.4 to 191.3]	91.1
0–700 m	241.6 [162.7 to 320.5]	55.6	151.5 [114.1 to 188.9]	52.4	75.4 [48.7 to 102.0]	49.5
700–2000 m	123.3 [96.0 to 150.5]	28.3	82.8 [59.9 to 105.6]	28.6	49.7 [29.0 to 70.4]	32.6
>2000 m	31.0 [15.7 to 46.4]	7.1	28.7 [14.5 to 43.0]	10.0	13.8 [7.0 to 20.6]	9.0
Land	21.8 [18.6 to 25.0]	5.0	13.7 [12.4 to 14.9]	4.7	7.2 [6.6 to 7.8]	4.7
Cryosphere	11.5 [9.0 to 14.0]	2.7	8.8 [7.0 to 10.5]	3.0	4.7 [3.3 to 6.2]	3.1
Atmosphere	5.6 [4.6 to 6.7]	1.3	3.8 [3.2 to 4.3]	1.3	1.6 [1.2 to 2.1]	1.1
TOTAL	**434.9 [324.5 to 545.3] ZJ**		**289.2 [220.3 to 358.1] ZJ**		**152.4 [100.0 to 204.9] ZJ**	
Heating Rate	**0.57 [0.43 to 0.72] W m^{-2}**		**0.72 [0.55 to 0.89] W m^{-2}**		**0.79 [0.52 to 1.06] W m^{-2}**	

period 1971–2006, the total energy gain was 282 [177 to 387] ZJ, with an equivalent Earth energy imbalance of 0.50 [0.32 to 0.69] W m^{-2}. To put these numbers in context, the 2006–2018 average Earth system heating is equivalent to approximately 20 times the annual rate of global energy consumption in 2018.[1]

Consistent with AR5 (Rhein et al., 2013), this Report finds that ocean warming dominates the changes in the global energy inventory (*high confidence*), accounting for 91% of the observed change for all periods considered (Table 7.1). The contributions from the other components across all periods are approximately 5% from land heating, 3% for cryosphere heating and 1% associated with warming of the atmosphere (*high confidence*). The assessed percentage contributions are similar to the recent study by von Schuckmann et al. (2020) and the total heating rates are consistent within the assessed uncertainties. Cross-validation of heating rates based on satellite and in situ observations (Section 7.2.2.1), and closure of the global sea level budget using consistent datasets (Cross-Chapter Box 9.1 and Table 9.5), strengthen scientific confidence in the assessed changes in the global energy inventory relative to AR5.

7.2.2.3 Changes in Earth's Surface Energy Budget

The AR5 (Hartmann et al., 2013) reported pronounced changes in multi-decadal records of in situ observations of surface solar radiation, including a widespread decline between the 1950s and 1980s, known as 'global dimming', and a partial recovery thereafter, termed 'brightening' (Section 12.4). These changes have interacted with closely related elements of climate change, such as global and regional warming rates (Z. Li et al., 2016; Wild, 2016; Du et al., 2017; Zhou et al., 2018a), glacier melt (Ohmura et al., 2007; Huss et al., 2009), the intensity of the global water cycle (Wild, 2012) and terrestrial carbon uptake (Mercado et al., 2009). These observed changes have also been used as emergent constraints to quantify aerosol effective radiative forcing (Section 7.3.3.3).

Since AR5, additional evidence for dimming and/or subsequent brightening up to several percent per decade, based on direct surface observations, has been documented in previously less-studied areas of the globe, such as Iran, Bahrain, Tenerife, Hawaii, the Taklaman Desert and the Tibetan Plateau (Elagib and Alvi, 2013; You et al., 2013; Garcia et al., 2014; Longman et al., 2014; Rahimzadeh et al., 2015). Strong decadal trends in surface solar radiation remain evident after careful data quality assessment and homogenization of long-term records (Sanchez-Lorenzo et al., 2013, 2015; Manara et al., 2015, 2016; Wang et al., 2015; Z. Li et al., 2016; Wang and Wild, 2016; Y. He et al., 2018; Yang et al., 2018). Since AR5, new studies on the potential effects of urbanization on solar radiation trends indicate that these effects are generally small, with the exception of some specific sites in Russia and China (Wang et al., 2014; Imamovic et al., 2016; Tanaka et al., 2016). Also, surface-based solar radiation observations have been shown to be representative over large spatial domains of up to several degrees latitude/longitude on monthly and longer time scales (Hakuba et al., 2014; Schwarz et al., 2018). Thus, there is *high confidence* that the observed dimming between the 1950s and 1980s and the subsequent brightening are robust and do not arise from measurement artefacts or localized phenomena.

As noted in AR5 (Hartmann et al., 2013) and supported by recent studies, the trends in surface solar radiation are less spatially coherent since the beginning of the 21st century, with evidence for continued brightening in parts of Europe and the USA, some stabilization in China and India, and dimming in other areas (Augustine and Dutton, 2013; Sanchez-Lorenzo et al., 2015; Manara et al., 2016; Soni et al., 2016; Wang and Wild, 2016; Jahani et al., 2018; Pfeifroth et al., 2018; Yang et al., 2018; Schwarz et al., 2020). The CERES-EBAF satellite-derived dataset of surface solar radiation (Kato et al., 2018) does not indicate a globally significant trend over the short period 2001–2012 (Zhang et al., 2015), whereas a statistically significant increase in surface solar radiation of +3.4 W m^{-2} per decade over the period 1996–2010 has been found in the Satellite Application Facility on Climate Monitoring (CM SAF) record of the geostationary satellite Meteosat, which views Europe, Africa and adjacent ocean (Posselt et al., 2014).

Since AR5, there is additional evidence that strong decadal changes in surface solar radiation have occurred under cloud-free conditions, as shown for long-term observational records in Europe, USA, China, India and Japan (Xu et al., 2011; Gan et al., 2014; Manara et al., 2016;

1 https://ourworldindata.org/energy, accessed 13 April 2021.

Soni et al., 2016; Tanaka et al., 2016; Kazadzis et al., 2018; J. Li et al., 2018; Yang et al., 2019; Wild et al., 2021). This suggests that changes in the composition of the cloud-free atmosphere, primarily in aerosols, contributed to these variations, particularly since the second half of the 20th century (Wild, 2016). Water vapour and other radiatively active gases seem to have played a minor role (Wild, 2009; Mateos et al., 2013; Posselt et al., 2014; Yang et al., 2019). For Europe and East Asia, modelling studies also point to aerosols as an important factor for dimming and brightening by comparing simulations that include or exclude variations in anthropogenic aerosol and aerosol-precursor emissions (Golaz et al., 2013; Nabat et al., 2014; Persad et al., 2014; Folini and Wild, 2015; Turnock et al., 2015; Moseid et al., 2020). Moreover, decadal changes in surface solar radiation have often occurred in line with changes in anthropogenic aerosol emissions and associated aerosol optical depth (Streets et al., 2006; Wang and Yang, 2014; Storelvmo et al., 2016; Wild, 2016; Kinne, 2019). However, further evidence for the influence of changes in cloudiness on dimming and brightening is emphasized in some studies (Augustine and Dutton, 2013; Parding et al., 2014; Stanhill et al., 2014; Pfeifroth et al., 2018; Antuña-Marrero et al., 2019). Thus, the contribution of aerosol and clouds to dimming and brightening is still debated. The relative influence of cloud-mediated aerosol effects versus direct aerosol radiative effects on dimming and brightening in a specific region may depend on the prevailing pollution levels (Section 7.3.3; Wild, 2016).

ESMs and reanalyses often do not reproduce the full extent of observed dimming and brightening (Wild and Schmucki, 2011; Allen et al., 2013; Zhou et al., 2017a; Storelvmo et al., 2018; Moseid et al., 2020; Wohland et al., 2020), potentially pointing to inadequacies in the representation of aerosol mediated effects or related emissions data. The inclusion of assimilated aerosol optical depth inferred from satellite retrievals in the MERRA2 reanalysis (Buchard et al., 2017; Randles et al., 2017) helps to improve the accuracy of the simulated surface solar radiation changes in China (Feng and Wang, 2019). However, non-aerosol-related deficiencies in model representations of clouds and circulation, and/or an underestimation of natural variability, could further contribute to the lack of dimming and brightening in ESMs (Wild, 2016; Storelvmo et al., 2018).

The AR5 reported evidence for an increase in surface downward thermal radiation based on different studies covering 1964 to 2008, in line with what would be expected from an increased radiative forcing from GHGs and the warming and moistening of the atmosphere. Updates of the longest observational records from the Baseline Surface Radiation Network continue to show an increase at the majority of sites, in line with an overall increase predicted by ESMs of the order of 2 W m^{-2} per decade (Wild, 2016). Upward longwave radiation at the surface is rarely measured but is expected to have increased over the same period due to rising surface temperatures.

Turbulent fluxes of latent and sensible heat are also an important part of the surface energy budget (Figure 7.2). Large uncertainties in measurements of surface turbulent fluxes continue to prevent the determination of their decadal changes. Nevertheless, over the ocean, reanalysis-based estimates of linear trends from 1948–2008 indicate high spatial variability and seasonality. Increases in magnitudes of 4 to 7 W m^{-2} per decade for latent heat and 2 to 3 W m^{-2} per decade for sensible heat in the western boundary current regions are mostly balanced by decreasing trends in other regions (Gulev and Belyaev, 2012). Over land, the terrestrial latent heat flux is estimated to have increased in magnitude by 0.09 W m^{-2} per decade from 1989–1997, and subsequently decreased by 0.13 W m^{-2} per decade from 1998–2005 due to soil-moisture limitation mainly in the Southern Hemisphere (derived from Mueller et al., 2013). These trends are small in comparison to the uncertainty associated with satellite-derived and in situ observations, as well as from land-surface models forced by observations and atmospheric reanalyses. Ongoing advances in remote sensing of evapotranspiration from space (Mallick et al., 2016; Fisher et al., 2017; McCabe et al., 2017a, b), as well as terrestrial water storage (Rodell et al., 2018) may contribute to future constraints on changes in latent heat flux.

In summary, since AR5, multi-decadal decreasing and increasing trends in surface solar radiation of up to several percent per decade have been detected at many more locations, even in remote areas. There is *high confidence* that these trends are widespread, and not localized phenomena or measurement artefacts. The origin of these trends is not fully understood, although there is evidence that anthropogenic aerosols have made a substantial contribution (*medium confidence*). There is *medium confidence* that downward and upward thermal radiation has increased since the 1970s, while there remains *low confidence* in the trends in surface sensible and latent heat.

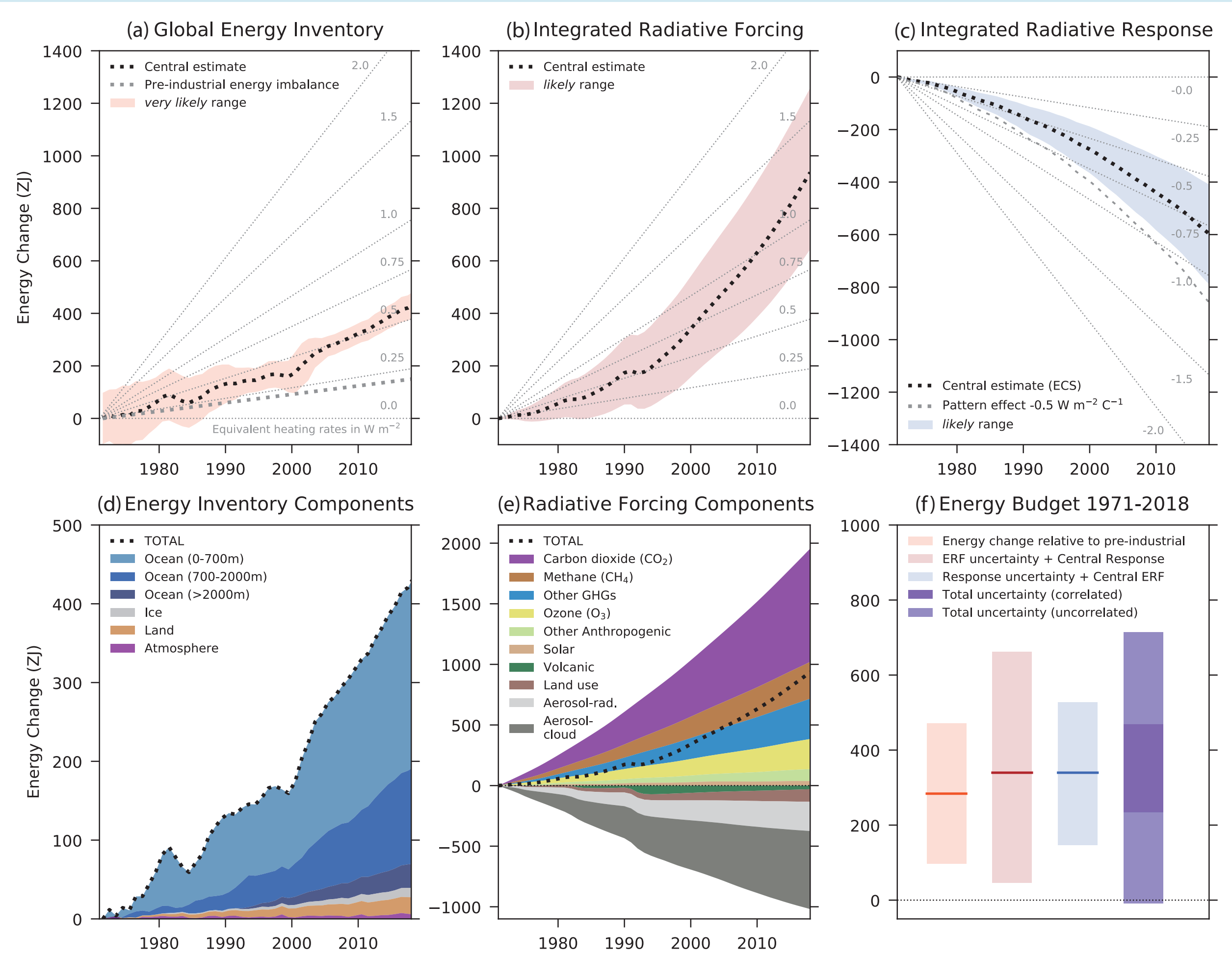
Box 7.2 | The Global Energy Budget

This box assesses the present knowledge of the global energy budget for the period 1971–2018, that is, the balance between radiative forcing, the climate system radiative response and observations of the changes in the global energy inventory (Box 7.2, Figure 1a,d).

The net effective radiative forcing (ERF) of the Earth system since 1971 has been positive (Section 7.3 and Box 7.2, Figure 1b,e), mainly as a result of increases in atmospheric greenhouse gas concentrations (Sections 2.2.8 and 7.3.2). The ERF of these positive forcing agents have been partly offset by that of negative forcing agents, primarily due to anthropogenic aerosols (Section 7.3.3), which dominate the overall uncertainty. The net energy inflow to the Earth system from ERF for the period 1971–2018 is estimated to be 937 ZJ (1 ZJ = 10^{21} J) with a *likely* range of 644 to 1259 ZJ (Box 7.2, Figure 1b).

Box 7.2 (continued)

The ERF-induced heating of the climate system results in increased thermal radiation to space via the Planck response, but the picture is complicated by a variety of climate feedbacks (Section 7.4.2 and Box 7.1) that also influence the climate system radiative response (Box 7.2, Figure 1c). The total radiative response is estimated by multiplying the assessed net feedback parameter, α, from process-based evidence (Section 7.4.2 and Table 7.10) with the observed GSAT change for the period (Cross Chapter Box 2.3) and time-integrating (Box 7.2, Figure 1c). The net energy outflow from the Earth system associated with the integrated radiative response for the period 1971–2018 is estimated to be 621 ZJ with a *likely* range of 419 to 823 ZJ. Assuming a pattern effect (Section 7.4.4) on α of –0.5 W m^{-2} °C^{-1} would lead to a systematically larger energy outflow by about 250 ZJ.



Box 7.2, Figure 1 | Estimates of the net cumulative energy change (ZJ = 10^{21} Joules) for the period 1971–2018 associated with: (a) observations of changes in the global energy inventory; (b) integrated radiative forcing; and (c) integrated radiative response. Black dotted lines indicate the central estimate with *likely* and *very likely* ranges as indicated in the legend. The grey dotted lines indicate the energy change associated with an estimated pre-industrial Earth energy imbalance of 0.2 W m^{-2} (a), and an illustration of an assumed pattern effect of –0.5 W m^{-2} °C^{-1} (c). Background grey lines indicate equivalent heating rates in W m^{-2} per unit area of Earth's surface. Panels **(d)** and **(e)** show the breakdown of components, as indicated in the legend, for the global energy inventory and integrated radiative forcing, respectively. Panel **(f)** shows the global energy budget assessed for the period 1971–2018, that is, the consistency between the change in the global energy inventory relative to pre-industrial and the implied energy change from integrated radiative forcing plus integrated radiative response under a number of different assumptions, as indicated in the legend, including assumptions of correlated and uncorrelated uncertainties in forcing plus response. Shading represents the *very likely* range for observed energy change relative to pre-industrial levels and *likely* range for all other quantities. Forcing and response time series are expressed relative to a baseline period of 1850–1900. Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

Combining the *likely* range of integrated radiative forcing (Box 7.2, Figure 1b) with the central estimate of integrated radiative response (Box 7.2, Figure 1c) gives a central estimate and *likely* range of 340 [47 to 662] ZJ (Box 7.2, Figure 1f). Combining the *likely* range of integrated radiative response with the central estimate of integrated radiative forcing gives a *likely* range of 340 [147 to 527] ZJ (Box 7.2, Figure 1f). Both calculations yield an implied energy gain in the climate system that is consistent with an independent observation-based assessment of the increase in the global energy inventory expressed relative to the estimated 1850–1900

Box 7.2 (continued)

Earth energy imbalance (Section 7.5.2 and Box 7.2, Figure 1a) with a central estimate and *very likely* range of 284 [96 to 471] ZJ (*high confidence*) (Box 7.2, Figure 1d; Table 7.1). Estimating the total uncertainty associated with radiative forcing and radiative response remains a scientific challenge and depends on the degree of correlation between the two (Box 7.2, Figure 1f). However, the central estimate of observed energy change falls well with the estimated *likely* range, assuming either correlated or uncorrelated uncertainties. Furthermore, the energy budget assessment would accommodate a substantial pattern effect (Section 7.4.4.3) during 1971–2018 associated with systematically larger values of radiative response (Box 7.2, Figure 1c), and potentially improved closure of the global energy budget. For the period 1970–2011, AR5 reported that the global energy budget was closed within uncertainties (*high confidence*) and consistent with the *likely* range of assessed climate sensitivity (Church et al., 2013). This Report provides a more robust quantitative assessment based on additional evidence and improved scientific understanding.

In addition to new and extended observations (Section 7.2.2), confidence in the observed accumulation of energy in the Earth system is strengthened by cross-validation of heating rates based on satellite and in situ observations (Section 7.2.2.1) and closure of the global sea level budget using consistent datasets (Cross-Chapter Box 9.1 and Table 9.5). Overall, there is *high confidence* that the global energy budget is closed for 1971–2018 with improved consistency compared to AR5.

7.3 Effective Radiative Forcing

Effective radiative forcing (ERF) quantifies the energy gained or lost by the Earth system following an imposed perturbation (for instance in GHGs, aerosols or solar irradiance). As such it is a fundamental driver of changes in the Earth's TOA energy budget. ERF is determined by the change in the net downward radiative flux at the TOA (Box 7.1) after the system has adjusted to the perturbation but excluding the radiative response to changes in surface temperature. This section outlines the methodology for ERF calculations (Section 7.3.1) and then assesses the ERF due to greenhouse gases (Section 7.3.2), aerosols (Section 7.3.3) and other natural and anthropogenic forcing agents (Section 7.3.4). These are brought together in Section 7.3.5 for an overall assessment of the present-day ERF and its evolution over the historical time period from 1750 to 2019. The same section also evaluates the surface temperature response to individual ERFs.

7.3.1 Methodologies and Representation in Models: Overview of Adjustments

As introduced in Box 7.1, AR5 (Boucher et al., 2013; Myhre et al., 2013b) recommended ERF as a more useful measure of the climate effects of a physical driver than the stratospheric-temperature-adjusted radiative forcing (SARF) adopted in earlier assessments. The AR5 assessed that the ratios of surface temperature change to forcing resulting from perturbations of different forcing agents were more similar between species using ERF than SARF. ERF extended the SARF concept to account for not only adjustments to stratospheric temperatures, but also responses in the troposphere and effects on clouds and atmospheric circulation, referred to as 'adjustments'. For more details see Box 7.1. Since circulation can be affected, these responses are not confined to the locality of the initial perturbation (unlike the traditional stratospheric-temperature adjustment).

This chapter defines 'adjustments' as those changes caused by the forcing agent that are independent of changes in surface temperature, rather than defining a specific time scale. The AR5 used the term 'rapid adjustment', but in this assessment the definition is based on the independence from surface temperature rather than the rapidity. The definition of ERF in Box 7.1 aims to create a clean separation between forcing (energy budget changes that are not mediated by surface temperature) and feedbacks (energy budget changes that are mediated by surface temperature). This means that changes in land or ocean surface temperature patterns (for instance as identified by Rugenstein et al., 2016b) are not included as adjustments. As in previous assessments (Forster et al., 2007; Myhre et al., 2013b) ERFs can be attributed simply to changes in the forcing agent itself or attributed to components of emitted gases (Figure 6.12). Because ERFs can include chemical and biospheric responses to emitted gases, they can be attributed to precursor gases, even if those gases do not have a direct radiative effect themselves. Similar chemical and biospheric responses to forcing agents can also be included in the ERF in addition to their direct effects.

Instantaneous radiative forcing (IRF) is defined here as the change in the net TOA radiative flux following a perturbation, excluding any adjustments. SARF is defined here as the change in the net radiative flux at TOA following a perturbation including the response to stratospheric temperature adjustments. These differ from AR5 where these quantities were defined at the tropopause (Myhre et al., 2013b). The net IRF values will be different using the TOA definition. The net SARF values will be the same as with the tropopause definition, but will have a different partitioning between the longwave and shortwave. Defining all quantities at the TOA enables consistency in breaking down the ERF into its component parts.

The assessment of ERFs in AR5 was preliminary because ERFs were only available for a few forcing agents, so for many forcing agents the Report made the assumption that ERF and SARF were equivalent. This section discusses the body of work published since AR5. This work has computed ERFs across many more forcing agents and models; closely examined the methods of computation; quantified the processes involved in causing adjustments; and examined how well ERFs predict the ultimate temperature response. This work is assessed to have led to a much-improved understanding and increased confidence in the quantification of radiative forcing across the Report. These same techniques allow for an evaluation of radiative forcing within Earth system models (ESMs) as a key test of their ability to represent both historical and future temperature changes (Sections 3.3.1 and 4.3.4).

The ERF for a particular forcing agent is the sum of the IRF and the contribution from the adjustments, so in principle this could be constructed bottom-up by calculating the IRF and adding in the adjustment contributions one-by-one or together. However, there is no simple way to derive the global tropospheric adjustment terms or adjustments related to circulation changes without using a comprehensive climate model (e.g., CMIP5 or CMIP6). There have been two main modelling approaches used to approximate the ERF definition in Box 7.1. The first approach is to use the assumed linearity (Box 7.1, Equation 7.1) to regress the net change in the TOA radiation budget (ΔN) against change in global mean surface temperature (ΔT) following a step change in the forcing agent (Box 7.1, Figure 1; Gregory et al., 2004). The ERF (ΔF) is then derived from ΔN when $\Delta T = 0$. Regression-based estimates of ERF depend on the temporal resolution of the data used (Modak et al., 2016, 2018). For the first few months of a simulation both surface temperature change and stratospheric-temperature adjustment occur at the same time, leading to misattribution of the stratospheric-temperature adjustment to the surface temperature feedback. Patterns of sea surface temperature (SST) change also affect estimates of the forcing obtained by regression methods (Andrews et al., 2015). At multi-decadal time scales the curvature of the relationship between net TOA radiation and surface temperature can also lead to biases in the ERF estimated from the regression method (Section 7.4; Armour et al., 2013; Andrews et al., 2015; Knutti et al., 2017). The second modelling approach to estimate ERF is to set the ΔT term in Box 7.1 (Box 7.1, Equation 7.1) to zero. It is technically difficult to constrain land surface temperatures in ESMs (Shine et al., 2003; Ackerley and Dommenget, 2016; Andrews et al., 2021), so most studies reduce the ΔT term by prescribing the SSTs and sea ice concentrations in a pair of 'fixed-SST' (fSST) simulations with and without the change in forcing agent (Hansen et al., 2005b). An approximation to ERF (ΔF_{fsst}) is then given by the difference in ΔN_{fsst} between the simulations. The fSST method has less noise due to internal variability than the regression method. Nevertheless a 30-year fSST integration or 10 × 20-year regression ensemble needs to be conducted in order to reduce the 5–95% confidence range to 0.1 W m^{-2} (Forster et al., 2016).Neither the regression or fSST methods are practical for quantifying the ERF of agents with forcing magnitudes of the order of 0.1 W m^{-2} or smaller. The internal variability in the fSST method can be further constrained by nudging winds towards a prescribed climatology (Kooperman et al., 2012). This allows the determination of the ERF of forcing agents with smaller magnitudes but excludes adjustments associated with circulation responses (Schmidt et al., 2018). There are insufficient studies to assess whether these circulation adjustments are significant.

Since the near-surface temperature change over land, ΔT_{land}, is not constrained in the fSST method, this response needs to be removed for consistency with the Section 7.1 definition. These changes in the near-surface temperature will also induce further responses in the tropospheric temperature and water vapour that should also be removed to conform with the physical definition of ERF. The radiative response to ΔT_{land} can be estimated through radiative transfer modelling in which a kernel, k, representing the change in net TOA radiative flux per unit of change in near-surface temperature change over land (or an approximation using land surface temperature), is precomputed (Smith et al., 2018b, 2020b; Richardson et al., 2019; Tang et al., 2019). Thus ERF ≈ $\Delta F_{fsst} - k\ \Delta T_{land}$. Since k is negative this means that ΔF_{fsst} underestimates the ERF. For 2×CO_2, this underestimate is around 0.2 W m^{-2} (Smith et al., 2018b, 2020b). There have been estimates of the corrections due to tropospheric temperature and water vapour (Tang et al., 2019; Smith et al., 2020b) showing additional radiative responses of comparable magnitude to those directly from ΔT_{land}. An alternative to computing the response terms directly is to use the feedback parameter, α (Hansen et al., 2005b; Sherwood et al., 2015; Tang et al., 2019). This gives approximately double the correction compared to the kernel approach (Tang et al., 2019). The response to land surface temperature change varies with location and even for GSAT change k is not expected to be the same as α (Section 7.4). One study where land surface temperatures are constrained in a model (Andrews et al., 2021) finds this constraint adds +1.0 W m^{-2} to ΔF_{fsst} for 4×CO_2, thus confirming the need for a correction in calculations where this constraint is not applied. For this assessment the correction is conservatively based only on the direct radiative response kernel to ΔT_{land} as this has a strong theoretical basis to support it. While there is currently insufficient corroborating evidence to recommend including tropospheric temperature and water-vapour corrections in this assessment, it is noted that the science is progressing rapidly on this topic.

TOA radiative flux changes due to the individual adjustments can be calculated by perturbing the meteorological fields in a climate model's radiative transfer scheme (partial radiative perturbation approach) (Colman, 2015; Mülmenstädt et al., 2019) or by using precomputed radiative kernels of sensitivities of the TOA radiation fluxes to changes in these fields (as done for near-surface temperature change above; Vial et al., 2013; Zelinka et al., 2014; Zhang and Huang, 2014; Smith et al., 2018b, 2020b). The radiative kernel approach is easier to implement through post-processing of output from multiple ESMs, whereas it is recognized that the partial radiation perturbation approach gives a more accurate estimate of the adjustments within the setup of a single model and its own radiative transfer code. There is little difference between using a radiative kernel from the same or a different model when calculating the adjustment terms, except for stratospheric temperature adjustments where it is important to have sufficient vertical resolution in the stratosphere in the model used to derive the kernel (Smith et al., 2018b, 2020a).

For comparison with offline radiative transfer calculations the SARFs can be approximated by removing the adjustment terms (apart from stratospheric temperature) from the ERFs using radiative kernels to quantify the adjustment for each meteorological variable. Kernel analysis by Chung and Soden (2015) suggested a large spread in CO_2 SARF across climate models, but their analysis was based on regressing variables in a coupled-ocean experiment rather than using a fSST approach which leads to a large spread due to natural variability (Forster et al., 2016). Adjustments computed from radiative

Table 7.2 | SARF, ΔF_{fsst}, and ERF diagnosed from Earth system models for fixed-SST (fSST) CO_2 experiments. $2\times CO_2$ data taken from fixed atmospheric composition experiments (Smith et al., 2018b). $4\times CO_2$ data taken from CMIP6 experiments with interactive aerosols (and interactive gas phase chemistry in some; Smith et al., 2020b). The radiative forcings from the $4\times CO_2$ experiments are scaled by 0.476 for comparison with $2\times CO_2$ (Meinshausen et al., 2020). SARF is approximated by removing the (non-stratospheric-temperature) adjustment terms from the ERF. In Smith et al. (2018b), separation of temperature adjustments into tropospheric and stratospheric contributions is approximate based on a fixed tropopause of 100 hPa at the equator, varying linearly in latitude to 300 hPa at the poles. In Smith et al. (2020b), this separation is based on the model-diagnosed tropopause. ERF is approximated by removing the response to land surface temperature change from ΔF_{fsst}. The confidence range is based on the inter-model standard deviation.

$2\times CO_2$ Experiments (Smith et al., 2018b)	Stratospheric-temperature-adjusted Radiative Forcing (SARF, W m^{-2})	ΔF_{fsst} (W m^{-2})	Effective Radiative Forcing (ERF, W m^{-2})
HadGEM2-ES	3.45	3.37	3.58
NorESM1	3.67	3.50	3.70
GISS-E2-R	3.98	4.06	4.27
CanESM2	3.68	3.57	3.77
MIROC-SPRINTARS	3.89	3.62	3.82
NCAR-CESM1-CAM5	3.89	4.08	4.39
HadGEM3	3.48	3.64	3.90
IPSL-CM5A	3.50	3.39	3.61
MPI-ESM	4.27	4.14	4.38
NCAR-CESM1-CAM4	3.50	3.62	3.86
Multi-model mean and 5–95% confidence range	3.73 ± 0.44	3.70 ± 0.44	3.93 ± 0.48

$0.476\times 4\times CO_2$ Experiments (Smith et al., 2020b)	Stratospheric-temperature-adjusted Radiative Forcing (SARF, W m^{-2})	ΔF_{fsst} (W m^{-2})	Effective Radiative Forcing (ERF, W m^{-2})
ACCESS-CM2	3.56	3.78	3.98
CanESM5	3.67	3.62	3.82
CESM2	3.56	4.24	4.48
CNRM-CM6-1	3.99	3.81	4.01
CNRM-ESM2-1	3.99	3.77	3.94
EC-Earth3		3.85	4.04
GFDL-CM4	3.65	3.92	4.10
GFDL-ESM4	3.27	3.68	3.85
GISS-E2-1-G	3.78	3.50	3.69
HadGEM3-GC31-LL	3.61	3.85	4.07
IPSL-CM6A-LR	3.84	3.81	4.05
MIROC6	3.63	3.48	3.69
MPI-ESM1-2-LR	3.74	3.97	4.20
MRI-ESM2-0	3.76	3.64	3.80
NorESM2-LM	3.58	3.88	4.10
NorESM2-MM	3.62	3.99	4.22
UKESM1-0-LL	3.49	3.78	4.01
Multi-model mean and 5–95% confidence range	3.67 ± 0.29	3.80 ± 0.30	4.00 ± 0.32

kernels are shown for seven different climate drivers (using a fSST approach) in Figure 7.4. Table 7.2 shows the estimates of SARF, ΔF_{fsst} and ERF (corrected for land surface temperature change) for $2\times CO_2$ from the nine climate models analysed in Smith et al. (2018b). The SARF shows a smaller spread over previous studies (Pincus et al., 2016; Soden et al., 2018) and most estimates are within 10% of the multi-model mean and the assessment of $2\times CO_2$ SARF in Section 7.3.2 (3.75 W m^{-2}). It is not possible from these studies to determine how much of this reduction in spread is due to convergence in the model radiation schemes or the meteorological conditions of the model base states; nevertheless the level of agreement in this and earlier intercomparisons gives *medium confidence* in the ability of ESMs to represent radiative forcing from CO_2. The $4\times CO_2$ CMIP6 fSST experiments (Smith et al., 2020b) in Table 7.2 include ESMs with varying levels of complexity in aerosols and reactive gas chemistry. The CMIP6 experimental setup allows for further climate effects of CO_2 (including on aerosols and ozone) depending on model complexity. The chemical effects are adjustments to CO_2 but are not separable from the SARF in the diagnosis in Table 7.2. In these particular models, this leads to higher SARF than when only CO_2 varies, however there are insufficient studies to make a formal assessment of composition adjustments to CO_2.

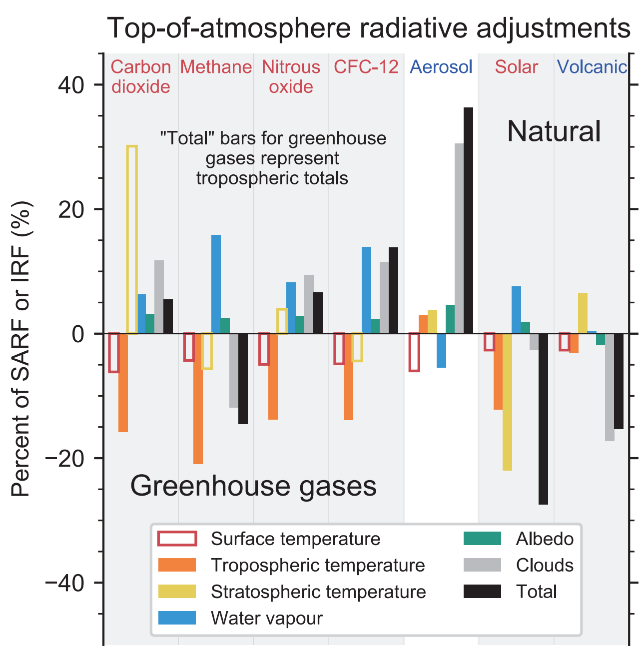


Figure 7.4 | Radiative adjustments at top of atmosphere for seven different climate drivers as a proportion of forcing. Tropospheric temperature (orange), stratospheric temperature (yellow), water vapour (blue), surface albedo (green), clouds (grey) and the total adjustment (black) is shown. For the greenhouse gases (carbon dioxide, methane, nitrous oxide and CFC-12) the adjustments are expressed as a percentage of stratospheric-temperature-adjusted radiative forcing (SARF), whereas for aerosol, solar and volcanic forcing they are expressed as a percentage of instantaneous radiative forcing (IRF). Land surface temperature response (outline red bar) is shown, but included in the definition of forcing. Data from Smith et al. (2018b) for carbon dioxide and methane; Smith et al. (2018b) and Gray et al. (2009) for solar; Hodnebrog et al. (2020b) for nitrous oxide and CFC-12; Smith et al. (2020b) for aerosol, and Marshall et al. (2020) for volcanic. Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

ERFs have been found to yield more consistent values of GSAT change per unit forcing than SARF, that is, α shows less variation across different forcing agents (Rotstayn and Penner, 2001; Shine et al., 2003; Hansen et al., 2005b; Marvel et al., 2016; Richardson et al., 2019). Having a consistent relationship between forcing and response is advantageous when making climate projections using simple models (Cross-Chapter Box 7.1) or emissions metrics (Section 7.6). The definition of ERF used in this assessment, which excludes the radiative response to land surface temperature changes, brings the α values into closer agreement than when SARF is used (Richardson et al., 2019), although for individual models there are still variations, particularly for more geographically localized forcing agents. However, even for ERF, studies find that α is not identical across all forcing agents (Shindell, 2014; Shindell et al., 2015; Modak et al., 2018; Modak and Bala, 2019; Richardson et al., 2019). Section 7.4.4 discusses the effect of different SST response patterns on α. Analysis of the climate feedbacks (Kang and Xie, 2014; Gregory et al., 2016, 2020; Marvel et al., 2016; Duan et al., 2018; Persad and Caldeira, 2018; Stuecker et al., 2018; Krishnamohan et al., 2019) suggests a weaker feedback (i.e., less-negative α) and hence larger sensitivity for forcing of the higher latitudes (particularly the Northern Hemisphere). Nonetheless, as none of these variations are robust across models, the ratio of $1/\alpha$ from non-CO_2 forcing agents (with approximately global distributions) to that from doubling CO_2 is within 10% of unity.

In summary, this Report adopts an estimate of ERF based on the change in TOA radiative fluxes in the absence of GSAT changes. This allows for a theoretically cleaner separation between forcing and feedbacks in terms of factors respectively unrelated and related to GSAT change (Box 7.1). ERF can be computed from prescribed SST and sea ice experiments after removing the TOA energy budget change associated with the land surface temperature response. In this assessment this is removed using a kernel accounting only for the direct radiative effect of the land surface temperature response. To compare these results with sophisticated high spectral resolution radiative transfer models the individual tropospheric adjustment terms can be removed to leave the SARF. SARFs for $2\times CO_2$ calculated by ESMs from this method agree within 10% with the more sophisticated models. The new studies highlighted above suggest that physical feedback parameters computed within this framework have less variation across forcing agents. There is *high confidence* that an α based on ERF as defined here varies by less (less than variation 10% across a range of forcing agents with global distributions), than α based on SARF. For geographically localized forcing agents there are fewer studies and less agreement between them, resulting in *low confidence* that ERF is a suitable estimator of the resulting global mean near-surface temperature response.

7.3.2 Greenhouse Gases

High spectral resolution radiative transfer models provide the most accurate calculations of radiative perturbations due to greenhouse gases (GHGs), with errors in the instantaneous radiative forcing (IRF) of less than 1% (Mlynczak et al., 2016; Pincus et al., 2020). They can calculate IRFs with no adjustments, or SARFs by accounting for the adjustment of stratospheric temperatures using a fixed dynamical heating. It is not possible with offline radiation models to account for other adjustments. The high-resolution model calculations of SARF for carbon dioxide, methane and nitrous oxide have been updated since AR5, which were based on Myhre et al. (1998). The new calculations include the shortwave forcing from methane and updates to the water vapour continuum (increasing the total SARF of methane by 25%) and account for the absorption band overlaps between carbon dioxide and nitrous oxide (Etminan et al., 2016). The associated simplified expressions, from a re-fitting of the Etminan et al. (2016) results by Meinshausen et al. (2020), are given in Supplementary Material, Table 7.SM.1. The shortwave contribution to the IRF of methane has been confirmed independently (Collins et al., 2018). Since they incorporate known missing effects we assess the new calculations as being a more appropriate representation than Myhre et al. (1998).

As described in Section 7.3.1, ERFs can be estimated using ESMs, however the radiation schemes in climate models are approximations to high spectral resolution radiative transfer models with variations and biases in results between the schemes (Pincus et al., 2015). Hence ESMs alone are not sufficient to establish ERF best estimates for the well-mixed GHGs (WMGHGs). This assessment therefore estimates ERFs from a combined approach that uses the SARF from radiative transfer models and adds the tropospheric adjustments derived from ESMs.

In AR5, the main information used to assess components of ERFs beyond SARF was from Vial et al. (2013) who found a near-zero non-stratospheric adjustment (without correcting for near-surface temperature changes over land) in $4\times CO_2$ CMIP5 model experiments, with an uncertainty of ±10% of the total CO_2 ERF. No calculations were available for other WMGHGs, so ERF was therefore assessed to be approximately equal to SARF (within 10%) for all WMGHGs.

The effect of WMGHGs in ESMs can extend beyond their direct radiative effects to include effects on ozone and aerosol chemistry and natural emissions of ozone and aerosol precursors, and in the case of CO_2 to vegetation cover through physiological effects. In some cases these can have significant effects on the overall radiative budget changes from perturbing WMGHGs within ESMs (Myhre et al., 2013b; Zarakas et al., 2020; O'Connor et al., 2021; Thornhill et al., 2021a). These composition adjustments are further discussed in Chapter 6 (Section 6.4.2).

7.3.2.1 Carbon Dioxide (CO_2)

The SARF for carbon dioxide (CO_2) has been slightly revised due to updates to spectroscopic data and inclusion of the absorption band overlaps between N_2O and CO_2 (Etminan et al., 2016). The formulae fitting to the Etminan et al. (2016) results in Meinshausen et al. (2020) are used. This increases the SARF due to doubling CO_2 slightly from 3.71 W m^{-2} in AR5 to 3.75 W m^{-2}. Tropospheric responses to CO_2 in fSST experiments have been found to lead to an approximate balance in their radiative effects between an increased radiative forcing due to water vapour, cloud and surface-albedo adjustments and a decrease due to increased tropospheric temperature and land surface temperature response (Table 7.3; Vial et al., 2013;

Table 7.3 | Adjustments to the top-of-atmosphere (TOA) carbon dioxide forcing due to changes in stratospheric temperature, surface and tropospheric temperatures, water vapour, clouds, and surface albedo, as a fraction of the stratospheric-temperature-adjusted radiative forcing (SARF). Effective radiative forcing (ERF) is defined in this Report as excluding the surface temperature response.

Percentage of SARF (source study)	Surface Temperature	Tropospheric Temperature	Stratospheric Temperature	Surface Albedo	Water Vapour	Clouds	Troposphere (Including Surface)	Troposphere (Excluding Surface)
Vial et al. (2013)	–20% combined		N/A	2%	6%	11%	–1%	N/A
Zhang and Huang (2014)	–23% combined		26%	N/A	6%	16%	–1%	N/A
Smith et al. (2018b)	–6%	–16%	30%	3%	6%	12%	–1%	+5%
Smith et al. (2020b)	–6%	–15%	35%	3%	6%	15%	+3%	+9%

Table 7.4 | Assessed effective radiative forcing (ERF), stratospheric-temperature-adjusted radiative forcing (SARF) and tropospheric adjustments to 2×CO_2 change since pre-industrial times compared to the AR5 assessed range (Myhre et al., 2013b). Adjustments are due to changes in tropospheric temperatures, water vapour, clouds and surface albedo and land cover and are taken from Smith et al. (2018b) and assessed as a percentage of SARF (Table 7.3). Uncertainties are based on multi-model spread in Smith et al. (2018b). Note some of the uncertainties are anticorrelated, which means that they do not sum linearly.

2×CO_2 Forcing	AR5 SARF/ERF (W m^{-2})	SARF (W m^{-2})	Tropospheric Temperature Adjustment (W m^{-2})	Water Vapour Adjustment (W m^{-2})	Cloud Adjustment (W m^{-2})	Surface Albedo and Land-cover Adjustment (W m^{-2})	Total Tropospheric Adjustment (W m^{-2})	ERF (W m^{-2})
2×CO_2 ERF components	3.71	3.75	–0.60	0.22	0.45	0.11	0.18	3.93
5–95% uncertainty ranges as percentage of ERF	10% (SARF) 20% (ERF)	<10%	±6%	±4%	±7%	±2%	±7%	±12%

Zhang and Huang, 2014; Smith et al., 2018b, 2020b). The ΔF_{fsst} includes any effects represented within the ESMs on tropospheric adjustments due to changes in evapotranspiration or leaf area (mainly affecting surface and boundary-layer temperature, low-cloud amount, and albedo) from the CO_2-physiological effects (Doutriaux-Boucher et al., 2009; Cao et al., 2010; T.B. Richardson et al., 2018). The effect on surface temperature (negative longwave response) is consistent with the expected physiological responses and needs to be removed for consistency with the ERF definition. The split between surface and tropospheric temperature responses was not reported in Vial et al. (2013) or Zhang and Huang (2014) but the total of surface and tropospheric temperature response agrees with Smith et al. (2018b, 2020b), giving *medium confidence* in this decomposition. Doutriaux-Boucher et al. (2009) and Andrews et al. (2021) (using the same land surface model) find a 13% and 10% increase respectively in ERF due to the physiological responses to CO_2. The physiological adjustments are therefore assessed to make a substantial contribution to the overall tropospheric adjustment for CO_2 (*high confidence*), but there is insufficient evidence to provide a quantification of the split between physiological and thermodynamic adjustments. These forcing adjustments due to the effects of CO_2 on plant physiology differ from the biogeophysical feedbacks due to the effects of temperature changes on vegetation discussed in Section 7.4.2.5. The adjustment is assumed to scale with the SARF in the absence of evidence for non-linearity. The tropospheric adjustment is assessed from Table 7.3 to be +5% of the SARF with an uncertainty of 5%, which is added to the Meinshausen et al. (2020) formula for SARF. Due to the agreement between the studies and the understanding of the physical mechanisms there is *medium confidence* in the mechanisms underpinning the tropospheric adjustment, but *low confidence* in its magnitude.

The ERF from doubling CO_2 (2×CO_2) from the 1750 level (278 ppm; Section 2.2.3.3) is assessed to be 3.93 ± 0.47 W m^{-2} (*high confidence*). Its assessed components are given in Table 7.4. The combined spectroscopic and radiative transfer modelling uncertainties give an uncertainty in the CO_2 SARF of around 10% or less (Etminan et al., 2016; Mlynczak et al., 2016). The overall uncertainty in CO_2 ERF is assessed as ±12%, as the more uncertain adjustments only account for a small fraction of the ERF (Table 7.3). The 2×CO_2 ERF estimate is 0.2 W m^{-2} larger than using the AR5 formula (Myhre et al., 2013b) due to the combined effects of tropospheric adjustments which were assumed to be zero in AR5. CO_2 concentrations have increased from 278 ppm in 1750 to 410 ppm in 2019 (Section 2.2.3.3). The historical ERF estimate from CO_2 is revised upwards from the AR5 value of 1.82 ± 0.38 W m^{-2} (1750–2011) to 2.16 ± 0.26 W m^{-2} (1750–2019) in this assessment, from a combination of the revisions described above (0.06 W m^{-2}) and the 19 ppm rise in atmospheric concentrations between 2011 and 2019 (0.27 W m^{-2}). The ESM estimates of 2×CO_2 ERF (Table 7.2) lie within ±12% of the assessed value (apart from CESM2). The definition of ERF can also include further physiological effects – for instance on dust, natural fires and biogenic emissions from the land and ocean – but these are not typically included in the modelling setup for 2×CO_2 ERF.

7.3.2.2 Methane (CH_4)

The SARF for methane (CH_4) has been substantially increased due to updates to spectroscopic data and inclusion of shortwave absorption (Etminan et al., 2016). Adjustments have been calculated in nine climate models by Smith et al. (2018b). Since CH_4 is found to absorb in the shortwave near infrared, only adjustments from those models including this absorption are taken into account.

7

For these models the adjustments act to reduce the ERF because the shortwave absorption leads to tropospheric heating and reductions in upper tropospheric cloud amounts. The adjustment is –14% ± 15%, which counteracts much of the increase in SARF identified by Etminan et al. (2016). Modak et al. (2018) also found negative forcing adjustments from a methane perturbation including shortwave absorption in the NCAR CAM5 model, in agreement with the above assessment. The uncertainty in the shortwave component leads to a higher radiative modelling uncertainty (14%) than for CO_2 (Etminan et al., 2016). When combined with the uncertainty in the adjustment, this gives an overall uncertainty of ±20%. There is *high confidence* in the spectroscopic revision but only *medium confidence* in the adjustment modification. CH_4 concentrations have increased from 729 ppb in 1750 to 1866 ppb in 2019 (Section 2.2.3.3). The historical ERF estimate from AR5 of 0.48 ± 0.10 W m^{-2} (1750–2011) is revised to 0.54 ± 0.11 W m^{-2} (1750 to 2019) in this assessment from a combination of spectroscopic radiative efficiency revisions (+0.12 W m^{-2}), adjustments (–0.08 W m^{-2}) and the 63 ppb rise in atmospheric CH_4 concentrations between 2011 and 2019 (+0.03 W m^{-2}). As the adjustments are assessed to be small, there is *high confidence* in the overall assessment of ERF from methane. Increased methane leads to tropospheric ozone production and increased stratospheric water vapour, so that an attribution of forcing to methane emissions gives a larger effect than that directly from the methane concentration itself. This is discussed in detail in Chapter 6 (Section 6.4.2) and shown in Figure 6.12.

7.3.2.3 Nitrous oxide (N_2O)

The tropospheric adjustments to nitrous oxide (N_2O) have been calculated from 5 ESMs as 7% ± 13% of the SARF (Hodnebrog et al., 2020b). This value is therefore taken as the assessed adjustment, but with *low confidence*. The radiative modelling uncertainty is ±10% (Etminan et al., 2016), giving an overall uncertainty of ±16%. Nitrous oxide concentrations have increased from 270 ppb in 1750 to 332 ppb in 2019 (Section 2.2.3.3). The historical ERF estimate from N_2O is revised upwards from 0.17 ± 0.06 W m^{-2} (1750–2011) in AR5 to 0.21 ± 0.03 W m^{-2} (1750–2019) in this assessment, of which 0.02 W m^{-2} is due to the 7 ppb increase in concentrations, and 0.02 W m^{-2} to the tropospheric adjustment. As the adjustments are assessed to be small there remains *high confidence* in the overall assessment.

Increased nitrous oxide leads to ozone depletion in the upper stratosphere which will make a positive contribution to the direct ERF here (Section 6.4.2 and Figure 6.12) when considering emissions-based estimates of ERF.

7.3.2.4 Halogenated Species

The stratospheric-temperature-adjusted radiative efficiencies (SARF per ppb increase in concentration) for halogenated compounds are reviewed extensively in Hodnebrog et al. (2020a), an update to those used in AR5. Many halogenated compounds have lifetimes short enough that they can be considered short-lived climate forcers (SLCFs; Table 6.1). As such, they are not completely 'well-mixed' and their vertical distributions are taken into account when determining their radiative efficiencies. The World Meteorological Organization (WMO, 2018) updated the lifetimes of many halogenated compounds and these were used in Hodnebrog et al. (2020a).

The tropospheric adjustments to chlorofluorocarbons (CFCs), specifically CFC-11 and CFC-12, have been quantified as 13% ± 10% and 12% ± 14% of the SARF, respectively (Hodnebrog et al., 2020b). The assessed adjustment to CFCs is therefore 12% ± 13% with *low confidence* due to the lack of corroborating studies. There have been no calculations for other halogenated species so for these the tropospheric adjustments are therefore assumed to be 0 ± 13% with *low confidence.* The radiative modelling uncertainties are 14% and 24% for compounds with lifetimes greater than and less than five years, respectively (Hodnebrog et al., 2020a). The overall uncertainty in the ERFs of halogenated compounds is therefore assessed to be 19% and 26% depending on the lifetime. The ERF from CFCs is slowly decreasing, but this is compensated for by the increased forcing from the replacement species (HCFCs and HFCs). The ERF from HFCs has increased by 0.028 ± 0.05 W m^{-2}. Thus, the concentration changes mean that the total ERF from halogenated compounds has increased since AR5 from 0.360 ± 0.036 W m^{-2} to 0.408 ± 0.078 W m^{-2} (Table 7.5). Of this, 0.034 W m^{-2} is due to increased radiative efficiencies and tropospheric adjustments, and 0.014 W m^{-2} is due to increases in concentrations. As the adjustments are assessed to be small there remains *high confidence* in the overall assessment.

Halogenated compounds containing chlorine and bromine lead to ozone depletion in the stratosphere which will reduce the associated ERF (Morgenstern et al., 2020). Chapter 6 (Section 6.4 and Figure 6.12) assesses the ERF contributions due to the chemical effects of reactive gases.

7.3.2.5 Ozone

Estimates of the pre-industrial to present-day tropospheric ozone radiative forcing are based entirely on models. The lack of pre-industrial ozone measurements prevents an observational determination. There have been limited studies of ozone ERFs (MacIntosh et al., 2016; Xie et al., 2016; Skeie et al., 2020). Skeie et al. (2020) found little net contribution to the ERF from tropospheric adjustment terms for 1850–2000 change in ozone (tropospheric and stratospheric ozone combined), although MacIntosh et al. (2016) suggested that increases in stratospheric or upper tropospheric ozone reduces high-cloud and increases low-cloud, whereas an increase in lower tropospheric ozone reduces low-cloud. Further studies suggest that changes in circulation due to decreases in stratospheric ozone affect Southern Hemisphere clouds and the atmospheric levels of sea salt aerosol that would contribute additional adjustments, possibly of comparable magnitude to the SARF from stratospheric ozone depletion (Grise et al., 2013, 2014; Xia et al., 2016, 2020). ESM responses to changes in ozone-depleting substances (ODS) in CMIP6 show a much more negative ERF than would be expected from offline calculations of SARF (Morgenstern et al., 2020; Thornhill et al., 2021b) again suggesting a negative contribution from adjustments. However there is insufficient evidence available to quantify this effect.

Without sufficient information to assess whether the ERFs differ from SARF, this assessment relies on offline radiative transfer calculations of SARF for both tropospheric and stratospheric ozone. Checa-Garcia et al. (2018) found SARF of 0.30 W m^{-2} for changes in ozone (1850–1860 to 2009–2014). These were based on precursor emissions and ODS concentrations from the Coupled Chemistry Model Initiative (CCMI) project (Morgenstern et al., 2017). Skeie et al. (2020) calculated an ozone SARF of 0.41 ± 0.12 W m^{-2} (1850–2010; from five climate models and one chemistry transport model) using CMIP6 precursor emissions and ODS concentrations (excluding models without fully interactive ozone chemistry and one model with excessive ozone depletion). The ozone precursor emissions are higher in CMIP6 than in CCMI, which explains much of the increase compared to Checa-Garcia et al. (2018).

Previous assessments have split the ozone forcing into tropospheric and stratospheric components. This does not correspond to the division between ozone production and ozone depletion and is sensitive to the choice of tropopause (*high confidence*) (Myhre et al., 2013b). The contributions to total SARF in CMIP6 (Skeie et al., 2020) are 0.39 ± 0.07 and 0.02 ± 0.07 W m^{-2} for troposphere and stratosphere respectively (using a 150 ppb ozone tropopause definition). This small positive (but with uncertainty encompassing negative values) stratospheric ozone SARF is due to contributions from ozone precursors to lower stratospheric ozone and some of the CMIP6 models showing ozone depletion in the upper stratosphere, where depletion contributes a positive radiative forcing (*medium confidence*).

As there is insufficient evidence to quantify adjustments, for total ozone the assessed central estimate for ERF is assumed to be equal to SARF (*low confidence*) and follows Skeie et al. (2020), since that study uses the most recent emissions data. The dataset is extended over the entire historical period following Skeie et al. (2020), with a SARF for 1750–1850 of 0.03 W m^{-2} and for 2010–2018 of 0.03 W m^{-2}, to give 0.47 [0.24 to 0.70] W m^{-2} for 1750–2019. This maintains the 50% uncertainty (5–95% range) from AR5 which is largely due to the uncertainty in pre-industrial emissions (Rowlinson et al., 2020). There is also *high confidence* that this range includes uncertainty due to the adjustments. The CMIP6 SARF is more positive than the AR5 value of 0.31 W m^{-2} for the period 1850–2011 (Myhre et al., 2013b) which was based on the Atmospheric Chemistry and Climate Intercomparison Project (ACCMIP; Shindell et al., 2013). The assessment is sensitive to the assumptions on precursor emissions used to drive the models, which are larger in CMIP6 than ACCMIP.

In summary, although there is insufficient evidence to quantify adjustments, there is *high confidence* in the assessed range of ERF for ozone changes over the 1750–2019 period, giving an assessed ERF of 0.47 [0.24 to 0.70] W m^{-2}.

7.3.2.6 Stratospheric Water Vapour

This section considers direct anthropogenic effects on stratospheric water vapour by oxidation of methane. Since AR5 the SARF from methane-induced stratospheric water vapour changes has been calculated in Winterstein et al., 2019, corresponding to 0.09 W m^{-2} when scaling to 1850 to 2014 methane changes. This is marginally larger than the AR5 assessed value of 0.07 ± 0.05 W m^{-2} (Myhre et al., 2013b). Wang and Huang (2020) quantified the adjustment terms to a stratospheric water vapour change equivalent to a forcing from a 2×CO_2 warming (which has a different vertical profile). They found that the ERF was less than 50% of the SARF due to high-cloud decrease and upper tropospheric warming. The assessed ERF is therefore 0.05 ± 0.05 W m^{-2} with a lower limit reduced to zero and the central value and upper limit reduced to allow for adjustment terms. This still encompasses the two recent SARF studies. There is *medium confidence* in the SARF from agreement with the recent studies and AR5. There is *low confidence* in the adjustment terms.

Stratospheric water vapour may also change as an adjustment to species that warm or cool the upper troposphere–lower stratosphere region (Forster and Joshi, 2005; Stuber et al., 2005), in which case it should be included as part of the ERF for that compound. Changes in GSAT are also associated with changes in stratospheric water vapour as part of the water-vapour–climate feedback (Section 7.4.2.2).

7.3.2.7 Synthesis

The ERF of GHGs (excluding ozone and stratospheric water vapour) over 1750–2019 is assessed to be 3.32 ± 0.29 W m^{-2}. It has increased by 0.49 W m^{-2} compared to AR5 (reference year 2011) (*high confidence*). Most of this has been due to an increase in CO_2 concentration since 2011 [0.27 ± 0.03] W m^{-2}, with concentration increases in CH_4, N_2O and halogenated compounds adding 0.02, 0.02 and 0.01 W m^{-2} respectively (Table 7.5). Changes in the radiative efficiencies (including adjustments) of CO_2, CH_4, N_2O and halogenated compounds have increased the ERF by an additional 0.15 W m^{-2} compared to the AR5 values (*high confidence*). Note that the ERFs in this section do not include chemical effects of GHGs on production or destruction of ozone or aerosol formation (Section 6.2.2). The ERF for ozone is considerably increased compared to AR5 due to an increase in the assumed ozone precursor emissions in CMIP6 compared to CMIP5, and better accounting for the effects of both ozone precursors and ODSs in the stratosphere. The ERF for stratospheric water vapour is slightly reduced. The combined ERF from ozone and stratospheric water vapour has increased since AR5 by 0.10 ± 0.50 W m^{-2} (*high confidence*), although the uncertainty ranges still include the AR5 values.

Table 7.5 | Present-day mole fractions in parts per trillion (pmol mol^{-1}), except where specified, and effective radiative forcing (ERF, in W m^{-2}) for the well-mixed greenhouse gases (WMGHGs). Data taken from Chapter 2 (Section 2.2.3). The data for 2011 (the time of the AR5 estimates) are also shown. Some of the concentrations vary slightly from those reported in AR5 owing to averaging different data sources. Individual species are reported where 1750–2019 ERF is at least 0.001 W m^{-2}. Radiative efficiencies for the minor gases are given in Supplementary Material, Table 7.SM.7. Uncertainties in the ERF for all gases are dominated by the uncertainties in the radiative efficiencies. Tabulated global mixing ratios of all WMGHGs and ERFs from 1750 to 2019 are provided in Annex III.

	Concentration				ERF with Respect to 1850		ERF with Respect to 1750	
	2019	2011	1850	1750	2019	2011	2019	2011
CO_2 (ppm)	409.9	390.5	285.5	278.3	2.012 ± 0.241	1.738	2.156 ± 0.259	1.882
CH_4 (ppb)	1866.3	1803.3	807.6	729.2	0.496 ± 0.099	0.473	0.544 ± 0.109	0.521
N_2O (ppb)	332.1	324.4	272.1	270.1	0.201 ± 0.030	0.177	0.208 ± 0.031	0.184
HFC-134a	107.6	62.7	0.0	0.0	0.018	0.010	0.018	0.010
HFC-23	32.4	24.1	0.0	0.0	0.006	0.005	0.006	0.005
HFC-32	20.0	4.7	0.0	0.0	0.002	0.001	0.002	0.001
HFC-125	29.4	10.3	0.0	0.0	0.007	0.002	0.007	0.002
HFC-143a	24.0	12.0	0.0	0.0	0.004	0.002	0.004	0.002
SF_6	10.0	7.3	0.0	0.0	0.006	0.004	0.006	0.004
CF_4	85.5	79.0	34.0	34.0	0.005	0.004	0.005	0.004
C_2F_6	4.8	4.2	0.0	0.0	0.001	0.001	0.001	0.001
CFC-11	226.2	237.3	0.0	0.0	0.066	0.070	0.066	0.070
CFC-12	503.1	528.6	0.0	0.0	0.180	0.189	0.180	0.189
CFC-113	69.8	74.6	0.0	0.0	0.021	0.022	0.021	0.022
CFC-114	16.0	16.3	0.0	0.0	0.005	0.005	0.005	0.005
CFC-115	8.7	8.4	0.0	0.0	0.002	0.002	0.002	0.002
HCFC-22	246.8	213.2	0.0	0.0	0.053	0.046	0.053	0.046
HCFC-141b	24.4	21.4	0.0	0.0	0.004	0.003	0.004	0.003
HCFC-142b	22.3	21.2	0.0	0.0	0.004	0.004	0.004	0.004
CCl_4	77.9	86.1	0.0	0.0	0.013	0.014	0.013	0.014
Sum of HFCs (HFC-134a equivalent)	237.1	128.6	0.0	0.0	0.040	0.022	0.040	0.022
Sum of CFCs+HCFCs+other ozone depleting gases covered by the Montreal Protocol (CFC-12 equivalent)	1031.9	1050.1	0.0	0.0	0.354	0.362	0.354	0.362
Sum of PFCs (CF_4 equivalent)	109.4	98.9	34.0	34.0	0.007	0.006	0.007	0.006
Sum of Halogenated species					0.408 ±0.078	0.394	0.408 ±0.078	0.394
Total					3.118 ±0.258	2.782	3.317 ±0.278	2.981

7.3.3 Aerosols

Anthropogenic activity, and particularly burning of biomass and fossil fuels, has led to a substantial increase in emissions of aerosols and their precursors, and thus to increased atmospheric aerosol concentrations since the pre-industrial era (Sections 2.2.6 and 6.3.5, and Figure 2.9). This is particularly true for sulphate and carbonaceous aerosols (Section 6.3.5). This has in turn led to changes in the scattering and absorption of incoming solar radiation, and also affected cloud micro- and macro-physics and thus cloud radiative properties. Aerosol changes are heterogeneous in both space and time and have impacted not just Earth's radiative energy budget but also air quality (Sections 6.1.1 and 6.6.2). Here, the assessment is focused exclusively on the global mean effects of aerosols on Earth's energy budget, while regional changes and changes associated with individual aerosol compounds are assessed in Chapter 6 (Sections 6.4.1 and 6.4.2).

Consistent with the terminology introduced in Box 7.1, the ERF due to changes from direct aerosol–radiation interactions (ERFari) is equal to the sum of the instantaneous top-of-atmosphere (TOA) radiation change (IRFari) and the subsequent adjustments. Likewise, the ERF following interactions between anthropogenic aerosols and clouds (ERFaci, referred to as 'indirect aerosol effects' in previous assessment reports) can be divided into an instantaneous forcing component (IRFaci) due to changes in cloud droplet (and indirectly also ice crystal) number concentrations and sizes, and the subsequent adjustments of cloud water content or extent. While these changes are thought to be induced primarily by changes in the abundance of cloud condensation nuclei (CCN), a change in the number of ice nucleating particles (INPs) in the atmosphere may also have occurred, and thereby contributed to ERFaci by affecting properties of mixed-phase and cirrus (ice) clouds. In the following, an assessment of IRFari and ERFari (Section 7.3.3.1) focusing on observation-based (Section 7.3.3.1.1) as well as model-based (Section 7.3.3.1.2) evidence is presented. The same lines of evidence are presented for IRFaci and ERFaci in Section 7.3.3.2. These lines of evidence are then compared with TOA energy budget constraints on the total aerosol ERF (Section 7.3.3.3) before an overall assessment of the total aerosol ERF is given in Section 7.3.3.4. For the model-based evidence, all estimates are generally valid for 2014 relative to 1750 (the time period spanned by CMIP6 historical simulations), while for observation-based evidence the assessed studies use slightly different end points, but they all generally fall within a decade (2010–2020).

7.3.3.1 Aerosol–Radiation Interactions

Since AR5, deeper understanding of the processes that govern aerosol radiative properties, and thus IRFari, has emerged. Combined with new insights into adjustments to aerosol forcing, this progress has informed new observation- and model-based estimates of ERFari and associated uncertainties.

7.3.3.1.1 Observation-based lines of evidence

Estimating IRFari requires an estimate of industrial-era changes in aerosol optical depth (AOD) and absorption AOD, which are often taken from global aerosol model simulations. Since AR5, updates to methods of estimating IRFari based on aerosol remote sensing or data-assimilated reanalyses of atmospheric composition have been published. Ma et al. (2014) applied the method of Quaas et al. (2008) to updated broadband radiative flux measurements from CERES, MODIS-retrieved AODs, and modelled anthropogenic aerosol fractions to find a clear-sky IRFari of –0.6 W m^{-2}. This would translate into an all-sky estimate of about –0.3 W m^{-2} based on the clear-sky to all-sky ratio implied by Kinne (2019). Rémy et al. (2018) applied the methods of Bellouin et al. (2013a) to the reanalysis by the Copernicus Atmosphere Monitoring Service, which assimilates MODIS total AOD. Their estimate of IRFari varies between –0.5 W m^{-2} and –0.6 W m^{-2} over the period 2003–2018, and they attribute those relatively small variations to variability in biomass-burning activity. Kinne (2019) provided updated monthly total AOD and absorption AOD climatologies, obtained by blending multi-model averages with ground-based sun-photometer retrievals, to find a best estimate of IRFari of –0.4 W m^{-2}. The updated IRFari estimates above are all scattered around the midpoint of the IRFari range of –0.35 ± 0.5 W m^{-2} assessed by AR5 (Boucher et al., 2013).

The more negative estimate of Rémy et al. (2018) is due to neglecting a small positive contribution from absorbing aerosols above clouds and obtaining a larger anthropogenic fraction than Kinne (2019). Rémy et al. (2018) also did not update their assumptions on black carbon anthropogenic fraction and its contribution to absorption to reflect recent downward revisions (Section 7.3.3.1.2). Kinne (2019) made those revisions, so more weight is given to that study to assess the central estimate of satellite-based IRFari to be only slightly stronger than reported in AR5 at –0.4 W m^{-2}. While uncertainties in the anthropogenic fraction of total AOD remain, improved knowledge of anthropogenic absorption results in a slightly narrower *very likely* range here than in AR5. The assessed best estimate and *very likely* IRFari range from observation-based evidence is therefore –0.4 ± 0.4 W m^{-2}, but with *medium confidence* due to the limited number of studies available.

7.3.3.1.2 Model-based lines of evidence

While observation-based evidence can be used to estimate IRFari, global climate models are needed to calculate the associated adjustments and the resulting ERFari, using the methods described in Section 7.3.1.

A range of developments since AR5 affect model-based estimates of IRFari. Global emissions of most major aerosol compounds and their precursors are found to be higher in the current inventories, and with increasing trends. Emissions of the sulphate precursor SO_2 are a notable exception; they are similar to those used in AR5 and approximately time-constant in recent decades (Hoesly et al., 2018). Myhre et al. (2017) showed, in a multi-model experiment, that the net result of these revised emissions is an IRFari trend that is relatively flat in recent years (post-2000), a finding confirmed by a single-model study by Paulot et al. (2018).

In AR5, the assessment of the black carbon (BC) contribution to IRFari was markedly strengthened in confidence by the review by Bond et al. (2013), where a key finding was a perceived model underestimate of atmospheric absorption when compared to Aeronet observations (Boucher et al., 2013). This assessment has since been revised considering: new knowledge on the effect of the temporal resolution of emissions inventories (Wang et al., 2016); the representativeness of Aeronet sites (Wang et al., 2018); issues with comparing absorption retrieval to models (E. Andrews et al., 2017); and the ageing (Peng et al., 2016), lifetime (Lund et al., 2018b) and average optical parameters (Zanatta et al., 2016) of BC. Consistent with these updates, Lund et al. (2018a) estimated the net IRFari in 2014 (relative to 1750) to be –0.17 W m^{-2}, using CEDS emissions (Hoesly et al., 2018) as input to a chemical transport model. They attributed the weaker estimate relative to AR5 (–0.35 ± 0.5 W m^{-2}; Myhre et al., 2013a) to stronger absorption by organic aerosol, updated parametrization of BC absorption, and slightly reduced sulphate cooling. Broadly consistent with Lund et al. (2018a), another single-model study by Petersik et al. (2018) estimated an IRFari of –0.19 W m^{-2}. Another single-model study by Lurton et al. (2020) reported a more negative estimate at –0.38 W m^{-2}, but is given less weight here because the model lacked interactive aerosols and instead used prescribed climatological aerosol concentrations.

The above estimates support a less negative central estimate and a slightly narrower range compared to those reported for IRFari from ESMs in AR5 of –0.35 [–0.6 to –0.13] W m^{-2}. The assessed central estimate and *very likely* IRFari range from model-based evidence alone is therefore –0.2 ± 0.2 W m^{-2} for 2014 relative to 1750, with *medium confidence* due to the limited number of studies available. Revisions due to stronger organic aerosol absorption, further developed BC parameterizations and somewhat reduced sulphate emissions in recent years.

Since AR5 considerable progress has been made in the understanding of adjustments in response to a wide range of climate forcings, as discussed in Section 7.3.1. The adjustments in ERFari are principally caused by cloud changes, but also by lapse rate and atmospheric water vapour changes, all mainly associated with absorbing aerosols like BC. Stjern et al. (2017) found that for BC, about 30% of the (positive) IRFari is offset by adjustments of clouds (specifically, an increase in low-clouds and decrease in high-clouds) and lapse rate, by analysing simulations by five Precipitation Driver Response Model Intercomparison Project (PDRMIP) models. Smith et al. (2018b) considered more models participating in PDRMIP and suggested that about half the IRFari was offset by adjustments for BC, a finding generally supported by single-model studies (Takemura and Suzuki, 2019; Zhao and Suzuki, 2019). Thornhill et al. (2021b) also reported a negative adjustment for BC based on AerChemMIP (Collins et al., 2017) but found it to be somewhat smaller in magnitude than those reported in Smith et al. (2018b) and Stjern et al. (2017). In contrast, Allen et al. (2019) found a positive adjustment for BC and suggested that most models simulate negative adjustment for BC because of a misrepresentation of aerosol atmospheric heating profiles.

Zelinka et al. (2014) used the approximate partial radiation perturbation technique to quantify the ERFari in 2000 relative to 1860 in nine CMIP5 models; they estimated the ERFari (accounting for a small contribution from longwave radiation) to be –0.27 ± 0.35 W m^{-2}. However, it should be noted that in Zelinka et al. (2014) adjustments of clouds caused by absorbing aerosols through changes in the thermal structure of the atmosphere (termed the semidirect effect of aerosols in AR5) are not included in ERFari but in ERFaci. The corresponding estimate emerging from the Radiative Forcing Model Intercomparison Project (RFMIP, Pincus et al., 2016) is –0.25 ± 0.40 W m^{-2} (Smith et al., 2020b), which is generally supported by single-model studies published since AR5 (Zhang et al., 2016; Fiedler et al., 2017; Nazarenko et al., 2017; Zhou et al., 2017c, 2018b; Grandey et al., 2018). A 5% inflation is applied to the CMIP5 and CMIP6 fixed-SST derived estimates of ERFari from Zelinka et al. (2014) and Smith et al. (2020b) to account for land surface cooling (Table 7.6). Based on the above, ERFari from model-based evidence is assessed to be –0.25 ± 0.25 W m^{-2}.

7.3.3.1.3 Overall assessment of IRFari and ERFari

The observation-based assessment of IRFari of –0.4 ± 0.4 W m^{-2} and the corresponding model-based assessment of –0.2 ± 0.2 W m^{-2} can be compared to the range of –0.45 to –0.05 W m^{-2} that emerged from a comprehensive review in which an observation-based estimate of anthropogenic AOD was combined with model-derived ranges for all relevant aerosol radiative properties (Bellouin et al., 2020). Based on the above, IRFari is assessed to be –0.25 ± 0.2 W m^{-2} (*medium confidence*).

ERFari from model-based evidence is –0.25 ± 0.25 W m^{-2}, which suggests a small negative adjustment relative to the model-based IRFari estimate, consistent with the literature discussed in Section 7.3.3.1.2. Adding this small adjustment to our assessed IRFari estimate of –0.25 W m^{-2}, and accounting for additional uncertainty in the adjustments, ERFari is assessed to –0.3 ± 0.3 (*medium confidence*).

Table 7.6 | Present-day effective radiative forcing (ERF) due to changes in aerosol–radiation interactions (ERFari) and changes in aerosol–cloud interactions (ERFaci), and total aerosol ERF (ERFari+aci) from GCM CMIP6 (2014 relative to 1850; Smith et al., 2020b and later model results) and CMIP5 (year 2000 relative to 1860; Zelinka et al., 2014). CMIP6 results are simulated as part of RFMIP (Pincus et al., 2016). An additional 5% is applied to the CMIP5 and CMIP6 model results to account for land-surface cooling (Figure 7.4; Smith et al., 2020a).

Models	ERFari (W m^{-2})	ERFaci (W m^{-2})	ERFari+aci (W m^{-2})
ACCESS-CM2	–0.24	–0.93	–1.17
ACCESS-ESM1-5	–0.07	–1.19	–1.25
BCC-ESM1	–0.79	–0.69	–1.48
CanESM5	–0.02	–1.09	–1.11
CESM2	+0.15	–1.65	–1.50
CNRM-CM6-1	–0.28	–0.86	–1.14
CNRM-ESM2-1	–0.15	–0.64	–0.79
EC-Earth3	–0.39	–0.50	–0.89
GFDL-CM4	–0.12	–0.72	–0.84
GFDL-ESM4	–0.06	–0.84	–0.90
GISS-E2-1-G (physics_version=1)	–0.55	–0.81	–1.36
GISS-E2-1-G (physics_version=3)	–0.64	–0.39	–1.02
HadGEM3-GC31-LL	–0.29	–0.87	–1.17
IPSL-CM6A-LR	–0.39	–0.29	–0.68
IPSL-CM6A-LR-INCA	–0.45	–0.35	–0.80
MIROC6	–0.22	–0.77	–0.99
MPI-ESM-1-2-HAM	+0.10	–1.40	–1.31
MRI-ESM2-0	–0.48	–0.74	–1.22
NorESM2-LM	–0.15	–1.08	–1.23
NorESM2-MM	–0.03	–1.26	–1.29
UKESM1-0-LL	–0.20	–0.99	–1.19
CMIP6 average and 5–95% confidence range (2014 relative to 1850)	–0.25 ± 0.40	–0.86 ± 0.57	–1.11 ± 0.38
CMIP5 average and 5–95% confidence range (2000 relative to 1860)	–0.27 ± 0.35	–0.96 ± 0.55	–1.23 ± 0.48

This assessment is consistent with the 5–95% confidence range for ERFari in Bellouin et al. (2020) of –0.71 to –0.14 W m^{-2}, and notably implies that it is *very likely* that ERFari is negative. Differences relative to Bellouin et al. (2020) reflect the range of estimates in Table 7.6 and the fact that an ERFari more negative than –0.6 W m^{-2} would require adjustments that considerably augment the assessed IRFari, which is not supported by the assessed literature.

7.3.3.2 Aerosol–Cloud Interactions

Anthropogenic aerosol particles primarily affect water clouds by serving as additional cloud condensation nuclei (CCN) and thus increasing cloud drop number concentration (N_d; Twomey, 1959). Increasing N_d while holding liquid water content constant reduces cloud drop effective radius (r_e), increases the cloud albedo, and induces an instantaneous negative radiative forcing (IRFaci). The clouds are thought to subsequently adjust by a slowing of the drop coalescence rate, thereby delaying or suppressing rainfall. Rain generally reduces cloud lifetime and thereby liquid water path (LWP, i.e., the vertically integrated cloud water) and/or cloud fractional coverage (Cf; Albrecht, 1989), thus any aerosol-induced rain delay or suppression would be expected to increase LWP and/or Cf. Such adjustments could potentially lead to an ERFaci considerably larger in magnitude than the IRFaci alone. However, adding aerosols to non-precipitating clouds has been observed to have the opposite effect (i.e., a reduction in LWP and/or Cf) (Lebsock et al., 2008; Christensen and Stephens, 2011). These findings have been explained by enhanced evaporation of the smaller droplets in the aerosol-enriched environments, and resultant enhanced mixing with ambient air, leading to cloud dispersal.

A small subset of aerosols can also serve as ice nucleating particles (INPs) that initiate the ice phase in supercooled water clouds, and thereby alter cloud radiative properties and/or lifetimes. However, the ability of anthropogenic aerosols (specifically BC) to serve as INPs in mixed-phase clouds has been found to be negligible in recent laboratory studies (e.g., Vergara-Temprado et al., 2018). No assessment of the contribution to ERFaci from cloud phase changes induced by anthropogenic INPs will therefore be presented.

In ice (cirrus) clouds (cloud temperatures less than –40°C), INPs can initiate ice crystal formation at relative humidity much lower than that required for droplets to freeze spontaneously. Anthropogenic INPs can thereby influence ice crystal numbers and thus cirrus cloud radiative properties. At cirrus temperatures, certain types of BC have in fact been demonstrated to act as INPs in laboratory studies (Ullrich et al., 2017; Mahrt et al., 2018), suggesting a non-negligible anthropogenic contribution to INPs in cirrus clouds. Furthermore, anthropogenic changes to drop number also alter the number of droplets available for spontaneous freezing, thus representing a second pathway through which anthropogenic emissions could affect cirrus clouds.

Table 7.7 | Studies quantifying aspects of the global effective radiative forcing due to aerosol–cloud interactions ERFaci that are mainly based on satellite retrievals and were published since AR5. All forcings/adjustments are presented as global annual mean values in W m^{-2}. Most studies split the ERFaci into instantaneous radiative forcing (IRFaci) and adjustments in liquid water path (LWP) and cloud fraction (Cf) separately. All published studies only considered liquid clouds. Some studies assessed the IRFaci and the LWP adjustment together and called this 'intrinsic forcing' (Christensen et al., 2017) and the cloud fraction adjustment 'extrinsic forcing'. Published uncertainty ranges are converted to 5–95% confidence intervals, and 'n/a' indicates that the study did not provide an estimate for the relevant IRF/ERF.

IRFaci (W m^{-2})	Liquid Water Path (LWP) Adjustment (W m^{-2})	Cloud Fraction (Cf) Adjustment (W m^{-2})	Reference
–0.6 ± 0.6	n/a	n/a	Bellouin et al. (2013b)
–0.4 [–0.2 to –1.0]	n/a	n/a	Gryspeerdt et al. (2017)
–1.0 ± 0.4	n/a	n/a	McCoy et al. (2017b)
n/a	n/a	–0.5 [–0.1 to –0.6]	Gryspeerdt et al. (2016)
n/a	+0.3 to 0.0	n/a	Gryspeerdt et al. (2019)
–0.8 ± 0.7	n/a	n/a	Rémy et al. (2018)
–0.53	+0.15	n/a	Toll et al. (2019)
–1.14 [–1.72 to –0.84]	n/a	n/a	Hasekamp et al. (2019)
–1.2 to –0.6	n/a	n/a	McCoy et al. (2020)
–0.69 [–0.99 to –0.44]	n/a	n/a	Diamond et al. (2020)
'Intrinsic Forcing'			
–0.5 ± 0.5		–0.5 ± 0.5	Chen et al. (2014)
–0.4 ± 0.3		n/a	Christensen et al. (2016a)
–0.3 ± 0.4		–0.4 ± 0.5	Christensen et al. (2017)

7.3.3.2.1 Observation-based evidence

Since AR5, the analysis of observations to investigate aerosol–cloud interactions has progressed along several axes: (i) The framework of forcing and adjustments introduced rigorously in AR5 has helped better categorize studies; (ii) the literature assessing statistical relationships between aerosol and cloud in satellite retrievals has grown, and retrieval uncertainties are better characterized; (iii) advances have been made to infer causality in aerosol–cloud relationships.

In AR5 the statistical relationship between cloud microphysical properties and aerosol index (AI; AOD multiplied by Ångström exponent) was used to make inferences about IRFaci were assessed alongside other studies which related cloud quantities to AOD. However, it is now well-documented that the latter approach leads to low estimates of IRFaci since AOD is a poor proxy for cloud-base CCN (Penner et al., 2011; Stier, 2016). Gryspeerdt et al. (2017) demonstrated that the statistical relationship between droplet concentration and AOD leads to an inferred IRFaci that is underestimated by at least 30%, while the use of AI leads to estimates of IRFaci to within ±20%, if the anthropogenic perturbation of AI is known.

Further, studies assessed in AR5 mostly investigated linear relationships between cloud droplet concentration and aerosol (Boucher et al., 2013). Since in most cases the relationships are not linear, this leads to a bias (Gryspeerdt et al., 2016). Several studies did not relate cloud droplet concentration, but cloud droplet effective radius, to the aerosol (Brenguier et al., 2000). This is problematic because in order to infer IRFaci, stratification by cloud LWP is required (McComiskey and Feingold, 2012). Where LWP positively co-varies with aerosol retrievals (which is often the case), IRFaci inferred from such relationships is biased towards low values. Also, it is increasingly evident that different cloud regimes show different sensitivities to aerosols (Stevens and Feingold, 2009). Averaging statistics over regimes thus biases the inferred IRFaci (Gryspeerdt et al., 2014b). The AR5 concluded that IRFaci estimates tied to satellite studies generally show weak IRFaci (Boucher et al., 2013), but when correcting for the biases discussed above, this is no longer the case.

Since AR5, several studies assessed the global IRFaci from satellite observations using different methods (Table 7.7). All studies relied on statistical relationships between aerosol and cloud quantities to infer sensitivities. Four studies inferred IRFaci by estimating the anthropogenic perturbation of N_d (cloud drop number concentration). For this, Bellouin et al. (2013b) and Rémy et al. (2018) made use of regional-seasonal regressions between satellite-derived N_d and AOD following Quaas et al. (2008), while Gryspeerdt et al. (2017)

used AI instead of AOD in the regression to infer IRFaci. McCoy et al. (2017b) instead used the sulphate-specific mass derived in the MERRA aerosol reanalysis that assimilated MODIS AOD (Rienecker et al., 2011). All approaches have in common the need to identify the anthropogenic perturbation of the aerosol to assess IRFaci. Gryspeerdt et al. (2017) and Rémy et al. (2018) used the same approach as Bellouin et al. (2013b), while McCoy et al. (2017b) used an anthropogenic fraction from the AEROCOM multi-model ensemble (Schulz et al., 2006). Chen et al. (2014), Christensen et al. (2016a) and Christensen et al. (2017) derived the combination of IRFaci and the LWP adjustment to IRFaci ('intrinsic forcing' in their terminology). They relate AI and cloud albedo statistically and use the anthropogenic aerosol fraction from Bellouin et al. (2013b). This was further refined by Hasekamp et al. (2019) who used additional polarimetric satellite information over ocean to obtain a better proxy for CCN. They derived an IRFaci of –1.14 [–1.72 to –0.84] W m^{-2}. The variant by Christensen et al. (2017) is an update compared to the Chen et al. (2014) and Christensen et al. (2016a) studies in that it better accounts for ancillary influences on the aerosol retrievals such as aerosol swelling and three-dimensional radiative effects. McCoy et al. (2020) used the satellite-observed hemispheric difference in N_d as an emergent constraint on IRFaci as simulated by GCMs to obtain a range of –1.2 to –0.6 W m^{-2} (95% confidence interval). Diamond et al. (2020) analysed the difference in clouds affected by ship emissions with unperturbed clouds and based on this inferred a global IRFaci of –0.69 [–0.99 to –0.44] W m^{-2}.

Summarizing the above findings related to statistical relationships and causal aerosol effects on cloud properties, there is *high confidence* that anthropogenic aerosols lead to an increase in cloud droplet concentrations. Taking the average across the studies providing IRFaci estimates discussed above and considering the general agreement among estimates (Table 7.7), IRFaci is assessed to be –0.7 ± 0.5 W m^{-2} (*medium confidence*).

Multiple studies have found a positive relationship between cloud fraction and/or cloud LWP and aerosols (e.g., Nakajima et al., 2001; Kaufman and Koren, 2006; Quaas et al., 2009). Since AR5, however, it has been documented that factors independent of causal aerosol–cloud interactions heavily influence such statistical relationships. These include the swelling of aerosols in the high relative humidity in the vicinity of clouds (Grandey et al., 2013) and the contamination of aerosol retrievals next to clouds by cloud remnants and cloud-side scattering (Várnai and Marshak, 2015; Christensen et al., 2017). Stratifying relationships by possible influencing factors such as relative humidity (Koren et al., 2010) does not yield satisfying results since observations of the relevant quantities are not available at the resolution and quality required. Another approach to tackle this problem was to assess the relationship of cloud fraction with droplet concentration (Gryspeerdt et al., 2016; Michibata et al., 2016; Sato et al., 2018). The relationship between satellite-retrieved cloud fraction and N_d was found to be positive (Christensen et al., 2016a, 2017; Gryspeerdt et al., 2016), implying an overall adjustment that leads to a more negative ERFaci. However, since retrieved N_d is biased low for broken clouds this result has been called into question (Grosvenor et al., 2018). Zhu et al. (2018) proposed to circumvent this problem by considering N_d of only continuous thick cloud covers, on the basis of which Rosenfeld et al. (2019) still obtained a positive relationship between cloud fraction and N_d relationship.

The relationship between LWP and cloud droplet number is debated. Most recent studies (primarily based on MODIS data) find negative statistical relationships (Michibata et al., 2016; Toll et al., 2017; Sato et al., 2018; Gryspeerdt et al., 2019), while Rosenfeld et al. (2019) obtained a modest positive relationship. To increase confidence that observed relationships between aerosol emissions and cloud adjustments are causal, known emissions of aerosols and aerosol precursor gases into otherwise pristine conditions have been exploited. Ship exhaust is one such source. Goren and Rosenfeld (2014) suggested that both LWP and Cf increase in response to ship emissions, contributing approximately 75% to the total ERFaci in mid-latitude stratocumulus. Christensen and Stephens (2011) found that such strong adjustments occur for open-cell stratocumulus regimes, while adjustments are comparatively small in closed-cell regimes. Volcanic emissions have been identified as another important source of information (Gassó, 2008). From satellite observations, Yuan et al. (2011) documented substantially larger Cf, higher cloud tops, reduced precipitation likelihood, and increased albedo in cumulus clouds in the plume of the Kīlauea volcano in Hawaii. Ebmeier et al. (2014) confirmed the increased LWP and albedo for other volcanoes. In contrast, for the large Holuhraun eruption in Iceland, Malavelle et al. (2017) did not find any large-scale change in LWP in satellite observations. However, when accounting for meteorological conditions, McCoy et al. (2018) concluded that for cyclonic conditions, the extra Holuhraun aerosol did enhance LWP. Toll et al. (2017) examined a large sample of volcanoes and found a distinct albedo effect, but only modest LWP changes, on average. Gryspeerdt et al. (2019) demonstrated that the negative LWP–N_d relationship becomes very small when conditioned on a volcanic eruption, and therefore concluded that LWP adjustments are small in most regions. Similarly, Toll et al. (2019) studied clouds downwind of various anthropogenic aerosol sources using satellite observations and inferred an IRFaci of –0.52 W m^{-2} that was partly offset by 29% due to aerosol-induced LWP decreases.

Apart from adjustments involving LWP and Cf, several studies have also documented a negative relationship between cloud-top temperature and AOD/AI in satellite observations (e.g., Koren et al., 2005). Wilcox et al. (2016) proposed that this could be explained by black-carbon (BC) absorption reducing boundary-layer turbulence, which in turn could lead to taller clouds. However, it has been demonstrated that the satellite-derived relationships are affected by spurious co-variation (Gryspeerdt et al., 2014a), and it therefore remains unclear whether a systematic causal effect exists.

Identifying relationships between INP concentrations and cloud properties from satellites is intractable because the INPs generally represent a very small subset of the overall aerosol population at any given time or location. For ice clouds, only a few satellite studies have so far investigated responses to aerosol perturbations. Gryspeerdt et al. (2018) find a positive relationship between aerosol and ice crystal number for cold cirrus under strong dynamical forcing, which could be explained by an overall larger number of solution droplets available for homogeneous freezing in polluted regions.

Zhao et al. (2018) conclude that the sign of the relationship between ice crystal size and aerosol depends on humidity. While these studies support modelling results finding that ice clouds do respond to anthropogenic aerosols (Section 7.3.3.2.2), no quantitative conclusions about IRFaci or ERFaci for ice clouds can be drawn based on satellite observations.

Only a handful of studies have estimated the LWP and Cf adjustments that are needed for satellite-based estimates of ERFaci. Chen et al. (2014) and Christensen et al. (2017) used the relationship between cloud fraction and AI to infer the cloud fraction adjustment. Gryspeerdt et al. (2017) used a similar approach but tried to account for non-causal coorelations between aerosols and cloud fraction by using N_d as a mediating factor. These three studies together suggest a global Cf adjustment that augments ERFaci relative to IRFaci by –0.5 ± 0.4 W m^{-2} (*medium confidence*). For global estimates of the LWP adjustment, evidence is even scarcer. Gryspeerdt et al. (2019) derived an estimate of the LWP adjustment using a method similar to Gryspeerdt et al. (2016). They estimated that the LWP adjustment offsets 0–60% of the (negative) IRFaci (0.0 to +0.3 W m^{-2}). Supporting an offsetting LWP adjustment, Toll et al. (2019) estimated a moderate LWP adjustment of 29% (+0.15 W m^{-2}). The adjustment due to LWP is assessed to be small, with a central estimate and *very likely* range of 0.2 ± 0.2 W m^{-2}, but with *low confidence* due to the limited number of studies available.

Combining IRFaci and the associated adjustments in Cf and LWP (adding uncertainties in quadrature), considering only liquid-water clouds and evidence from satellite observations alone, the central estimate and *very likely* range for ERFaci is assessed to be –1.0 ± 0.7 W m^{-2} (*medium confidence*). The confidence level and wider range for ERFaci compared to IRFaci reflect the relatively large uncertainties that remain in the adjustment contribution to ERFaci.

7.3.3.2.2 Model-based evidence

As in AR5, the representation of aerosol–cloud interactions in ESMs remains a challenge, due to the limited representation of important sub-gridscale processes, from the emissions of aerosols and their precursors to precipitation formation. ESMs that simulate ERFaci typically include aerosol–cloud interactions in liquid stratiform clouds only, while very few include aerosol interactions with mixed-phase, convective and ice clouds. Adding to the spread in model-derived estimates of ERFaci is the fact that model configurations and assumptions vary across studies, for example when it comes to the treatment of oxidants, which influence aerosol formation, and their changes through time (Karset et al., 2018).

In AR5, ERFaci was assessed as the residual of the total aerosol ERF and ERFari, as the total aerosol ERF was easier to calculate based on available model simulations (Boucher et al., 2013). The central estimates of total aerosol ERF and ERFari in AR5 were –0.9 W m^{-2} and –0.45 W m^{-2}, respectively, yielding an ERFaci estimate of –0.45 W m^{-2}. This value is much less negative than the bottom-up estimate of ERFaci from ESMs presented in AR5 (–1.4 W m^{-2}) and efforts have been made since to reconcile this difference. Zelinka et al. (2014) estimated ERFaci to be –0.96 ± 0.55 W m^{-2} (including semi-direct effects, and with land-surface cooling effect applied), based on nine CMIP5 models (Table 7.6). The corresponding ERFaci estimate based on 17 RFMIP models from CMIP6 is slightly less negative at –0.86 ± 0.57 W m^{-2} (Table 7.6). Other post-AR5 estimates of ERFaci based on single-model studies are either in agreement with or slightly larger in magnitude than the CMIP6 estimate (Gordon et al., 2016; Fiedler et al., 2017, 2019; Neubauer et al., 2017; Karset et al., 2018; Regayre et al., 2018; Zhou et al., 2018b; Golaz et al., 2019; Diamond et al., 2020).

The adjustment contribution to the CMIP6 ensemble mean ERFaci is –0.20 W m^{-2}, though with considerable differences between the models (Smith et al., 2020b). Generally, this adjustment in ESMs arises mainly from LWP changes (e.g., Ghan et al., 2016), while satellite observations suggest that cloud cover adjustments dominate and that aerosol effects on LWP are overestimated in ESMs (Bender et al., 2019). Large-eddy-simulations also tend to suggest an overestimated aerosol effect on cloud lifetime in ESMs, but some report an aerosol-induced decrease in cloud cover that is at odds with satellite observations (Seifert et al., 2015). Despite this potential disagreement when it comes to the dominant adjustment mechanism, a substantial negative contribution to ERFaci from adjustments is supported both by observational and modelling studies.

Contributions to ERFaci from anthropogenic aerosols acting as INPs are generally not included in CMIP6 models. Two global modelling studies incorporating parametrizations based on recent laboratory studies both found a negative contribution to ERFaci (Penner et al., 2018; McGraw et al., 2020), with central estimates of –0.3 and –0.13 W m^{-2}, respectively. However, previous studies have produced model estimates of opposing signs (Storelvmo, 2017). There is thus *limited evidenc*e and *medium agreement* for a small negative contribution to ERFaci from anthropogenic INP-induced cirrus modifications (*low confidence*).

Similarly, aerosol effects on deep convective clouds are typically not incorporated in ESMs. However, cloud-resolving modelling studies support non-negligible aerosol effects on the radiative properties of convective clouds and associated detrained cloud anvils (Tao et al., 2012). While global ERF estimates are currently not available for these effects, the fact that they are missing in most ESMs adds to the uncertainty range for the model-based ERFaci.

From model-based evidence, ERFaci is assessed to –1.0 ± 0.8 W m^{-2} (*medium confidence*). This assessment uses the mean ERFaci in Table 7.6 as a starting point, but further allows for a small negative ERF contribution from cirrus clouds. The uncertainty range is based on those reported in Table 7.6, but widened to account for uncertain but *likely* non-negligible processes currently unaccounted for in ESMs.

7.3.3.2.3 Overall assessment of ERFaci

The assessment of ERFaci based on observational evidence alone (–1.0 ± 0.7 W m^{-2}) is very similar to the one based on model evidence alone (–1.0 ± 0.8 W m^{-2}), in strong contrast to what was reported in AR5. This reconciliation of observation-based and model-based estimates is the result of considerable scientific progress and reflects comparable revisions of both model-based and observation-based estimates. The strong agreement between the two largely independent lines of evidence increases confidence in the overall assessment of the central estimate and *very likely* range for ERFaci of –1.0 ± 0.7 W m^{-2} (*medium confidence*). The assessed range is consistent with but narrower than that reported by the review of Bellouin et al. (2020) of –2.65 to –0.07 W m^{-2}. The difference is primarily due to a wider range in the adjustment contribution to ERFaci in Bellouin et al. (2020), however adjustments reported relative to IRFaci ranging from 40% to 150% in that study are fully consistent with the ERFaci assessment presented here.

7.3.3.3 Energy Budget Constraints on the Total Aerosol ERF

Energy balance models of reduced complexity have in recent years increasingly been combined with Monte Carlo approaches to provide valuable 'top-down' (also called inverse) observational constraints on the total aerosol ERF. These top-down approaches report ranges of aerosol ERF that are found to be consistent with the global mean temperature record and, in some cases, also observed ocean heat uptake. However, the total aerosol ERF is also used together with the historical temperature record in Section 7.5 to constrain equilibrium climate sensitivity (ECS) and transient climate response (TCR). Using top-down estimates as a separate line of evidence also for the total aerosol ERF would therefore be circular. Nevertheless, it is useful to examine the development of these estimates since AR5, and the degree to which these estimates are consistent with the upper and lower bounds of the assessments of total aerosol ERF (ERFari+aci).

When the first top-down estimates emerged (e.g., Knutti et al., 2002), it became clear that some of the early ('bottom-up') ESM estimates of total aerosol ERF were inconsistent with the plausible top-down range. However, as more inverse estimates have been published, it has increasingly become clear that they too are model-dependent and span a wide range of ERF estimates, with confidence intervals that in some cases do not overlap (Forest, 2018). It has also become evident that these methods are sensitive to revised estimates of other forcings and/or updates to observational datasets. A recent review of 19 such estimates reported a mean of –0.77 W m^{-2} for the total aerosol ERF, and a 95% confidence interval of [–1.15 to –0.31] W m^{-2} (Forest, 2018). Adding to that review, a more recent study using the same approach reported an estimate of total aerosol ERF of –0.89 [–1.82 to –0.01] W m^{-2} (Skeie et al., 2018). However, in the same study, an alternative way of incorporating ocean heat content in the analysis produced a total aerosol ERF estimate of –1.34 [–2.20 to –0.46] W m^{-2}, illustrating the sensitivity to the manner in which observations are included. A new approach to inverse estimates took advantage of independent climate radiative response estimates from eight prescribed SST and sea ice-concentration simulations over the historical period to estimate the total anthropogenic ERF. From this a total aerosol ERF of –0.8 [–1.6 to +0.1] W m^{-2} was derived (valid for near-present relative to the late 19th century). This range was found to be more invariant to parameter choices than earlier inverse approaches (Andrews and Forster, 2020).

Beyond the inverse estimates described above, other efforts have been made since AR5 to constrain the total aerosol ERF. For example, Stevens (2015) used a simple (one-dimensional) model to simulate the historical total aerosol ERF evolution consistent with the observed temperature record. Given the lack of temporally extensive cooling trends in the 20th-century record and the fact that the historical evolution of GHG forcing is relatively well constrained, the study concluded that a more negative total aerosol ERF than –1.0 W m^{-2} was incompatible with the historical temperature record. This was countered by Kretzschmar et al. (2017), who argued that the model employed in Stevens (2015) was too simplistic to account for the effect of geographical redistributions of aerosol emissions over time. Following the logic of Stevens (2015), but basing their estimates on a subset of CMIP5 models as opposed to a simplified modelling framework, Kretzschmar et al. argued that a total aerosol ERF as negative as –1.6 W m^{-2} was consistent with the observed temperature record. Similar arguments were put forward by Booth et al. (2018), who emphasized that the degree of non-linearity of the total aerosol ERF with aerosol emissions is a central assumption in Stevens (2015).

The historical temperature record was also the key observational constraint applied in two additional studies (Rotstayn et al., 2015; Shindell et al., 2015) based on a subset of CMIP5 models. Rotstayn et al. (2015) found a strong temporal correlation (>0.9) between the total aerosol ERF and the global surface temperature. They used this relationship to produce a best estimate for the total aerosol ERF of –0.97 W m^{-2}, but with considerable unquantified uncertainty, in part due to uncertainties in the TCR. Shindell et al. (2015) came to a similar best estimate for the total aerosol ERF of –1.0 W m^{-2} and a 95% confidence interval of –1.4 to –0.6 W m^{-2} but based this on spatial temperature and ERF patterns in the models in comparison with observed spatial temperature patterns.

A separate observational constraint on the total ERF was proposed by Cherian et al. (2014), who compared trends in downward fluxes of solar radiation observed at surface stations across Europe (described in Section 7.2.2.3) to those simulated by a subset of CMIP5 models. Based on the relationship between solar radiation trends and the total aerosol ERF in the models, they inferred a total aerosol ERF of –1.3 W m^{-2} and a standard deviation of ± 0.4 W m^{-2}.

Based solely on energy balance considerations or other observational constraints, it is *extremely likely* that the total aerosol ERF is negative (*high confidence*), but *extremely unlikely* that the total aerosol ERF is more negative than –2.0 W m^{-2} (*high confidence*).

7.3.3.4 Overall Assessment of Total Aerosol ERF

In AR5 (Boucher et al., 2013), the overall assessment of total aerosol ERF (ERFari+aci) used the median of all ESM estimates published prior to AR5 of –1.5 [–2.4 to –0.6] W m^{-2} as a starting point, but placed more confidence in a subset of models that were deemed more complete in their representation of aerosol–cloud interactions. These models, which included aerosol effects on mixed-phase, ice and/or convective clouds, produced a smaller estimate of –1.38 W m^{-2}. Likewise, studies that constrained models with satellite observations (five in total), which produced a median estimate of –0.85 W m^{-2}, were given extra weight. Furthermore, a longwave ERFaci of 0.2 W m^{-2} was added to studies that only reported shortwave ERFaci values. Finally, based on higher resolution models, doubt was raised regarding the ability of ESMs to represent the cloud-adjustment component of ERFaci with fidelity. The expert judgement was therefore that aerosol effects on cloud lifetime were too strong in the ESMs, further reducing the overall ERF estimate. The above lines of argument resulted in a total aerosol assessment of –0.9 [–1.9 to –0.1] W m^{-2} in AR5.

Here, the best estimate and range is revised relative to AR5 (Boucher et al., 2013), partly based on updates to the above lines of argument. Firstly, the studies that included aerosol effects on mixed-phase clouds in AR5 relied on the assumption that anthropogenic black carbon (BC) could act as INPs in these clouds, which has since been challenged by laboratory experiments (Kanji et al., 2017; Vergara-Temprado et al., 2018). There is no observational evidence of appreciable ERFs associated with aerosol effects on mixed-phase and ice clouds (Section 7.3.3.2.1), and modelling studies disagree when it comes to both their magnitude and sign (Section 7.3.3.2.2). Likewise, very few ESMs incorporate aerosol effects on deep convective clouds, and cloud-resolving modelling studies report different effects on cloud radiative properties depending on environmental conditions (Tao et al., 2012). Thus, it is not clear whether omitting such effects from ESMs would lead to any appreciable ERF biases, or if so, what the sign of such biases would be. As a result, all ESMs are given equal weight in this assessment. Furthermore, there is now a considerably expanded body of literature which suggests that early modelling studies that incorporated satellite observations may have resulted in overly conservative estimates of the magnitude of ERFaci (Section 7.3.3.2.1). Finally, based on an assessment of the longwave ERFaci in the CMIP5 models, the offset of +0.2 W m^{-2} applied in AR5 appears to be too large (Heyn et al., 2017). As in AR5, there is still reason to question the ability of ESMs to simulate adjustments in LWP and cloud cover in response to aerosol perturbation, but it is not clear that this will result in biases that exclusively increase the magnitude of the total aerosol ERF (Section 7.3.3.2.2).

The assessment of total aerosol ERF here uses the following lines of evidence: satellite-based evidence for IRFari; model-based evidence for IRFari and ERFari; satellite-based evidence of IRFaci and ERFaci; and finally model-based evidence for ERFaci. Based on this, ERFari and ERFaci for 2014 relative to 1750 are assessed to be –0.3 ± 0.3 W m^{-2} and –1.0 ± 0.7 W m^{-2}, respectively. There is thus strong evidence for a substantive negative total aerosol ERF, which is supported by the broad agreement between observation-based and model-based lines of evidence for both ERFari and ERFaci that has emerged since AR5 (Gryspeerdt et al., 2020). However, considerable uncertainty remains, particularly with regards to the adjustment contribution to ERFaci, as well as missing processes in current ESMs, notably aerosol effects on mixed-phase, ice and convective clouds. This leads to a *medium confidence* in the estimate of ERFari+aci and a slight narrowing of the uncertainty range. Because the estimates informing the different lines of evidence are generally valid for approximately 2014 conditions, the total aerosol ERF assessment is considered valid for 2014 relative to 1750.

Combining the lines of evidence and adding uncertainties in quadrature, the ERFari+aci estimated for 2014 relative to 1750 is assessed to be –1.3 [–2.0 to –0.6] W m^{-2} (*medium confidence*). The corresponding range from Bellouin et al. (2019) is –3.15 to –0.35 W m^{-2}, thus there is agreement for the upper bound while the lower bound assessed here is less negative. A lower bound more negative than –2.0 W m^{-2} is not supported by any of the assessed lines of evidence. There is *high confidence* that ERFaci contributes most (75–80%) to the total aerosol effect (ERFari+aci). In contrast to AR5 (Boucher et al., 2013), it is now *virtually certain* that the total aerosol ERF is negative. Figure 7.5 depicts the aerosol ERFs from the different lines of evidence along with the overall assessments.

As most modelling and observational estimates of aerosol ERF have end points in 2014 or earlier, there is *limited evidence* available for the assessment of how aerosol ERF has changed from 2014 to 2019. However, based on a general reduction in global mean AOD over this period (Section 2.2.6 and Figure 2.9), combined with a reduction in emissions of aerosols and their precursors in updated emissions inventories (Hoesly et al., 2018), the aerosol ERF is assessed to have decreased in magnitude from about 2014 to 2019 (*medium confidence*). Consistent with Figure 2.10, the change in aerosol ERF from about 2014 to 2019 is assessed to be +0.2 W m^{-2}, but with *low confidence* due to *limited evidence*. Aerosols are therefore assessed to have contributed an ERF of –1.1 [–1.7 to –0.4] W m^{-2} over 1750–2019 (*medium confidence*).

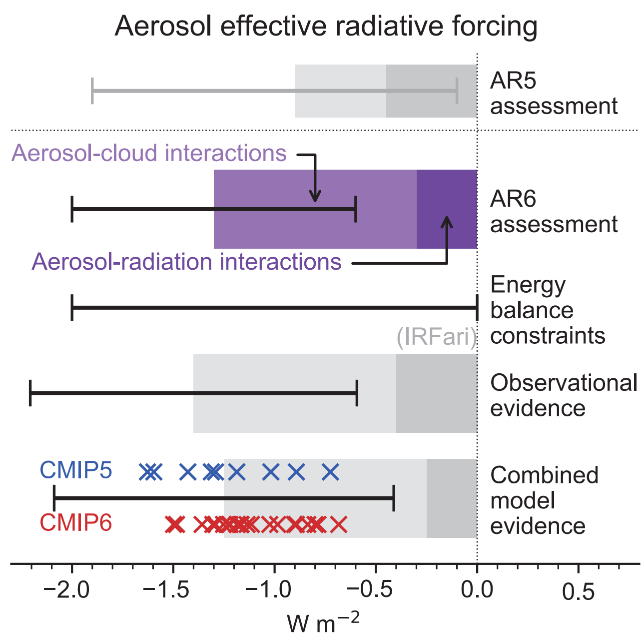


Figure 7.5 | Net aerosol effective radiative forcing (ERF) from different lines of evidence. The headline AR6 assessment of –1.3 [–2.0 to –0.6] W m^{-2} is highlighted in purple for 1750–2014 and compared to the AR5 assessment of –0.9 [–1.9 to –0.1] W m^{-2} for 1750–2011. The evidence comprising the AR6 assessment is shown below this: energy balance constraints [–2 to 0 W m^{-2} with no best estimate]; observational evidence from satellite retrievals of –1.4 [–2.2 to –0.6] W m^{-2}; and climate model-based evidence of –1.25 [–2.1 to –0.4] W m^{-2}. Estimates from individual CMIP5 (Zelinka et al., 2014) and CMIP6 (Smith et al., 2020b and Table 7.6) models are depicted by blue and red crosses respectively. For each line of evidence the assessed best-estimate contributions from ERFari and ERFaci are shown with darker and paler shading respectively. The observational assessment for ERFari is taken from the IRFari. Uncertainty ranges are represented by black bars for the total aerosol ERF and depict *very likely* ranges. Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

7

7.3.4 Other Agents

In addition to the large anthropogenic ERFs associated with WMGHGs and atmospheric aerosols assessed in Sections 7.3.2 and 7.3.3, land-use change, contrails and aviation-induced cirrus, and light-absorbing particles deposited on snow and ice have also contributed to the overall anthropogenic ERF and are assessed in Sections 7.3.4.1, 7.3.4.2 and 7.3.4.3. Changes in solar irradiance, galactic cosmic rays, and volcanic eruptions since pre-industrial times combined represent the natural contribution to the total (anthropogenic + natural) ERF and are discussed in Sections 7.3.4.4, 7.3.4.5 and 7.3.4.6.

7.3.4.1 Land Use

Land-use forcing is defined as those changes in land-surface properties directly caused by human activity rather than by climate processes (see also Section 2.2.7). Land-use change affects the surface albedo. For example, deforestation typically replaces darker forested areas with brighter cropland, and thus imposes a negative radiative forcing on climate, while afforestation and reforestation can have the opposite effect. Precise changes depend on the nature of the forest, crops and underlying soil. Land-use change also affects the amount of water transpired by vegetation (Devaraju et al., 2015). Irrigation of land directly affects evaporation (Sherwood et al., 2018), causing a global increase of 32,500 m^3 s^{-1} due to human activity. Changes in evaporation and transpiration affect the latent heat budget, but do not directly affect the top-of-atmosphere (TOA) radiative fluxes. The lifetime of water vapour is so short that the effect of changes in evaporation on the greenhouse contribution of water vapour are negligible (Sherwood et al., 2018). However, evaporation can affect the ERF through adjustments, particularly through changes in low-cloud amounts. Land management affects the emissions or removal of GHGs from the atmosphere (such as CO_2, CH_4, N_2O). These emissions changes have the greatest effect on climate (Ward et al., 2014), however they are already included in GHG inventories. Land-use change also affects the emissions of dust and biogenic volatile organic compounds (BVOCs), which form aerosols and affect the atmospheric concentrations of ozone and methane (Section 6.2.2). The effects of land use on surface temperature and hydrology were recently assessed in SRCCL (Jia et al., 2019).

Using the definition of ERF from Section 7.1, the adjustment in land-surface temperature is excluded from the definition of ERF, but changes in vegetation and snow cover (resulting from land-use change) are included (Boisier et al., 2013). Land-use change in the mid-latitudes induces a substantial amplifying adjustment in snow cover. Few climate model studies have attempted to quantify the ERF of land-use change. T. Andrews et al. (2017) calculated a very large surface albedo ERF (–0.47 W m^{-2}) from 1860 to 2005 in the HadGEM2-ES model, although they did not separate out the surface albedo change from snow cover change. HadGEM2-ES is known to overestimate the amount of boreal trees and shrubs in the unperturbed state (Collins et al., 2011) so will tend to overestimate the ERF associated with land-use change. The increases in dust in HadGEM2-ES contributed an extra –0.25 W m^{-2}, whereas cloud cover changes added a small positive adjustment (0.15 W m^{-2}) consistent with a reduction in transpiration. A multi-model quantification of land-use forcing in CMIP6 models (excluding one outlier) (Smith et al., 2020b) found an IRF of –0.15 ± 0.12 W m^{-2} (1850–2014), and an ERF (correcting for land-surface temperature change) of –0.11 ± 0.09 W m^{-2}. This shows a small positive adjustment term (mainly from a reduction in cloud cover). CMIP5 models show an IRF of –0.11 [–0.16 to –0.04] W m^{-2} (1850–2000) after excluding unrealistic models (Lejeune et al., 2020).

The contribution of land-use change to albedo changes has recently been investigated using MODIS and AVHRR to attribute surface albedo to geographically specific land-cover types (Ghimire et al., 2014). When combined with a historical land-use map (Hurtt et al., 2011) this gives a SARF of –0.15 ± 0.01 W m^{-2} for the period 1700–2005, of which approximately –0.12 W m^{-2} is from 1850. This study accounted for correlations between vegetation type and snow cover, but not the adjustment in snow cover identified in T. Andrews et al. (2017).

The indirect contributions of land-use change through biogenic emissions is very uncertain. Decreases in BVOCs reduce ozone and methane (Unger, 2014), but also reduce the formation of organic aerosols and their effects on clouds (Scott et al., 2017). Adjustments through changes in aerosols and chemistry are model dependent (Zhu et al., 2019b; Zhu and Penner, 2020), and it is not yet possible to make an assessment based on a limited number of studies.

The contribution of irrigation (mainly to low-cloud amount) is assessed as –0.05 [–0.1 to 0.05] W m^{-2} for the historical period (Sherwood et al., 2018).

Because the CMIP5 and CMIP6 modelling studies are in agreement with Ghimire et al. (2014), that study is used as the assessed albedo ERF. Adding the irrigation effect to this gives an overall assessment of the ERF from land-use change of –0.20 ± 0.10 W m^{-2} (*medium confidence*). Changes in ERF since 2014 are assumed to be small compared to the uncertainty, so this ERF applies to the period 1750–2019. The uncertainty range includes uncertainties in the adjustments.

7.3.4.2 Contrails and Aviation-induced Cirrus

ERF from contrails and aviation-induced cirrus is taken from the assessment of Lee et al. (2020), at 0.057 [0.019 to 0.098] W m^{-2} in 2018 (see Section 6.6.2 for an assessment of the total effects of aviation). This is rounded up to address its *low confidence* and the extra year of air traffic to give an assessed ERF over 1750–2019 of 0.06 [0.02 to 0.10] W m^{-2}. This assessment is given *low confidence* due to the potential that processes missing from the assessment would affect the magnitude of contrails and aviation-induced cirrus ERF.

7.3.4.3 Light-absorbing Particles on Snow and Ice

In AR5, it was assessed that the effects of light-absorbing particles (LAPs) did probably not significantly contribute to recent reductions in Arctic ice and snow (Vaughan et al., 2013). The SARF from LAPs on snow and ice was assessed to 0.04 [0.02 to 0.09] W m^{-2} (Boucher et al., 2013), a range appreciably lower than the estimates given in AR4 (Forster et al., 2007). This effect was assessed to be *low confidence* (*medium evidence*, *low agreement*) (Table 8.5 in Myhre et al., 2013b).

Since AR5 there has been progress in the understanding of the physical state and processes in snow that govern the albedo reduction by black carbon (BC). The SROCC (IPCC, 2019a) assessed that there is *high confidence* that darkening of snow by deposition of BC and other light-absorbing aerosol species increases the rate of snow melt (Section 2.2 in Hock et al., 2019; Section 3.4 in Meredith et al., 2019). C. He et al. (2018) found that taking into account both the non-spherical shape of snow grains and internal mixing of BC in snow significantly altered the effects of BC on snow albedo. The reductions of snow albedo by dust and BC have been measured and characterized in the Arctic, the Tibetan Plateau, and mid-latitude regions subject to seasonal snowfall, including North America and northern and eastern Asia (Qian et al., 2015).

Since AR5, two further studies of global IRF from black carbon on snow deposition are available, with best estimates of 0.01 W m^{-2} (Lin et al., 2014) and 0.045 W m^{-2} (Namazi et al., 2015). Organic carbon deposition on snow and ice has been estimated to contribute a small positive IRF of 0.001 to 0.003 W m^{-2} (Lin et al., 2014). No comprehensive global assessments of mineral dust deposition on snow are available, although the effects are potentially large in relation to the total effect of LAPs on snow and ice forcing (Yasunari et al., 2015).

Most radiative forcing estimates have a regional emphasis. The regional focus makes estimating a global mean radiative forcing from aggregating different studies challenging, and the relative importance of each region is expected to change if the global pattern of emissions sources changes (Bauer et al., 2013). The lower bound of the assessed range of BC on snow and ice is extended to zero to encompass Lin et al. (2014), with the best estimate unchanged, resulting in 0.04 [0.00 to 0.09] W m^{-2}. The efficacy of BC on snow forcing was estimated to be 2 to 4 times as large as for an equivalent CO_2 forcing as the effects are concentrated at high latitudes in the cryosphere (Bond et al., 2013). However, it is unclear how much of this effect is due to radiative adjustments leading to a higher ERF, and how much comes from a less negative feedback α due to the high-latitude nature of the forcing. To estimate the overall ERF, the IRF is doubled assuming that part of the increased efficacy is due to adjustments. This gives an overall assessed ERF of +0.08 [0.00 to 0.18] W m^{-2}, with *low confidence*.

7.3.4.4 Solar

Variations in the total solar irradiance (TSI) represent a natural external forcing agent. The dominant cycle is the solar 11-year activity cycle, which is superimposed on longer cycles (Section 2.2). Over the last three 11-year cycles, the peak-to-trough amplitude in TSI has differed by about 1 W m^{-2} between solar maxima and minima (Figure 2.2).

The fractional variability in the solar irradiance, over the solar cycle and between solar cycles, is much greater at short wavelengths in the 200–400 nanometre (nm) band than for the broad visible/infrared band that dominates TSI (Krivova et al., 2006). The IRF can be derived simply by $\Delta TSI \times (1 - \text{albedo})/4$ irrespective of wavelength, where the best estimate of the planetary albedo is usually taken to be 0.29 and ΔTSI represents the change in total solar irradiance (Stephens et al., 2015). (The factor 4 arises because TSI is per unit area of Earth cross section presented to the Sun and IRF is per unit area of Earth's surface). The adjustments are expected to be wavelength dependent. Gray et al. (2009) determined a stratospheric temperature adjustment of –22% to spectrally resolved changes in the solar radiance over one solar cycle. This negative adjustment is due to stratospheric heating from increased absorption by ozone at the short wavelengths, increasing the outgoing longwave radiation to space. A multi-model comparison (Smith et al., 2018b) calculated adjustments of –4% due to stratospheric temperatures and –6% due to tropospheric processes (mostly clouds), for a change in TSI across the spectrum (Figure 7.4). The smaller magnitude of the stratospheric temperature adjustment is consistent with the broad spectral change rather than the shorter wavelengths characteristic of solar variation. A single-model study also found an adjustment that acts to reduce the forcing (Modak et al., 2016). While there has not yet been a calculation based on the appropriate spectral change, the –6% tropospheric adjustment from Smith et al. (2018b) is adopted along with the Gray et al. (2009) stratospheric temperature adjustment. The ERF due to solar variability over the historical period is therefore represented by $0.72 \times \Delta TSI \times (1 - \text{albedo})/4$ using the TSI timeseries from Chapter 2 (Section 2.2.1).

The AR5 (Myhre et al., 2013b) assessed solar SARF from around 1750 to 2011 to be 0.05 [0.00 to 0.10] W m^{-2} which was computed from the seven-year mean around the solar minima in 1745 (being closest to 1750) and 2008 (being the most recent solar minimum). The inclusion of tropospheric adjustments that reduce ERF (compared to SARF in AR5) has a negligible effect on the overall forcing. Prior to the satellite era, proxy records are used to reconstruct historical solar activity. In AR5, historical records were constructed using observations of solar magnetic features. In this assessment historical time series are constructed from radiogenic compounds in the biosphere and in ice cores that are formed from cosmic rays (Steinhilber et al., 2012).

In this assessment the TSI from the Paleoclimate Model Intercomparison Project Phase 4 (PMIP4) reconstruction is used (Section 2.2.1; Jungclaus et al., 2017). Proxies constructed from the ^{14}C and ^{10}Be radiogenic records for the SATIRE-M model (Vieira et al., 2011) and ^{14}C record for the PMOD model (Shapiro et al., 2011) for the 1745 solar minimum provide ERFs for 1745–2008 of –0.01, –0.02 and 0.00 W m^{-2} respectively. An independent dataset from the National Oceanic and Atmospheric Administration's Climate Data Record (Coddington et al., 2016; Lean, 2018) provides an ERF for 1745–2008 of +0.03 W m^{-2}. One substantially higher ERF estimate of +0.35 W m^{-2} derived from TSI reconstructions is provided by Egorova et al. (2018). However, the estimate from Egorova et al. (2018) hinges on assumptions about long-term changes in the quiet Sun for which there is no observed evidence. Lockwood and Ball (2020) analysed the relationship between observed changes in cosmic ray fluxes and recent, more accurate, TSI data and derived ERF between –0.01 and +0.02 W m^{-2}, and Yeo et al. (2020) modelling showed the maximum possible ERF to be 0.26 ± 0.09 W m^{-2}. Hence the Egorova et al. (2018) estimate is not explicitly taken into account in the assessment presented in this section.

In contrast to AR5, the solar ERF in this assessment uses full solar cycles rather than solar minima. The pre-industrial TSI is defined as the mean from all complete solar cycles from the start of the ^{14}C SATIRE-M proxy record in 6755 BCE to 1744 CE. The mean TSI from solar cycle 24 (2009–2019) is adopted as the assessment period for 2019. The best estimate solar ERF is assessed to be 0.01 W m^{-2}, using the ^{14}C reconstruction from SATIRE-M, with a *likely* range of –0.06 to +0.08 W m^{-2} (*medium confidence*). The uncertainty range is adopted from the evaluation of Lockwood and Ball (2020) using a Monte Carlo analysis of solar activity from the Maunder Minimum to 2019 from several datasets, leading to an ERF of –0.12 to +0.15 W m^{-2}. The Lockwood and Ball (2020) full uncertainty range is halved as the period of reduced solar activity in the Maunder Minimum had ended by 1750 (*medium confidence*).

7.3.4.5 Galactic Cosmic Rays

Variations in the flux of galactic cosmic rays (GCR) reaching the atmosphere are modulated by solar activity and affect new particle formation in the atmosphere through their link to ionization of the troposphere (Lee et al., 2019). It has been suggested that periods of high GCR flux correlate with increased aerosol and CCN concentrations and therefore also with cloud properties (e.g., Dickinson, 1975; Kirkby, 2007).

Since AR5, the link between GCR and new particle formation has been more thoroughly studied, particularly by experiments in the CERN CLOUD chamber (Cosmics Leaving OUtdoor Droplets; Dunne et al., 2016; Kirkby et al., 2016; Pierce, 2017). By linking the GCR-induced new particle formation from CLOUD experiments to CCN, Gordon et al. (2017) found that the CCN concentration for low-clouds differed by 0.2–0.3% between solar maximum and solar minimum. Combined with relatively small variations in the atmospheric ion concentration over centennial time scales (Usoskin et al., 2015), it is therefore unlikely that cosmic ray intensity affects present-day climate via nucleation (Yu and Luo, 2014; Dunne et al., 2016; Pierce, 2017; Lee et al., 2019).

Studies continue to seek a relationship between GCR and properties of the climate system based on correlations and theory. Svensmark et al. (2017) proposed a new mechanism for ion-induced increase in aerosol growth rate and subsequent influence on the CCN concentration. The study does not include an estimate of the resulting effect on atmospheric CCN concentration and cloud radiative properties. Furthermore, Svensmark et al. (2009, 2016) find correlations between GCRs and aerosol and cloud properties in satellite and ground-based data. Multiple studies investigating this link have challenged such correlations (Kristjánsson et al., 2008; Calogovic et al., 2010; Laken, 2016).

AR5 concluded that the GCR effect on CCN is too weak to have any detectable effect on climate and no robust association was found between GCR and cloudiness (Boucher et al., 2013). Published literature since AR5 robustly supports these conclusions with key laboratory, theoretical and observational evidence. There is *high confidence* that GCRs contribute a negligible ERF over the period 1750–2019.

7.3.4.6 Volcanic Aerosols

There is large episodic negative radiative forcing associated with sulphur dioxide (SO_2) being ejected into the stratosphere from explosive volcanic eruptions, accompanied by more frequent smaller eruptions (Figure 2.2 and Cross-Chapter Box 4.1). From SO_2 gas, reflective sulphate aerosol is formed in the stratosphere where it may persist for months to years, reducing the incoming solar radiation. The volcanic SARF in AR5 (Myhre et al., 2013b) was derived by scaling the stratospheric aerosol optical depth (SAOD) by a factor of –25 W m^{-2} per unit SAOD from Hansen et al. (2005b). Quantification of the adjustments to SAOD perturbations from climate model simulations have determined a significant positive adjustment driven by a reduction in cloud amount (Figure 7.4; Marshall et al., 2020). Analysis of CMIP5 models provides a mean ERF of –20 W m^{-2} per unit SAOD (Larson and Portmann, 2016). Single-model studies with successive generations of Hadley Centre climate models produce estimates between –17 and –19 W m^{-2} per unit SAOD (Gregory et al., 2016; Marshall et al., 2020), with some evidence that ERF may be non-linear with SAOD for large eruptions (Marshall et al., 2020). Analysis of the volcanically active periods of 1982–1985 and 1990–1994 using the CESM1(WACCM) aerosol–climate model provided an SAOD-to-ERF relationship of –21.5 (± 1.1) W m^{-2} per unit SAOD (Schmidt et al., 2018). Volcanic SO_2 emissions may contribute a positive forcing through effects on upper tropospheric ice clouds, due to additional ice nucleation on volcanic sulphate particles (Friberg et al., 2015; Schmidt et al., 2018), although one observational study found no significant effect (Meyer et al., 2015). Due to *low agreement*, the contribution of sulphate aerosol effects on ice clouds to volcanic ERF is not included in the overall assessment.

Non-explosive volcanic eruptions generally yield negligible global ERFs due to the short atmospheric lifetimes (a few weeks) of volcanic aerosols in the troposphere. However, as discussed in Section 7.3.3.2, the massive fissure eruption in Holuhraun, Iceland persisted for months in 2014 and 2015 and did in fact result in a marked and persistent reduction in cloud droplet radii and a corresponding increase in cloud albedo regionally (Malavelle et al., 2017). This shows that non-explosive fissure eruptions can lead to strong regional and even global ERFs, but because the Holuhraun eruption occurred in Northern Hemisphere winter, solar insolation was weak and the observed albedo changes therefore did not result in an appreciable global ERF (Gettelman et al., 2015).

The ERF for volcanic stratospheric aerosols is assessed to be –20 ± 5 W m^{-2} per unit SAOD (*medium confidence*) based on the CMIP5 multi-model mean from the Larson and Portmann (2016) SAOD forcing efficiency calculations combined with the single-model results of Gregory et al. (2016), Schmidt et al. (2018) and Marshall et al. (2020). This is applied to the SAOD time series from Chapter 2 (Section 2.2.2) to generate a time series of ERF and temperature response shown in Chapter 2 (Figure 2.2 and Figure 7.8, respectively).

The period from 500 BCE to 1749 CE, spanning back to the start of the record of Toohey and Sigl (2017), is defined as the pre-industrial baseline and the volcanic ERF is calculated using an SAOD anomaly from this long-term mean. As in AR5, a pre-industrial to present-day ERF assessment is not provided due to the episodic nature of volcanic eruptions.

7.3.5 Synthesis of Global Mean Radiative Forcing, Past and Future

7.3.5.1 Major Changes in Forcing since the IPCC Fifth Assessment Report

The AR5 introduced the concept of effective radiative forcing (ERF) and radiative adjustments, and made a preliminary assessment that the tropospheric adjustments were zero for all species other than the effects of aerosol–cloud interaction and black carbon. Since AR5, new studies have allowed for a tentative assessment of values for tropospheric adjustments to CO_2, CH_4, N_2O, some CFCs, solar forcing, and stratospheric aerosols, and to place a tighter constraint on adjustments from aerosol–cloud interaction (Sections 7.3.2, 7.3.3 and 7.3.4). In AR6, the definition of ERF explicitly removes the land-surface temperature change as part of the forcing, in contrast to AR5 where only sea surface temperatures were fixed. The ERF is assessed to be a better predictor of modelled equilibrium temperature change (i.e., less variation in feedback parameter) than SARF (Section 7.3.1).

As discussed in Section 7.3.2, the radiative efficiencies for CO_2, CH_4 and N_2O have been updated since AR5 (Etminan et al., 2016). There has been a small (1%) increase in the stratospheric-temperature-adjusted CO_2 radiative efficiency, and a +5% tropospheric adjustment has been added. The stratospheric-temperature-adjusted radiative efficiency for CH_4 is increased by approximately 25% (*high confidence*). The tropospheric adjustment is tentatively assessed to be –14% (*low confidence*). A +7% tropospheric adjustment has been added to the radiative efficiency for N_2O and +12% to CFC-11 and CFC-12 (*low confidence*).

For aerosols there has been a convergence of model and observational estimates of aerosol forcing, and the partitioning of the total aerosol ERF has changed. Compared to AR5 a greater fraction of the ERF is assessed to come from ERFaci compared to the ERFari. It is now assessed as *virtually certain* that the total aerosol ERF (ERFari+aci) is negative.

7.3.5.2 Summary ERF Assessment

Figure 7.6 shows the industrial-era ERF estimates for 1750 to 2019 for the concentration change in different forcing agents. The assessed uncertainty distributions for each individual component are combined with a 100,000-member Monte Carlo simulation that samples the different distributions, assuming they are independent, to obtain the overall assessment of total present-day ERF (Supplementary Material 7.SM.1). The corresponding emissions-based ERF figure is shown in Chapter 6 (Figure 6.12).

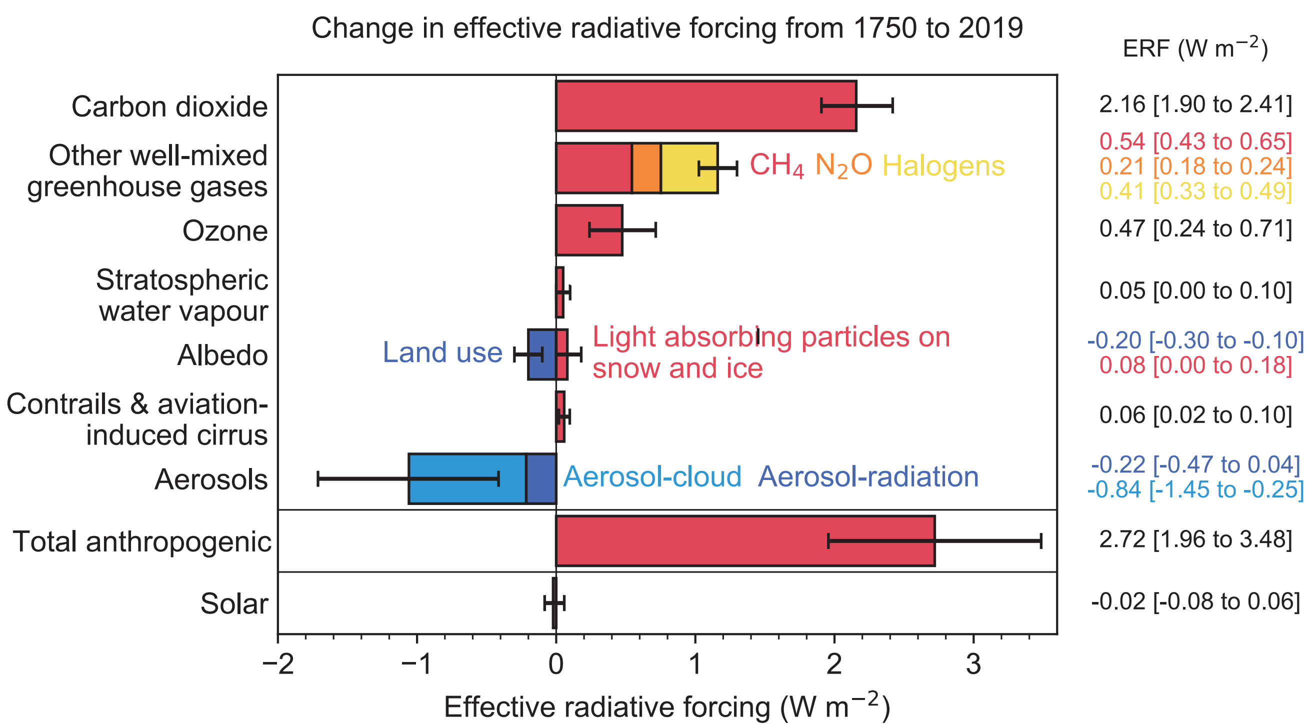


Figure 7.6 | Change in effective radiative forcing (ERF) from 1750 to 2019 by contributing forcing agents (carbon dioxide, other well-mixed greenhouse gases (WMGHGs), ozone, stratospheric water vapour, surface albedo, contrails and aviation-induced cirrus, aerosols, anthropogenic total, and solar). Solid bars represent best estimates, and *very likely* (5–95%) ranges are given by error bars. Non-CO_2 WMGHGs are further broken down into contributions from methane (CH_4), nitrous oxide (N_2O) and halogenated compounds. Surface albedo is broken down into land-use changes and light-absorbing particles on snow and ice. Aerosols are broken down into contributions from aerosol–cloud interactions (ERFaci) and aerosol–radiation interactions (ERFari). For aerosols and solar, the 2019 single-year values are given (Table 7.8), which differ from the headline assessments in both cases. Volcanic forcing is not shown due to the episodic nature of volcanic eruptions. Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

Table 7.8 | Summary table of effective radiative forcing (ERF) estimates for AR6 and comparison with the four previous IPCC assessment reports. Prior to AR5 values are stratospheric-temperature-adjusted radiative forcing (SARF). For AR5 aerosol–radiation interactions (ari) and aerosol–cloud interactions (aci) are ERF; all other values assume ERF equals SARF. Ranges shown are 5–95%. Volcanic ERF is not added to the table due to the episodic nature of volcanic eruptions which makes it difficult to compare to the other forcing mechanisms. Solar ERF is based on total solar irradiance (TSI) and not spectral variation.

Driver	Global Mean Effective Radiative Forcing (W m^{-2})					Comment
	SAR (1750–1993)	TAR (1750–1998)	AR4 (1750–2005)	AR5 (1750–2011)	AR6 (1750–2019)	
CO_2	1.56 [1.33 to 1.79]	1.46 [1.31 to 1.61]	1.66 [1.49 to 1.83]	1.82 [1.63 to 2.01]	2.16 [1.90 to 2.41]	Increases in concentrations. Changes to radiative efficiencies. Inclusion of tropospheric adjustments.
CH_4	0.47 [0.40 to 0.54	0.48 [0.41 to 0.55]	0.48 [0.43 to 0.53]	0.48 [0.43 to 0.53]	0.54 [0.43 to 0.65]	
N_2O	0.14 [0.12 to 0.16]	0.15 [0.14 to 0.16]	0.16 [0.14 to 0.18]	0.17 [0.14 to 0.20]	0.21 [0.18 to 0.24]	
Halogenated species	0.26 [0.22 to 0.30]	0.36 [0.31 to 0.41]	0.33 [0.30 to 0.36]	0.36 [0.32 to 0.40]	0.41 [0.33 to 0.49]	
Tropospheric ozone	0.4 [0.2 to 0.6]	0.35 [0.20 to 0.50]	0.35 [0.25 to 0.65]	0.40 [0.20 to 0.60]	0.47 [0.24 to 0.71]	Revised precursor emissions. No tropospheric adjustment assessed. No troposphere–stratosphere separation.
Stratospheric ozone	–0.1 [–0.2 to –0.05]	–0.15 [–0.25 to –0.05]	–0.05 [–0.15 to 0.05]	–0.05 [–0.15 to 0.05]		
Stratospheric water vapour	Not estimated	[0.01 to 0.03]	0.07 [0.02 to 0.1]	0.07 [0.02 to 0.12]	0.05 [0.00 to 0.10]	Downward revision due to adjustments.
Aerosol–radiation interactions	–0.5 [–0.25 to –1.0]	Not estimated	–0.50 [–0.90 to –0.10]	–0.45 [–0.95 to 0.05]	–0.22 [–0.47 to 0.04]	ERFari magnitude reduced by about 50% compared to AR5, based on agreement between observation-based and modelling-based evidence.
Aerosol–cloud interactions	[–1.5 to 0.0] (sulphate only)	[–2.0 to 0.0] (all aerosols)	–0.7 [–1.8 to –0.3] (all aerosols)	–0.45 [–1.2 to 0.0]	–0.84 [–1.45 to –0.25]	ERFaci magnitude increased by about 85% compared to AR5, based on agreement between observation-based and modelling-based lines of evidence.
Land use	Not estimated	–0.2 [–0.4 to 0.0]	–0.2 [–0.4 to 0.0]	–0.15 [–0.25 to –0.05]	–0.20 [–0.30 to –0.10]	Includes irrigation.
Surface albedo (black + organic carbon aerosol on snow and ice)	Not estimated	Not estimated	0.10 [0.00 to 0.20]	0.04 [0.02 to 0.09]	0.08 [0.00 to 0.18]	Increased since AR5 to better account for temperature effects.
Combined contrails and aviation-induced cirrus	Not estimated	[0.00 to 0.04]	Not estimated	0.05 [0.02 to 0.15]	0.06 [0.02 to 0.10]	Narrower range since AR5.
Total anthropogenic	Not estimated	Not estimated	1.6 [0.6 to 2.4]	2.3 [1.1 to 3.3]	**2.72 [1.96 to 3.48]**	Increase due to GHGs, compensated slightly by aerosol ERFaci.
Solar irradiance	0.3 [0.1 to 0.5]	0.3 [0.1 to 0.5]	0.12 [0.06 to 0.30]	0.05 [0.0 to 0.10]	0.01 [–0.06 to 0.08]	Revised historical TSI estimates and methodology.

The total anthropogenic ERF over the industrial era (1750–2019) is estimated as 2.72 [1.96 to 3.48] W m^{-2} (*high confidence*) (Table 7.8 and Annex III). This represents a 0.43 W m^{-2} increase over the assessment made in AR5 (Myhre et al., 2013b) for the period 1750–2011. This increase is a result of compensating effects. Atmospheric concentration increases of GHGs since 2011 and upwards revisions of their forcing estimates have led to a 0.59 W m^{-2} increase in their ERF. However, the total aerosol ERF is assessed to be more negative compared to AR5, due to revised estimates rather than trends (*high confidence*).

Greenhouse gases, including ozone and stratospheric water vapour from methane oxidation, are estimated to contribute an ERF of 3.84 [3.46 to 4.22] W m^{-2} over 1750–2019. Carbon dioxide continues to contribute the largest part (56 ± 16%) of this GHG ERF (*high confidence*).

As discussed in Section 7.3.3, aerosols have in total contributed an ERF of –1.1 [–1.7 to –0.4] W m^{-2} over 1750–2019 (*medium confidence*). Aerosol–cloud interactions contribute approximately 75–80% of this ERF with the remainder due to aerosol–radiation interactions (Table 7.8).

For the purpose of comparing forcing changes with historical temperature change (Section 7.5.2), longer averaging periods are useful. The change in ERF from the second half of the 19th century (1850–1900) compared with a recent period (2006–2019) is +2.20 [1.53 to 2.91] W m^{-2}, of which 1.71 [1.51 to 1.92] W m^{-2} is due to CO_2.

7.3.5.3 Temperature Contribution of Forcing Agents

The estimated contribution of forcing agents to the 2019 global surface air temperature (GSAT) change relative to 1750 is shown in Figure 7.7. These estimates were produced using the concentration-derived ERF time series presented in Figure 2.10 and described in Supplementary Material 7.SM.1.3. The resulting GSAT changes over time are shown in Figure 7.8. The historical time series of ERFs for the WMGHGs can be derived by applying the ERF calculations of Section 7.3.2 to the observed time series of WMGHG concentrations in Chapter 2 (Section 2.2).

These ERF timeseries are combined with a two-layer emulator (Cross-Chapter Box 7.1 and Supplementary Material 7.SM.2) using a 2237-member constrained Monte Carlo sample of both forcing uncertainty (by sampling ERF ranges) and climate response (by sampling ECS, TCR and ocean heat capacity ranges). The net model warming over the historical period is matched to the assessment of historical GSAT warming from 1850–1900 to 1995–2014 of 0.85 [0.67 to 0.98] °C (Cross-Chapter Box 2.3) and ocean heat content change from 1971 to 2018 (Section 7.2.2.2). Therefore the model gives the breakdown of the GSAT trend associated with different forcing mechanisms that are consistent with the overall GSAT change. The model assumes that there is no variation in feedback parameter across forcing mechanisms (Section 7.3.1) and variations in the effective feedback parameter over the historical record (Section 7.4.4). The distribution of ECS was informed by Section 7.5.5 and chosen to approximately maintain the best estimate and *likely*/*very likely* ranges assessed in that section (see also Supplementary Material 7.SM.2). The TCR has an ensemble median value of 1.81°C, in good agreement with Section 7.5.5. Two error bars are shown in Figure 7.7. The dashed error bar shows the contribution of ERF uncertainty (as assessed in the subsections of Section 7.3) employing the best estimate of climate response with an ECS of 3.0°C. The solid bar is the total response uncertainty using the Section 7.5.5 assessment of ECS. The uncertainty in the historical temperature contributions ofthe different forcing agents is mostly due to uncertainties in ERF, yet for the WMGHG the uncertainty is dominated by the climate response as its ERF is relatively well known (Figure 7.7). From the assessment of emulator responses in Cross-Chapter Box 7.1, there is *high confidence* that calibrated emulators such as the one employed here can represent the historical GSAT change between 1850–1900 and 1995–2014 to within 5% for the best estimate and 10% for the *very likely* range (Supplementary Material, Table 7.SM.4). This gives *high confidence* in the overall assessment of GSAT change for the response to ERFs over 1750–2019 derived from the emulator.

The total human forced GSAT change from 1750 to 2019 is calculated to be 1.29 [1.00 to 1.65] °C (*high confidence*). Although the total emulated GSAT change has *high confidence*, the confidence of the individual contributions matches those given for the ERF assessment in the subsections of Section 7.3. The calculated GSAT change is comprised

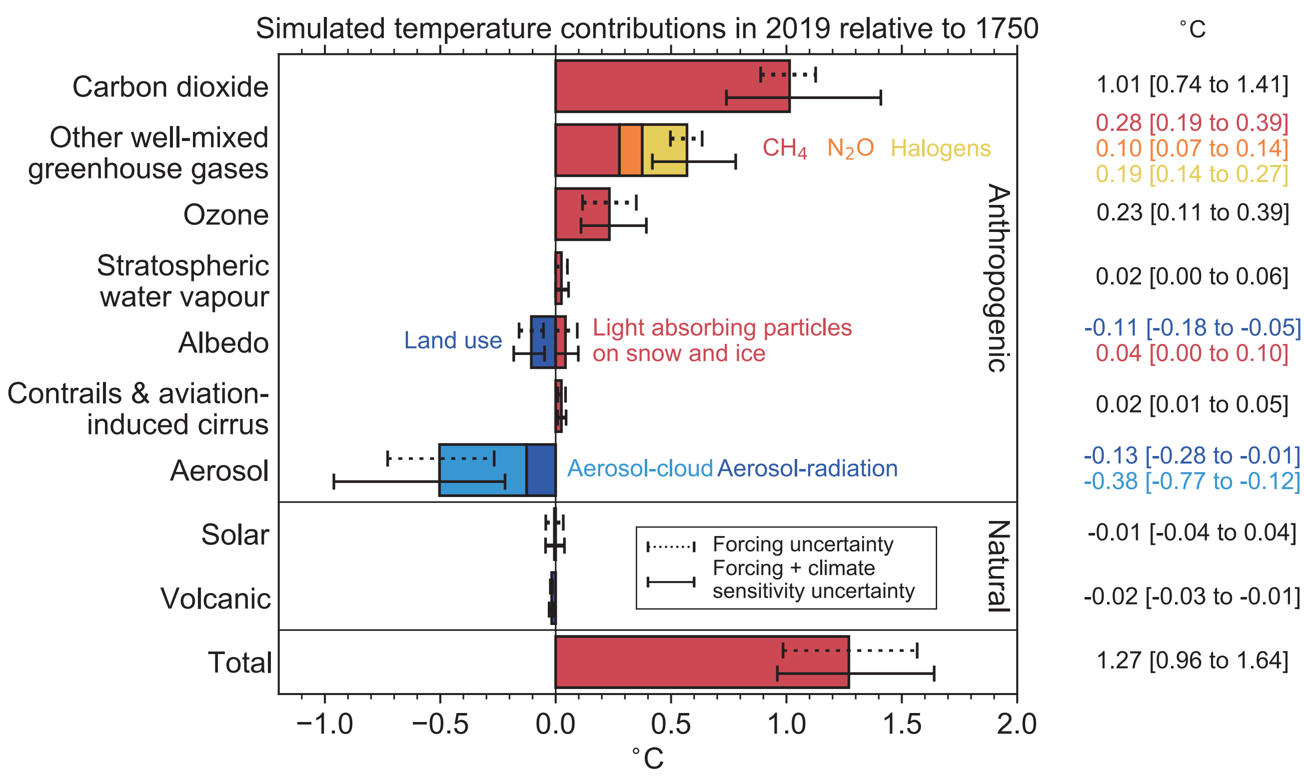


Figure 7.7 | The contribution of forcing agents to 2019 temperature change relative to 1750 produced using the two-layer emulator (Supplementary Material 7.SM.2), constrained to assessed ranges for key climate metrics described in Cross-Chapter Box 7.1. The results are from a 2237-member ensemble. Temperature contributions are expressed for carbon dioxide, other well-mixed greenhouse gases (WMGHGs), ozone, stratospheric water vapour, surface albedo, contrails and aviation-induced cirrus, aerosols, solar, volcanic, and total. Solid bars represent best estimates, and *very likely* (5–95%) ranges are given by error bars. Dashed error bars show the contribution of forcing uncertainty alone, using best estimates of ECS (3.0°C), TCR (1.8°C) and two-layer model parameters representing the CMIP6 multi-model mean. Solid error bars show the combined effects of forcing and climate response uncertainty using the distribution of ECS and TCR from Tables 7.13 and 7.14, and the distribution of calibrated model parameters from 44 CMIP6 models. Non-CO_2 WMGHGs are further broken down into contributions from methane (CH_4), nitrous oxide (N_2O) and halogenated compounds. Surface albedo is broken down into land-use changes and light-absorbing particles on snow and ice. Aerosols are broken down into contributions from aerosol–cloud interactions (ERFaci) and aerosol–radiation interactions (ERFari). Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

of a WMGHG warming of 1.58 [1.17 to 2.17] °C (*high confidence*), a warming from ozone changes of 0.23 [0.11 to 0.39] °C (*high confidence*), and a cooling of –0.50 [–0.22 to –0.96] °C from aerosol effects (*medium confidence*). The aerosol cooling has considerable regional time dependence (Section 6.4.3) but has weakened slightly over the last 20 years in the global mean (Figures 2.10 and 7.8). There is also a –0.06 [–0.15 to +0.01] °C contribution from surface reflectance changes which is dominated by land-use change (*medium confidence*). Changes in solar and volcanic activity are assessed to have together contributed a small change of –0.02 [–0.06 to +0.02] °C since 1750 (*medium confidence*).

The total (anthropogenic + natural) emulated GSAT between 1850–1900 and 2010–2019 is 1.14 [0.89 to 1.45] °C, compared to the assessed GSAT of 1.06 [0.88 to 1.21] °C (Section 2.3.1 and Cross Chapter Box 2.3). The emulated response is slightly warmer than the observations and has a larger uncertainty range. As the emulated response attempts to constrain to multiple lines of evidence (Supplementary Material 7.SM.2), only one of which is GSAT, they should not necessarily be expected to exactly agree. The larger uncertainty range in the emulated GSAT compared to the observations is reflective of the uncertainties in ECS, TCR and ERF (particularly the aerosol ERF) that drive the emulator response.

The emulator gives a range of GSAT response for the period 1750 to 1850–1900 of 0.09 [0.04 to 0.14] °C from anthropogenic ERFs. These results are used as a line of evidence for the assessment of this change in Chapter 1 (Cross-Chapter Box 1.2), which gives an overall assessment of 0.1°C [*likely* range –0.1 to +0.3] °C.

Figure 7.8 presents the GSAT time series using ERF time series for individual forcing agents rather than their aggregation. It shows that for most of the historical period the long time scale total GSAT trend estimate from the emulator closely follows the CO_2 contribution. The GSAT estimate from non-CO_2 greenhouse gas forcing (from other WMGHGs and ozone) has been approximately cancelled out in the global average by a cooling GSAT trend from aerosols. However, since 1980 the aerosol cooling trend has stabilized and may have started to reverse, so that over the last few decades the long-term warming has been occurring at a faster rate than would be expected due to CO_2 alone (*high confidence*) (see also Sections 2.2.6 and 2.2.8). Throughout the record, but especially prior to 1930, periods of volcanic cooling dominate decadal variability. These estimates of the forced response are compared with model simulations and attributable warming estimates in Chapter 3 (Section 3.3.1).

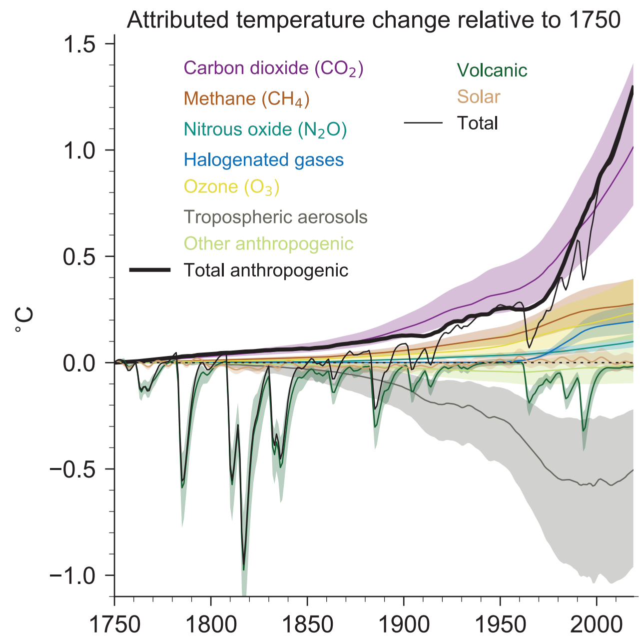


Figure 7.8 | Attributed global surface air temperature change (GSAT) from 1750 to 2019 produced using the two-layer emulator (Supplementary Material 7.SM.2), forced with ERF derived in this chapter (displayed in Figure 2.10) and climate response constrained to assessed ranges for key climate metrics described in Cross-Chapter Box 7.1. The results shown are the medians from a 2237-member ensemble that encompasses uncertainty in forcing and climate response (year-2019 best estimates and uncertainties are shown in Figure 7.7 for several components). Temperature contributions are expressed for carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), other well-mixed greenhouse gases (WMGHGs), ozone (O_3), aerosols, and other anthropogenic forcings, as well as total anthropogenic, solar, volcanic, and total forcing. Shaded uncertainty bands show *very likely* (5–95%) ranges. Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

Cross-Chapter Box 7.1 | Physical Emulation of Earth System Models for Scenario Classification and Knowledge Integration in AR6

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Climate model emulators are simple physically based models that are used to approximate large-scale climate responses of complex Earth system models (ESMs). Due to their low computational cost they can populate or span wide uncertainty ranges that ESMs cannot. They need to be calibrated to do this and, once calibrated, they can aid inter-ESM comparisons and act as ESM extrapolation tools to reflect and combine knowledge from ESMs and many other lines of evidence (Geoffroy et al., 2013a; Good et al., 2013; Smith et al., 2018a). In AR6, the term 'climate model emulator' (or simply 'emulator') is preferred over 'simple' or 'reduced-complexity climate model' to reinforce their use as specifically calibrated tools (Cross-Chapter Box 7.1, Figure 1). Nonetheless, simple physically based

Cross-Chapter Box 7.1 (continued)

climate models have a long history of use in previous IPCC reports (Section 1.5.3.4). Climate model emulators can include carbon and other gas cycles and can combine uncertainties along the cause–effect chain, from emissions to temperature response. AR5 (M. Collins et al., 2013) used the MAGICC6 emulator (Meinshausen et al., 2011a) in a probabilistic setup (Meinshausen et al., 2009) to explore the uncertainty in future projections. A simple impulse response emulator (Good et al., 2011) was also used to ensure a consistent set of ESM projections could be shown across a range of scenarios. Chapter 8 in AR5 WGI (Myhre et al., 2013b) employed a two-layer emulator for quantifying global temperature-change potentials (GTP). In AR5 WGIII (Clarke et al., 2014), MAGICC6 was also used for the classification of scenarios, and in AR5 Synthesis Report (IPCC, 2014) this information was used to estimate carbon budgets. In SR1.5, two emulators were used to provide temperature projections of scenarios: the MAGICC6 model, which was used for the scenario classification, and the FaIR1.3 model (Millar et al., 2017; Smith et al., 2018a).

The SR1.5 found that the physically based emulators produced different projected non-CO_2 forcing and identified the largely unexplained differences between the two emulators used as a key knowledge gap (Forster et al., 2018). This led to a renewed effort to test the skill of various emulators. The Reduced Complexity Model Intercomparison Project (RCMIP; Nicholls et al., 2020) found that the latest generation of the emulators can reproduce key characteristics of the observed changes in global surface air temperature (GSAT) together with other key responses of ESMs (Cross-Chapter Box 7.1, Figure 1a). In particular, despite their reduced structural complexity, some emulators are able to replicate the non-linear aspects of ESM GSAT response over a range of scenarios. GSAT emulation has been more thoroughly explored in the literature than other types of emulation. Structural differences between emulation approaches lead to different outcomes and there are problems with emulating particular ESMs. In conclusion, there is *medium confidence* that emulators calibrated to single ESM runs can reproduce ESM projections of the forced GSAT response to other similar emissions scenarios to within natural variability (Meinshausen et al., 2011b; Geoffroy et al., 2013a; Dorheim et al., 2020; Nicholls et al., 2020; Tsutsui, 2020), although larger differences can remain for scenarios with very different forcing characteristics. For variables other than GSAT there has not yet been a comprehensive effort to evaluate the performance of emulators.

Application of emulators in AR6 WGI

Cross-Chapter Box 7.1 Table 1 shows the use of emulators within the WGI Report. The main use of emulation in the Report is to estimate GSAT change from effective radiative forcing (ERF) or concentration changes, where various versions of a two-layer energy budget emulator are used. The two-layer emulator is equivalent to a two-timescale impulse-response model (Supplementary Material 7.SM.2; Geoffroy et al., 2013b). Both a single configuration version and probabilistic forms are used. The emulator is an extension of the energy budget equation (Box 7.1, Equation 7.1) and allows for heat exchange between the upper- and deep-ocean layers, mimicking the ocean heat uptake that reduces the rate of surface warming under radiative forcing (Gregory, 2000; Held et al., 2010; Winton et al., 2010; Armour, 2017; Mauritsen and Pincus, 2017; Rohrschneider et al., 2019). Although the same energy budget emulator approach is used, different calibrations are employed in various sections, to serve different purposes and keep lines of evidence as independent as possible. Chapter 9 additionally employs projections of ocean heat content from the Chapter 7 two-layer emulator to estimate the thermostatic component of future sea level rise (Section 9.6.3 and Supplementary Material 7.SM.2).

Cross-Chapter Box 7.1, Table 1 | Use of emulation within the WGI Report.

Section	Application and Emulator Type	Emulated Variables
Cross Chapter-Box 1.2	Estimate anthropogenic temperature change pre-1850, based on radiative forcing time series from Chapter 7. Uses the Chapter 7 calibrated two-layer emulator: a two-layer energy budget emulator, probabilistically calibrated to AR6 ECS, TCR, historical warming and ocean heat uptake ranges, driven by the Chapter 7 concentration-based ERFs.	GSAT
Section 3.3 Section 7.3	Investigation of the historical temperature response to individual forcing mechanisms to complement detection and attribution results. Uses the Chapter 7 calibrated two-layer emulator.	GSAT
Box 4.1	Understanding the spread in GSAT increase of CMIP6 models and comparison to other assessments; assessment of contributions to projected temperature uncertainty. Uses a two-layer emulator calibrated to the Chapter 7 ECS and TCR assessment driven by Chapter 7 best-estimate ERFs.	GSAT
Section 4.6	Emulators used to assess differences in radiative forcing and GSAT response between RCP and SSP scenarios. Uses the Chapter 7 ERF time series and the MAGICC7 probabilistic emissions-driven emulator for GSAT calibrated to the WGI assessment.	ERF, GSAT
Section 4.7	Emulator used for long-term GSAT projections (post-2100) to complement the small number of ESMs with data beyond 2100. Uses the MAGICC7 probabilistic emissions-driven emulator calibrated to the WGI assessment.	GSAT
Section 5.5	Estimated non-CO_2 warming contributions of mitigation scenarios at the time of their net zero CO_2 emissions for integration in the assessment of remaining carbon budgets. Uses the MAGICC7 probabilistic emissions-driven emulator calibrated to the WGI assessment.	GSAT

Cross-Chapter Box 7.1 (continued)

Section	Application and Emulator Type	Emulated Variables
Section 6.6 Section 6.7	Estimated contributions to future warming from SLCFs across SSP scenarios based on ERF time series. Uses a single two-layer emulator configuration derived from the medians of MAGICC7 and FaIRv1.6.2 AR6 WG1 GSAT probabilistic responses and the best-estimate of ECS and TCR.	GSAT
Section 7.5	Estimating a process-based TCR from a process-based ECS. Uses a two-layer emulator in probabilistic form calibrated to process-based estimates from Chapter 7; a different calibration compared to the main Chapter 7 emulator.	TCR
Section 7.6	Deriving emissions metrics. Uses two-layer emulator configurations derived from MAGICC7 and FaIRv1.6.2 AR6 WG1 probabilistic GSAT responses.	GTPs and their uncertainties
Section 9.6	Deriving global mean sea level projections. Uses the Chapter 7 calibrated two-layer emulator for GSAT and ocean heat content, where GSAT drives regional statistical emulators of ice sheets and glaciers.	Sea level and ice loss
Section 11.2 and Cross-Chapter Box 11.1	Regional patterns of response are compared to global mean trends. Assessed literature includes projections with a regional pattern scaling and variability emulator.	Various regional information

Emissions-driven emulators (as opposed to ERF-driven or concentration-driven emulators) are also used in the Report. In Chapter 4 (Section 4.6) MAGICC7 is used to emulate GSAT beyond 2100 since its long-term response has been assessed to be fit-for-purpose to represent the behaviour of ESMs. In Chapter 5 (Section 5.5) MAGICC7 is used to explore the non-CO_2 GSAT contribution in emissions scenarios. In Chapter 6 and Chapter 7 (Section 7.6), two-layer model configurations are tuned to match the probabilistic GSAT responses of FaIRv1.6.2 and MAGICC7 emissions-driven emulators. For Chapter 6 the two median values from FaIRv1.6.2 and MAGICC7 emulators are averaged and then matched to the best-estimate ECS of 3°C and TCR of 1.8°C (Tables 7.13 and 7.14) under the best-estimate ERF due to a doubling of CO_2 of 3.93 W m^{-2} (Table 7.4). For Section 7.6 a distribution of responses is used from the two emulators to estimate uncertainties in global temperature change potentials (GTP).

Emissions-driven emulators for scenario classification in AR6 WGIII

As in AR5 and SR1.5, emissions-driven emulators are used to communicate outcomes of the physical climate science assessment and uncertainties to quantify the temperature outcome associated with different emissions scenarios. In particular, the computational efficiency of these emulators allows the analysis of a large number of multi-gas emissions scenarios in terms of multiple characteristics, e.g., year of peak temperature or 2030 emissions levels, in line with keeping global warming to below 1.5°C or 2.0°C.

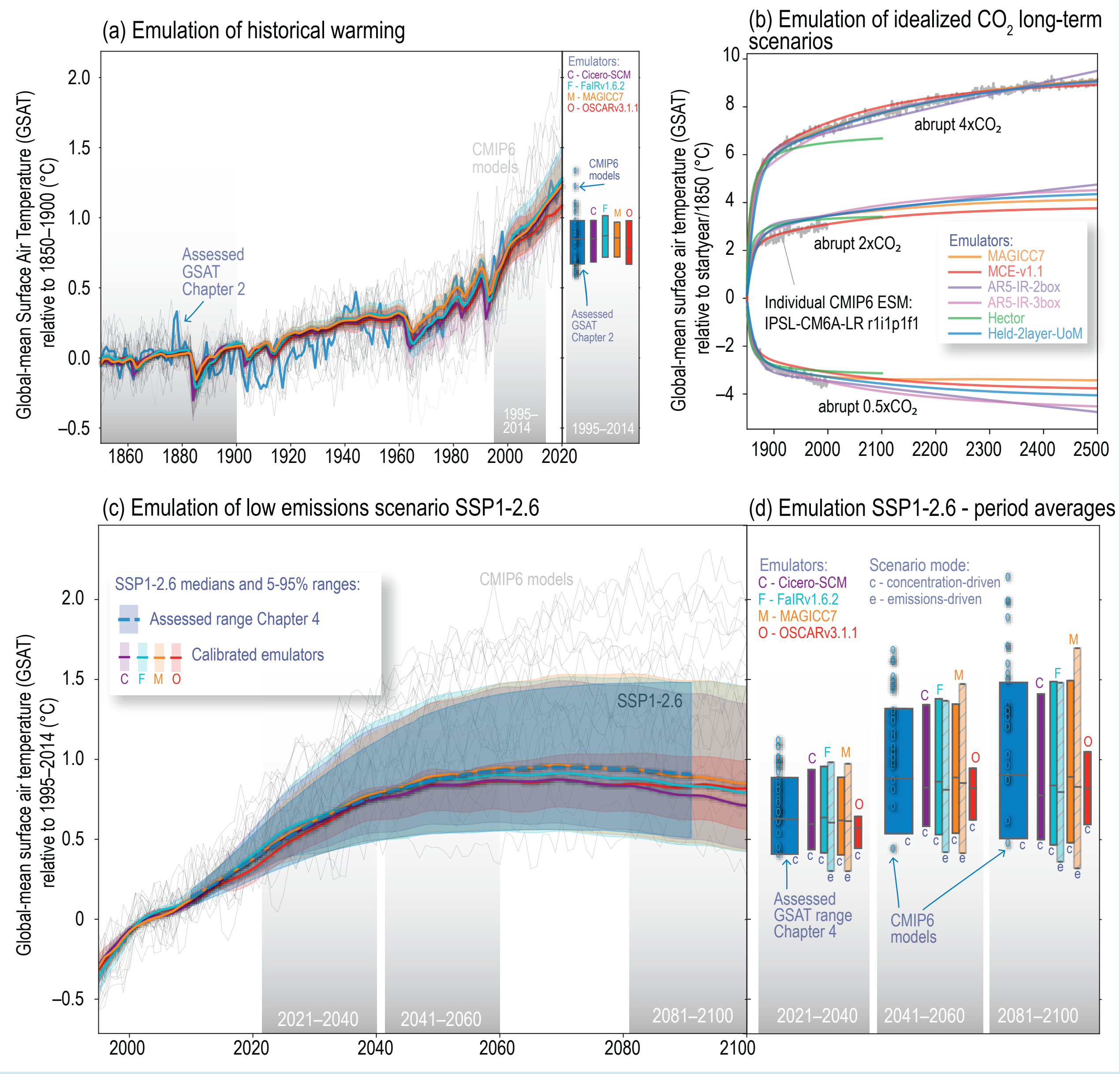
Four emissions-driven emulators have been considered as tools for WGIII to explore the range of GSAT response to multiple scenarios beyond those assessed in WGI. The four emulators are CICERO-SCM (Skeie et al., 2017, 2021), FaIRv1.6.2 (Millar et al., 2017; Smith et al., 2018a), MAGICC7 (Meinshausen et al., 2009) and OSCARv3.1.1 (Gasser et al., 2017a, 2020). Each emulator's probabilistic distribution has been calibrated to capture the relationship between emissions and GSAT change. The calibration is informed by the WGI assessed ranges of ECS, TCR, historical GSAT change, ERF, carbon cycle metrics and future warming projections under the (concentration-driven) SSP scenarios. The emulators are then provided as a tool for WGIII to perform a GSAT-based classification of mitigation scenarios consistent with the physical understanding assessed in WGI. The calibration step reduced the emulator differences identified in SR1.5. Note that evaluation of both central and range estimates of each emulator's probabilistic projections is important to assess the fitness-for-purpose for the classification of scenarios in WGIII, based on information beyond the central estimate of GSAT warming.

MAGICC7 and FaIRv1.6.2 emissions-based emulators are able to represent the WGI assessment to within small differences (defined here as within typical rounding precisions of ±5% for central estimates and ±10% for ranges) across more than 80% of metric ranges (Cross-Chapter Box 7.1, Table 2). Both calibrated emulators are consistent with assessed ranges of ECS, historical GSAT, historical ocean heat uptake, total greenhouse gas ERF, methane ERF and the majority of the assessed SSP warming ranges. FaIRv1.6.2 also matches the assessed central value of TCRE and airborne fraction. Whereas, MAGICC7 matches the assessed TCR ranges as well as providing a closer fit to the SSP warming ranges for the lower-emissions scenarios. In the evaluation framework considered here, CICERO-SCM represents historical warming to within 2% of the assessed ranges and also represents future temperature ranges across the majority of the assessment, although it lacks the representation of the carbon cycle. In this framework, OSCARv3.1.1 is less able to represent the assessed projected GSAT ranges although it matches the range of airborne fraction estimates closely and the assessed historical GSAT *likely* range to within 0.5%. Despite these identified limitations, both CICERO-SCM and OSCARv3.1.1 provide additional information for evaluating the sensitivity of scenario classification to model choice.

How emulators match the assessed ranges used for the evaluation framework is summarized here and in Table 2. The first is too-low projections for 2081–2100 under SSP1-1.9 (8% or 15% too low for the central estimate and 15% or 25% too low for the lower end in

Cross-Chapter Box 7.1 (continued)

the case of MAGICC7 or FaIRv1.6.2, respectively). The second is the representation of the aerosol ERF (both MAGICC7 and FaIRv1.6.2 are greater than 8% less negative than the central assessed range and greater than 10% less negative for the lower assessed range), as energy balance models struggle to reproduce an aerosol ERF with a magnitude as strong as the assessed best estimate and still match historical warming estimates. Both emulators have medium to large differences compared to the TCRE and airborne fraction ranges (see notes beneath Cross-Chapter Box 7.1, Table 2). Finally, there is also a slight overestimate of the low end of the assessed historical GSAT range.



Cross-Chapter Box 7.1, Figure 1 | A comparison between the global surface air temperature (GSAT) response of various calibrated simple climate models, assessed ranges and Earth system models (ESMs). (a) and **(b)** compare the assessed historical GSAT time series (Section 2.3.1) with four multi-gas emulators calibrated to replicate numerous assessed ranges (panel (a); Cross-Chapter Box 7.1, Table 2) and also compares idealized CO_2-only concentration scenario response for one ESM (IPSL CM6A-LR) and multiple emulators which participated in RCMIP Phase 1 (Nicholls et al., 2020) calibrated to that single ESM (panel (b)). **(c)** and **(d)** compare this Report's assessed ranges for GSAT warming (Box 4.1) under the multi-gas scenario SSP1-2.6 with the same calibrated emulators as in (a). For context, a range of CMIP6 ESM results are also shown (thin lines in (c) and open circles in (d)). Panel (b) adapted from Nicholls et al. (2020). Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

Cross-Chapter Box 7.1 (continued)

Overall, there is *high confidence* that emulated historical and future ranges of GSAT change can be calibrated to be internally consistent with the assessment of key physical-climate indicators in this Report: greenhouse gas ERFs, ECS and TCR. When calibrated to match the assessed ranges of GSAT and multiple physical climate indicators, physically based emulators can reproduce the best estimate of GSAT change over 1850–1900 to 1995–2014 to within 5% and the *very likely* range of this GSAT change to within 10%. MAGICC7 and FaIRv1.6.2 match at least two-thirds of the Chapter 4 assessed projected GSAT changes to within these levels of precision.

Cross-Chapter Box 7.1, Table 2 | Percentage differences between the emulator value and the WGI assessed best estimate and range for key metrics. Values are given for four emulators in their respective AR6-calibrated probabilistic setups. Absolute values of these indicators are shown in Supplementary Material, Table 7.SM.4.

Emulator		CICERO-SCM			FaIRv1.6.2			MAGICC7			OSCARv3.1.1		
Assessed Range		Lower	Central	Upper	Lower	Central	Upper	Lower	Central	Upper	Lower	Central	Upper
Key metrics													
ECS (°C)		26%	2%	–18%	3%	–2%	1%	–3%	–1%	–3%	–8%	–15%	–22%
TCRE (°C per 1000 GtC)**					29%	–7%	–21%	37%	5%	–5%	50%	–8%	–20%
TCR (°C)		15%	–5%	–3%	14%	0%	3%	6%	4%	9%	26%	1%	–14%
Historical warming and Effective Radiative Forcing													
GSAT warming (°C) 1995–2014 rel. 1850–1900		2%	0%	0%	7%	3%	4%	7%	1%	–1%	–0%	–8%	–0%
Ocean heat content change (ZJ)* 1971–2018		–24%	–27%	–29%	5%	–4%	–9%	–1%	–3%	–6%	–47%	–39%	10%
Total Aerosol ERF (W m^{-2}) 2005–2014 rel. 1750		36%	37%	10%	16%	12%	0%	10%	8%	8%	38%	15%	–31%
GHG ERF (W m^{-2}) 2019 rel. 1750		4%	–5%	–13%	1%	2%	1%	2%	1%	–0%	1%	3%	–3%
Methane ERF (W m^{-2}) 2019 rel. 1750		31%	4%	–13%	3%	3%	3%	0%	–0%	3%	8%	–1%	–5%
Carbon Cycle metrics													
Airborne Fraction *1pctCO$_2$* (dimensionless)* 2×CO_2					8%	–3%	–11%	12%	6%	–1%	1%	–0%	8%
Airborne Fraction *1pctCO$_2$* (dimensionless)* 4×CO_2					12%	1%	–9%	15%	4%	–6%	5%	–1%	–1%
Future warming (GSAT) relative to 1995–2014													
SSP1-1.9 (°C)	2021–2040	10%	–4%	10%	3%	1%	11%	2%	–0%	4%	12%	–9%	–25%
	2041–2060	8%	–9%	7%	–11%	–8%	6%	–1%	–1%	7%	12%	–8%	–31%
	2081–2100	–12%	–25%	–2%	–25%	–15%	4%	–15%	–8%	3%	7%	–10%	–31%
SSP1-2.6 (°C)	2021–2040	7%	–5%	5%	2%	1%	8%	–1%	–2%	–0%	9%	–9%	–28%
	2041–2060	8%	–6%	2%	–2%	–2%	5%	0%	1%	2%	15%	–6%	–28%
	2081–2100	–2%	–14%	–5%	–8%	–7%	1%	–6%	–1%	1%	17%	–9%	–29%
SSP2-4.5 (°C)	2021–2040	8%	–5%	5%	7%	–1%	2%	3%	–3%	–2%	–5%	–14%	–30%
	2041–2060	4%	–4%	3%	1%	–1%	2%	1%	1%	2%	8%	–8%	–28%
	2081–2100	–1%	–10%	–3%	–2%	–3%	1%	–2%	1%	3%	8%	–4%	–25%
SSP3-7.0 (°C)	2021–2040	11%	–4%	1%	14%	1%	–1%	10%	1%	–0%	–5%	–15%	–29%
	2041–2060	4%	–5%	–0%	6%	0%	–1%	7%	4%	1%	7%	–8%	–26%
	2081–2100	–0%	–8%	–3%	3%	–1%	–1%	6%	3%	6%	5%	–6%	–25%
SSP5-8.5 (°C)	2021–2040	5%	–7%	2%	9%	2%	4%	7%	1%	2%	1%	–14%	–30%
	2041–2060	2%	–8%	–1%	4%	0%	4%	3%	2%	4%	10%	–6%	–24%
	2081–2100	4%	–7%	–3%	6%	–0%	1%	8%	4%	7%	9%	–4%	–25%

Cross-Chapter Box 7.1 (continued)

Notes. Metrics calibrated against are equilibrium climate sensitivity, ECS (Section 7.5); transient climate response to cumulative CO_2 emissions, TCRE (Section 5.5); transient climate response, TCR (Section 7.5), historical GSAT change (Section 2.3); ocean heat uptake (Sections 7.2 and 2.3); effective radiative forcing, ERF (Section 7.3); carbon cycle metrics, namely airborne fractions of idealized CO_2 scenarios (taking the *likely* range as twice the standard deviation across the models analysed in Arora et al. (2020; see also Table 5.7, 'cross-AR6 lines of evidence' row); and GSAT projections under the concentration-driven SSP scenarios for the near term (2021–2040), mid-term (2041–2060) and long term (2081–2100) relative to 1995–2014 (Table 4.2). See Supplementary Material, Table 7.SM.4 for a version of this table with the absolute values rather than percentage differences. The columns labelled 'upper' and 'lower' indicate 5–95% ranges, except for the variables demarcated with an asterisk or double asterisk (* or **), where they denote *likely* ranges from 17–83%. Note that the TCRE assessed range (**) is wider than the combination of the TCR and airborne fraction to account for uncertainties related to model limitations (Table 5.7) hence it is expected that the emulators are too narrow on this particular metric and/or too wide on TCR and airborne fraction. For illustrative purposes, the cells are coloured as follows: white cells indicate small differences (up to ±5% for the central value and +10% for the ranges), light blue and light yellow cells indicate medium differences (up to +10% and –10% for light blue and light yellow for central values, respectively; up to ±20% for the ranges) and darker cells indicate larger positive (blue) or negative (yellow) differences. Note that values are rounded after the colours are applied.

7.4 Climate Feedbacks

The magnitude of global surface temperature change primarily depends on the strength of the radiative forcings and feedbacks, the latter defined as the changes of the net energy budget at the top-of-atmosphere (TOA) in response to a change in the GSAT (Box 7.1, Equation 7.1). Feedbacks in the Earth system are numerous, and it can be helpful to categorize them into three groups: (i) physical feedbacks; (ii) biogeophysical and biogeochemical feedbacks; and (iii) long-term feedbacks associated with ice sheets. The physical feedbacks (e.g., those associated with changes in lapse rate, water vapour, surface albedo, or clouds; Sections 7.4.2.1–7.4.2.4) and biogeophysical/biogeochemical feedbacks (e.g., those associated with changes in methane, aerosols, ozone, or vegetation; Section 7.4.2.5) act both on time scales that are used to estimate the equilibrium climate sensitivity (ECS) in models (typically 150 years, see Box 7.1) and on longer time scales required to reach equilibrium. Long-term feedbacks associated with ice sheets (Section 7.4.2.6) are relevant primarily after several centuries or more. The feedbacks associated with biogeophysical/biogeochemical processes and ice sheets, often collectively referred to as Earth system feedbacks, had not been included in conventional estimates of the climate feedback (e.g., Hansen et al., 1984), but the former can now be quantified and included in the assessment of the total (net) climate feedback. Feedback analysis represents a formal framework for the quantification of the coupled interactions occurring within a complex Earth system in which everything influences everything else (e.g., Roe, 2009). As used here (as presented in Section 7.4.1), the primary objective of feedback analysis is to identify and understand the key processes that determine the magnitude of the surface temperature response to an external forcing. For each feedback, the basic underlying mechanisms and their assessments are presented in Section 7.4.2.

Up until AR5, process understanding and quantification of feedback mechanisms were based primarily on global climate models. Since AR5, the scientific community has undertaken a wealth of alternative approaches, including observational and fine-scale modelling approaches. This has in some cases led to more constrained feedbacks and, on the other hand, uncovered shortcomings in global climate models, which are starting to be corrected. Consequently, AR6 achieves a more robust assessment of feedbacks in the climate system that is less reliant on global climate models than in earlier assessment reports.

It has long been recognized that the magnitude of climate feedbacks can change as the climate state evolves over time (Manabe and Bryan, 1985; Murphy, 1995), but the implications for projected future warming have been investigated only recently. Since AR5, progress has been made in understanding the key mechanisms behind this time- and state-dependence. Specifically, the state-dependence is assessed by comparing climate feedbacks between warmer and colder climate states inferred from paleoclimate proxies and model simulations (Section 7.4.3). The time-dependence of the feedbacks is evident between the historical period and future projections and is assessed to arise from the evolution of the surface warming pattern related to changes in zonal and meridional temperature gradients (Section 7.4.4).

7.4.1 Methodology of the Feedback Assessment

The global surface temperature changes of the climate system are generally analysed with the classical forcing–feedback framework as described in Box 7.1 (Equation 7.1). In this equation α is the net feedback parameter (W m^{-2} °C^{-1}). As surface temperature changes in response to the TOA energy imbalance, many other climate variables also change, thus affecting the radiative flux at the TOA. The aggregate feedback parameter can then be decomposed into an approximate sum of terms $\alpha = \Sigma_x \alpha_x$, where x is a vector representing variables that have a direct effect on the net TOA radiative flux N and

$$\alpha_x = \frac{\partial N}{\partial x}\frac{dx}{dT}$$

Following the conventional definition, the physical climate feedbacks are here decomposed into terms associated with a vertically uniform temperature change (Planck response, P), changes in the water-vapour plus temperature lapse-rate (WV+LR), surface albedo (A) and clouds (C). The water-vapour plus temperature lapse rate feedback is further decomposed using two different approaches, one based on changes in specific humidity, the other on changes in relative humidity. Biogeochemical feedbacks arise due to changes in aerosols and atmospheric chemical composition in response to changes in surface temperature, and Gregory et al. (2009) and Raes et al. (2010) show that they can be analysed using the same framework as for the physical climate feedbacks (Sections 5.4 and 6.4.5). Similarly, feedbacks associated with biogeophysical and ice-sheet changes can also be incorporated.

In global climate models, the feedback parameters α_x in global warming conditions are often estimated as the mean differences in the radiative fluxes between atmosphere-only simulations in which the change in SST is prescribed (Cess et al., 1990), or as the regression slope of change in radiation flux against change in GSAT using atmosphere–ocean coupled simulations with abrupt CO_2 changes (*abrupt4xCO2*) for 150 years (Box 7.1; Gregory et al., 2004; Andrews et al., 2012; Caldwell et al., 2016). Neither method is perfect, but both are useful and yield consistent results (Ringer et al., 2014). In the regression method, the radiative effects of land warming are excluded from the ERF due to doubling of CO_2 (Section 7.3.2), which may overestimate feedback values by about 15%. At the same time, the feedback calculated using the regression over years 1–150 ignores its state-dependence on multi-centennial time scales (Section 7.4.3), probably giving an underestimate of α by about 10% (Rugenstein et al., 2019). These effects are both small and approximately cancel each other in the ensemble mean, justifying the use of regression over 150 years as an approximation to feedbacks in ESMs.

The change of the TOA radiative flux N as a function of the change of a climate variable x (such as water vapour) is commonly computed using the 'radiative kernel' method (Soden et al., 2008). In this method, the kernel $\partial N/\partial x$ is evaluated by perturbing x within a radiation code. Then multiplying the kernel by $\mathrm{d}x/\mathrm{d}T$ inferred from observations, meteorological analysis or GCMs produces a value of α_x.

Feedback parameters from lines of evidence other than global models are estimated in various ways. For example, observational data combined with GCM simulations could produce an emergent constraint on a particular feedback (Hall and Qu, 2006; Klein and Hall, 2015), or the observed interannual fluctuations in the global mean TOA radiation and the surface air temperature, to which the linear regression analysis is applied, could generate a direct estimate of the climate feedback, assuming that the feedback associated with internal climate variability at short time scales can be a surrogate of the feedback to CO_2-induced warming (Dessler, 2013; Loeb et al., 2016). The assumption is not trivial, but can be justified given that the climate feedbacks are fast enough to occur at the interannual time scale. Indeed, a broad agreement has been obtained in estimates of individual physical climate feedbacks based on interannual variability and longer climate change time scales in GCMs (Zhou et al., 2015; Colman and Hanson, 2017). This means that the climate feedbacks estimated from the observed interannual fluctuations are representative of the longer-term feedbacks (decades to centuries). Care must be taken for these observational estimates because they can be sensitive to details of the calculation such as data sets and periods used (Dessler, 2013; Proistosescu et al., 2018). In particular, there would be a dependence of physical feedbacks on the surface warming pattern at the interannual time scale due, for example, to El Niño–Southern Oscillation. However, this effect both amplifies and suppresses the feedback when data include the positive and negative phases of the interannual fluctuation, and therefore the net bias will be small.

In summary, the classical forcing–feedback framework has been extended to include biogeophysical and non-CO_2 biogeochemical feedbacks in addition to the physical feedbacks. It has also been used to analyse seasonal and interannual-to-decadal climate variations in observations and ESMs, in addition to long-term climate changes as seen in *abrupt4xCO2* experiments. These developments allow an assessment of the feedbacks based on a larger variety of lines of evidence compared to AR5.

7.4.2 Assessing Climate Feedbacks

This section provides an overall assessment of individual feedback parameters, α_x, by combining different lines of evidence from observations, theory, process models and ESMs. To achieve this, we review the understanding of the key processes governing the feedbacks, why the feedback estimates differ among models, studies or approaches, and the extent to which these approaches yield consistent results. The individual terms assessed are the Planck response (Section 7.4.2.1) and feedbacks associated with changes in water vapour and lapse rate (Section 7.4.2.2), surface albedo (Section 7.4.2.3), clouds (Section 7.4.2.4), biogeophysical and non-CO_2 biogeochemical processes (Section 7.4.2.5), and ice sheets (Section 7.4.2.6). A synthesis is provided in Section 7.4.2.7. Climate feedbacks in CMIP6 models are then evaluated in Section 7.4.2.8, with an explanation of how they have been incorporated into the assessment.

7.4.2.1 Planck Response

The Planck response represents the additional thermal or longwave (LW) emission to space arising from vertically uniform warming of the surface and the atmosphere. The Planck response α_P, often called the Planck feedback, plays a fundamental stabilizing role in Earth's climate and has a value that is strongly negative: a warmer planet radiates more energy to space. A crude estimate of α_P can be made using the normalized greenhouse effect $\tilde{g}$, defined as the ratio between the greenhouse effect G and the upwelling LW flux at the surface (Raval and Ramanathan, 1989). Current estimates (Section 7.2, Figure 7.2) give $G = 159$ W m^{-2} and $\tilde{g} \approx 0.4$. Assuming $\tilde{g}$ is constant, one obtains for a surface temperature $T_s = 288$ K, $\alpha_P = (g - 1)\ 4\ \sigma\ T_s^3 \approx -3.3$ W m^{-2} °C^{-1}, where σ is the Stefan–Boltzmann constant. This parameter α_P is estimated more accurately using kernels obtained from meteorological reanalysis or climate simulations (Soden and Held, 2006; Dessler, 2013; Vial et al., 2013; Caldwell et al., 2016; Colman and Hanson, 2017; Zelinka et al., 2020). Discrepancies among estimates primarily arise because differences in cloud distributions make the radiative kernels differ (Kramer et al., 2019). Using six different kernels, Zelinka et al. (2020) obtained a spread of ±0.1 W m^{-2} °C^{-1} (one standard deviation). Discrepancies among estimates secondarily arise from differences in the pattern of equilibrium surface temperature changes among ESMs. For the CMIP5 and CMIP6 models this introduces a spread of ±0.04 W m^{-2} °C^{-1} (one standard deviation). The multi-kernel and multi-model mean of α_P is equal to –3.20 W m^{-2} °C^{-1} for the CMIP5 and –3.22 W m^{-2} °C^{-1} for the CMIP6 models (Supplementary Material, Table 7.SM.5). Overall, there is *high confidence* in the estimate of the Planck response, which is assessed to be $\alpha_P = -3.22$ W m^{-2} °C^{-1} with a *very likely* range of –3.4 to –3.0 W m^{-2} °C^{-1} and a *likely range* of –3.3 to –3.1 W m^{-2} °C^{-1}.

The Planck temperature response ΔT_P is the equilibrium temperature change in response to a forcing ΔF when the net feedback parameter is equal to the Planck response parameter: $\Delta T_P = -\Delta F / \alpha_P$.

7.4.2.2 Water-vapour and Temperature Lapse-rate Feedbacks

Two decompositions are generally used to analyse the feedbacks associated with a change in the water-vapour and temperature lapse-rate in the troposphere. As in any system, many feedback decompositions are possible, each of them highlighting a particular property or aspect of the system (Ingram, 2010; Held and Shell, 2012; Dufresne and Saint-Lu, 2016). The first decomposition considers separately the changes (and therefore feedbacks) in the lapse rate (LR) and specific humidity (WV). The second decomposition considers changes in the lapse rate assuming constant relative humidity (LR*) separately from changes in relative humidity (RH).

The specific humidity (WV) feedback, also known as the water-vapour feedback, quantifies the change in radiative flux at the TOA due to changes in atmospheric water vapour concentration associated with a change in global mean surface air temperature. According to theory, observations and models, the water vapour increase approximately follows the Clausius–Clapeyron relationship at the global scale with regional differences dominated by dynamical processes (Section 8.2.1; Sherwood et al., 2010a; Chung et al., 2014; Romps, 2014; R. Liu et al., 2018; Schröder et al., 2019). Greater atmospheric water vapour content, particularly in the upper troposphere, results in enhanced absorption of LW and SW radiation and reduced outgoing radiation. This is a positive feedback. Atmospheric moistening has been detected in satellite records (Section 2.3.1.3.3), it is simulated by climate models (Section 3.3.2.2), and the estimates agree within model and observational uncertainty (Soden et al., 2005; Dessler, 2013; Gordon et al., 2013; Chung et al., 2014). The estimate of this feedback inferred from satellite observations is $\alpha_{WV} = 1.85 \pm 0.32$ W m^{-2} °C^{-1} (R. Liu et al., 2018). This is consistent with the value $\alpha_{WV} = 1.77 \pm 0.20$ W m^{-2} °C^{-1} (one standard deviation) obtained with CMIP5 and CMIP6 models (Zelinka et al., 2020).

The lapse-rate (LR) feedback quantifies the change in radiative flux at the TOA due to a nonuniform change in the vertical temperature profile. In the tropics, the vertical temperature profile is mainly driven by moist convection and is close to a moist adiabat. The warming is larger in the upper troposphere than in the lower troposphere (Manabe and Wetherald, 1975; Santer et al., 2005; Bony et al., 2006), leading to a larger radiative emission to space and therefore a negative feedback. This larger warming in the upper troposphere than at the surface has been observed over the last 20 years thanks to the availability of sufficiently accurate observations (Section 2.3.1.2.2). In the extratropics, the vertical temperature profile is mainly driven by a balance between radiation, meridional heat transport and ocean heat uptake (Rose et al., 2014). Strong winter temperature inversions lead to warming that is larger in the lower troposphere (Payne et al., 2015; Feldl et al., 2017a) and a positive LR feedback in polar regions (Section 7.4.4.1; Manabe and Wetherald, 1975; Bintanja et al., 2012; Pithan and Mauritsen, 2014). However, the tropical contribution dominates, leading to a negative global mean LR feedback (Soden and Held, 2006; Dessler, 2013; Vial et al., 2013; Caldwell et al., 2016). The LR feedback has been estimated at interannual time scales using meteorological reanalysis and satellite measurements of TOA fluxes (Dessler, 2013). These estimates from climate variability are consistent between observations and ESMs (Dessler, 2013; Colman and Hanson, 2017). The mean and standard deviation of this feedback under global warming based on the cited studies are $\alpha_{LR} = -0.50 \pm 0.20$ W m^{-2} °C^{-1} (Dessler, 2013; Caldwell et al., 2016; Colman and Hanson, 2017; Zelinka et al., 2020).

The second decomposition was proposed by Held and Shell (2012) to separate the response that would occur under the assumption that relative humidity remains constant from that due to the change in relative humidity. The feedback is decomposed into three: (i) change in water vapour due to an identical temperature increase at the surface and throughout the troposphere assuming constant relative humidity, which will be called the Clausius–Clapeyron (CC) feedback here; (ii) change in LR assuming constant relative humidity (LR*); (iii) change in relative humidity (RH). Since AR5 it has been clarified that by construction, the sum of the temperature lapse rate and specific humidity (LR + WV) feedbacks is equal to the sum of the Clausius–Clapeyron feedback, the lapse rate feedback assuming constant relative humidity, and the feedback from changes in relative humidity (that is, CC + LR* + RH). Therefore, each of these two sums may simply be referred to as the 'water-vapour plus lapse-rate' feedback.

The CC feedback has a large positive value due to well understood thermodynamic and radiative processes: $\alpha_{CC} = 1.36 \pm 0.04$ W m^{-2} °C^{-1} (one standard deviation; Held and Shell, 2012; Zelinka et al., 2020). The lapse-rate feedback assuming a constant relative humidity (LR*) in CMIP6 models has small absolute values ($\alpha_{LR^*} = -0.10 \pm 0.07$ W m^{-2} °C^{-1} (one standard deviation)), as expected from theoretical arguments (Ingram, 2010, 2013). It includes the pattern effect of surface warming that modulates the lapse rate and associated specific humidity changes (Po-Chedley et al., 2018b). The relative humidity feedback is close to zero ($\alpha_{RH} = 0.00 \pm 0.06$ W m^{-2} °C^{-1} (one standard deviation)) and the spread among models is confined to the tropics (Sherwood et al., 2010b; Vial et al., 2013; Takahashi et al., 2016; Po-Chedley et al., 2018b). The change in upper tropospheric RH is closely related to model representation of current climate (Sherwood et al., 2010b; Po-Chedley et al., 2019), and a reduction in model RH biases is expected to reduce the uncertainty of the RH feedback. At interannual time scales, it has been shown that the change in RH in the tropics is related to the change of the spatial organization of deep convection (Holloway et al., 2017; Bony et al., 2020).

Both decompositions allow estimates of the sum of the lapse-rate and specific humidity feedbacks α_{LR+WV}. The multi-kernel and multi-model mean of α_{LR+WV} is equal to 1.24 and 1.26 W m^{-2} °C^{-1} respectively for CMIP5 and CMIP6 models, with a standard deviation of 0.10 W m^{-2} °C^{-1} (Zelinka et al., 2020). These values are larger than the recently assessed value of 1.15 W m^{-2} °C^{-1} by Sherwood et al. (2020) as a larger set of kernels, including those obtained from meteorological reanalysis, are used here.

Since AR5, the effect of the water vapour increase in the stratosphere as a result of global warming has been investigated by different studies. This increase produces a positive feedback between 0.1 and

0.3 W m^{-2} °C^{-1} if the stratospheric radiative response is computed assuming temperatures that are adjusted with fixed dynamical heating (Dessler et al., 2013; Banerjee et al., 2019). However, various feedbacks reduce this temperature adjustment and the overall physical (water vapour, temperature and dynamical) stratospheric feedback becomes much smaller (0.0 to 0.1 W m^{-2} °C^{-1}; Huang et al., 2016, 2020; Li and Newman, 2020), with uncertainty arising from limitations of current ESMs in simulating stratospheric processes. The total stratospheric feedback is assessed at 0.05 ± 0.1 W m^{-2} °C^{-1} (one standard deviation).

The combined 'water-vapour plus lapse-rate' feedback is positive. The main physical processes that drive this feedback are well understood and supported by multiple lines of evidence including models, theory and observations. The combined 'water-vapour plus lapse-rate' feedback parameter is assessed to be α_{LR+WV} = 1.30 W m^{-2} °C^{-1}, with a *very likely* range of 1.1 to 1.5 W m^{-2} °C^{-1} and a *likely* range of 1.2 to 1.4 W m^{-2} °C^{-1} with *high confidence.*

7.4.2.3 Surface-albedo Feedback

Surface albedo is determined primarily by reflectance at Earth's surface, but also by the spectral and angular distribution of incident solar radiation. Changes in surface albedo result in changes in planetary albedo that are roughly reduced by two-thirds, owing to atmospheric absorption and scattering, with variability and uncertainty arising primarily from clouds (Bender, 2011; Donohoe and Battisti, 2011; Block and Mauritsen, 2013). Temperature change induces surface-albedo change through several direct and indirect means. In the present climate and at multi-decadal time scales, the largest contributions by far are changes in the extent of sea ice and seasonal snow cover, as these media are highly reflective and are located in regions that are close to the melting temperature (Sections 2.3.2.1 and 2.3.2.2). Reduced snow cover on sea ice may contribute as much to albedo feedback as reduced extent of sea ice (Zhang et al., 2019). Changes in the snow metamorphic rate, which generally reduces snow albedo with warmer temperature, and warming-induced consolidation of light-absorbing impurities near the surface, also contribute secondarily to the albedo feedback (Flanner and Zender, 2006; Qu and Hall, 2007; Doherty et al., 2013; Tuzet et al., 2017). Other contributors to albedo change include vegetation state (assessed separately in Section 7.4.2.5), soil wetness and ocean roughness.

Several studies have attempted to derive surface-albedo feedback from observations of multi-decadal changes in climate, but only over limited spatial and inconsistent temporal domains, inhibiting a purely observational synthesis of global surface-albedo feedback (α_A). Flanner et al. (2011) applied satellite observations to determine that the northern hemisphere (NH) cryosphere contribution to global α_A over the period 1979–2008 was 0.48 [*likely* range 0.29 to 0.78] W m^{-2} °C^{-1}, with roughly equal contributions from changes in land snow cover and sea ice. Since AR5, and over similar periods of observation, Crook and Forster (2014) found an estimate of 0.8 ± 0.3 W m^{-2} °C^{-1} (one standard deviation) for the total NH extratropical surface-albedo feedback, when averaged over global surface area. For Arctic sea ice alone, Pistone et al. (2014) and Cao et al. (2015) estimated the contribution to global α_A to be 0.31 ± 0.04 W m^{-2} °C^{-1} (one standard deviation) and 0.31 ± 0.08 W m^{-2} °C^{-1} (one standard deviation), respectively, whereas Donohoe et al. (2020) estimated it to be only 0.16 ± 0.04 W m^{-2} °C^{-1} (one standard deviation). Much of this discrepancy can be traced to different techniques and data used for assessing the attenuation of surface-albedo change by Arctic clouds. For the NH land snow, Chen et al. (2016) estimated that observed changes during 1982–2013 contributed (after converting from NH temperature change to global mean temperature change) by 0.1 W m^{-2} °C^{-1} to global α_A, smaller than the estimate of 0.24 W m^{-2} °C^{-1} from Flanner et al. (2011). The contribution of the Southern Hemisphere (SH) to global α_A is expected to be small because seasonal snow cover extent in the SH is limited, and trends in SH sea ice extent are relatively flat over much of the satellite record (Section 2.3.2).

CMIP5 and CMIP6 models show moderate spread in global α_A, determined from century time scale changes (Qu and Hall, 2014; Schneider et al., 2018; Thackeray and Hall, 2019; Zelinka et al., 2020), owing to variations in modelled sea ice loss and snow cover response in boreal forest regions. The multi-model mean global-scale α_A (from all contributions) over the 21st century in CMIP5 models under the RCP8.5 scenario was derived by Schneider et al. (2018) to be 0.40 ± 0.10 W m^{-2} °C^{-1} (one standard deviation). Moreover, they found that modelled α_A does not decline over the 21st century, despite large losses of snow and sea ice, though a weakened feedback is apparent after 2100. Using the idealized *abrupt4xCO2*, as for the other feedbacks, the estimate of the global-scale albedo feedback in the CMIP5 models is 0.35 ± 0.08 W m^{-2} °C^{-1} (one standard deviation; Vial et al., 2013; Caldwell et al., 2016). The CMIP6 multi-model mean varies from 0.3 to 0.5 W m^{-2} °C^{-1} depending on the kernel used (Zelinka et al., 2020). Donohoe et al. (2020) derived a multi-model mean α_A and its inter-model spread of 0.37 ± 0.19 W m^{-2} °C^{-1} from the CMIP5 *abrupt4xCO2* ensemble, employing model-specific estimates of atmospheric attenuation and thereby avoiding bias associated with use of a single radiative kernel.

The surface-albedo feedback estimates using centennial changes have been shown to be highly correlated to those using seasonal regional changes for NH land snow (Qu and Hall, 2014) and Arctic sea ice (Thackeray and Hall, 2019). For the NH land snow, because the physics underpinning this relationship are credible, this opens the possibility to use it as an emergent constraint (Qu and Hall, 2014). Considering only the eight models whose seasonal cycle of albedo feedback falls within the observational range does not change the multi-model mean contribution to global α_A (0.08 W m^{-2} °C^{-1}) but decreases the inter-model spread by a factor of two (from ±0.03 to ±0.015 W m^{-2} °C^{-1}; Qu and Hall, 2014). For Arctic sea ice, Thackeray and Hall (2019) show that the seasonal cycle also provides an emergent constraint, at least until mid-century when the relationship degrades. They find that the CMIP5 multi-model mean of the Arctic sea ice contribution to α_A is 0.13 W m^{-2} °C^{-1} and that the inter-model spread is reduced by a factor of two (from ±0.04 to ±0.02 W m^{-2} °C^{-1}) when the emergent constraint is used. This model estimate is smaller than observational estimates (Pistone et al., 2014; Cao et al., 2015) except those of Donohoe et al. (2020). This can be traced to CMIP5 models generally underestimating the rate of Arctic sea ice loss during recent decades (Section 9.3.1; Stroeve et al., 2012;

Flato et al., 2013), though this may also be an expression of internal variability, since the observed behaviour is captured within large ensemble simulations (Notz, 2015). CMIP6 models better capture the observed Arctic sea ice decline (Section 3.4.1). In the SH the opposite situation is observed. Observations show relatively flat trends in SH sea ice over the satellite era (Section 2.3.2.1) whereas CMIP5 models simulate a small decrease (Section 3.4.1). SH α_A is presumably larger in models than observations but only contributes about one quarter of the global α_A. Thus, we assess that α_A estimates are consistent, at global scale, in CMIP5 and CMIP6 models and satellite observations, though hemispheric differences and the role of internal variability need to be further explored.

Based on the multiple lines of evidence presented above that include observations, CMIP5 and CMIP6 models and theory, the global surface-albedo feedback is assessed to be positive with *high confidence*. The basic phenomena that drive this feedback are well understood and the different studies cover a large variety of hypotheses or behaviours, including how the evolution of clouds affects this feedback. The value of the global surface-albedo feedback is assessed to be α_A = 0.35 W m^{-2} °C^{-1}, with a *very likely* range from 0.10 to 0.60 W m^{-2} °C^{-1} and a *likely* range from 0.25 to 0.45 W m^{-2} °C^{-1} with *high confidence*.

7.4.2.4 Cloud Feedbacks

7.4.2.4.1 Decomposition of clouds into regimes

Clouds can be formed almost anywhere in the atmosphere when moist air parcels rise and cool, enabling the water vapour to condense. Clouds consist of liquid water droplets and/or ice crystals, and these droplets and crystals can grow into larger particles of rain, snow or drizzle. These microphysical processes interact with aerosols, radiation and atmospheric circulation, resulting in a highly complex set of processes governing cloud formation and life cycles that operate across a wide range of spatial and temporal scales.

Clouds have various types, from optically thick convective clouds to thin stratus and cirrus clouds, depending upon thermodynamic conditions and large-scale circulation (Figure 7.9). Over the equatorial warm pool and inter-tropical convergence zone (ITCZ) regions, high SSTs stimulate the development of deep convective cloud systems, which are accompanied by anvil and cirrus clouds near the tropopause where the convective air outflows. The large-scale circulation associated with these convective clouds leads to subsidence over the subtropical cool ocean, where deep convection is suppressed by a lower tropospheric inversion layer maintained by the subsidence and promoting the formation of shallow cumulus and stratocumulus clouds. In the extratropics, mid-latitude storm tracks control cloud formation, which occurs primarily in the frontal bands of extratropical cyclones. Since liquid droplets do not freeze spontaneously at temperatures warmer than approximately –40°C and ice nucleating particles that can aid freezing at warmer temperatures are scarce (see Section 7.3.3), extratropical clouds often consist both of super-cooled liquid and ice crystals, resulting in mixed-phase clouds.

In the global energy budget at TOA, clouds affect shortwave (SW) radiation by reflecting sunlight due to their high albedo (cooling the climate system) and also longwave (LW) radiation by absorbing the energy from the surface and emitting at a lower temperature to space, that is, contributing to the greenhouse effect, warming the climate system. In general, the greenhouse effect of clouds strengthens with height whereas the SW reflection depends on the cloud optical properties. The effects of clouds on Earth's energy budget are measured by the cloud radiative effect (CRE), which is the difference in the TOA radiation between clear and all skies

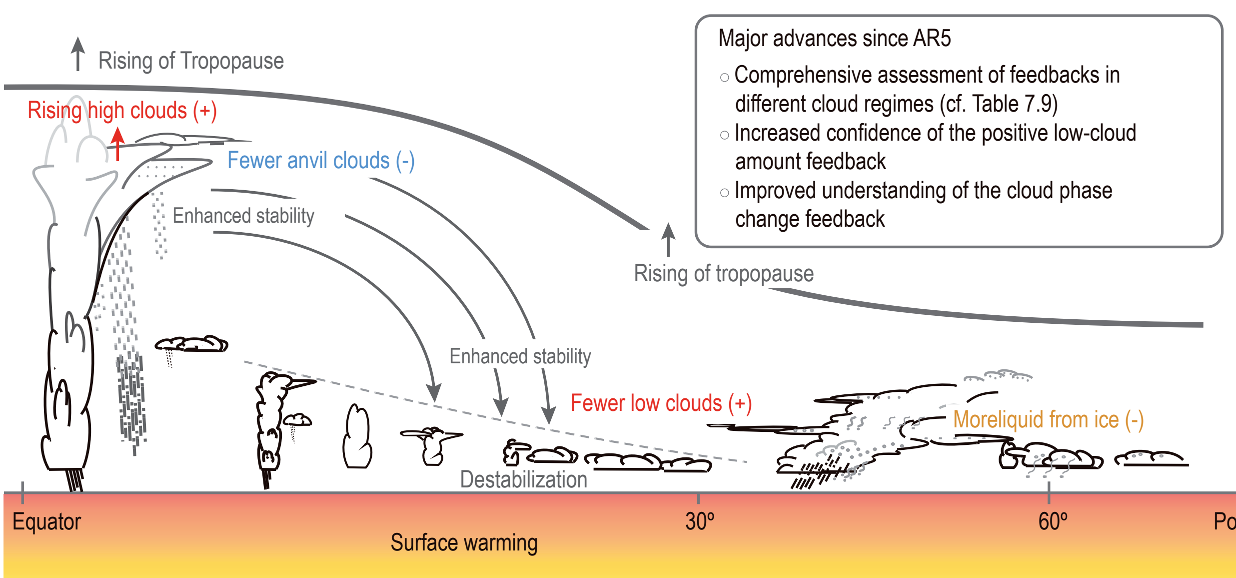


Figure 7.9 | Schematic cross section of diverse cloud responses to surface warming from the tropics to polar regions. Thick solid and dashed curves indicate the tropopause and the subtropical inversion layer in the current climate, respectively. Thin grey text and arrows represent robust responses in the thermodynamic structure to greenhouse warming, of relevance to cloud changes. Text and arrows in red, orange and green show the major cloud responses assessed with *high*, *medium* and *low confidence*, respectively, and the sign of their feedbacks to the surface warming is indicated in the parenthesis. Major advances since AR5 are listed in the box. Figure adapted from Boucher et al. (2013).

(see Section 7.2.1). In the present climate, the SW CRE tends to be compensated by the LW CRE over the equatorial warm pool, leading to the net CRE pattern showing large negative values over the eastern part of the subtropical ocean and the extratropical ocean due to the dominant influence of highly reflective marine low-clouds.

In a first attempt to systematically evaluate equilibrium climate sensitivity (ECS) based on fully coupled general circulation models (GCMs) in AR4, diverging cloud feedbacks were recognized as a dominant source of uncertainty. An advance in understanding the cloud feedback was to assess feedbacks separately for different cloud regimes (Gettelman and Sherwood, 2016). A thorough assessment of cloud feedbacks in different cloud regimes was carried out in AR5 (Boucher et al., 2013), which assigned *high* or *medium confidence* for some cloud feedbacks but *low* or *no confidence* for others (Table 7.9). Many studies that estimate the net cloud feedback using CMIP5 simulations (Vial et al., 2013; Caldwell et al., 2016; Zelinka et al., 2016; Colman and Hanson, 2017) show different values depending on the methodology and the set of models used, but often report a large inter-model spread of the feedback, with the 90% confidence interval spanning both weak negative and strong positive net feedbacks. Part of this diversity arises from the dependence of the model cloud feedbacks on the parametrization of clouds and their coupling to other sub-grid-scale processes (Zhao et al., 2015).

Since AR5, community efforts have been undertaken to understand and quantify the cloud feedbacks in various cloud regimes coupled with large-scale atmospheric circulation (Bony et al., 2015). For some cloud regimes, alternative tools to ESMs, such as observations, theory, high-resolution cloud resolving models (CRMs), and large eddy simulations (LES), help quantify the feedbacks. Consequently, the net cloud feedback derived from ESMs has been revised by assessing the regional cloud feedbacks separately and summing them with weighting by the ratio of fractional coverage of those clouds over the globe to give the global feedback, following an approach adopted in Sherwood et al. (2020). This 'bottom-up' assessment is explained below with a summary of updated confidence of individual cloud feedback components (Table 7.9). Dependence of cloud feedbacks on evolving patterns of surface warming will be discussed in Section 7.4.4 and is not explicitly taken into account in the assessment presented in this section.

7.4.2.4.2 Assessment for individual cloud regimes

High-cloud altitude feedback

It has long been argued that cloud-top altitude rises under global warming, concurrent with the rising of the tropopause at all latitudes (Marvel et al., 2015; Thompson et al., 2017). This increasing altitude of high-clouds was identified in early generation GCMs and the tropical high-cloud altitude feedback was assessed to be positive with *high confidence* in AR5 (Boucher et al., 2013). This assessment is supported by a theoretical argument called the 'fixed anvil temperature mechanism', which ensures that the temperature of the convective detrainment layer does not change when the altitude of high-cloud tops increases with the rising tropopause (Hartmann and Larson, 2002). Because the cloud-top temperature does not change significantly with global warming, cloud LW emission does not increase even though the surface warms, resulting in an enhancement of the high-cloud greenhouse effect (a positive feedback; Yoshimori et al. (2020)). The upward shift of high-clouds with surface warming is detected in observed interannual variability and trends in satellite records for recent decades (Chepfer et al., 2014; Norris et al., 2016; Saint-Lu et al., 2020). The observational detection is not always successful (Davies et al., 2017), but the cloud altitude shifts similarly in many CRM experiments (Khairoutdinov and Emanuel, 2013; Tsushima et al., 2014; Narenpitak et al., 2017). The high-cloud altitude feedback was estimated to be 0.5 W m^{-2} °C^{-1} based on GCMs in AR5, but is revised, using a recent re-evaluation that excludes aliasing effects by reduced low-cloud amounts, downward to 0.22 ± 0.12 W m^{-2} °C^{-1} (one standard deviation; Zhou et al., 2014; Zelinka et al., 2020). In conclusion, there is *high confidence* in the positive high-cloud altitude feedback simulated in ESMs as it is supported by theoretical, observational, and process modelling studies.

Tropical high-cloud amount feedback

Updrafts in convective plumes lead to detrainment of moisture at a level where the buoyancy diminishes, and thus deep convective clouds over high SSTs in the tropics are accompanied by anvil and cirrus clouds in the upper troposphere. These clouds, rather than the convective plumes themselves, play a substantial role in the global TOA radiation budget. In the present climate, the net CRE of these clouds is small due to a cancellation between the SW and LW components (Hartmann et al., 2001). However, high-clouds with different optical properties could respond to surface warming differently, potentially perturbing this radiative balance and therefore leading to a non-zero feedback.

A thermodynamic mechanism referred to as the 'stability iris effect' has been proposed to explain that the anvil cloud amount decreases with surface warming (Bony et al., 2016). In this mechanism, a temperature-mediated increase of static stability in the upper troposphere, where convective detrainment occurs, acts to balance a weakened mass outflow from convective clouds, and thereby reduce anvil cloud areal coverage (Figure 7.9). The reduction of anvil cloud amount is accompanied by enhanced convective aggregation that causes a drying of the surrounding air and thereby increases the LW emission to space that acts as a negative feedback (Bony et al., 2020). This phenomenon is found in many CRM simulations (Emanuel et al., 2014; Wing and Emanuel, 2014; Wing et al., 2020) and also identified in observed interannual variability (Stein et al., 2017; Saint-Lu et al., 2020).

Despite the reduction of anvil cloud amount supported by several lines of evidence, estimates of radiative feedback due to high-cloud amount changes is highly uncertain in models. The assessment presented here is guided by combined analyses of TOA radiation and cloud fluctuations at interannual time scale using multiple satellite datasets. The observationally based local cloud amount feedback associated with optically thick high-clouds is negative, leading to its global contribution (by multiplying the mean tropical anvil cloud fraction of about 8%) of –0.24 ± 0.05 W m^{-2} °C^{-1} (one standard deviation) for LW (Vaillant de Guélis et al., 2018). Also, there is a positive feedback due to increase of optically thin cirrus clouds in the tropopause layer, estimated to be 0.09 ± 0.09 W m^{-2} °C^{-1}

7

(one standard deviation; Zhou et al., 2014). The negative LW feedback due to reduced amount of thick high-clouds is partly compensated by the positive SW feedback (due to less reflection of solar radiation), so that the tropical high-cloud amount feedback is assessed to be equal to or smaller than their sum. Consistently, the net high-cloud feedback in the tropical convective regime, including a part of the altitude feedback, is estimated to have the global contribution of -0.13 ± 0.06 W m^{-2} °C^{-1} (one standard deviation; Williams and Pierrehumbert, 2017). The negative cloud LW feedback is considerably biased in CMIP5 GCMs (Mauritsen and Stevens, 2015; Su et al., 2017; Li et al., 2019) and highly uncertain, primarily due to differences in the convective parametrization (Webb et al., 2015). Furthermore, high-resolution CRM simulations cannot alone be used to constrain uncertainty because the results depend on parametrized cloud microphysics and turbulence (Bretherton et al., 2014; Ohno et al., 2019). Therefore, the tropical high-cloud amount feedback is assessed as negative but with *low confidence* given the lack of modelling evidence. Taking observational estimates altogether and methodological uncertainty into account, the global contribution of the high-cloud amount feedback is assessed to be -0.15 ± 0.2 W m^{-2} °C^{-1} (one standard deviation).

Subtropical marine low-cloud feedback

It has long been argued that the response of marine boundary-layer clouds over the subtropical ocean to surface warming was the largest contributor to the spread among GCMs in the net cloud feedback (Boucher et al., 2013). However, uncertainty of the marine low-cloud feedback has been reduced considerably since AR5 through combined knowledge from theoretical, modelling and observational studies (Klein et al., 2017). Processes that control the low-clouds are complex and involve coupling with atmospheric motions on multiple scales, from the boundary-layer turbulence to the large-scale subsidence, which may be represented by a combination of shallow and deep convective mixing (Sherwood et al., 2014).

In order to disentangle the large-scale processes that cause the cloud amount either to increase or decrease in response to the surface warming, the cloud feedback has been expressed in terms of several 'cloud controlling factors' (Qu et al., 2014, 2015; Zhai et al., 2015; Brient and Schneider, 2016; Myers and Norris, 2016; McCoy et al., 2017a). The advantage of this approach over conventional calculation of cloud feedbacks is that the temperature-mediated cloud response can be estimated without using information of the simulated cloud responses that are less well-constrained than the changes in the environmental conditions. Two dominant factors are identified for the subtropical low-clouds: a thermodynamic effect due to rising SST that acts to reduce low-cloud by enhancing cloud-top entrainment of dry air, and a stability effect accompanied by an enhanced inversion strength that acts to increase low-cloud (Qu et al., 2014, 2015; Kawai et al., 2017). These controlling factors compensate with a varying degree in different ESMs, but can be constrained by referring to the observed seasonal or interannual relationship between the low-cloud amount and the controlling factors in the environment as a surrogate. The analysis leads to a positive local feedback that has the global contribution of 0.14 to 0.36 W m^{-2} °C^{-1} (Klein et al., 2017), to which the feedback in the stratocumulus regime dominates over the feedback in the trade cumulus regime (Cesana et al., 2019; Radtke et al., 2021). The stratocumulus feedback may be underestimated because explicit simulations using LES show a larger local feedback of up to 2.5 W m^{-2} °C^{-1}, corresponding to the global contribution of 0.2 W m^{-2} °C^{-1} by multiplying the mean tropical stratocumulus fraction of about 8% (Bretherton, 2015). Supported by different lines of evidence, the subtropical marine low-cloud feedback is assessed as positive with *high confidence*. Based on the combined estimate using LESs and the cloud controlling factor analysis, the global contribution of the feedback due to marine low-clouds equatorward of 30° is assessed to be 0.2 ± 0.16 W m^{-2} °C^{-1} (one standard deviation), for which the range reflects methodological uncertainties.

Land cloud feedback

Intensification of the global hydrological cycle is a robust feature of global warming, but at the same time, many land areas in the subtropics will experience drying at the surface and in the atmosphere (Section 8.2.2). This occurs due to limited water availability in these regions, where the cloudiness is consequently expected to decrease. Reduction in clouds over land is consistently identified in the CMIP5 models and also in a GCM with explicit convection (Bretherton et al., 2014; Kamae et al., 2016a). Because low-clouds make up the majority of subtropical land clouds, this reduced amount of low-clouds reflects less solar radiation and leads to a positive feedback similar to the marine low-clouds. The mean estimate of the global land cloud feedback in CMIP5 models is smaller than the marine low-cloud feedback, 0.08 ± 0.08 W m^{-2} °C^{-1} (Zelinka et al., 2016). These values are nearly unchanged in CMIP6 (Zelinka et al., 2020). However, ESMs still have considerable biases in the climatological temperature and cloud fraction over land, and the magnitude of this feedback has not yet been supported by observational evidence. Therefore, the feedback due to decreasing land clouds is assessed to be 0.08 ± 0.08 W m^{-2} °C^{-1} (one standard deviation) with *low confidence*.

Mid-latitude cloud amount feedback

Poleward shifts in the mid-latitude jets are evident since the 1980s (Section 2.3.1.4.3) and are a feature of the large-scale circulation change in future projections (Section 4.5.1.6). Because mid-latitude clouds over the North Pacific, North Atlantic and Southern Ocean are induced mainly by extratropical cyclones in the storm tracks along the jets, it has been suggested that the jet shifts should be accompanied by poleward shifts in the mid-latitude clouds, which would result in a positive feedback through the reduced reflection of insolation (Boucher et al., 2013). However, studies since AR5 have revealed that this proposed mechanism does not apply in practice (Ceppi and Hartmann, 2015). While a poleward shift of mid-latitude cloud maxima in the free troposphere has been identified in satellite and ground-based observations (Bender et al., 2012; Eastman and Warren, 2013), associated changes in net CRE are small because the responses in high and low-clouds to the jet shift act to cancel each other (Grise and Medeiros, 2016; Tselioudis et al., 2016; Zelinka et al., 2018). This cancellation is not well captured in ESMs (Lipat et al., 2017), but the above findings show that the mid-latitude cloud feedback is not dynamically driven by the poleward jet shifts, which are rather suggested to occur partly in response to changes in high clouds (Y. Li et al., 2018).

Thermodynamics play an important role in controlling extratropical cloud amount equatorward of about 50° latitude. Recent studies showed, using observed cloud controlling factors, that the mid-latitude low-cloud fractions decrease with rising SST, which also acts to weaken stability of the atmosphere unlike in the subtropics (McCoy et al., 2017a). ESMs consistently show a decrease of cloud amounts and a resultant positive SW feedback in the 30°–40° latitude bands, which can be constrained using observations of seasonal migration of cloud amount (Zhai et al., 2015). Based on the qualitative agreement between observations and ESMs, the mid-latitude cloud amount feedback is assessed as positive with *medium confidence.* Following these emergent constraint studies using observations and CMIP5/6 models, the global contribution of net cloud amount feedback over 30°–60° ocean areas, covering 27% of the globe, is assessed at 0.09 ± 0.1 W m^{-2} °C^{-1} (one standard deviation), in which the uncertainty reflects potential errors in models' low-cloud response to changes in thermodynamic conditions.

Extratropical cloud optical depth feedback

Mixed-phase clouds that consist of both liquid and ice are dominant over the Southern Ocean (50°S–80°S), which accounts for 20% of the net CRE in the present climate (Matus and L'Ecuyer, 2017). It has been argued that the cloud optical depth (opacity) will increase over the Southern Ocean as warming drives the replacement of ice-dominated clouds with liquid-dominated clouds (Tan et al., 2019). Liquid clouds generally consist of many small cloud droplets, while the crystals in ice clouds are orders of magnitude fewer in number and much larger, causing the liquid clouds to be optically thicker and thereby resulting in a negative feedback (Boucher et al., 2013). However, this phase-change feedback works effectively only below freezing temperature (Lohmann and Neubauer, 2018; Terai et al., 2019) and other processes that increase or decrease liquid water path (LWP) may also affect the optical depth feedback (McCoy et al., 2019).

Due to insufficient amounts of super-cooled liquid water in the simulated atmospheric mean state, many CMIP5 models overestimated the conversion from ice to liquid clouds with climate warming and the resultant negative phase-change feedback (Kay et al., 2016a; Tan et al., 2016; Lohmann and Neubauer, 2018). This feedback can be constrained using satellite-derived LWP observations over the past 20 years that enable estimates of both long-term trends and the interannual relationship with SST variability (Gordon and Klein, 2014; Ceppi et al., 2016; Manaster et al., 2017). The observationally-constrained SW feedback ranges from –0.91 to –0.46 W m^{-2} °C^{-1} over 40°S–70°S depending on the methodology (Ceppi et al., 2016; Terai et al., 2016). In some CMIP6 models, representation of super-cooled liquid water content has been improved, leading to weaker negative optical depth feedback over the Southern Ocean closer to observational estimates (Bodas-Salcedo et al., 2019; Gettelman et al., 2019). This improvement at the same time results in a positive optical depth feedback over other extratropical ocean where LWP decreased in response to reduced stability in those CMIP6 models (Zelinka et al., 2020). Given the accumulated observational estimates and an improved agreement between ESMs and observations, the extratropical optical depth feedback is assessed to be small negative with *medium confidence.* Quantitatively, the global contribution of this feedback is assessed to have a value of –0.03 ± 0.05 W m^{-2} °C^{-1} (one standard deviation) by combining estimates based on observed interannual variability and the cloud controlling factors.

Arctic cloud feedback

Clouds in polar regions, especially over the Arctic, form at low altitude above or within a stable to neutral boundary layer and are known to co-vary with sea ice variability beneath. Because the clouds reflect sunlight during summer but trap LW radiation throughout the year, seasonality plays an important role in cloud effects on Arctic climate (Kay et al., 2016b). AR5 assessed that Arctic low-cloud amount will increase in boreal autumn and winter in response to declining sea ice in a warming climate, due primarily to an enhanced upward moisture flux over open water. The cloudier conditions during these seasons result in more downwelling LW radiation, acting as a positive feedback on surface warming (Kay and Gettelman, 2009). Over recent years, further evidence of the cloud contribution to the Arctic amplification has been obtained (Section 7.4.4.1; Goosse et al., 2018). Space-borne lidar (light detection and ranging) observations show that the cloud response to summer sea ice loss is small and cannot overcome the cloud effect in autumn (Taylor et al., 2015; Morrison et al., 2019). The seasonality of the cloud response to sea ice variability is reproduced in GCM simulations (Laîné et al., 2016; Yoshimori et al., 2017). The agreement between observations and models indicates that the Arctic cloud feedback is positive at the surface. This leads to an Arctic cloud feedback at TOA that is *likely* positive, but very small in magnitude, as found in some climate models (Pithan and Mauritsen, 2014; Morrison et al., 2019). The observational estimates are sensitive to the analysis period and the choice of reanalysis data, and a recent estimate of the TOA cloud feedback over 60°N–90°N using atmospheric reanalysis data and CERES satellite observations suggests a regional value ranging from –0.3 to +0.5 W m^{-2} °C^{-1}, which corresponds to a global contribution of –0.02 to +0.03 W m^{-2} °C^{-1} (R. Zhang et al., 2018). Based on the overall agreement between ESMs and observations, the Arctic cloud feedback is assessed to be small positive and has the value of 0.01 ± 0.05 W m^{-2} °C^{-1} (one standard deviation). The assessed range indicates that a negative feedback is almost as probable as a positive feedback, and the assessment that the Arctic cloud feedback is positive is therefore given *low confidence*.

7.4.2.4.3 Synthesis for the net cloud feedback

The understanding of the response of clouds to warming and associated radiative feedback has deepened since AR5 (Figure 7.9 and FAQ 7.2). Particular progress has been made in the assessment of the marine low-cloud feedback, which has historically been a major contributor to the cloud feedback uncertainty but is no longer the largest source of uncertainty. Multiple lines of evidence (theory, observations, emergent constraints and process modelling) are now available in addition to ESM simulations, and the positive low-cloud feedback is consequently assessed with *high confidence*.

The best estimate of net cloud feedback is obtained by summing feedbacks associated with individual cloud regimes and assessed to be α_C = 0.42 W m^{-2} °C^{-1}. By assuming that the uncertainties of individual cloud feedbacks are independent of each other, their standard deviations are added in quadrature, leading to the *likely* range of 0.12 to 0.72 W m^{-2} °C^{-1} and the *very likely* range

Table 7.9 | Assessed sign and confidence level of cloud feedbacks in different regimes in AR5 and AR6. For some cloud regimes, the feedback was not assessed in AR5, indicated by N/A.

Feedback	AR5	AR6
High-cloud altitude feedback	Positive (*high confidence*)	Positive (*high confidence*)
Tropical high-cloud amount feedback	N/A	Negative (*low confidence*)
Subtropical marine low-cloud feedback	N/A (*low confidence*)	Positive (*high confidence*)
Land cloud feedback	N/A	Positive (*low confidence*)
Mid-latitude cloud amount feedback	Positive (*medium confidence*)	Positive (*medium confidence*)
Extratropical cloud optical depth feedback	N/A	Small negative (*medium confidence*)
Arctic cloud feedback	Small positive (*very low confidence*)	Small positive (*low confidence*)
Net cloud feedback	Positive (*medium confidence*)	Positive (*high confidence*)

of –0.10 to +0.94 W m^{-2} °C^{-1} (Table 7.10). This approach potentially misses feedbacks from cloud regimes that are not assessed, but almost all the major cloud regimes were taken into consideration (Gettelman and Sherwood, 2016) and therefore additional uncertainty will be small. This argument is also supported by an agreement between the net cloud feedback assessed here and the net cloud feedback directly estimated using observations. The observational estimate, which is sensitive to the period considered and is based on two atmospheric reanalyses (ERA-Interim and MERRA) and TOA radiation budgets derived from the CERES satellite observations for the years 2000–2010, is 0.54 ± 0.7 W m^{-2} °C^{-1} (one standard deviation; Dessler, 2013). The observational estimate overlaps with the assessed range of the net cloud feedback. The assessed *very likely* range is reduced by about 50% compared to AR5, but is still wide compared to those of other climate feedbacks (Table 7.10). The largest contribution to this uncertainty range is the estimate of tropical high-cloud amount feedback which is not yet well quantified using models.

In reality, different types of cloud feedback may occur simultaneously in one cloud regime. For example, an upward shift of high-clouds associated with the altitude feedback could be coupled to an increase/decrease of cirrus/anvil cloud fractions associated with the cloud amount feedback. Alternatively, slowdown of the tropical circulation with surface warming (Section 4.5.3 and Figure 7.9) could affect both high and low-clouds so that their feedbacks are co-dependent. Quantitative assessments of such covariances require further knowledge about cloud feedback mechanisms, which will further narrow the uncertainty range.

In summary, deepened understanding of feedback processes in individual cloud regimes since AR5 leads to an assessment of the positive net cloud feedback with *high confidence*. A small probability (less than 10%) of a net negative cloud feedback cannot be ruled out, but this would require an extremely large negative feedback due to decreases in the amount of tropical anvil clouds or increases in optical depth of extratropical clouds over the Southern Ocean; neither is supported by current evidence.

7.4.2.5 Biogeophysical and Non-CO_2 Biogeochemical Feedbacks

The feedbacks presented in the previous sections (Sections 7.4.2.1–7.4.2.4) are directly linked to physical climate variables (for example temperature, water vapour, clouds, or sea ice). The central role of climate feedbacks associated with these variables has been recognized since early studies of climate change. However, in addition to these physical climate feedbacks, the Earth system includes feedbacks for which the effect of global mean surface temperature change on the TOA energy budget is mediated through other mechanisms, such as the chemical composition of the atmosphere, or by vegetation changes. Among these additional feedbacks, the most important is the CO_2 feedback that describes how a change of the global surface temperature affects the atmospheric CO_2 concentration. In ESM simulations in which CO_2 emissions are prescribed, changes in surface carbon fluxes affect the CO_2 concentration in the atmosphere, the TOA radiative energy budget, and eventually the global mean surface temperature. In ESM simulations in which the CO_2 concentration is prescribed, changes in the carbon cycle allow compatible CO_2 emissions to be calculated, that is, the CO_2 emissions that are compatible with both the prescribed CO_2 concentration and the representation of the carbon cycle in the ESM. The CO_2 feedback is assessed in Chapter 5 (Section 5.4). The framework presented in this chapter assumes that the CO_2 concentration is prescribed, and our assessment of the net feedback parameter, α, does not include carbon cycle feedbacks on the atmospheric CO_2 concentration (Section 7.1 and Box 7.1). However, our assessment of α does include non-CO_2 biogeochemical feedbacks (including effects due to changes in atmospheric methane concentration; Section 7.4.2.5.1) and biogeophysical feedbacks (Section 7.4.2.5.2). A synthesis of the combination of biogeophysical and non-CO_2 biogeochemical feedbacks is given in Section 7.4.2.5.3.

7.4.2.5.1 Non-CO_2 biogeochemical feedbacks

The chemical composition of the atmosphere (beyond CO_2 and water vapour changes) is expected to change in response to a warming climate. These changes in greenhouse gases (methane, nitrous oxide and ozone) and aerosol amount (including dust) have the potential to alter the TOA energy budget and are collectively referred to as 'non-CO_2 biogeochemical feedbacks'. Methane (CH_4) and nitrous oxide (N_2O) feedbacks arise partly from changes in their emissions from natural sources in response to temperature change; these are assessed in Chapter 5 (Section 5.4.7; see also Figure 5.29c). Here we exclude the permafrost CH_4 feedback (Section 5.4.9.1.2) because, although associated emissions are projected to increase under warming on multi-decadal to centennial time scales, on longer time scales these emissions would eventually substantially decline as the permafrost carbon pools were depleted (Schneider von Deimling et al., 2012, 2015). This leaves the wetland CH_4, land N_2O, and ocean N_2O feedbacks, the assessed mean values of which sum to a positive feedback parameter of +0.04 [0.02 to 0.06] W m^{-2} °C^{-1} (Section 5.4.7). Other non-CO_2 biogeochemical feedbacks that are relevant to the net feedback parameter are assessed in Chapter 6 (Section 6.4.5 and Table 6.8). These feedbacks are associated with sea salt, dimethyl sulphide, dust, ozone, biogenic volatile organic compounds, lightning, and CH_4 lifetime, and sum to a negative feedback parameter of –0.20 [–0.41 to +0.01] W m^{-2} °C^{-1}. The overall feedback parameter for non-CO_2 biogeochemical feedbacks is obtained by summing the Chapter 5 and Chapter 6 assessments, which gives –0.16 [–0.37 to +0.05] W m^{-2} °C^{-1}. However, there is *low confidence* in the estimates of both the individual non-CO_2 biogeochemical feedbacks as well as their total effect, as evident from the large range in the magnitudes of α from different studies, which can be attributed to diversity in how models account for these feedbacks and limited process-level understanding.

7.4.2.5.2 Biogeophysical feedbacks

Biogeophysical feedbacks are associated with changes in the spatial distribution and/or biophysical properties of vegetation, induced by surface temperature change and attendant hydrological cycle change. These vegetation changes can alter radiative fluxes directly via albedo changes, or via surface momentum or moisture flux changes and hence changes in cloud properties. However, the direct physiological response of vegetation to changes in CO_2, including changes in stomatal conductance, is considered part of the CO_2 effective radiative forcing rather than a feedback (Section 7.3.2.1). The time scale on which vegetation responds to climate change is relatively uncertain but can be from decades to hundreds of years (Willeit et al., 2014), and could occur abruptly or as a tipping point (Sections 5.4.9.1.1, 8.6.2.1 and 8.6.2.2); equilibrium only occurs when the soil system and associated nutrient and carbon pools equilibrate, which can take millennia (Brantley, 2008; Sitch et al., 2008). The overall effects of climate-induced vegetation changes may be comparable in magnitude to those from anthropogenic land-use and land-cover change (Davies-Barnard et al., 2015). Climate models that include a dynamical representation of vegetation (e.g., Reick et al., 2013; Harper et al., 2018) are used to explore the importance of biogeophysical feedbacks (Notaro et al., 2007; Brovkin et al., 2009; O'ishi et al., 2009; Port et al., 2012; Willeit et al., 2014; Alo and Anagnostou, 2017; W. Zhang et al., 2018; Armstrong et al., 2019). In AR5, it was discussed that such model experiments predicted that expansion of vegetation in the high latitudes of the Northern Hemisphere would enhance warming due to the associated surface-albedo change, and that reduction of tropical forests in response to climate change would lead to regional surface warming, due to reduced evapotranspiration (M. Collins et al., 2013), but there was no assessment of the associated feedback parameter. The SRCCL stated that regional climate change can be dampened or enhanced by changes in local land cover, but that this depends on the location and the season; however, in general the focus was on anthropogenic land-cover change, and no assessment of the biogeophysical feedback parameter was carried out. There are also indications of a marine biogeophysical feedback associated with surface-albedo change due to changes in phytoplankton (Frouin and Iacobellis, 2002; Park et al., 2015), but there is not currently enough evidence to quantitatively assess this feedback.

Since AR5, several studies have confirmed that a shift from tundra to boreal forests and the associated albedo change leads to increased warming in Northern Hemisphere high latitudes (*high confidence*) (Willeit et al., 2014; W. Zhang et al., 2018; Armstrong et al., 2019). However, regional modelling indicates that vegetation feedbacks may act to cool climate in the Mediterranean (Alo and Anagnostou, 2017), and in the tropics and subtropics the regional response is in general not consistent across models. On a global scale, several modelling studies have either carried out a feedback analysis (Stocker et al., 2013; Willeit et al., 2014) or presented simulations that allow a feedback parameter to be estimated (O'ishi et al., 2009; Armstrong et al., 2019), in such a way that the physiological response can be accounted for as a forcing rather than a feedback. The central estimates of the biogeophysical feedback parameter from these studies range from close to zero (Willeit et al., 2014) to +0.13 W m^{-2} °C^{-1} (Stocker et al., 2013). An additional line of evidence comes from the mid-Pliocene warm period (MPWP, Chapter 2, Cross-Chapter Box 2.1), for which paleoclimate proxies provide evidence of vegetation distribution and CO_2 concentrations. Model simulations that include various combinations of modern versus MPWP vegetation and CO_2 allow an associated feedback parameter to be estimated, as long as account is also taken of the orographic forcing (Lunt et al., 2010, 2012b). This approach has the advantage over pure modelling studies in that the reconstructed vegetation is based on (paleoclimate) observations, and is in equilibrium with the CO_2 forcing. However, there are uncertainties in the vegetation reconstruction in regions with little or no proxy data, and it is uncertain how much of the vegetation change is associated with the physiological response to CO_2. This paleoclimate approach gives an estimate for the biogeophysical feedback parameter of +0.3 W m^{-2} °C^{-1}.

Given the limited number of studies, we take the full range of estimates discussed above for the biogeophysical feedback parameter, and assess the *very likely* range to be from 0.0 to +0.3 W m^{-2} °C^{-1}, with a central estimate of +0.15 W m^{-2} °C^{-1} (*low confidence*). Although this assessment is based on evidence from both models and paleoclimate proxies, and the studies above agree on the sign of the change, there is nonetheless *limited evidence*. Higher confidence could be obtained if there were more studies that allowed calculation of a biogeophysical feedback parameter (particularly from paleoclimates), and if the partitioning between biogeophysical feedbacks and physiological forcing were clearer for all lines of evidence.

7.4.2.5.3 Synthesis of biogeophysical and non-CO_2 biogeochemical feedbacks

The non-CO_2 biogeochemical feedbacks are assessed in Section 7.4.2.5.1 to be –0.16 [–0.37 to +0.05] W m^{-2} °C^{-1} and the biogeophysical feedbacks are assessed in Section 7.4.2.5.2 to be +0.15 [0.0 to +0.3] W m^{-2} °C^{-1}. The sum of the biogeophysical and non-CO_2 biogeochemical feedbacks is assessed to have a central value of –0.01 W m^{-2} °C^{-1} and a *very likely* range from

–0.27 to +0.25 W m^{-2} °C^{-1} (Table 7.10). Given the relatively long time scales associated with the biological processes that mediate the biogeophysical and many of the non-CO_2 biogeochemical feedbacks, in comparison with the relatively short time scale of many of the underlying model simulations, combined with the small number of studies for some of the feedbacks, and the relatively small signals, this overall assessment has *low confidence*.

Some supporting evidence for this overall assessment can be obtained from the CMIP6 ensemble, which provides some pairs of instantaneous 4×CO_2 simulations carried out using related models, with and without biogeophysical and non-CO_2 biogeochemical feedbacks. This is not a direct comparison because these pairs of simulations may differ by more than just their inclusion of these additional feedbacks; furthermore, not all biogeophysical and non-CO_2 biogeochemical feedbacks are fully represented. However, a comparison of the pairs of simulations does provide a first-order estimate of the magnitude of these additional feedbacks. Séférian et al. (2019) find a slightly more negative feedback parameter in CNRM-ESM2-1 (with additional feedbacks) then in CNRM-CM6-1 (a decrease of 0.02 W m^{-2} °C^{-1}, using the linear regression method from years 10–150). Andrews et al. (2019) also find a slightly more negative feedback parameter when these additional feedbacks are included (a decrease of 0.04 W m^{-2} °C^{-1} in UKESM1 compared with HadGEM3-GC3.1). Both of these studies suggest a small but slightly negative feedback parameter for the combination of biogeophysical and non-CO_2 biogeochemical feedbacks, but with relatively large uncertainty given (i) interannual variability and (ii) that feedbacks associated with natural terrestrial emissions of CH_4 and N_2O were not represented in either pair.

7.4.2.6 Long-Term Radiative Feedbacks Associated with Ice Sheets

Although long-term radiative feedbacks associated with ice sheets are not included in our definition of ECS (Box 7.1), the relevant feedback parameter is assessed here because the time scales on which these feedbacks act are relatively uncertain, and the long-term temperature response to CO_2 forcing of the entire Earth system may be of interest.

Earth's ice sheets (Greenland and Antarctica) are sensitive to climate change (Section 9.4; Pattyn et al., 2018). Their time evolution is determined by both their surface mass balance and ice dynamic processes, with the latter being particularly important for the West Antarctic Ice Sheet. Surface mass balance depends on the net energy and hydrological fluxes at their surface, and there are mechanisms of ice-sheet instability that depend on ocean temperatures and basal melt rates (Section 9.4.1.1). The presence of ice sheets affects Earth's radiative budget, hydrology, and atmospheric circulation due to their characteristic high albedo, low roughness length, and high altitude, and they influence ocean circulation through freshwater input from calving and melt (e.g., Fyke et al., 2018). Ice-sheet changes also modify surface albedo through the attendant change in sea level and therefore land area (Abe-Ouchi et al., 2015). The time scale for ice sheets to reach equilibrium is of the order of thousands of years (Clark et al., 2016). Due to the long time scales involved, it is a major challenge to run coupled climate–ice sheet models to equilibrium, and as a result, long-term simulations are often carried out with lower complexity models, and/or are asynchronously coupled.

In AR5, it was described that both the Greenland and Antarctic ice sheets would continue to lose mass in a warming world (M. Collins et al., 2013), with a continuation in sea level rise beyond the year 2500 assessed as *virtually certain*. However, there was *low confidence* in the associated radiative feedback mechanisms, and as such, there was no assessment of the magnitude of long-term radiative feedbacks associated with ice sheets. That assessment is consistent with SROCC, wherein it was stated that 'with limited published studies to draw from and no simulations run beyond 2100, firm conclusions regarding the net importance of atmospheric versus ocean melt feedbacks on the long-term future of Antarctica cannot be made.'

The magnitude of the radiative feedback associated with changes to ice sheets can be quantified by comparing the global mean long-term equilibrium temperature response to increased CO_2 concentrations in simulations that include interactive ice sheets with that of simulations that do not include the associated ice sheet–climate interactions (Swingedouw et al., 2008; Vizcaíno et al., 2010; Goelzer et al., 2011; Bronselaer et al., 2018; Golledge et al., 2019). These simulations indicate that on multi-centennial time scales, ice-sheet mass loss leads to freshwater fluxes that can modify ocean circulation (Swingedouw et al., 2008; Goelzer et al., 2011; Bronselaer et al., 2018; Golledge et al., 2019). This leads to reduced surface warming (by about 0.2°C in the global mean after 1000 years; Section 7.4.4.1.1; Goelzer et al., 2011), although other work suggests no net global temperature effect of ice-sheet mass loss (Vizcaíno et al., 2010). However, model simulations in which the Antarctic Ice Sheet is removed completely in a paleoclimate context indicate a positive global mean feedback on multi-millennial time scales due primarily to the surface-albedo change (Goldner et al., 2014a; Kennedy-Asser et al., 2019); in Chapter 9 (Section 9.6.3) it is assessed that such ice-free conditions could eventually occur given 7°C–13°C of warming. This net positive feedback from ice-sheet mass loss on long time scales is also supported by model simulations of the mid-Pliocene Warm Period (MPWP; Cross-chapter Box 2.1) in which the volume and area of the Greenland and West Antarctic ice sheets are reduced in model simulations in agreement with geological data (Chandan and Peltier, 2018), leading to surface warming. As such, overall, on multi-centennial time scales the feedback parameter associated with ice sheets is *likely* negative (*medium confidence*), but on multi-millennial time scales by the time the ice sheets reach equilibrium, the feedback parameter is *very likely* positive (*high confidence*) (Table 7.10). However, a relative lack of models carrying out simulations with and without interactive ice sheets over centennial to millennial time scales means that there is currently not enough evidence to quantify the magnitude of these feedbacks, or the time scales on which they act.

7.4.2.7 Synthesis

Table 7.10 summarizes the estimates and the assessment of the individual and the net feedbacks presented in the above sections. The uncertainty range of the net climate feedback was obtained by adding standard deviations of individual feedbacks in quadrature, assuming that they are independent and follow the Gaussian distribution. It is *virtually certain* that the net climate feedback is negative, primarily due to the Planck temperature response, indicating that climate acts to stabilize in response to radiative forcing imposed to the system. Supported by the level of confidence associated with the individual feedbacks, it is also *virtually certain* that the sum of the non-Planck feedbacks is positive. Based on Table 7.10 these climate feedbacks amplify the Planck temperature response by about 2.8 [1.9 to 5.9] times. Cloud feedback remains the largest contributor to uncertainty of the net feedback, but the uncertainty is reduced compared to AR5. A secondary contribution to the net feedback uncertainty is the biogeophysical and non-CO_2 biogeochemical feedbacks, which together are assessed to have a central value near zero and thus do not affect the central estimate of ECS. The net climate feedback is assessed to be –1.16 W m^{-2} °C^{-1}, *likely* from –1.54 to –0.78 W m^{-2} °C^{-1}, and *very likely* from –1.81 to –0.51 W m^{-2} °C^{-1}.

Feedback parameters in climate models are calculated assuming that they are independent of each other, except for a well-known co-dependency between the water vapour (WV) and lapse rate (LR) feedbacks. When the inter-model spread of the net climate feedback is computed by adding in quadrature the inter-model spread of individual feedbacks, it is 17% wider than the spread of the net climate feedback directly derived from the ensemble. This indicates that the feedbacks in climate models are partly co-dependent. Two possible co-dependencies have been suggested (Huybers, 2010; Caldwell et al., 2016). One is a negative covariance between the LR and longwave cloud feedbacks, which may be accompanied by a deepening of the troposphere (O'Gorman and Singh, 2013; Yoshimori et al., 2020) leading both to greater rising of high-clouds and a larger upper-tropospheric warming. The other is a negative covariance between albedo and shortwave cloud feedbacks, which may originate from the Arctic regions: a reduction in sea ice enhances the shortwave cloud radiative effect because the ocean surface is darker than sea ice (Gilgen et al., 2018). This covariance is reinforced as the decrease of sea ice leads to an increase in low-level clouds (Mauritsen et al., 2013). However, the mechanism causing these co-dependences between feedbacks is not well understood yet and a quantitative assessment based on multiple lines of evidence is difficult. Therefore, this synthesis assessment does not consider any co-dependency across individual feedbacks.

The assessment of the net climate feedback presented above is based on a single approach (i.e., process understanding) and directly results in a value for ECS given in Section 7.5.1; this is in contrast to the synthesis assessment of ECS in Section 7.5.5 which combines multiple approaches. The total (net) feedback parameter consistent with the final synthesis assessment of the ECS and Equation 7.1 (Box 7.1) is provided there.

7.4.2.8 Climate Feedbacks in ESMs

Since AR5, many modelling groups have newly participated in CMIP experiments, leading to an increase in the number of models in CMIP6 (Section 1.5.4). Other modelling groups that contributed to CMIP5 also updated their ESMs for carrying out CMIP6 experiments. While some of the CMIP6 models share components and are therefore not independent, they are analysed independently when calculating climate feedbacks. This, and more subtle forms of model inter-dependence, creates challenges when determining appropriate model weighting schemes (Section 1.5.4). Additionally, it must be kept in mind that the ensemble sizes of the CMIP5 and CMIP6 models are not sufficiently large to sample the full range of model uncertainty.

The multi-model mean values of all physical climate feedbacks are calculated using the radiative kernel method (Section 7.4.1) and compared with the assessment in the previous sections (Figure 7.10). For CMIP models, there is a discrepancy between the net climate feedback calculated directly using the time evolutions of ΔT and ΔN in each model and the accumulation of individual feedbacks, but it is negligibly small (Supplementary Material 7.SM.4). Feedbacks due to biogeophysical and non-CO_2 biogeochemical processes are included in some models but neglected in the kernel analysis. In AR6, biogeophysical and non-CO_2 biogeochemical feedbacks are explicitly assessed (Section 7.4.2.5).

All the physical climate feedbacks apart from clouds are very similar in the CMIP5 and CMIP6 model ensembles (see also Table 7.10). These values, where possible supported by other lines of evidence, are used for assessing feedbacks in Sections 7.4.2.1–7.4.2.3. A difference found between CMIP5 and CMIP6 models is the net cloud feedback,

Table 7.10 | Synthesis assessment of climate feedbacks (central estimate shown in bold). The mean values and their 90% ranges in CMIP5/6 models, derived using multiple radiative kernels (Zelinka et al., 2020) are also presented for comparison.

Feedback Parameter α_x (W m^{-2} °C^{-1})	CMIP5 GCMs	CMIP6 ESMs	AR6 Assessed Ranges			
	Mean and 5–95% Interval	Mean and 5–95% Interval	Central Estimate	*Very likely* Interval	*Likely* Interval	Level of Confidence
Planck	–3.20 [–3.3 to –3.1]	–3.22 [–3.3 to –3.1]	**–3.22**	–3.4 to –3.0	–3.3 to –3.1	*high*
WV+LR	1.24 [1.08 to 1.35]	1.25 [1.14 to 1.45]	**1.30**	1.1 to 1.5	1.2 to 1.4	*high*
Surface albedo	0.41 [0.25 to 0.56]	0.39 [0.26 to 0.53]	**0.35**	0.10 to 0.60	0.25 to 0.45	*medium*
Clouds	0.41 [–0.09 to 1.1]	0.49 [–0.08 to 1.1]	**0.42**	–0.10 to 0.94	0.12 to 0.72	*high*
Biogeophysical and non-CO_2 biogeochemical	Not evaluated	Not evaluated	**–0.01**	–0.27 to 0.25	–0.16 to 0.14	*low*
Residual of kernel estimates	0.06 [–0.17 to 0.29]	0.05 [–0.18 to 0.28]				
Net (i.e., relevant for ECS)	–1.08 [–1.61 to –0.68]	–1.03 [–1.54 to –0.62]	**–1.16**	–1.81 to –0.51	–1.54 to –0.78	*medium*
Long-term ice-sheet feedbacks (millennial scale)				>0.0		*high*

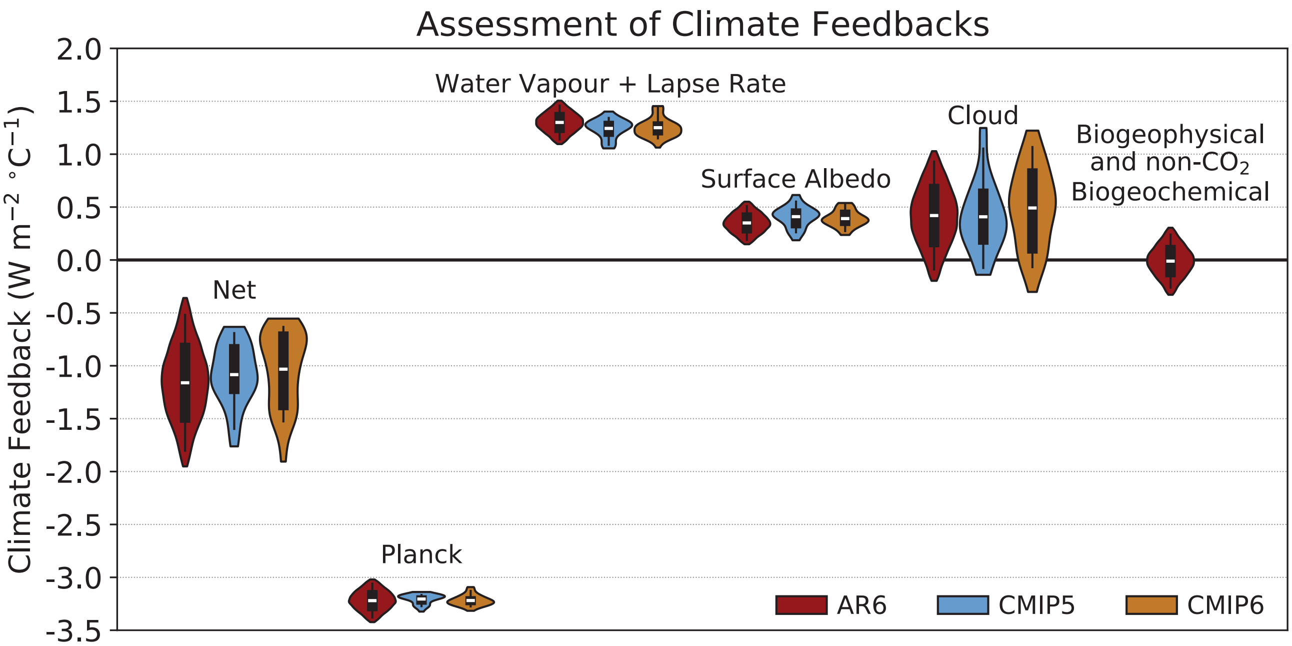


Figure 7.10 | Global mean climate feedbacks estimated in *abrupt4xCO2* simulations of 29 CMIP5 models (light blue) and 49 CMIP6 models (orange), compared with those assessed in this Report (red). Individual feedbacks for CMIP models are averaged across six radiative kernels as computed in Zelinka et al. (2020). The white line, black box and vertical line indicate the mean, 66% and 90% ranges, respectively. The shading represents the probability distribution across the full range of GCM/ESM values and for the 2.5–97.5 percentile range of the AR6 normal distribution. The unit is W m^{-2} °C^{-1}. Feedbacks associated with biogeophysical and non-CO_2 biogeochemical processes are assessed in AR6, but they are not explicitly estimated from general circulation models (GCMs)/Earth system models (ESMs) in CMIP5 and CMIP6. Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

which is larger in CMIP6 by about 20%. This change is the major cause of less-negative values of the net climate feedback in CMIP6 than in CMIP5 and hence an increase in modelled ECS (Section 7.5.1).

A remarkable improvement of cloud representation in some CMIP6 models is the reduced error of the too-weak negative shortwave CRE over the Southern Ocean (Bodas-Salcedo et al., 2019; Gettelman et al., 2019) due to a more realistic simulation of supercooled liquid droplets and associated cloud optical depths that were biased low commonly in CMIP5 models (McCoy et al., 2014a, b). Because the negative cloud optical depth feedback occurs due to 'brightening' of clouds via phase change from ice to liquid cloud particles in response to surface warming (Cesana and Storelvmo, 2017), the extratropical cloud shortwave feedback tends to be less negative or even slightly positive in models with reduced errors (Bjordal et al., 2020; Zelinka et al., 2020). The assessment of cloud feedbacks in Section 7.4.2.4 incorporates estimates from these improved ESMs. Yet, there still remain other shared model errors, such as in the subtropical low-clouds (Calisto et al., 2014) and tropical anvil clouds (Mauritsen and Stevens, 2015), hampering an assessment of feedbacks associated with these cloud regimes based only on ESMs (Section 7.4.2.4).

7.4.3 Dependence of Feedbacks on Climate Mean State

In the standard framework of forcings and feedbacks (Section 7.4.1 and Box 7.1), the approximation is made that the strength of climate feedbacks is independent of the background global mean surface temperature. More generally, the individual feedback parameters, α_x, are often assumed to be constant over a range of climate states, including those reconstructed from the past (encompassing a range of states warmer and colder than today, with varying continental geographies) or projected for the future. If this approximation holds, then the equilibrium global surface temperature response to a fixed radiative forcing will be constant, regardless of the climate state to which that forcing is applied.

This approximation will break down if climate feedbacks are not constant, but instead vary as a function of, for example, background temperature (Roe and Baker, 2007; Zaliapin and Ghil, 2010; Roe and Armour, 2011; Bloch-Johnson et al., 2015), continental configuration (Farnsworth et al., 2019), or configuration of ice sheets (Yoshimori et al., 2009). If the real climate system exhibits this state-dependence, then the future equilibrium temperature change in response to large forcing may be different from that inferred using the standard framework, and/or different to that inferred from paleoclimates. Such considerations are important for the assessment of ECS (Section 7.5). Climate models generally include representations of feedbacks that allow state-dependent behaviour, and so model results may also differ from the predictions from the standard framework.

In AR5 (Boucher et al., 2013), there was a recognition that climate feedbacks could be state-dependent (Colman and McAvaney, 2009), but modelling studies that explored this (e.g., Manabe and Bryan, 1985; Voss and Mikolajewicz, 2001; Stouffer and Manabe, 2003; Hansen et al., 2005b) were not assessed in detail. Also in AR5 (Masson-Delmotte et al., 2013), it was assessed that some models exhibited weaker sensitivity to Last Glacial Maximum (LGM; Cross-Chapter Box 2.1) forcing than to 4×CO_2 forcing, due to state-dependence in shortwave cloud feedbacks.

Here, recent evidence for state-dependence in feedbacks from modelling studies (Section 7.4.3.1) and from the paleoclimate record (Section 7.4.3.2) are assessed, with an overall assessment in Section 7.4.3.3. The focus is on temperature-dependence of feedbacks when the system is in equilibrium with the forcing; evidence for transient changes in the net feedback parameter associated with evolving spatial patterns of warming is assessed separately in Section 7.4.4.

7.4.3.1 State-dependence of Feedbacks in Models

There are several modelling studies since AR5 in which ESMs of varying complexity have been used to explore temperature dependence of feedbacks, either under modern (Hansen et al., 2013; Jonko et al., 2013; Meraner et al., 2013; Good et al., 2015; Duan et al., 2019; Mauritsen et al., 2019; Rohrschneider et al., 2019; Stolpe et al., 2019; Bloch-Johnson et al., 2020; Rugenstein et al., 2020) or paleo (Caballero and Huber, 2013; Zhu et al., 2019a) climate conditions, typically by carrying out multiple simulations across successive CO_2 doublings. A non-linear temperature response to these successive doublings may be partly due to forcing that increases more (or less) than expected from a purely logarithmic dependence (Section 7.3.2; Etminan et al., 2016), and partly due to state-dependence in feedbacks; however, not all modelling studies have partitioned the non-linearities in temperature response between these two effects. Nonetheless, there is general agreement among ESMs that the net feedback parameter, α, increases (i.e., becomes less negative) as temperature increases from pre-industrial levels (i.e., sensitivity to forcing increases as temperature increases; e.g., Meraner et al., 2013; see Figure 7.11). The associated increase in sensitivity to forcing is, in most models, due to the water vapour (Section 7.4.2.2) and cloud (Section 7.4.2.4) feedback parameters increasing with warming (Caballero and Huber, 2013; Meraner et al., 2013; Zhu et al., 2019a; Rugenstein et al., 2020; Sherwood et al., 2020). These changes are offset partially by the surface-albedo feedback parameter decreasing (Jonko et al., 2013; Meraner et al., 2013; Rugenstein et al., 2020), as a consequence of a reduced amount of snow and sea ice cover in a much warmer climate. At the same time, there is little change in the Planck response (Section 7.4.2.1), which has been shown in one model to be due to competing effects from increasing Planck emission at warmer temperatures and decreasing planetary emissivity due to increased CO_2 and water vapour (Mauritsen et al., 2019). Analysis of the spatial patterns of the non-linearities in temperature response (Good et al., 2015) suggests that these patterns are linked to a reduced weakening of the AMOC, and changes to evapotranspiration. The temperature dependence of α is also found in model simulations of high-CO_2 paleoclimates (Caballero and Huber, 2013; Zhu et al., 2019a). The temperature dependence is not only evident at very high CO_2 concentrations in excess of $4\times CO_2$, but also apparent in the difference in temperature response to a $2\times CO_2$ forcing compared with to a $4\times CO_2$ forcing (Mauritsen et al., 2019; Rugenstein et al., 2020), and as such is relevant for interpreting century-scale climate projections.

Despite the general agreement that α increases as temperature increases from pre-industrial levels (Figure 7.11), other modelling studies have found the opposite (Duan et al., 2019; Stolpe et al., 2019). Modelling studies exploring state-dependence in climates colder than today, including in cold paleoclimates such as the LGM, provide conflicting evidence of either decreased (Yoshimori et al., 2011) or increased (Kutzbach et al., 2013; Stolpe et al., 2019) temperature response per unit forcing during cold climates compared to the modern era.

In contrast to most ESMs, the majority of Earth system models of intermediate complexity (EMICs) do not exhibit state-dependence, or have a net feedback parameter that decreases with increasing temperature (Pfister and Stocker, 2017). This is unsurprising since EMICs usually do not include process-based representations of water-vapour and cloud feedbacks. Although this shows that care must be taken when interpreting results from current generation EMICs, Pfister and Stocker (2017) also suggest that non-linearities in feedbacks can take a long time to emerge in model simulations due to slow adjustment time scales associated with the ocean; longer simulations also allow better estimates of equilibrium warming (Bloch-Johnson et al., 2020). This implies that multi-century simulations (Rugenstein et al., 2020) could increase confidence in ESM studies examining state-dependence.

The possibility of more substantial changes in climate feedbacks, sometimes accompanied by hysteresis and/or irreversibility, has been suggested from some theoretical and modelling studies. It has been postulated that such changes could occur on a global scale and across relatively narrow temperature changes (Popp et al., 2016; von der Heydt and Ashwin, 2016; Steffen et al., 2018; Schneider et al., 2019; Ashwin and von der Heydt, 2020; Bjordal et al., 2020). However, the associated mechanisms are highly uncertain, and as such there is *low confidence* as to whether such behaviour exists at all, and in the temperature thresholds at which it might occur.

Overall, the modelling evidence indicates that there is *medium confidence* that the net feedback parameter, α, increases (i.e., becomes less negative) with increasing temperature (i.e., that sensitivity to forcing increases with increasing temperature), under global surface background temperatures at least up to 40°C (Meraner et al., 2013; Seeley and Jeevanjee, 2021), and *medium confidence* that this temperature dependence primarily derives from increases in the water-vapour and shortwave cloud feedbacks. This assessment is further supported by recent analysis of CMIP6 model simulations (Bloch-Johnson et al., 2020) in the framework of nonlinMIP (Good et al., 2016), which showed that out of 10 CMIP6 models, seven of them showed an increase of the net feedback parameter with temperature, primarily due to the water-vapour feedback.

7.4.3.2 State-dependence of Feedbacks in the Paleoclimate Proxy Record

Several studies have estimated ECS from observations of the glacial–interglacial cycles of the last approximately 2 million years, and found a state-dependence, with more-negative α (i.e., lower sensitivity to forcing) during colder periods of the cycles and less-negative α during warmer periods (von der Heydt et al., 2014; Köhler et al., 2015, 2017; Friedrich et al., 2016; Royer, 2016; Snyder, 2019); see summaries in Skinner (2012) and von der Heydt et al. (2016). However, the nature of the state-dependence derived from these observations is dependent on the assumed ice-sheet forcing

(Köhler et al., 2015; Stap et al., 2019), which is not well known, due to a relative lack of proxy indicators of ice-sheet extent and distribution prior to the LGM (Cross-Chapter Box 2.1). Furthermore, many of these glacial–interglacial studies estimate a very strong temperature-dependence of α (Figure 7.11) that is hard to reconcile with the other lines of evidence, including proxy estimates from warmer paleoclimates. However, if the analysis excludes time periods when the temperature and CO_2 data are not well correlated, which occurs in general at times when sea level is falling and obliquity is decreasing, the state-dependence reduces (Köhler et al., 2018). Despite these uncertainties, due to the agreement in the sign of the temperature-dependence from all these studies, there is *medium confidence* from the paleoclimate proxy record that the net feedback parameter, α, was less negative in the warm periods than in the cold periods of the glacial–interglacial cycles.

Paleoclimate proxy evidence from past high-CO_2 time periods much warmer than present (the early Eocene and Paleocene–Eocene Thermal Maximum, PETM; Cross-Chapter Box 2.1) show that the feedback parameter increases as temperature increases (Anagnostou et al., 2016, 2020; Shaffer et al., 2016). However, such temperature-dependence of feedbacks was not found in the warm Pliocene relative to the cooler Pleistocene (Martínez-Botí et al., 2015), although the temperature changes are relatively small at this time, making temperature-dependence challenging to detect given the uncertainties in reconstructing global mean temperature and forcing. Overall, the paleoclimate proxy record provides *medium confidence* that the net feedback parameter, α, was less negative in these past warm periods than in the present day.

7.4.3.3 Synthesis of State-dependence of Feedbacks from Modelling and Paleoclimate Records

Overall, independent lines of evidence from models (Section 7.4.3.1) and from the paleoclimate proxy record (Section 7.4.3.2) lead to *high confidence* that the net feedback parameter, α, increases (i.e., becomes less negative) as temperature increases; that is, that sensitivity to forcing increases as temperature increases (Figure 7.11). This temperature-dependence should be considered when estimating ECS from ESM simulations in which CO_2 is quadrupled (Section 7.5.5) or from paleoclimate observations from past time periods colder or warmer than today (Section 7.5.4). Although individual lines of evidence give only *medium confidence*, the overall high confidence comes from the multiple models that show the same sign of the temperature-dependence of α, the general agreement in evidence from the paleo proxy and modelling lines of evidence, and the agreement between proxy evidence from both cold and warm past climates. However, due to the large range in estimates of the magnitude of the temperature-dependence of α across studies (Figure 7.11), a quantitative assessment cannot currently be given, which provides a challenge for including this temperature-dependence in emulator-based future projections (Cross-Chapter Box 7.1). Greater confidence in the modelling lines of evidence could be obtained from simulations carried out for several hundreds of years (Rugenstein et al., 2020), substantially longer than in many studies, and from more models carrying out simulations at multiple CO_2 concentrations. Greater confidence in the paleoclimate lines of evidence would be obtained from stronger constraints on atmospheric CO_2 concentrations, ice-sheet forcing, and temperatures, during past warm climates.

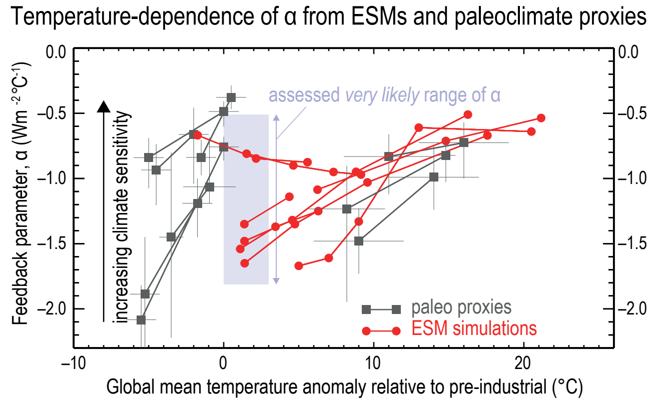


Figure 7.11 | Feedback parameter, α (W m^{-2} °C^{-1}), as a function of global mean surface air temperature anomaly relative to pre-industrial, for ESM simulations (red circles and lines) (Caballero and Huber, 2013; Jonko et al., 2013; Meraner et al., 2013; Good et al., 2015; Duan et al., 2019; Mauritsen et al., 2019; Stolpe et al., 2019; Zhu et al., 2019a), **and derived from paleoclimate proxies (grey squares and lines)** (von der Heydt et al., 2014; Anagnostou et al., 2016, 2020; Friedrich et al., 2016; Royer, 2016; Shaffer et al., 2016; Köhler et al., 2017; Snyder, 2019; Stap et al., 2019). For the ESM simulations, the value on the *x*-axis refers to the average of the temperature before and after the system has equilibrated to a forcing (in most cases a CO_2 doubling), and is expressed as an anomaly relative to an associated pre-industrial global mean temperature from that model. The light blue shaded square extends across the assessed range of α (Table 7.10) on the *y*-axis, and on the *x*-axis extends across the approximate temperature range over which the assessment of α is based (taken as from zero to the assessed central value of ECS; see Table 7.13). Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

7.4.4 Relationship Between Feedbacks and Temperature Patterns

The large-scale patterns of surface warming in observations since the 19th century (Section 2.3.1) and climate model simulations (Section 4.3.1 and Figure 7.12a) share several common features. In particular, surface warming in the Arctic is greater than for the global average and greater than in the Southern Hemisphere (SH) high latitudes; and surface warming is generally greater over land than over the ocean. Observations and climate model simulations also show some notable differences. ESMs generally simulate a weakening of the equatorial Pacific Ocean zonal (east–west) SST gradient on multi-decadal to centennial time scales, with greater warming in the east than the west, but this trend has not been seen in observations (Section 9.2.1 and Figure 2.11b).

Chapter 4 (Section 4.5.1) discusses patterns of surface warming for 21st-century climate projections under the Shared Socio-economic Pathways (SSP) scenarios. Chapter 9 (Section 9.2.1) assesses historical SST trends and the ability of coupled ESMs to replicate the observed changes. Chapter 4 (Section 4.5.1) discusses the processes that cause the land to warm more than the ocean (land–ocean warming contrast). This section assesses process understanding of the large-scale patterns of surface temperature response from the perspective of a regional energy budget. It then assesses evidence from the paleoclimate proxy record for patterns of surface warming during past time periods associated with changes in atmospheric CO_2 concentrations. Finally, it assesses how radiative feedbacks depend on the spatial pattern of surface temperature, and thus how they can change in magnitude as that pattern evolves over time, with implications for the assessment of ECS based on historical warming (Sections 7.4.4.3 and 7.5.2.1).

7.4.4.1 Polar Amplification

Polar amplification describes the phenomenon where surface temperature change at high latitudes exceeds the global average surface temperature change in response to radiative forcing of the climate system. Arctic amplification, often defined as the ratio of Arctic to global surface warming, is a ubiquitous emergent feature of climate model simulations (Section 4.5.1 and Figure 7.12a; Holland and Bitz, 2003; Pithan and Mauritsen, 2014) and is also seen in observations (Section 2.3.1). However, both climate models and observations show relatively less warming of the SH high latitudes compared to the Northern Hemisphere (NH) high latitudes over the historical record (Section 2.3.1), a characteristic that is projected to continue over the 21st century (Section 4.5.1). Since AR5 there is a much-improved understanding of the processes that drive polar amplification in the NH and delay its emergence in the SH (Section 7.4.4.1.1). Furthermore, the paleoclimate record provides evidence for polar amplification from multiple time periods associated with changes in CO_2 (Hollis et al., 2019; Cleator et al., 2020; McClymont et al., 2020; Tierney et al., 2020b), and allows an evaluation of polar amplification in model simulations of these periods (Section 7.4.4.1.2). Research since AR5 identifies changes in the degree of polar amplification over time, particularly in the SH, as a key factor affecting how radiative feedbacks may evolve in the future (Section 7.4.4.3).

7.4.4.1.1 Critical processes driving polar amplification

Several processes contribute to polar amplification under greenhouse gas forcing, including the loss of sea ice and snow (an amplifying surface-albedo feedback), the confinement of warming to near the surface in the polar atmosphere (an amplifying lapse-rate feedback), and increases in poleward atmospheric and oceanic heat transport (Pithan and Mauritsen, 2014; Goosse et al., 2018; Dai et al., 2019; Feldl et al., 2020). Modelling and process studies since AR5 have led to an improved understanding of the combined effect of these different processes in driving polar amplification and how they differ between the hemispheres.

Idealized modelling studies suggest that polar amplification would occur even in the absence of any amplifying polar surface-albedo or lapse-rate feedbacks owing to changes in poleward atmospheric heat transport under global warming (Hall, 2004; Alexeev et al., 2005; Graversen and Wang, 2009; Alexeev and Jackson, 2013; Graversen et al., 2014; Roe et al., 2015; Merlis and Henry, 2018; Armour et al., 2019). Poleward heat transport changes reflect compensating changes in the transport of latent energy (moisture) and dry-static energy (sum of sensible and potential energy) by atmospheric circulations (Alexeev et al., 2005; Held and Soden, 2006; Hwang and Frierson, 2010; Hwang et al., 2011; Kay et al., 2012; Huang and Zhang, 2014; Feldl et al., 2017a; Donohoe et al., 2020). ESMs project that within the mid-latitudes, where eddies dominate the heat transport, an increase in poleward latent energy transport arises from an increase in the equator-to-pole gradient in atmospheric moisture with global warming, with moisture in the tropics increasing more than at the poles as described by the Clausius–Clapeyron relation (Section 8.2). This change is partially compensated by a decrease in dry-static energy transport arising from a weakening of the equator-to-pole temperature gradient as the polar regions warm more than the tropics.

Energy balance models that approximate atmospheric heat transport in terms of a diffusive flux down the meridional gradient of near-surface moist static energy (sum of dry-static and latent energy) are able to reproduce the atmospheric heat transport changes seen within ESMs (Flannery, 1984; Hwang and Frierson, 2010; Hwang et al., 2011; Rose et al., 2014; Roe et al., 2015; Merlis and Henry, 2018), including the partitioning of latent and dry-static energy transports (Siler et al., 2018b; Armour et al., 2019). These models suggest that polar amplification is driven by enhanced poleward latent heat transport and that the magnitude of polar amplification can be enhanced or diminished by the latitudinal structure of radiative feedbacks. Amplifying polar feedbacks enhance polar warming and in turn cause a decrease in the dry-static energy transport to high latitudes (Alexeev and Jackson, 2013; Rose et al., 2014; Roe et al., 2015; Bonan et al., 2018; Merlis and Henry, 2018; Armour et al., 2019; Russotto and Biasutti, 2020). Poleward latent heat transport changes act to favour polar amplification and inhibit tropical amplification (Armour et al., 2019), resulting in a strongly polar-amplified warming response to polar forcing and a more latitudinally uniform warming response to tropical forcing within ESMs (Alexeev et al., 2005; Rose et al., 2014; Stuecker et al., 2018). The important role for poleward latent energy transport in polar amplification is supported by studies of atmospheric reanalyses and ESMs showing that episodic increases in latent heat transport into the Arctic can enhance surface downwelling radiation and drive sea ice loss on sub-seasonal time scales (Woods and Caballero, 2016; Gong et al., 2017; Lee et al., 2017; B. Luo et al., 2017), however this may be a smaller driver of sea ice variability than atmospheric temperature fluctuations (Olonscheck et al., 2019).

Regional energy budget analyses are commonly used to diagnose the relative contributions of radiative feedbacks and energy fluxes to polar amplification as projected by ESMs under increased CO_2 concentrations (Figure 7.12; Feldl and Roe, 2013; Pithan and Mauritsen, 2014; Goosse et al., 2018; Stuecker et al., 2018). These analyses suggest that a primary cause of amplified Arctic warming in ESMs is the latitudinal structure of radiative feedbacks, which warm the Arctic more than the tropics (Figure 7.12b), and enhanced latent energy transport into the Arctic. That net atmospheric heat transport into the Arctic does not change substantially within ESMs, on average, under CO_2 forcing (Figure 7.12b) reflects a compensating decrease in poleward dry-static energy transport as a response to polar amplified warming (Hwang et al., 2011; Armour et al., 2019; Donohoe et al., 2020). The latitudinal structure of radiative feedbacks primarily reflects that of

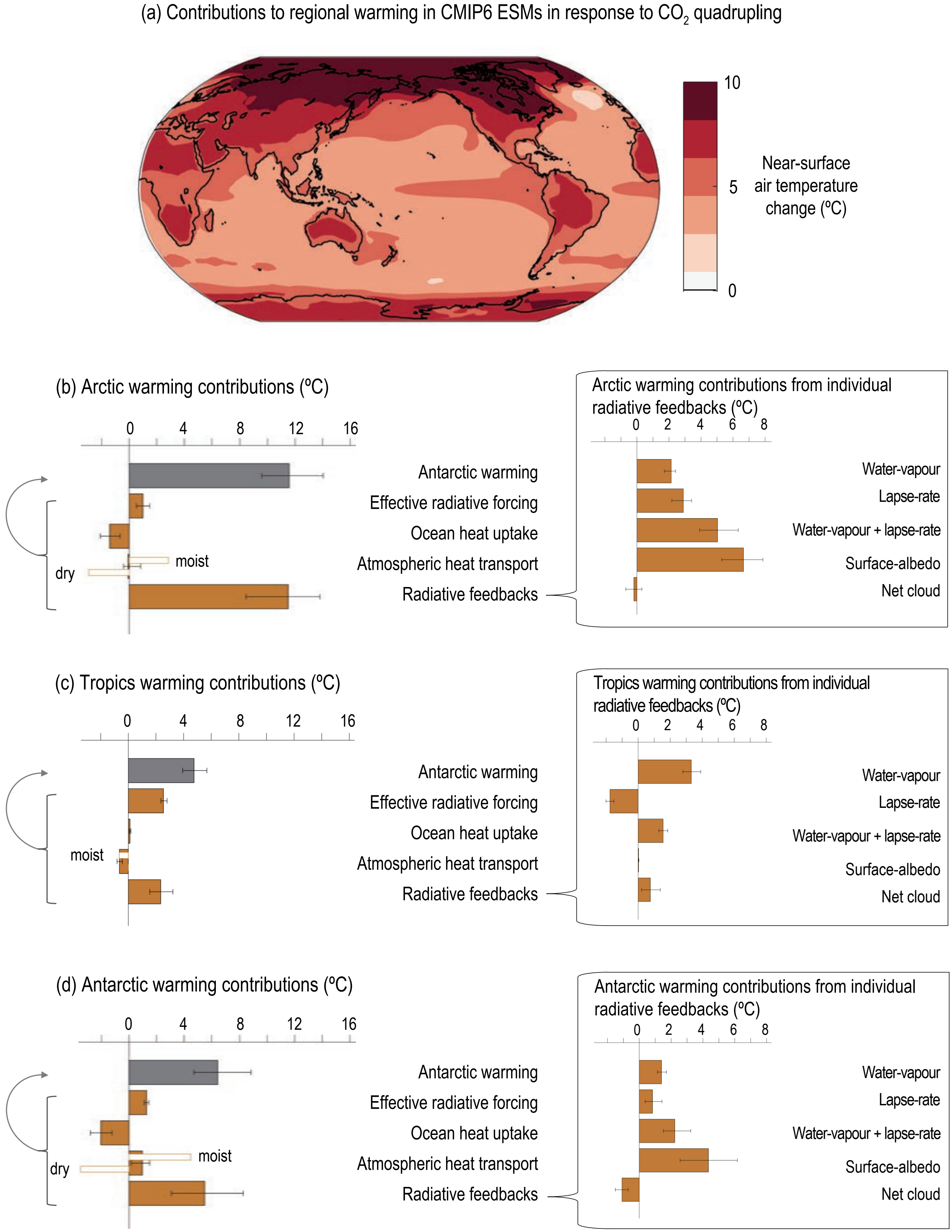


Figure 7.12 | Contributions of effective radiative forcing, ocean heat uptake, atmospheric heat transport, and radiative feedbacks to regional surface temperature changes at year 100 of *abrupt4xCO2* simulations of CMIP6 Earth system models (ESMs).

7

Figure 7.12 (continued): (a) Pattern of near-surface air temperature change. **(b–d)** Contributions to net Arctic (>60°N), tropical (30°S–30°N), and Antarctic (<60°S) warming calculated by dividing regional-average energy inputs by the magnitude of the regional-average Planck response. The contributions from radiative forcing, changes in moist, dry-static, and total atmospheric energy transport, ocean heat uptake, and radiative feedbacks (orange bars) all sum to the value of net warming (grey bar). Inset shows regional warming contributions associated with individual feedbacks, all summing to the total feedback contribution. Uncertainties (represented by black whiskers) show the interquartile range (25th and 75th percentiles) across models. The warming contributions (units of °C) for each process are diagnosed by calculating the energy flux (units of W m^{-2}) that each process contributes to the atmosphere over a given region, either at the top-of-atmosphere or surface, then dividing that energy flux by the magnitude of the regional Planck response (around 3.2 W m^{-2} $°C^{-1}$ but varying with region). By construction, the individual warming contributions sum to the total warming in each region. Radiative kernel methods (Section 7.4.1) are used to decompose the net energy input from radiative feedbacks into contributions from changes in atmospheric water vapour, lapse rate, clouds, and surface albedo (Zelinka et al. (2020) using the Huang et al. (2017) radiative kernel). The CMIP6 models included are those analysed by Zelinka et al. (2020) and the warming contribution analysis is based on that of Goosse et al. (2018). Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

the surface-albedo and lapse-rate feedbacks, which preferentially warm the Arctic (Graversen et al., 2014; Pithan and Mauritsen, 2014; Goosse et al., 2018). Latitudinal structure in the lapse-rate feedback reflects weak radiative damping to space with surface warming in polar regions, where atmospheric warming is constrained to the lower troposphere owing to stably stratified conditions, and strong radiative damping in the tropics, where warming is enhanced in the upper troposphere owing to moist convective processes. This is only partially compensated by latitudinal structure in the water-vapour feedback (Taylor et al., 2013), which favours tropical warming (Pithan and Mauritsen, 2014). While cloud feedbacks have been found to play little role in Arctic amplification in CMIP5 models (Pithan and Mauritsen, 2014; Goosse et al., 2018; Figure 7.12b), less-negative cloud feedbacks at high latitude, as seen within some CMIP6 models (Zelinka et al., 2020), tend to favour stronger polar amplification (Dong et al., 2020). A weaker Planck response at high latitudes, owing to less efficient radiative damping where surface and atmospheric temperatures are lower, also contributes to polar amplification (Pithan and Mauritsen, 2014). The effective radiative forcing of CO_2 is larger in the tropics than at high latitudes, suggesting that warming would be tropically amplified if not for radiative feedbacks and poleward latent heat transport changes (Figure 7.12b–d; Stuecker et al., 2018).

While the contributions to regional warming can be diagnosed within ESM simulations (Figure 7.12), assessment of the underlying role of individual factors is limited by interactions inherent to the coupled climate system. For example, polar feedback processes are coupled and influenced by warming at lower latitudes (Screen et al., 2012; Alexeev and Jackson, 2013; Graversen et al., 2014; Graversen and Burtu, 2016; Rose and Rencurrel, 2016; Feldl et al., 2017a, 2020; Yoshimori et al., 2017; Garuba et al., 2018; Po-Chedley et al., 2018b; Stuecker et al., 2018; Dai et al., 2019), while atmospheric heat transport changes are in turn influenced by the latitudinal structure of regional feedbacks, radiative forcing, and ocean heat uptake (Hwang et al., 2011; Zelinka and Hartmann, 2012; Feldl and Roe, 2013; Huang and Zhang, 2014; Merlis, 2014; Rose et al., 2014; Roe et al., 2015; Feldl et al., 2017b; Stuecker et al., 2018; Armour et al., 2019). The use of different feedback definitions, such as a lapse-rate feedback partitioned into upper and lower tropospheric components (Feldl et al., 2020) or including the influence of water vapour at constant relative humidity (Held and Shell, 2012; Section 7.4.2), would also change the interpretation of which feedbacks contribute most to polar amplification.

The energy budget analyses (Figure 7.12) suggest that greater surface warming in the Arctic than the Antarctic under greenhouse gas forcing arises from two main processes. The first is large surface heat uptake in the Southern Ocean (Figure 7.12c) driven by the upwelling of deep waters that have not yet felt the effects of the radiative forcing; the heat taken up is predominantly transported away from Antarctica by northward-flowing surface waters (Section 9.2.1; Marshall et al., 2015; Armour et al., 2016). Strong surface heat uptake also occurs in the subpolar North Atlantic Ocean under global warming (Section 9.2.1). However, this heat is partially transported northward into the Arctic, which leads to increased heat fluxes into the Arctic atmosphere (Figure 7.12b; Rugenstein et al., 2013; Jungclaus et al., 2014; Koenigk and Brodeau, 2014; Marshall et al., 2015; Nummelin et al., 2017; Singh et al., 2017; Oldenburg et al., 2018). The second main process contributing to differences in Arctic and Antarctic warming is the asymmetry in radiative feedbacks between the poles (Yoshimori et al., 2017; Goosse et al., 2018). This primarily reflects the weaker lapse-rate and surface-albedo feedbacks and more-negative cloud feedbacks in the SH high latitudes (Figure 7.12). However, note the SH cloud feedbacks are uncertain due to possible biases in the treatment of mixed phase clouds (Hyder et al., 2018). Idealized modelling suggests that the asymmetry in the polar lapse-rate feedback arises from the height of the Antarctic Ice Sheet precluding the formation of deep atmospheric inversions that are necessary to produce the stronger positive lapse-rate feedbacks seen in the Arctic (Salzmann, 2017; Hahn et al., 2020). ESM projections of the equilibrium response to CO_2 forcing show polar amplification in both hemispheres, but generally with less warming in the Antarctic than the Arctic (C. Li et al., 2013; Yoshimori et al., 2017).

Because multiple processes contribute to polar amplification, it is a robust feature of the projected long-term response to greenhouse gas forcing in both hemispheres. At the same time, contributions from multiple processes make projections of the magnitude of polar warming inherently more uncertain than global mean warming (Holland and Bitz, 2003; Roe et al., 2015; Bonan et al., 2018; Stuecker et al., 2018). The magnitude of Arctic amplification ranges from a factor of two to four in ESM projections of 21st-century warming (Section 4.5.1). While uncertainty in both global and tropical warming under greenhouse gas forcing is dominated by cloud feedbacks (Section 7.5.7; Vial et al., 2013), uncertainty in polar warming arises from polar surface-albedo, lapse-rate, and cloud feedbacks, changes in atmospheric and oceanic poleward heat transport, and ocean heat uptake (Hwang et al., 2011; Mahlstein and Knutti, 2011; Pithan and Mauritsen, 2014; Bonan et al., 2018).

The magnitude of polar amplification also depends on the type of radiative forcing applied (Section 4.5.1.1; Stjern et al., 2019), with Chapter 6 (Section 6.4.3) discussing changes in sulphate aerosol emissions and the deposition of black carbon aerosols on ice and snow as potential drivers of amplified Arctic warming. The timing of the emergence of SH polar amplification remains uncertain due to insufficient knowledge of the time scales associated with Southern Ocean warming and the response to surface wind and freshwater forcing (Bintanja et al., 2013; Kostov et al., 2017, 2018; Pauling et al., 2017; Purich et al., 2018). ESM simulations indicate that freshwater input from melting ice shelves could reduce Southern Ocean warming by up to several tenths of a °C over the 21st century by increasing stratification of the surface ocean around Antarctica (*low confidence* due to *medium agreement* but *limited evidence*) (Sections 7.4.2.6 and 9.2.1, and Box 9.3; Bronselaer et al., 2018; Golledge et al., 2019; Lago and England, 2019). However, even a large reduction in the Atlantic Meridional Overturning Circulation (AMOC) and associated northward heat transport due, for instance, to greatly increased freshwater runoff from Greenland would be insufficient to eliminate Arctic amplification (*medium confidence* based on *medium agreement* and *medium evidence*) (Liu et al., 2017; Y. Liu et al., 2018; Wen et al., 2018).

Arctic amplification has a distinct seasonality with a peak in early winter (November to January) owing to sea ice loss and associated increases in heat fluxes from the ocean to the atmosphere resulting in strong near-surface warming (Pithan and Mauritsen, 2014; Dai et al., 2019). Surface warming may be further amplified by positive cloud and lapse-rate feedbacks in autumn and winter (Burt et al., 2016; Morrison et al., 2019; Hahn et al., 2020). Arctic amplification is weak in summer owing to surface temperatures remaining stable as excess energy goes into thinning the summertime sea ice cover, which remains at the melting point, or into the ocean mixed layer. Arctic amplification can also be interpreted through changes in the surface energy budget (Burt et al., 2016; Woods and Caballero, 2016; Boeke and Taylor, 2018; Kim et al., 2019), however such analyses are complicated by the finding that a large portion of the changes in downward longwave radiation can be attributed to the lower troposphere warming along with the surface itself (Vargas Zeppetello et al., 2019).

7.4.4.1.2 Polar amplification from proxies and models during past climates associated with CO_2 change

Paleoclimate proxy data provide observational evidence of large-scale patterns of surface warming in response to past forcings, and allow an evaluation of the modelled response to these forcings (Sections 3.3.1.1 and 3.8.2.1). In particular, paleoclimate data provide evidence for long-term changes in polar amplification during time periods in which the primary forcing was a change in atmospheric CO_2, although data sparsity means that for some time periods this evidence may be limited to a single hemisphere or ocean basin, or the evidence may come primarily from the mid-latitudes as opposed to the polar regions. In this context, there has been a modelling and data focus on the Last Glacial Maximum (LGM) in the context of PMIP4 (Cleator et al., 2020; Tierney et al., 2020b; Kageyama et al., 2021), the mid-Pliocene Warm Period (MPWP) in the context of PlioMIP2 (Cross-Chapter Box 2.4; Salzmann et al., 2013; Haywood et al., 2020; McClymont et al., 2020), the Early Eocene Climatic Optimum (EECO) in the context of DeepMIP (Hollis et al., 2019; Lunt et al., 2021), and there is growing interest in the Miocene (Goldner et al., 2014b; Steinthorsdottir et al., 2021; for definitions of time periods see Cross-Chapter Box 2.1). For all these time periods, in addition to the CO_2 forcing there are long-term feedbacks associated with ice sheets (Section 7.4.2.6), and in particular for the Early Eocene there is a forcing associated with paleogeographic change (Farnsworth et al., 2019). However, because these non-CO_2 effects can all be included as boundary conditions in model simulations, these time periods allow an assessment of the patterns of modelled response to known forcing (although uncertainty in the forcing increases further back in time). Because these changes to boundary conditions can be complex to implement in models, and because long simulations (typically longer than 500 years) are required to approach equilibrium, these simulations have been carried out mostly by pre-CMIP6 models, with relatively few (or none for the Early Eocene) fully coupled CMIP6 models in the ensembles.

At the time of AR5, polar amplification was evident in proxy reconstructions of paleoclimate sea surface temperature (SST) and surface air temperature (SAT) from the LGM, MPWP and the Early Eocene, but uncertainties associated with proxy calibrations (Waelbroeck et al., 2009; Dowsett et al., 2012; Lunt et al., 2012a) and the role of orbital forcing (for the MPWP; Lisiecki and Raymo, 2005) meant that the degree of polar amplification during these time periods was not accurately known. Furthermore, although some models (CCSM3; Winguth et al., 2010; Huber and Caballero, 2011) at that time were able to reproduce the strong polar amplification implied by temperature proxies of the Early Eocene, this was achieved at higher CO_2 concentrations (>2000 ppm) than those indicated by CO_2 proxies (<1500 ppm; Beerling and Royer, 2011).

Since AR5 there has been progress in improving the accuracy of proxy temperature reconstructions of the LGM (Cleator et al., 2020; Tierney et al., 2020b), the MPWP (McClymont et al., 2020), and the Early Eocene (Hollis et al., 2019) time periods. In addition, reconstructions of the MPWP have been focused on a short time slice with an orbit similar to modern-day (isotopic stage KM5C; Haywood et al., 2013, 2016b). Furthermore, there are more robust constraints on CO_2 concentrations from the MPWP (Martínez-Botí et al., 2015; de la Vega et al., 2020) and the Early Eocene (Anagnostou et al., 2016, 2020). As such, polar amplification during the LGM, MPWP, and Early Eocene time periods can now be better quantified than at the time of AR5, and the ability of climate models to reproduce this pattern can be better assessed; model-data comparisons for SAT and SST for these three time periods are shown in Figure 7.13.

Since AR5, there has been progress in the simulation of polar amplification by paleoclimate models of the Early Eocene. Initial work indicated that changes to model parameters associated with aerosols and/or clouds could increase simulated polar amplification and improve agreement between models and paleoclimate data (Kiehl and Shields, 2013; Sagoo et al., 2013), but such parameter changes were not physically based. In support of these initial findings, a more recent (CMIP5) climate model, that includes a process-based representation of cloud microphysics, exhibits polar amplification in better agreement with proxies when compared to the models assessed in AR5 (Zhu et al., 2019a). Since then, some other CMIP3 and CMIP5 models in the DeepMIP multi-model ensemble (Lunt et al., 2021) have obtained polar amplification for the EECO that is consistent with proxy indications of both polar amplification and CO_2. Although there is a lack of tropical proxy SAT estimates, both

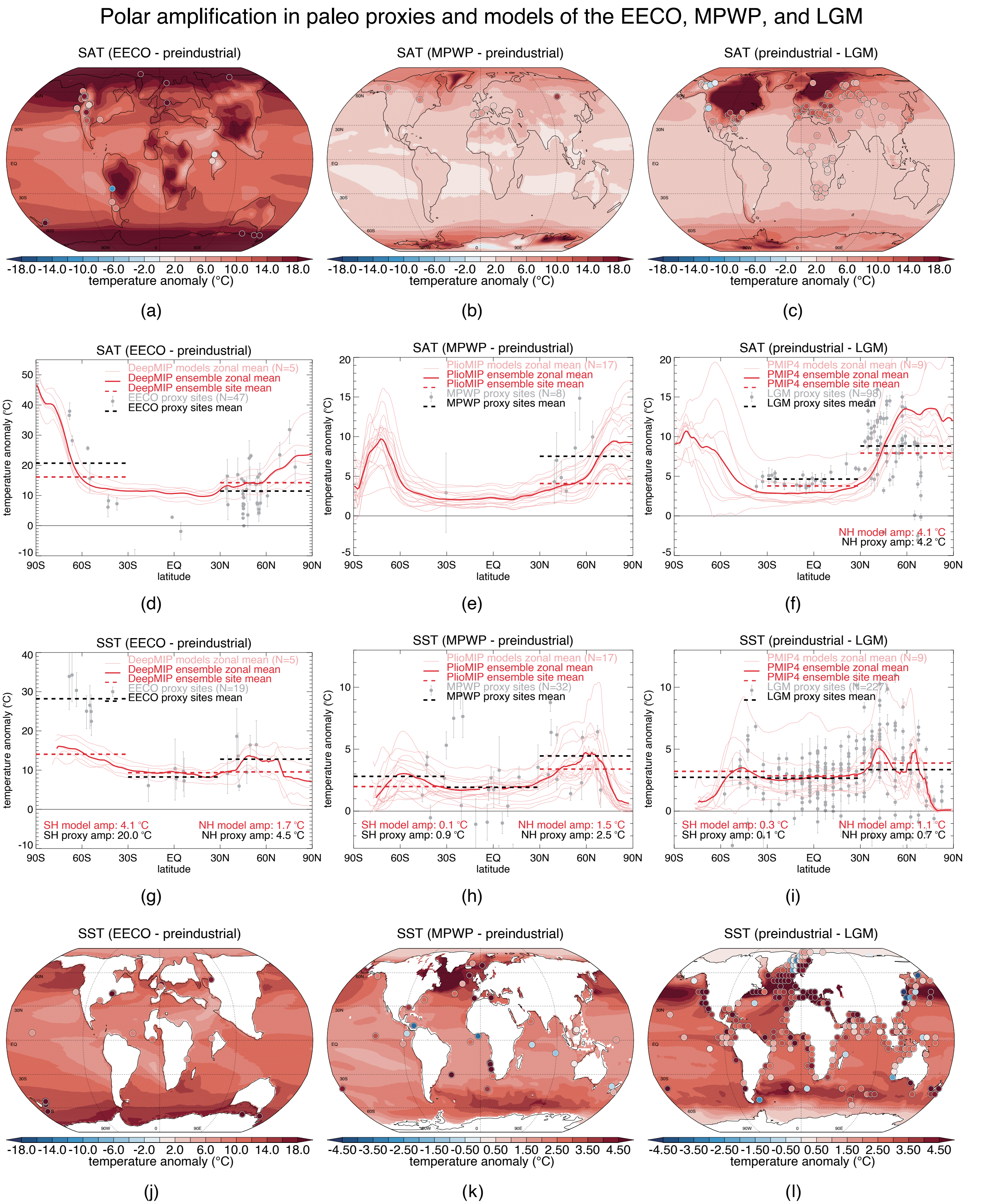


Figure 7.13 | Polar amplification in paleo proxies and models of the Early Eocene Climatic Optimum (EECO), the Mid-Pliocene Warm Period (MPWP) and the Last Glacial Maximum (LGM).

Figure 7.13 (continued): Temperature anomalies compared with pre-industrial (equivalent to CMIP6 simulation 'piControl') are shown for the high-CO_2 EECO and MPWP time periods, and for the low-CO_2 LGM (expressed as pre-industrial minus LGM). **(a), (b) and (c)** Modelled near-surface air temperature anomalies for ensemble-mean simulations of the (a) EECO (Lunt et al., 2021); (b) MPWP (Haywood et al., 2020; Zhang et al., 2021); and (c) LGM (Kageyama et al., 2021; Zhu et al., 2021). Also shown are proxy near-surface air temperature anomalies (coloured circles). **(d), (e) and (f)** Proxy near-surface air temperature anomalies (grey circles), including published uncertainties (grey vertical bars), model ensemble mean zonal mean anomaly (solid red line) for the same model ensembles as in (a–c), light-red lines show the modelled temperature anomaly for the individual models that make up each ensemble (LGM, N=9; MPWP, N=17; EECO, N=5). Black dashed lines show the average of the proxy values in each latitude band: 90°S–30°S, 30°S–30°N, and 30°N–90°N. Red dashed lines show the same banded average in the model ensemble mean, calculated from the same locations as the proxies. Black and red dashed lines are only shown if there are five or more proxy points in that band. Mean differences between the 90°S/N to 30°S/N and 30°S to 30°N bands are quantified for the models and proxies in each plot. Panels **(g), (h) and (i)** are like panels (d–f) but for sea surface temperature (SST) instead of near-surface air temperature. Panels **(j), (k) and (l)** are like panels (a–c) but for SST instead of near-surface air temperature. For the EECO maps – (a) and (j) – the anomalies are relative to the zonal mean of the pre-industrial, due to the different continental configuration. Proxy datasets are: (a) and (d) Hollis et al. (2019); (b) and (e) Salzmann et al. (2013); Vieira et al. (2018), (c) and (f) Cleator et al. (2020) at the sites defined in Bartlein et al. (2011); (g) and (j) Hollis et al. (2019); (h) and (k) McClymont et al. (2020); (i) and (l) Tierney et al. (2020b). Where there are multiple proxy estimations at a single site, a mean is taken. Model ensembles are (a), (d), (g) and (j) DeepMIP (only model simulations carried out with a mantle-frame paleogeography, and carried out under CO_2 concentrations within the range assessed in Table 2.2, are shown); (b), (e), (h) and (k) PlioMIP; and (c), (f), (i) and (l) PMIP4. Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

proxies and DeepMIP models show greater terrestrial warming in the high latitudes than the mid-latitudes in both hemispheres (Figure 7.13a,d). SST proxies also exhibit polar amplification in both hemispheres, but the magnitude of this polar amplification is too low in the models, in particular in the south-west Pacific (Figure 7.13g,j).

For the MPWP, model simulations are now in better agreement with proxies than at the time of AR5 (Haywood et al., 2020; McClymont et al., 2020). In particular, in the tropics new proxy reconstructions of SSTs are warmer and in better agreement with the models, due in part to the narrower time window in the proxy reconstructions. There is also better agreement at higher latitudes (primarily in the North Atlantic), due in part to the absence of some very warm proxy SSTs due to the narrower time window (McClymont et al., 2020), and in part to a modified representation of Arctic gateways in the most recent Pliocene model simulations (Otto-Bliesner et al., 2017), which have resulted in warmer modelled SSTs in the North Atlantic (Haywood et al., 2020). Furthermore, as for the Eocene, improvements in the representation of aerosol–cloud interactions have also led to improved model-data consistency at high latitudes (Feng et al., 2019). Although all PlioMIP2 models exhibit polar amplification of SAT, due to the relatively narrow time window there are insufficient terrestrial proxies to assess this (Figure 7.13b,e). However, polar SST amplification in the PlioMIP2 ensemble mean is in reasonably good agreement with that from SST proxies in the Northern Hemisphere (Figure 7.13h,k).

The Last Glacial Maximum (LGM) also gives an opportunity to evaluate model simulation of polar amplification under CO_2 forcing, albeit under colder conditions than today (Kageyama et al., 2021). Terrestrial SAT and marine SST proxies exhibit clear polar amplification in the Northern Hemisphere, and the PMIP4 models capture this well (Figure 7.13c,f,i,l), particularly for SAT. There is less proxy data in the mid- to high latitudes of the Southern Hemisphere, but here the models exhibit polar amplification of both SST and SAT. LGM regional model-data agreement is also assessed in Chapter 3 (Section 3.8.2).

Overall, the proxy reconstructions give *high confidence* that there was polar amplification in the LGM, MPWP and EECO, and this is further supported by model simulations of these time periods (Figure 7.13; Zhu et al., 2019a; Haywood et al., 2020; Kageyama et al., 2021; Lunt et al., 2021). For both the MPWP and EECO, models are more consistent with the temperature and CO_2 proxies than at the time of AR5 (*high confidence*). For the LGM Northern Hemisphere, which is the region with the most data and the time period with the least uncertainty in model boundary conditions, polar amplification in the PMIP4 ensemble mean is in good agreement with the proxies, especially for SAT (*medium confidence*). Overall, the confidence in the ability of models to accurately simulate polar amplification is higher than at the time of AR5, but a more complete model evaluation could be carried out if there were more CMIP6 paleoclimate simulations included in the assessment.

7.4.4.1.3 Overall assessment of polar amplification

Based on mature process understanding of the roles of poleward latent heat transport and radiative feedbacks in polar warming, a high degree of agreement across a hierarchy of climate models, observational evidence, paleoclimate proxy records of past climates associated with CO_2 change, and ESM simulations of those past climates, there is *high confidence* that polar amplification is a robust feature of the long-term response to greenhouse gas forcing in both hemispheres. Stronger warming in the Arctic than the global average has already been observed (Section 2.3.1) and its causes are well understood. It is *very likely* that the warming in the Arctic will be more pronounced than the global average over the 21st century (*high confidence*) (Section 4.5.1.1). This is supported by models' improved ability to simulate polar amplification during past time periods, compared with at the time of AR5 (*high confidence*); although this is based on an assessment of mostly non-CMIP6 models.

Southern Ocean SSTs have been slow to warm over the instrumental period, with cooling since about 1980 owing to a combination of upper-ocean freshening from ice-shelf melt, intensification of surface westerly winds from ozone depletion, and variability in ocean convection (Section 9.2.1). This stands in contrast to the equilibrium warming pattern either inferred from the proxy record or simulated by ESMs under CO_2 forcing. There is *high confidence* that the SH high latitudes will warm more than the tropics on centennial time scales as the climate equilibrates with radiative forcing and Southern Ocean heat uptake is reduced. However, there is only *low confidence* that this feature will emerge this century.

7.4.4.2 Tropical Pacific Sea Surface Temperature Gradients

Research published since AR5 identifies changes in the tropical Pacific Ocean zonal SST gradient over time as a key factor affecting how radiative feedbacks may evolve in the future (Section 7.4.4.3).

There is now a much-improved understanding of the processes that govern the tropical Pacific SST gradient (Section 7.4.4.2.1) and the paleoclimate record provides evidence for its equilibrium changes from time periods associated with changes in CO_2 (Section 7.4.4.2.2).

7.4.4.2.1 Critical processes determining changes in tropical Pacific sea surface temperature gradients

A weakening of the equatorial Pacific Ocean east–west SST gradient, with greater warming in the east than the west, is a common feature of the climate response to greenhouse gas forcing as projected by ESMs on centennial and longer time scales (e.g., Figure 7.14b; see Section 4.5.1). There are thought to be several factors contributing to this pattern. In the absence of any changes in atmospheric or oceanic circulations, the east–west surface temperature difference is theorized to decrease owing to weaker evaporative damping, and thus greater warming in response to forcing, where climatological temperatures are lower in the eastern Pacific cold tongue (Xie et al., 2010; Luo et al., 2015). Within atmospheric ESMs coupled to a mixed-layer ocean, this gradient in damping has been linked to the rate of change with warming of the saturation specific humidity, which is set by the Clausius–Clapeyron relation (Merlis and Schneider, 2011). Gradients in low-cloud feedbacks may also favour eastern equatorial Pacific warming (DiNezio et al., 2009).

In the coupled climate system, changes in atmospheric and oceanic circulations will influence the east-west temperature gradient as well. It is expected that as global temperature increases and as the east–west temperature gradient weakens, east–west sea level pressure gradients and easterly trade winds (characterizing the Walker circulation) will weaken as well (Sections 4.5.3, 8.2.2.2 and 8.4.2.3, and Figure 7.14b; Vecchi et al., 2006, 2008). This would, in turn, weaken the east–west temperature gradient through a reduction of equatorial upwelling of cold water in the east Pacific and a reduction in the transport of warmer water to the western equatorial Pacific and Indian Ocean (England et al., 2014; Dong and McPhaden, 2017; Li et al., 2017; Maher et al., 2018).

Research published since AR5 (Burls and Fedorov, 2014b; Fedorov et al., 2015; Erfani and Burls, 2019) has built on an earlier theory (Liu and Huang, 1997; Barreiro and Philander, 2008) linking the east–west temperature gradient to the north–south temperature gradient. In particular, model simulations suggest that a reduction in the equator-to-pole temperature gradient (polar amplification) increases the temperature of water subducted in the extra-tropics, which in turn is upwelled in the eastern Pacific. Thus, polar amplified warming, with greater warming in the mid-latitudes and subtropics than in the deep tropics, is expected to contribute to the weakening of the east–west equatorial Pacific SST gradient on decadal to centennial time scales.

The transient adjustment of the equatorial Pacific SST gradient is influenced by upwelling waters which delay surface warming in the east since they have not been at the surface for years-to-decades to experience the greenhouse gas forcing. This 'thermostat mechanism' (Clement et al., 1996; Cane et al., 1997) is not thought to persist to equilibrium since it does not account for the eventual increase in temperatures of upwelled waters (Liu et al., 2005; Xie et al., 2010; Y. Luo et al., 2017) which will occur as the subducting waters in mid-latitudes warm by more than the tropics on average as polar amplification emerges. An individual CMIP5 ESM (GFDL's ESM2M) has been found to exhibit a La Niña-like pattern of Pacific temperature change through the 21st century, similar to the SST trends seen over the historical record (Section 9.2.1 and Figure 7.14a), owing to a weakening asymmetry between El Niño and La Niña events (Kohyama et al., 2017), but this pattern of warming may not persist to equilibrium (Paynter et al., 2018).

Since 1870, observed SSTs in the tropical western Pacific Ocean have increased while those in the tropical eastern Pacific Ocean have changed less (Figure 7.14a and Section 9.2.1). Much of the resultant strengthening of the equatorial Pacific temperature gradient has occurred since about 1980 due to strong warming in the west and cooling in the east (Figure 2.11b) concurrent with an intensification of the surface equatorial easterly trade winds and Walker circulation (Sections 3.3.3.1, 3.7.6, 8.3.2.3 and 9.2, and Figures 3.16f and 3.39f; England et al., 2014). This temperature pattern is also reflected in regional ocean heat content trends and sea level changes observed from satellite altimetry since 1993 (Bilbao et al., 2015; Richter et al., 2020). The observed changes may have been influenced by one or a combination of temporary factors including sulphate aerosol forcing (Smith et al., 2016; Takahashi and Watanabe, 2016; Hua et al., 2018), internal variability within the Indo-Pacific Ocean (Luo et al., 2012; Chung et al., 2019), teleconnections from multi-decadal tropical Atlantic SST trends (Kucharski et al., 2011, 2014, 2015; McGregor et al., 2014; Chafik et al., 2016; X. Li et al., 2016; Kajtar et al., 2017; Sun et al., 2017), teleconnections from multi-decadal Southern Ocean SST trends (Hwang et al., 2017), and coupled ocean–atmosphere dynamics which slow warming in the equatorial eastern Pacific (Clement et al., 1996; Cane et al., 1997; Seager et al., 2019). CMIP3 and CMIP5 ESMs have difficulties replicating the observed trends in the Walker circulation and Pacific Ocean SSTs over the historical record (Sohn et al., 2013; Zhou et al., 2016; Coats and Karnauskas, 2017), possibly due to model deficiencies including insufficient multi-decadal Pacific Ocean SST variability (Laepple and Huybers, 2014; Bilbao et al., 2015; Chung et al., 2019), mean state biases affecting the forced response or the connection between Atlantic and Pacific basins (Kucharski et al., 2014; Kajtar et al., 2018; Luo et al., 2018; McGregor et al., 2018; Seager et al., 2019), and/or a misrepresentation of radiative forcing (Sections 9.2.1 and 3.7.6). However, the observed trends in the Pacific Ocean SSTs are still within the range of internal variability as simulated by large initial condition ensembles of CMIP5 and CMIP6 models (Olonscheck et al., 2020; Watanabe et al., 2021). Because the causes of observed equatorial Pacific temperature gradient and Walker circulation trends are not well understood (Section 3.3.3.1), there is *low confidence* in their attribution to anthropogenic influences (Section 8.3.2.3), while there is *medium confidence* that the observed changes have resulted from internal variability (Sections 3.7.6 and 8.2.2.2).

7.4.4.2.2 Tropical Pacific temperature gradients in past high-CO_2 climates

The AR5 stated that paleoclimate proxies indicate a reduction in the longitudinal SST gradient across the equatorial Pacific during the Mid-Pliocene Warm Period (MPWP; Masson-Delmotte et al., 2013;

see Cross-Chapter Box 2.1 and Cross-Chapter Box 2.4 in this Report). This assessment was based on SST reconstructions between two sites situated very close to the equator in the heart of the western Pacific warm pool and eastern Pacific cold tongue, respectively. Multiple SST reconstructions based on independent paleoclimate proxies generally agreed that during the Pliocene the SST gradient between these two sites was reduced compared with the modern long-term mean (Wara et al., 2005; Dekens et al., 2008; Fedorov et al., 2013).

Since AR5, the generation of new SST records has led to a variety of revised gradient estimates, specifically the generation of a new record for the warm pool (Zhang et al., 2014), the inclusion of SST reconstructions from sites in the South China Sea as warm pool estimates (O'Brien et al., 2014; Zhang et al., 2014), and the inclusion of several new sites from the eastern Pacific as cold tongue estimates (Zhang et al., 2014; Fedorov et al., 2015). Published estimates of the reduction in the longitudinal SST difference for the Late Pliocene, relative to either Late Quaternary (0–0.5 million years ago) or pre-industrial values, include 1°C to 1.5°C (Zhang et al., 2014), 0.1°C to 1.9°C (Tierney et al., 2019), and about 3°C (Ravelo et al., 2014; Fedorov et al., 2015; Wycech et al., 2020). All of these studies report a further weakening of the longitudinal gradient based on records extending into the Early Pliocene. While these revised estimates differ in magnitude due to differences in the sites and SST proxies used, they all agree that the longitudinal gradient was weaker, and this is supported by the probabilistic approach of Tierney et al. (2019). However, given that there are currently relatively few western equatorial Pacific records from independent site locations, and due to uncertainties associated with the proxy calibrations (Haywood et al., 2016a), there is only *medium confidence* that the average longitudinal gradient in the tropical Pacific was weaker during the Pliocene than during the Late Quaternary.

To avoid the influence of local biases, changes in the longitudinal temperature difference within Pliocene model simulations are typically evaluated using domain-averaged SSTs within chosen east and west Pacific regions and as such there is sensitivity to methodology. Unlike the reconstructed estimates, longitudinal gradient changes simulated by the Pliocene Model Intercomparison Project Phase 1 (PlioMIP1) models do not agree on the change in sign and are reported as spanning approximately –0.5°C to +0.5°C by Brierley et al. (2015) and approximately –1°C to +1°C by Tierney et al. (2019). Initial PlioMIP Phase 2 (PlioMIP2) analysis suggests responses similar to PlioMIP1 (Feng et al., 2019; Haywood et al., 2020). Models that include hypothetical modifications to cloud albedo or ocean mixing are required to simulate the substantially weaker longitudinal differences seen in reconstructions of the Early Pliocene (Fedorov et al., 2013; Burls and Fedorov, 2014a).

While more western Pacific warm pool temperature reconstructions are needed to refine estimates of the longitudinal gradient, several Pliocene SST reconstructions from the east Pacific indicate enhanced warming in the centre of the eastern equatorial cold tongue upwelling region (Liu et al., 2019). This enhanced warming in the east Pacific cold tongue appears to be dynamically consistent with reconstruction of enhanced subsurface warming (Ford et al., 2015) and enhanced warming in coastal upwelling regions, suggesting that the tropical thermocline was deeper and/or less stratified during the Pliocene. The Pliocene data therefore suggest that the observed cooling trend over the last 60 years in parts of the eastern equatorial Pacific (Section 9.2.1.1 and Figure 9.3; Seager et al., 2019), whether forced or due to internal variability, involves transient processes that are probably distinct from the longer-time scale process (Burls and Fedorov, 2014a, b; Luo et al., 2015; Heede et al., 2020) that maintained warmer eastern Pacific SST during the Pliocene.

7.4.4.2.3 Overall assessment of tropical Pacific sea surface temperature gradients under CO_2 forcing

The paleoclimate proxy record and ESM simulations of the MPWP, process understanding, and ESM projections of climate response to CO_2 forcing provide *medium evidence* and a *medium agreement* and thus *medium confidence* that equilibrium warming in response to elevated CO_2 will be characterized by a weakening of the east–west tropical Pacific SST gradient.

Overall the observed pattern of warming over the instrumental period, with a warming minimum in the eastern tropical Pacific Ocean (Figure 7.14a), stands in contrast to the equilibrium warming pattern either inferred from the MPWP proxy record or simulated by ESMs under CO_2 forcing. There is *medium confidence* that the observed strengthening of the east–west SST gradient is temporary and will transition to a weakening of the SST gradient on centennial time scales. However, there is only *low confidence* that this transition will emerge this century owing to a low degree of agreement across studies about the factors driving the observed strengthening of the east–west SST gradient and how those factors will evolve in the future. These trends in tropical Pacific SST gradients reflect changes in the climatology, rather than changes in ENSO amplitude or variability, which are assessed in Chapter 4 (Section 4.3.3).

7.4.4.3 Dependence of Feedbacks on Temperature Patterns

The expected time-evolution of the spatial pattern of surface warming in the future has important implications for values of ECS inferred from the historical record of observed warming. In particular, changes in the global top-of-atmosphere (TOA) radiative energy budget can be induced by changes in the regional variations of surface temperature, even without a change in the global mean temperature (Zhou et al., 2016; Ceppi and Gregory, 2019). Consequently, the global radiative feedback, characterizing the net TOA radiative response to global surface warming, depends on the *spatial pattern* of that warming. Therefore, if the equilibrium warming pattern under CO_2 forcing (similar to CMIP6 projections in Figure 7.12a) is distinct from that observed over the historical record or indicated by paleoclimate proxies (Sections 7.4.4.1 and 7.4.4.2), then ECS will be different from the effective ECS (Box 7.1) that is inferred from those periods. Accounting for the dependence of radiative feedbacks on the spatial pattern of warming has helped to reconcile values of ECS inferred from the historical record with values of ECS based on other lines of evidence and simulated by climate models (Section 7.5.2.1; Armour, 2017; Proistosescu and Huybers, 2017; Andrews et al., 2018) but has not yet been examined in the paleoclimate context.

This temperature 'pattern effect' (Stevens et al., 2016) can result from both internal variability and radiative forcing of the climate system. Importantly, it is distinct from potential radiative feedback dependencies on the global surface temperature, which are assessed in Section 7.4.3. While changes in global radiative feedbacks under transient warming have been documented in multiple generations of climate models (Williams et al., 2008; Andrews et al., 2015; Ceppi and Gregory, 2017; Dong et al., 2020), research published since AR5 has developed a much-improved understanding of the role of evolving SST patterns in driving feedback changes (Armour et al., 2013; Andrews et al., 2015, 2018; Gregory and Andrews, 2016; Zhou et al., 2016, 2017b; Ceppi and Gregory, 2017; Haugstad et al., 2017; Proistosescu and Huybers, 2017; Andrews and Webb, 2018; Marvel et al., 2018; Silvers et al., 2018; Dong et al., 2019, 2020). This section assesses process understanding of the pattern effect, which is dominated by the evolution of SSTs. Section 7.5.2.1 describes how potential feedback changes associated with the pattern effect are important to interpreting ECS estimates based on historical warming.

The radiation changes most sensitive to warming patterns are those associated with low-cloud cover (affecting global albedo) and the tropospheric temperature profile (affecting thermal emission to space) (Ceppi and Gregory, 2017; Zhou et al., 2017b; Andrews et al., 2018; Dong et al., 2019). The mechanisms and radiative effects of these changes are illustrated in Figure 7.14a,b. SSTs in regions of deep convective ascent (e.g., in the western Pacific warm pool) govern the temperature of the tropical free troposphere and, in turn, affect low-clouds through the strength of the inversion that caps the boundary layer (i.e., the lower-tropospheric stability) in subsidence regions (Wood and Bretherton, 2006; Klein et al., 2017). Surface warming within ascent regions thus warms the free troposphere and increases low-cloud cover, causing an increase in emission of thermal radiation to space and a reduction in absorbed solar radiation. In contrast, surface warming in regions of overall descent preferentially warms the boundary layer and enhances convective mixing with the dry free troposphere, decreasing low-cloud cover (Bretherton et al., 2013; Qu et al., 2014; Zhou et al., 2015). This leads to an increase in absorption of solar radiation but little change in thermal emission to space. Consequently, warming in tropical ascent regions results in negative lapse-rate and cloud feedbacks while warming in tropical descent regions results in positive lapse-rate and cloud feedbacks (Figure 7.14; Rose and Rayborn, 2016; Zhou et al., 2017b; Andrews and Webb, 2018; Dong et al., 2019). Surface warming in mid-to-high latitudes causes a weak radiative response owing to compensating changes in thermal emission (Planck and lapse-rate feedbacks) and absorbed solar radiation (shortwave cloud and surface-albedo feedbacks; Rose and Rayborn, 2016; Dong et al., 2019), however this compensation may weaken due to less-negative shortwave cloud feedbacks at high warming (Frey and Kay, 2018; Bjordal et al., 2020; Dong et al., 2020).

The spatial pattern of SST changes since 1870 shows relatively little warming in key regions of less-negative radiative feedbacks, including the eastern tropical Pacific Ocean and Southern Ocean (Sections 7.4.4.1 and 7.4.4.2, and Figures 2.11b and 7.14a). Cooling in these regions since 1980 has occurred along with an increase in the strength of the capping inversion in tropical descent regions, resulting in an observed increase in low-cloud cover over the tropical eastern Pacific (Figure 7.14a; Zhou et al., 2016; Ceppi and Gregory, 2017; Fueglistaler and Silvers, 2021). Thus, tropical low-cloud cover increased over recent decades even as global surface temperature increased, resulting in a negative low-cloud feedback which is at odds with the positive low-cloud feedback expected for the pattern of equilibrium warming under CO_2 forcing (Section 7.4.2.4 and Figure 7.14b).

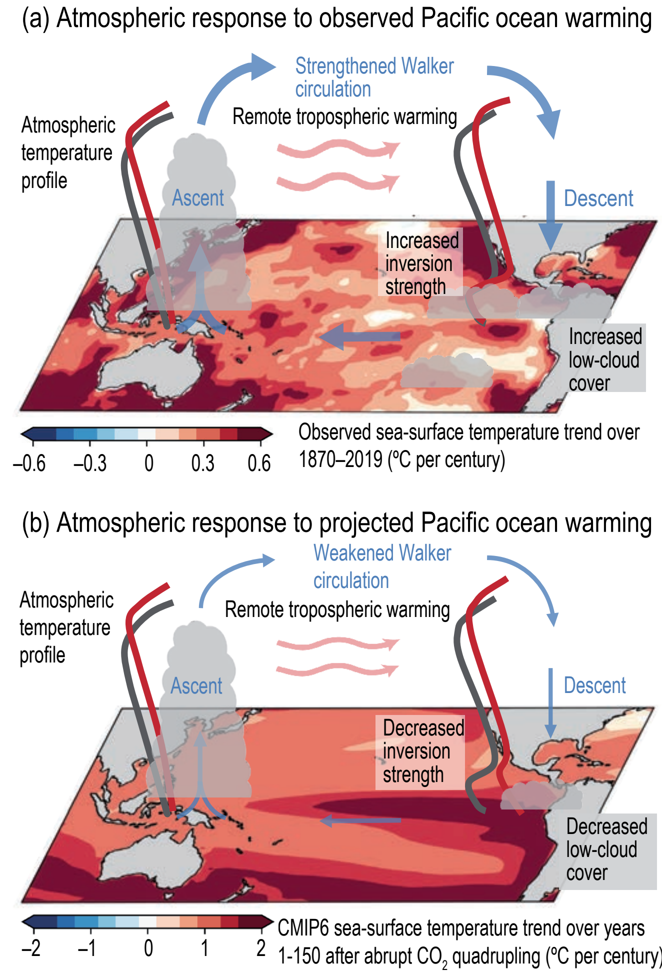


Figure 7.14 | Illustration of tropospheric temperature and low-cloud response to observed and projected Pacific Ocean sea surface temperature trends. (a) Atmospheric response to linear sea surface temperature trend observed over 1870–2019 (HadISST1 dataset; Rayner et al., 2003). **(b)** Atmospheric response to linear sea-surface temperature trend over 150 years following *abrupt4xCO2* forcing as projected by CMIP6 ESMs (Dong et al., 2020). Relatively large historical warming in the western tropical Pacific has been communicated aloft (a shift from grey to red atmospheric temperature profile), remotely warming the tropical free troposphere and increasing the strength of the inversion in regions of the tropics where warming has been slower, such as the eastern equatorial Pacific. In turn, an increased inversion strength has increased the low-cloud cover (Zhou et al., 2016) causing an anomalously negative cloud and lapse-rate feedbacks over the historical record (Andrews et al., 2018; Marvel et al., 2018). Relatively large projected warming in the eastern tropical Pacific is trapped near the surface (shift from grey to red atmospheric temperature profile), decreasing the strength of the inversion locally. In turn, a decreased inversion strength combined with surface warming is projected to decrease the low-cloud cover, causing the cloud and lapse-rate feedbacks to become less negative in the future. Figure adapted from Mauritsen (2016). Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

Andrews et al. (2018) analysed available CMIP5/6 ESM simulations (six in total) comparing effective feedback parameters diagnosed within atmosphere-only ESMs using prescribed historical SST and sea ice concentration patterns with the equilibrium feedback parameters as estimated within coupled ESMs (using identical atmospheres) driven by abrupt 4×CO_2 forcing. The atmosphere-only ESMs show pronounced multi-decadal variations in their effective feedback parameters over the last century, with a trend towards strongly negative values since about 1980 owing primarily to negative shortwave cloud feedbacks driven by warming in the western equatorial Pacific Ocean and cooling in the eastern equatorial Pacific Ocean (Zhou et al., 2016; Andrews et al., 2018; Marvel et al., 2018; Dong et al., 2019). Yet, all six models show a less-negative net feedback parameter under *abrupt4xCO2* than for the historical period (based on regression since 1870 following Andrews et al., 2018). The average change in net feedback parameter between the historical period and the equilibrium response to CO_2 forcing, denoted here as α', for these simulations is α' = +0.6 W m^{-2} °C^{-1} (+0.3 to +1.0 W m^{-2} °C^{-1} range across models; Figure 7.15b). These feedback parameter changes imply that the value of ECS may be substantially larger than that inferred from the historical record (Section 7.5.2.1). These findings can be understood from the fact that, due to a combination of internal variability and transient response to forcing (Section 7.4.4.2), historical sea surface warming has been relatively large in regions of tropical ascent (Figure 7.14a), leading to an anomalously large net negative radiative feedback; however, future warming is expected to be largest in tropical descent regions, such as the eastern equatorial Pacific, and at high latitudes (Sections 7.4.4.1 and 7.4.4.2 and Figure 7.14b), leading to a less-negative net radiative feedback and higher ECS.

A similar behaviour is seen within transient simulations of coupled ESMs, which project SST warming patterns that are initially characterized by relatively large warming rates in the western equatorial Pacific Ocean on decadal time scales and relatively large warming in the eastern equatorial Pacific and Southern Ocean on centennial time scales (Andrews et al., 2015; Proistosescu and Huybers, 2017; Dong et al., 2020). Recent studies based on simulations of 1% yr^{-1} CO_2 increase (*1pctCO₂*) or *abrupt4xCO2* as analogues for historical warming suggest characteristic values of α' = +0.05 W m^{-2} °C^{-1} (–0.2 to +0.3 W m^{-2} °C^{-1} range across models) based on CMIP5 and CMIP6 ESMs (Armour 2017, Lewis and Curry 2018, Dong et al. 2020). Using historical simulations of one CMIP6 ESM (HadGEM3-GC3.1-LL), Andrews et al. (2019) find an average feedback parameter change of α' = +0.2 W m^{-2} °C^{-1} (–0.2 to +0.6 W m^{-2} °C^{-1} range across four ensemble members). Using historical simulations from another CMIP6 ESM (GFDL CM4.0), Winton et al. (2020) find an average feedback parameter change of α' = +1.5 W m^{-2} °C^{-1} (+1.2 to +1.7 W m^{-2} °C^{-1} range across three ensemble members). This value is larger than the α' = +0.7 W m^{-2} °C^{-1} within GFDL CM4.0 for historical CO_2 forcing only, suggesting that the value of α' may depend on historical non-CO_2 forcings such as those associated with tropospheric and stratospheric aerosols (Marvel et al., 2016; Gregory et al., 2020; Winton et al., 2020).

The magnitude of the net feedback parameter change α' found within coupled CMIP5 and CMIP6 ESMs is generally smaller than that found when prescribing observed warming patterns within atmosphere-only ESMs (Figure 7.15; Andrews et al., 2018). This arises from the fact that the forced spatial pattern of warming within transient simulations of most coupled ESMs are distinct from observed warming patterns over the historical record in key regions such as the equatorial Pacific Ocean and Southern Ocean (Sections 7.4.4.1 and 7.4.4.2), while being more similar to the equilibrium pattern simulated under *abrupt4xCO2*. However, historical simulations with HadGEM3-GC3.1-LL (Andrews et al., 2019) and GFDL CM4.0 (Winton et al., 2020) show substantial spread in the value of α' across ensemble members, indicating a potentially important role for internal variability in setting the magnitude of the pattern effect over the historical period. Using the 100-member historical simulation ensemble of MPI-ESM1.1, Dessler et al. (2018) find that internal climate variability alone results in a 0.5 W m^{-2} °C^{-1} spread in the historical effective feedback parameter, and thus also in the value of α'. Estimates of α' using prescribed historical warming patterns provide a more realistic representation of the historical pattern effect because they account for the net effect of the transient response to historical forcing and internal variability in the observed record (Andrews et al., 2018).

The magnitude of α', as quantified by ESMs, depends on the accuracy of both the projected patterns of SST and sea ice concentration changes in response to CO_2 forcing and the radiative response to those patterns (Andrews et al., 2018). Model biases that affect the long-term warming pattern (e.g., SST and relative humidity biases in the equatorial Pacific cold tongue as suggested by Seager et al., 2019) will affect the value of α'. The value of α' also depends on the accuracy of the historical SST and sea ice concentration conditions prescribed within atmosphere-only versions of ESMs to quantify the historical radiative feedback (Figure 7.15b). Historical SSTs are particularly uncertain for the early portion of the historical record (Section 2.3.1), and there are few constraints on sea ice concentration prior to the satellite era. Using alternative SST datasets, Andrews et al. (2018) found little change in the value of α' within two models (HadGEM3 and HadAM3), while Lewis and Mauritsen (2021) found a smaller value of α' within two other models (ECHAM6.3 and CAM5). The sensitivity of results to the choice of dataset represents a major source of uncertainty in the quantification of the historical pattern effect using atmosphere-only ESMs that has yet to be systematically explored, but the preliminary findings of Lewis and Mauritsen (2021) and Fueglistaler and Silvers (2021) suggest that α' could be smaller than the values reported in Andrews et al. (2018).

While there are not yet direct observational constraints on the magnitude of the pattern effect, satellite measurements of variations in TOA radiative fluxes show strong co-variation with changing patterns of SSTs, with a strong dependence on SST changes in regions of deep convective ascent (e.g., in the western Pacific warm pool; Loeb et al., 2018a; Fueglistaler, 2019). Cloud and TOA radiation responses to observed warming patterns in atmospheric models have been found to compare favourably with those observed by satellite (Section 7.2.2.1 and Figure 7.3; Zhou et al., 2016; Loeb et al., 2020). This observational and modelling evidence indicates the potential for a strong pattern effect in nature that will only be negligible if the observed pattern of warming since pre-industrial levels persists to

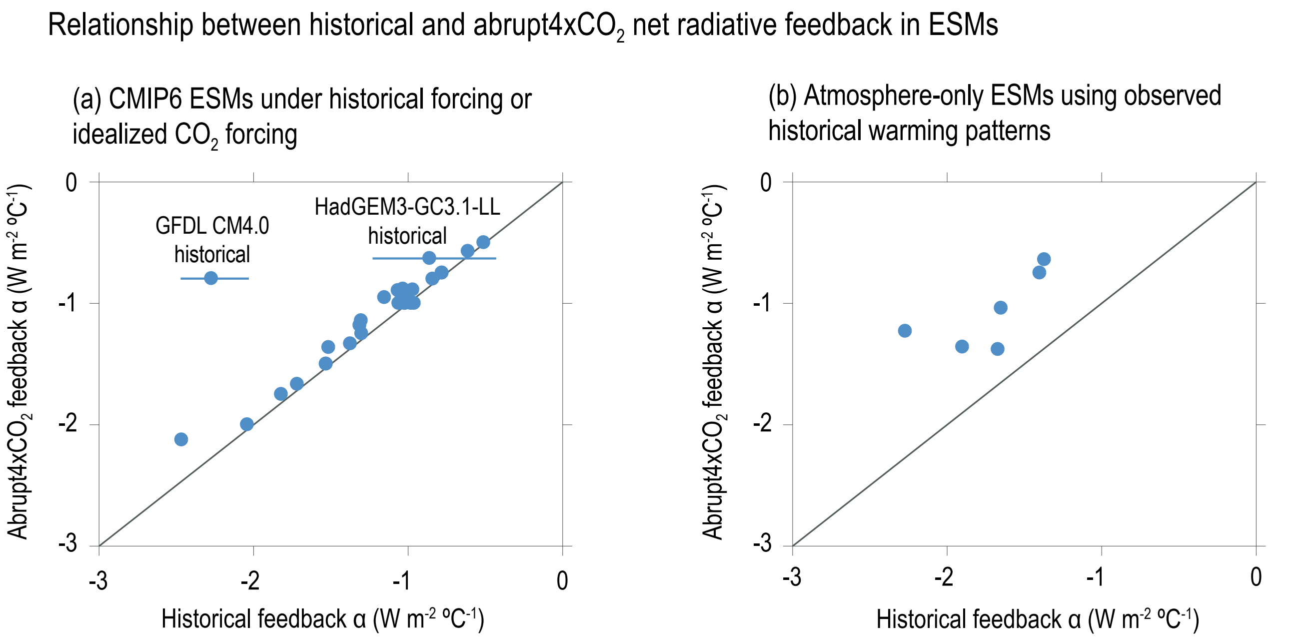


Figure 7.15 | Relationship between *historical* and *abrupt4xCO2* net radiative feedbacks in ESMs. (a) Radiative feedbacks in CMIP6 ESMs estimated under historical forcing (values for GFDL CM4.0 and HadGEM3-CG3.1-LL from Winton et al. (2020) and Andrews et al. (2019), respectively); horizontal lines show the range across ensemble members. The other points show effective feedback values for 29 ESMs estimated using regression over the first 50 years of *abrupt4xCO2* simulations as an analogue for historical warming (Dong et al., 2020). **(b)** Historical radiative feedbacks estimated from atmosphere-only ESMs with prescribed observed sea-surface temperature and sea-ice concentration changes (Andrews et al., 2018) based on a linear regression of global top-of-atmosphere (TOA) radiation against global near-surface air temperature over the period 1870–2010 (pattern of warming similar to Figure 7.14a) and compared with equilibrium feedbacks in *abrupt4xCO2* simulations of coupled versions of the same ESMs (pattern of warming similar to Figure 7.14b). In all cases, the equilibrium feedback magnitudes are estimated as CO_2 ERF divided by ECS where ECS is derived from regression over years 1–150 of *abrupt4xCO2* simulations (Box 7.1); similar results are found if the equilibrium feedback is estimated directly from the slope of the linear regression. Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

equilibrium – an improbable scenario given that Earth is in a relatively early phase of transient warming and that reaching equilibrium would take multiple millennia (C. Li et al., 2013). Moreover, paleoclimate proxies, ESM simulations, and process understanding indicate that strong warming in the eastern equatorial Pacific Ocean (with *medium confidence*) and Southern Ocean (with *high confidence*) will emerge on centennial time scales as the response to CO_2 forcing dominates temperature changes in these regions (Sections 7.4.4.1, 7.4.4.2 and 9.2.1). However, there is *low confidence* that these features, which have been largely absent over the historical record, will emerge this century (Sections 7.4.4.1, 7.4.4.2 and Section 9.2.1). This leads to *high confidence* that radiative feedbacks will become less negative as the CO_2-forced pattern of surface warming emerges ($\alpha' > 0$ W m^{-2} °C^{-1}), but *low confidence* that these feedback changes will be realized this century. There is also substantial uncertainty in the magnitude of the net radiative feedback change between the present warming pattern and the projected equilibrium warming pattern in response to CO_2 forcing owing to the fact that its quantification currently relies solely on ESM results and is subject to uncertainties in historical SST patterns. Thus, based on the pattern of warming since 1870, α' is estimated to be in the range 0.0 to 1.0 W m^{-2} °C^{-1} but with a *low confidence* in the upper end of this range. A value of $\alpha' = +0.5 \pm 0.5$ W m^{-2} °C^{-1} is used to represent this range in Box 7.2 and Section 7.5.2, which respectively assess the implications of changing radiative feedbacks for Earth's energy imbalance and estimates of ECS based on the instrumental record. The value of α' is larger if quantified based on the observed pattern of warming since 1980 (Figure 2.11b) which is more distinct from the equilibrium warming pattern expected under CO_2 forcing (*high confidence*) (similar to CMIP6 projections shown in Figure 7.12a; Andrews et al., 2018).

7.5 Estimates of ECS and TCR

Equilibrium climate sensitivity (ECS) and transient climate response (TCR) are metrics of the global surface air temperature (GSAT) response to forcing, as defined in Box 7.1. ECS is the magnitude of the long-term GSAT increase in response to a doubling of atmospheric CO_2 concentration after the planetary energy budget is balanced, though leaving out feedbacks associated with ice sheets; whereas the TCR is the magnitude of GSAT increase at year 70 when CO_2 concentration is doubled in a 1% yr^{-1} increase scenario. Both are idealized quantities, but can be inferred from paleoclimate or observational records or estimated directly using climate simulations, and are strongly correlated with the climate response in realistic future projections (Sections 4.3.4 and 7.5.7; Grose et al., 2018).

TCR is always smaller than ECS because ocean heat uptake acts to reduce the rate of surface warming. Yet, TCR is related to ECS across CMIP5 and CMIP6 models (Grose et al., 2018; Flynn and Mauritsen, 2020) as expected since TCR and ECS are inherently measures of climate response to forcing; both depend on effective radiative forcing (ERF) and the net feedback parameter, α. The relationship between TCR and ECS is, however, non-linear and becomes more so for higher ECS values (Hansen et al., 1985; Knutti et al., 2005; Millar et al., 2015; Flynn and Mauritsen, 2020; Tsutsui, 2020) owing to ocean heat uptake processes and surface temperature pattern effects temporarily reducing the rate of surface warming. When α is small in magnitude, and correspondingly ECS is large (recall that ECS is inversely proportional to α), these temporary effects are increasingly important in reducing the ratio of TCR to ECS.

Before AR6, the assessment of ECS relied on either CO_2-doubling experiments using global atmospheric models coupled with mixed-layer ocean or standardized CO_2-quadrupling (*abrupt4xCO2*) experiments using fully coupled ocean–atmosphere models or Earth system models (ESMs). The TCR has similarly been diagnosed from ESMs in which the CO_2 concentration is increased at 1% yr^{-1} (*1pctCO₂*, an approximately linear increase in ERF over time) and is in practice estimated as the average over a 20-year period centred at the time of atmospheric CO_2 doubling, that is, year 70. In AR6, the assessments of ECS and TCR are made based on multiple lines of evidence, with ESMs representing only one of several sources of information. The constraints on these climate metrics are based on radiative forcing and climate feedbacks assessed from process understanding (Section 7.5.1), climate change and variability seen within the instrumental record (Section 7.5.2), paleoclimate evidence (Section 7.5.3), emergent constraints (Section 7.5.4), and a synthesis of all lines of evidence (Section 7.5.5). In AR5, these lines of evidence were not explicitly combined in the assessment of climate sensitivity, but as demonstrated by Sherwood et al. (2020) their combination narrows the uncertainty ranges of ECS compared to that assessed in AR5. ECS values found in CMIP6 models, some of which exhibit values higher than 5°C (Meehl et al., 2020; Zelinka et al., 2020), are discussed in relation to the AR6 assessment in section 7.5.6.

7.5.1 Estimates of ECS and TCR Based on Process Understanding

This section assesses the estimates of ECS and TCR based on process understanding of the ERF due to a doubling of CO_2 concentration and the net climate feedback (Sections 7.3.2 and 7.4.2). This process-based assessment is made in Section 7.5.1.1 and applied to TCR in Section 7.5.1.2.

7.5.1.1 ECS Estimated Using Process-based Assessments of Forcing and Feedbacks

The process-based assessment is based on the global energy budget equation (Box 7.1, Equation 7.1), where the ERF (ΔF) is set equal to the effective radiative forcing due to a doubling of CO_2 concentration (denoted as $\Delta F_{2\times CO2}$) and the climate state reaches a new equilibrium, that is, Earth's energy imbalance averages to zero ($\Delta N = 0$). ECS is calculated as the ratio between the ERF and the net feedback parameter: ECS = $-\Delta F_{2\times CO2}/\alpha$. Estimates of $\Delta F_{2\times CO2}$ and α are obtained separately based on understanding of the key processes that determine each of these quantities. Specifically, $\Delta F_{2\times CO2}$ is estimated based on instantaneous radiative forcing that can be accurately obtained using line-by-line calculations, to which uncertainty due to adjustments are added (Section 7.3.2). The range of α is derived by aggregating estimates of individual climate feedbacks based not only on ESMs but also on theory, observations, and high-resolution process modelling (Section 7.4.2).

The effective radiative forcing of CO_2 doubling is assessed to be $\Delta F_{2\times CO2} = 3.93 \pm 0.47$ W m^{-2} (Section 7.3.2.1), while the net feedback parameter is assessed to be $\alpha = -1.16 \pm 0.40$ W m^{-2} °C^{-1} (Table 7.10), where the ranges indicate one standard deviation. These values are slightly different from those directly calculated from ESMs because more information is used to assess them, as explained above. Assuming $\Delta F_{2\times CO2}$ and α each follow an independent normal distribution, the uncertainty range of ECS can be obtained by substituting the respective probability density function into the expression of ECS (red curved bar in Figure 7.16). Since α is in the denominator, the normal distribution leads to a long tail in ECS towards high values, indicating the large effect of uncertainty in α in estimating the likelihood of a high ECS (Roe and Baker, 2007; Knutti and Hegerl, 2008).

The wide range of the process-based ECS estimate is not due solely to uncertainty in the estimates of $\Delta F_{2\times CO2}$ and α, but is partly explained by the assumption that $\Delta F_{2\times CO2}$ and α are independent in this approach. In CMIP5 and CMIP6 ensembles, $\Delta F_{2\times CO2}$ and α are negatively correlated when they are calculated using linear regression in *abrupt4xCO2* simulations ($r^2 = 0.34$; Andrews et al., 2012; Webb et al., 2013; Zelinka et al., 2020). The negative correlation leads to compensation between the inter-model spreads of these quantities, thereby reducing the ECS range estimated directly from the models. If the process-based ECS distribution is reconstructed from probability distributions of $\Delta F_{2\times CO2}$ and α assuming that they are correlated as in CMIP model ensembles, the range of ECS will be narrower by 14% (pink curved bar in Figure 7.16). If, however, the covariance between $\Delta F_{2\times CO2}$ and α is not adopted, there is no change in the mean, but the wide range still applies.

A significant correlation between $\Delta F_{2\times CO2}$ and α also occurs when the two parameters are estimated separately from atmospheric ESM fixed-SST experiments (Section 7.3.1) or fixed CO_2 concentration experiments (Section 7.4.1; Ringer et al., 2014; Chung and Soden, 2018). Hence the relationship is not expected to be an artefact of calculating the parameters using linear regression in *abrupt4xCO2* simulations. A possible physical cause of the correlation may be a compensation between the cloud adjustment and the cloud feedback over the tropical ocean (Ringer et al., 2014; Chung and Soden, 2018). It has been shown that the change in the hydrological cycle is a controlling factor for the low-cloud adjustment (Dinh and Fueglistaler, 2019) and for the low-cloud feedback (Watanabe et al., 2018), and therefore the responses of these clouds to the direct CO_2 radiative forcing and to the surface warming may not be independent. However, robust physical mechanisms are not yet established, and furthermore, the process-based assessment of the tropical low-cloud feedback is only indirectly based on ESMs given that physical processes which control the low-clouds are not sufficiently well-simulated in models (Section 7.4.2.4). For these reasons, the co-dependency between $\Delta F_{2\times CO2}$ and α is assessed to have *low confidence* and, therefore, the more conservative assumption that they are independent for the process-based assessment of ECS is retained.

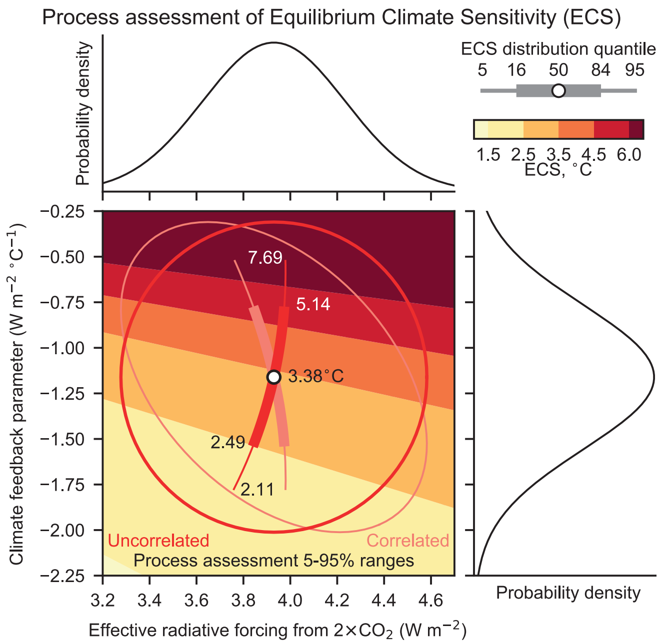


Figure 7.16 | Probability distributions of ERF to CO_2 doubling ($\Delta F_{2\times CO2}$; top) and the net climate feedback (α; right), derived from process-based assessments in Sections 7.3.2 and 7.4.2. Central panel shows the joint probability density function calculated on a two-dimensional plane of $\Delta F_{2\times CO2}$ and α (red), on which the 90% range shown by an ellipse is imposed to the background theoretical values of ECS (colour shading). The white dot, and thick and thin curves inside the ellipse represent the mean, *likely* and *very likely* ranges of ECS. An alternative estimation of the ECS range (pink) is calculated by assuming that $\Delta F_{2\times CO2}$ and α have a covariance. The assumption about the co-dependence between $\Delta F_{2\times CO2}$ and α does not alter the mean estimate of ECS but affects its uncertainty. Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

In summary, the ECS based on the assessed values of $\Delta F_{2\times CO2}$ and α is assessed to have a median value of 3.4°C with a *likely* range of 2.5 to 5.1 °C and *very likely* range of 2.1 to 7.7 °C. To this assessed range of ECS, the contribution of uncertainty in α is approximately three times as large as the contribution of uncertainty in $\Delta F_{2\times CO2}$.

7.5.1.2 Emulating Process-based ECS to TCR

ECS estimated using the ERF due to a doubling of CO_2 concentration and the net feedback parameter (ECS = $-\Delta F_{2\times CO2}/\alpha$) can be translated into the TCR so that both climate sensitivity metrics provide consistent information about the climate response to forcing. Here a two-layer energy budget emulator is used to transfer the process-based assessment of forcing, feedback, efficacy and heat uptake to TCR (Supplementary Material 7.SM.2.1 and Cross-Chapter Box 7.1). The emulator can reproduce the transient surface temperature evolution in ESMs under *1pctCO₂* simulations and other climate change scenarios, despite the very low number of degrees of freedom (Held et al., 2010; Geoffroy et al., 2012, 2013a; Palmer et al., 2018). Using this model with parameters given from assessments in Sections 7.2, 7.3, and 7.4, TCR is assessed based on the process-based understanding.

In the two-layer energy balance emulator, additional parameters are introduced: heat capacities of the upper and deep ocean, heat uptake efficiency (γ), and the so-called efficacy parameter (ε) that represents the dependence of radiative feedbacks and heat uptake on the evolving SST pattern under CO_2 forcing alone (Section 7.4.4). In the real world, natural internal variability and aerosol radiative forcing also affect the efficacy parameter, but these effects are excluded for the current discussion.

The analytical solution of the energy balance emulator reveals that the global surface temperature change to abrupt increase of the atmospheric CO_2 concentration is expressed by a combination of a fast adjustment of the surface components of the climate system and a slow response of the deep ocean, with time scales of several years and several centuries, respectively (grey curve in Figure 7.17b). The equilibrium response of upper ocean temperature, approximating SST and the surface air temperature response, depends, by definition, only on the radiative forcing and the net feedback parameter. Uncertainty in α dominates (80–90%) the corresponding uncertainty range for ECS in CMIP5 models (Vial et al., 2013), and also an increase of ECS in CMIP6 models (Section 7.5.5) is attributed by about 60–80% to a change in α (Zelinka et al., 2020). For the range of TCR, the contribution from uncertainty in α is reduced to 50–60% while uncertainty in $\Delta F_{2\times CO2}$ becomes relatively more important (Geoffroy et al., 2012; Lutsko and Popp, 2019). TCR reflects the fast response occurring approximately during the first 20 years in the *abrupt4xCO2* simulation (Held et al., 2010), but the fast response is not independent of the slow response because there is a non-linear co-dependence between them (Andrews et al., 2015). The non-linear relationship between ECS and TCR indicates that the probability of high TCR is not very sensitive to changes in the probability of high ECS (Meehl et al., 2020).

Considering an idealized time evolution of ERF (1% increase per year until CO_2 doubling and held fixed afterwards, see Figure 7.17a), the TCR defined by the surface temperature response at year 70 is derived by substituting the process-based ECS into the analytical solution of the emulator (Figure 7.17b, see also Supplementary Material 7.SM.2.1). When additional parameters in the emulator are prescribed by using CMIP6 multi-model mean values of those estimates (Smith et al., 2020b), this calculation translates the range of ECS in Section 7.5.2.1 to the range of TCR. The transient temperature response, in reality, varies with different estimates of the ocean heat uptake efficiency (γ) and efficacy (ε). When the emulator was calibrated to the transient responses in CMIP5 models, it shows that uncertainty in heat capacities is negligible and differences in γ and ε explain 10–20% of the inter-model spread of TCR among GCMs (Geoffroy et al., 2012). Specifically, their product, $\kappa = \gamma\varepsilon$, appearing in a simplified form of the solution, that is, TCR $\cong -\Delta F_{2\times CO2}/(\alpha - \kappa)$, gives a single parameter quantifying the damping effects of heat uptake (Jiménez-de-la-Cuesta and Mauritsen, 2019). This parameter is positive and acts to slow down the temperature response in a similar manner to the 'pattern effect' (Sections 7.4.4.3 and 7.5.2.1). The ocean heat uptake in nature is controlled by multiple processes associated with advection and mixing (Exarchou et al., 2014; Kostov et al., 2014; Kuhlbrodt et al., 2015) but is simplified to be represented by a single term of heat exchange between the upper and deep ocean in the emulator. Therefore, it is challenging to constrain γ and ε from process-based understanding (Section 7.5.2). Because the estimated values are only weakly correlated across models, the mean value and one standard deviation of κ are calculated as

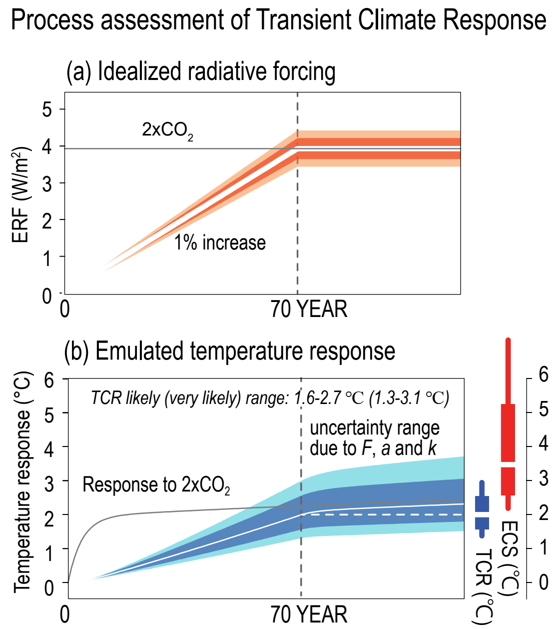


Figure 7.17 | (a) Time evolution of the effective radiative forcing (ERF) to the CO_2 concentration increased by 1% per year until year 70 (equal to the time of doubling) and kept fixed afterwards (white line). The *likely* and *very likely* ranges of ERF indicated by light and dark orange have been assessed in Section 7.3.2.1. **(b)** Surface temperature response to the CO_2 forcing calculated using the emulator with a given value of ECS, considering uncertainty in $\Delta F_{2\times CO2}$, α, and κ associated with the ocean heat uptake and efficacy (white line). The *likely* and *very likely* ranges are indicated by cyan and blue, respectively. For comparison, the temperature response to abrupt doubling of the CO_2 concentration is displayed by a grey curve. The mean, *likely* and *very likely* ranges of ECS and TCR are shown at the right (the values of TCR also presented in the panel). Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

$\kappa = 0.84 \pm 0.38$ W m^{-2} °C^{-1} (one standard deviation) by ignoring their covariance (the mean value is very similar to that used for Box 4.1, Figure 1; see Supplementary Material 7.SM.2.1). By incorporating this inter-model spread in κ, the range of TCR is widened by about 10% (blue bar in Figure 7.17b). Yet, the dominant contribution to the uncertainty range of TCR arises from the net feedback parameter α, consistent with analyses of CMIP6 models (Williams et al., 2020), and this assessment remains unchanged from AR5 stating that uncertainty in ocean heat uptake is of secondary importance.

In summary, the process-based estimate of TCR is assessed to have the central value of 2.0°C with the *likely* range from 1.6 to 2.7 °C and the *very likely* range from 1.3 to 3.1 °C (*high confidence*). The upper bound of the assessed range was slightly reduced from AR5 but can be further constrained using multiple lines of evidence (Section 7.5.5).

7.5.2 Estimates of ECS and TCR Based on the Instrumental Record

This section assesses the estimates of ECS and TCR based on the instrumental record of climate change and variability with an emphasis on new evidence since AR5. Several lines of evidence are assessed including the global energy budget (Section 7.5.2.1), the use of simple climate models evaluated against the historical temperature record (Section 7.5.2.2), and internal variability in global temperature and TOA radiation (Section 7.5.2.3). Section 7.5.2.4 provides an overall assessment of TCR and ECS based on these lines of evidence from the instrumental record.

7.5.2.1 Estimates of ECS and TCR Based on the Global Energy Budget

The GSAT change from 1850–1900 to 2006–2019 is estimated to be 1.03 [0.86 to 1.18] °C (Cross-chapter Box 2.3). Together with estimates of Earth's energy imbalance (Section 7.2.2) and the global ERF that has driven the observed warming (Section 7.3), the instrumental temperature record enables global energy budget estimates of ECS and TCR. While energy budget estimates use instrumental data, they are not based purely on observations. A conceptual model typically based on the global mean forcing and response energy budget framework (Box 7.1) is needed to relate ECS and TCR to the estimates of global warming, ERF and Earth's energy imbalance (Forster, 2016; Knutti et al., 2017). Moreover, ESM simulations partly inform estimates of the historical ERF (Section 7.3) as well as Earth's energy imbalance in the 1850–1900 climate (the period against which changes are measured; Forster, 2016; Lewis and Curry, 2018). ESMs are also used to estimate uncertainty due the internal climate variability that may have contributed to observed changes in temperature and energy imbalance (e.g., Palmer and McNeall, 2014; Sherwood et al., 2020). Research since AR5 has shown that global energy budget estimates of ECS may be biased low when they do not take into account how radiative feedbacks depend on the spatial pattern of surface warming (Section 7.4.4.3) or when they do not incorporate improvements in the estimation of global surface temperature trends which take better account of data-sparse regions and are more consistent in their treatment of surface temperature data (Section 2.3.1). Together with updated estimates of global ERF and Earth's energy imbalance, these advances since AR5 have helped to reconcile energy budget estimates of ECS with estimates of ECS from other lines of evidence.

The traditional global mean forcing and response energy budget framework (Section 7.4.1 and Box 7.1; Gregory et al., 2002) relates the difference between the ERF (ΔF) and the radiative response to observed global warming ($\alpha\Delta T$) to the Earth's energy imbalance (ΔN): $\Delta N = \alpha\Delta T + \Delta F$. Given the relationship ECS $= -\Delta F_{2\times CO2}/\alpha$, where $\Delta F_{2\times CO2}$ is the ERF from CO_2 doubling, ECS can be estimated from historical estimates of ΔT, ΔF, ΔN and $\Delta F_{2\times CO2}$: ECS $= \Delta F_{2\times CO2}\Delta T/(\Delta F - \Delta N)$. Since TCR is defined as the temperature change at the time of CO_2 doubling under an idealized 1% yr^{-1} CO_2 increase, it can be inferred from the historical record as: TCR $= \Delta F_{2\times CO2}\,\Delta T/\Delta F$, under the assumption that radiative forcing increases quickly compared to the adjustment time scales of the deep ocean, but slowly enough and over a sufficiently long time that the upper ocean is adjusted, so that ΔT and ΔN increases approximately in proportion to ΔF. Because ΔN is positive, TCR is always smaller than ECS, reflecting weaker transient warming than equilibrium warming. TCR is better constrained than ECS owing to the fact that the denominator of TCR, without the quantity ΔN, is more certain and further from zero than is the denominator of ECS. The upper bounds of both TCR and ECS estimated from historical warming are inherently less certain than their lower bounds because ΔF is uncertain and in the denominator.

The traditional energy budget framework lacks a representation of how radiative feedbacks depend on the spatial pattern of warming. Thus, studies employing this framework (Otto et al., 2013; Lewis and Curry, 2015, 2018; Forster, 2016) implicitly assume that the net radiative feedback has a constant magnitude, producing an estimate of the effective ECS (defined as the value of ECS that would occur if α does not change from its current value) rather than of the true ECS. As summarized in Section 7.4.4.3, there are now multiple lines of evidence providing *high confidence* that the net radiative feedback will become less negative as the warming pattern evolves in the future (the pattern effect). This arises because historical warming has been relatively larger in key negative feedback regions (e.g., western tropical Pacific Ocean) and relatively smaller in key positive feedback regions (e.g., eastern tropical Pacific Ocean and Southern Ocean) than is projected in the near-equilibrium response to CO_2 forcing (Section 7.4.4.3; Held et al., 2010; Proistosescu and Huybers, 2017; Dong et al., 2019), implying that the true ECS will be larger than the effective ECS inferred from historical warming. This section first assesses energy budget constraints on TCR and the effective ECS based on updated estimates of historical warming, ERF, and Earth's energy imbalance. It then assesses what these energy budget constraints imply for values of ECS once the pattern effect is accounted for.

Energy budget estimates of TCR and ECS have evolved in the literature over recent decades. Prior to AR4, the global energy budget provided relatively weak constraints, primarily due to large uncertainty in the tropospheric aerosol forcing, giving ranges of the effective ECS that typically included values above 10°C (Forster, 2016; Knutti et al., 2017). Revised estimates of aerosol forcing together with a larger greenhouse gas forcing by the time of AR5 led to an estimate of ΔF that was more positive and with reduced uncertainty relative to AR4. Using energy budget estimates and radiative forcing estimates updated to 2009, Otto et al. (2013) estimated that TCR was 1.3 [0.9 to 2.0] °C, and that the effective ECS was 2.0 [1.2 to 3.9] °C. This AR5-based energy budget estimate of ECS was lower than estimates based on other lines of evidence, leading AR5 to expand the assessed *likely* range of ECS to include lower values relative to AR4. Studies since AR5 using similar global energy budget methods have produced similar or slightly narrower ranges for TCR and effective ECS (Forster, 2016; Knutti et al., 2017).

Energy budget estimates of TCR and ECS assessed here are based on improved observations and understanding of global surface temperature trends extended to the year 2020 (Section 2.3.1), revised estimates of Earth's energy imbalance (Section 7.2), and revised estimates of ERF (Section 7.3). Accurate, in situ-based estimates of Earth's energy imbalance can be made from around 2006 based on near-global ocean temperature observations from the ARGO array of autonomous profiling floats (Sections 2.3 and 7.2). Over the period 2006–2018 the Earth's energy imbalance is estimated to be 0.79 ± 0.27 W m^{-2} (Section 7.2) and it is assumed that this value is also representative for the period 2006–2019. Anomalies are taken with respect to the baseline period 1850–1900, although other baselines could be chosen to avoid major volcanic activity (Otto et al., 2013; Lewis and Curry, 2018). Several lines of evidence, including ESM simulations (Lewis and Curry, 2015), energy balance modelling (Armour, 2017), inferred ocean warming given observed SSTs using ocean models (Gebbie and Huybers, 2019; Zanna et al., 2019), and ocean warming reconstructed from noble gas thermometry (Baggenstos et al., 2019) suggest a 1850–1900 Earth energy imbalance of 0.2 ± 0.2 W m^{-2}. Combined with estimates of internal variability in Earth's energy imbalance, calculated using periods of equivalent lengths of years as used in unforced ESM simulations (Palmer and McNeall, 2014; Sherwood et al., 2020), the anomalous energy imbalance between 1850–1900 and 2006–2019 is estimated to be $\Delta N = 0.59 \pm 0.35$ W m^{-2}. GSAT change between 1850–1900 and 2006–2019 is estimated to be $\Delta T = 1.03°C \pm 0.20$ °C (Cross-Chapter Box 2.3 and Box 7.2) after accounting for internal temperature variability derived from unforced ESM simulations (Sherwood et al., 2020). The ERF change between 1850–1900 and 2006–2019 is estimated to be $\Delta F = 2.20$ [1.53 to 2.91] W m^{-2} (Section 7.3.5) and the ERF for a doubling of CO_2 is estimated to be $\Delta F_{2\times CO2} = 3.93 \pm 0.47$ W m^{-2} (Section 7.3.2). Employing these values within the traditional global energy balance framework described above (following the methods of Otto et al. (2013) and accounting for correlated uncertainties between ΔF and $\Delta F_{2\times CO2}$) produces a TCR of 1.9 [1.3 to 2.7] °C and an effective ECS of 2.5 [1.6 to 4.8] °C. These TCR and effective ECS values are higher than those in the recent literature (Otto et al., 2013; Lewis and Curry, 2015, 2018) but are comparable to those of Sherwood et al. (2020) who also used updated estimates of observed warming, Earth's energy imbalance, and ERF.

The trend estimation method applied to global surface temperature affects derived values of ECS and TCR from the historical record. In this Report, the effective ECS is inferred from estimates that use global coverage of GSAT to estimate the surface temperature trends. The GSAT trend is assessed to have the same best estimate as the observed global mean surface temperature (GMST), although the GSAT trend is assessed to have larger uncertainty (see Cross-Chapter Box 2.3). Many previous studies have relied on HadCRUT4 GMST estimates that used the blended observations and did not interpolate over regions of incomplete observational coverage such as the Arctic. As a result, the ECS and TCR derived from these studies has smaller ECS and TCR values than those derived from model-inferred estimates (M. Richardson et al., 2016, 2018). The energy budget studies assessing ECS in AR5 employed HadCRUT4 or similar measures of GMST trends. As other lines of evidence in that report used GSAT trends, this could partly explain why AR5-based energy budget estimates of ECS were lower than those estimated from other lines of evidence, adding to the overall disparity in M. Collins et al. (2013). In this report, GSAT is chosen as the standard measure of global surface temperature to aid comparison with previous model- and process-based estimates of ECS, TCR and climate feedbacks (see Cross-Chapter Box 2.3).

The traditional energy budget framework has been evaluated within ESM simulations by comparing the effective ECS estimated under historical forcing with the ECS estimated using regression methods (Box 7.1) under *abrupt4xCO2* (Andrews et al., 2019; Winton et al., 2020). For one CMIP6 model (GFDL-CM4.0), the value of effective ECS derived from historical energy budget constraints is 1.8°C while ECS is estimated to be 5.0°C (Winton et al., 2020). For another model

(HadGEM3-GC3.1-LL) the effective ECS derived from historical energy budget constraints is 4.1°C (average of four ensemble members) while ECS is estimated to be 5.5°C (Andrews et al., 2019). These modelling results suggest that the effective ECS under historical forcing could be lower than the true ECS owing to differences in radiative feedbacks induced by the distinct patterns of historical and equilibrium warming (Section 7.4.4.3). Using GFDL-CM4, Winton et al. (2020) also find that the value of TCR estimated from energy budget constraints within a historical simulation (1.3°C) is substantially lower than the true value of TCR (2.1°C) diagnosed within a *1pctCO₂* simulation owing to a combination of the pattern effect and differences in the efficiency of ocean heat uptake between historical and *1pctCO₂* forcing. This section next considers how the true ECS can be estimated from the historical energy budget by accounting for the pattern effect. However, owing to *limited evidence* this section does not attempt to account for these effects in estimates of TCR.

Research since AR5 has introduced extensions to the traditional energy budget framework that account for the feedback dependence on temperature patterns by allowing for multiple radiative feedbacks operating on different time scales (Armour et al., 2013; Geoffroy et al., 2013a; Armour, 2017; Proistosescu and Huybers, 2017; Goodwin, 2018; Rohrschneider et al., 2019), by allowing feedbacks to vary with the spatial pattern or magnitude of ocean heat uptake (Winton et al., 2010; Rose et al., 2014; Rugenstein et al., 2016a), or by allowing feedbacks to vary with the type of radiative forcing agent (Kummer and Dessler, 2014; Shindell, 2014; Marvel et al., 2016; Winton et al., 2020). A direct way to account for the pattern effect is to use the relationship ECS = $-\Delta F_{2\times CO2}/(\alpha + \alpha')$, where $\alpha = (\Delta N - \Delta F)/\Delta T$ is the effective feedback parameter (Box 7.1) estimated from historical global energy budget changes and α' represents the change in the feedback parameter between the historical period and the equilibrium response to CO_2 forcing, which can be estimated using ESMs (Section 7.4.4.3; Armour, 2017; Andrews et al., 2018, 2019; Lewis and Curry, 2018; Dong et al., 2020; Winton et al., 2020).

The net radiative feedback change between the historical warming pattern and the projected equilibrium warming pattern in response to CO_2 forcing (α') is estimated to be in the range 0.0 to 1.0 W m^{-2} °C^{-1} (Figure 7.15). Using the value $\alpha' = +0.5 \pm 0.5$ W m^{-2} °C^{-1} to represent this range illustrates the effect of changing radiative feedbacks on estimates of ECS. While the effective ECS inferred from historical warming is 2.5 [1.6 to 4.8] °C, ECS = $-\Delta F_{2\times CO2}/(\alpha + \alpha')$ is 3.5 [1.7 to 13.8] °C. For comparison, values of α' derived from the response to historical and idealized CO_2 forcing within coupled climate models (Armour, 2017; Lewis and Curry, 2018; Andrews et al., 2019; Dong et al., 2020; Winton et al., 2020) can be approximated as $\alpha' = +0.1 \pm 0.3$ W m^{-2} °C^{-1} (Section 7.4.4.3), corresponding to a value of ECS of 2.7 [1.7 to 5.9] °C. In both cases, the low end of the ECS range is similar to that of the effective ECS inferred using the traditional energy balance model framework that assumes $\alpha' = 0$, reflecting a weak dependence on the value of α' when ECS is small (Armour, 2017; Andrews et al., 2018); the low end of the ECS range is robust even in the hypothetical case that α' is slightly negative. However, the high end of the ECS range is substantially larger than that of the effective ECS and strongly dependent on the value of α'.

The values of ECS obtained from the techniques outlined above are all higher than those estimated from both AR5 and recently published estimates (M. Collins et al., 2013; Otto et al., 2013; Lewis and Curry, 2015, 2018; Forster, 2016). Four revisions made in this Report are responsible for this increase: (i) an upwards revision of historic global surface temperature trends from newly published trend estimates (Section 2.3.1); (ii) an 8% increase in the ERF for $\Delta F_{2\times CO2}$ (Section 7.3.2); (iii) a more negative central estimate of aerosol ERF, which acts to reduce estimates of historical ERF trends; and (iv) accounting for the pattern effect in ECS estimates. Values of ECS provided here are similar to those based on the historical energy budget found in Sherwood et al. (2020), with small differences owing to methodological differences and the use of different estimates of observed warming, Earth's energy imbalance, and ERF.

Overall, there is *high confidence* that the true ECS is higher than the effective ECS as inferred from the historical global energy budget, but there is substantial uncertainty in how much higher because of *limited evidence* regarding how radiative feedbacks may change in the future. While several lines of evidence indicate that $\alpha' > 0$, the quantitative accuracy of feedback changes is not known at this time (Section 7.4.4.3). Global energy budget constraints thus provide *high confidence* in the lower bound of ECS which is not sensitive to the value of α': ECS is *extremely unlikely* to be less than 1.6°C. Estimates of α' that are informed by idealized CO_2 forcing simulations of coupled ESMs (Armour, 2017; Lewis and Curry, 2018; Andrews et al., 2019; Dong et al., 2020; Winton et al., 2020) indicate a median value of ECS of around 2.7°C while estimates of α' that are informed by observed historical sea surface temperature patterns (Andrews et al., 2018) indicate a median value of ECS of around 3.5°C. Owing to large uncertainties in future feedback changes, the historical energy budget currently provides little information about the upper end of the ECS range.

7.5.2.2 Estimates of ECS and TCR Based on Climate Model Emulators

Energy budget emulators are far less complex than comprehensive ESMs (Section 1.5.3 and Cross-Chapter Box 7.1). For example, an emulator could represent the atmosphere, ocean, and land using a small number of connected boxes (e.g., Goodwin, 2016), or it could represent the global mean climate using two connected ocean layers (e.g., Cross-Chapter Box 7.1 and Supplementary Material 7.SM.2). The numerical efficiency of emulators means that they can be empirically constrained by observations: a large number of possible parameter values (e.g., feedback parameter, aerosol radiative forcing, and ocean diffusivity) are randomly drawn from prior distributions; forward integrations of the model are performed with these parameters and weighted against observations of surface or ocean warming, producing posterior estimates of quantities of interest such as TCR, ECS and aerosol forcing (Section 7.3). Owing to their reduced complexity, emulators lack full representations of the spatial patterns of sea surface temperature and radiative responses to changes in those patterns (discussed in Section 7.4.4.3) and many represent the net feedback parameter using a constant value. The ranges of ECS reported by studies using emulators are thus interpreted here as representative of the effective ECS over the historical record rather than of the true ECS.

Improved estimates of ocean heat uptake over the past two decades (Section 7.2) have diminished the role of ocean diffusivity in driving uncertainty in ECS estimates, leaving the main trade-off between posterior ranges in ECS and aerosol radiative forcing (Forest, 2002; Knutti et al., 2002; Frame et al., 2005). The AR5 (Bindoff et al., 2013) assessed a variety of estimates of ECS based on emulators and found that they were sensitive to the choice of prior parameter distributions and temperature datasets used, particularly for the upper end of the ECS range, though priors can be chosen to minimize the effect on results (e.g., Lewis, 2013). Emulators generally produced estimates of effective ECS between 1°C and 5°C and ranges of TCR between 0.9°C and 2.6°C. Padilla et al. (2011) use a simple global-average emulator with two time scales (Section 7.5.1.2; Supplementary Material 7.SM.2) to estimate a TCR of 1.6 [1.3 to 2.6] °C. Using the same model, Schwartz (2012) finds TCR in the range 0.9°C–1.9°C while Schwartz (2018) finds that an effective ECS of 1.7°C provides the best fit to the historical global surface temperature record while also finding a median aerosol forcing that is smaller than that assessed in Section 7.3. Using an eight-box representation of the atmosphere–ocean–terrestrial system constrained by historical warming, Goodwin (2016) found an effective ECS of 2.4 [1.4 to 4.4] °C while Goodwin (2018) found effective ECS to be in the range 2°C–4.3°C when using a prior for ECS based on paleoclimate constraints.

Using an emulator comprised of Northern and Southern hemispheres and an upwelling-diffusive ocean (Aldrin et al., 2012), with surface temperature and ocean heat content datasets updated to 2014, Skeie et al. (2018) estimate a TCR of 1.4 [0.9 to 2.0] °C and a median effective ECS of 1.9 [1.2 to 3.1] °C. Using a similar emulator comprised of land and ocean regions and an upwelling-diffusive ocean, with global surface temperature and ocean heat content datasets up to 2011, Johansson et al. (2015) find an effective ECS of 2.5 [2.0 to 3.2] °C. The estimate is found to be sensitive to the choice of dataset endpoint and the representation of internal variability meant to capture the El Niño–Southern Oscillation and Pacific Decadal Variability. Differences between these two studies arise, in part, from their different global surface temperature and ocean heat content datasets, different radiative forcing uncertainty ranges, different priors for model parameters, and different representations of internal variability. This leads to different estimates of effective ECS, with the median estimate of Skeie et al. (2018) lying below the 5–95% range of effective ECS from Johansson et al. (2015). Moreover, while the Skeie et al. (2018) emulator has a constant value of the net feedback parameter, the Johansson et al. (2015) emulator allows distinct radiative feedbacks for land and ocean, contributing to the different results.

The median estimates of TCR and effective ECS inferred from emulator studies generally lie within the 5–95% ranges of those inferred from historical global energy budget constraints (1.3 to 2.7 °C for TCR and 1.6 to 4.8 °C for effective ECS). Their estimates would be consistent with still-higher values of ECS when accounting for changes in radiative feedbacks as the spatial pattern of global warming evolves in the future (Section 7.5.2.1). Cross-Chapter Box 7.1 and references therein show that four very different physically based emulators can be calibrated to match the assessed ranges of historical GSAT change, ERF, ECS and TCR from across the report. Therefore, the fact that the emulator effective ECS values estimated from previous studies tend to lie at the lower end of the range inferred from historical global energy budget constraints may reflect that the energy budget constraints in Section 7.5.2.1 use updated estimates of Earth's energy imbalance, GSAT trends and ERF, rather than any methodological differences between the lines of evidence. The 'emergent constraints' on ECS based on observations of climate variability used in conjunction with comprehensive ESMs are assessed in Section 7.5.4.1.

7.5.2.3 Estimates of ECS Based on Variability in Earth's Top-of-atmosphere Radiation Budget

While continuous satellite measurements of top-of-atmosphere (TOA) radiative fluxes (Figure 7.3) do not have sufficient accuracy to determine the absolute magnitude of Earth's energy imbalance (Section 7.2.1), they provide accurate estimates of its variations and trends since the year 2002 that agree well with estimates based on observed changes in global ocean heat content (Loeb et al., 2012; Johnson et al., 2016; Palmer, 2017). When combined with global surface temperature observations and simple models of global energy balance, satellite measurements of TOA radiation afford estimates of the net feedback parameter associated with recent climate variability (Tsushima and Manabe, 2013; Donohoe et al., 2014; Dessler and Forster, 2018). These feedback estimates, derived from the regression of TOA radiation on surface temperature variability, imply values of ECS that are broadly consistent with those from other lines of evidence (Forster, 2016; Knutti et al., 2017). A history of regression-based feedbacks and their uncertainties is summarized in Bindoff et al. (2013), Forster (2016), and Knutti et al. (2017).

Research since AR5 has noted that regression-based feedback estimates depend on whether annual- or monthly-mean data are used and on the choice of lag employed in the regression, complicating their interpretation (Forster, 2016). The observed lead–lag relationship between global TOA radiation and global surface temperature, and its dependence on sampling period, is well replicated within unforced simulations of ESMs (Dessler, 2011; Proistosescu et al., 2018). These features arise because the regression between global TOA radiation and global surface temperature reflects a blend of different radiative feedback processes associated with several distinct modes of variability acting on different time scales (Annex IV), such as monthly atmospheric variability and interannual El Niño–Southern Oscillation (ENSO) variability (Lutsko and Takahashi, 2018; Proistosescu et al., 2018). Regression-based feedbacks thus provide estimates of the radiative feedbacks that are associated with internal climate variability (e.g., Brown et al., 2014), and do not provide a direct estimate of ECS (*high confidence*). Moreover, variations in global surface temperature that do not directly affect TOA radiation may lead to a positive bias in regression-based feedback, although this bias appears to be small, particularly when annual-mean data are used (Murphy and Forster, 2010; Spencer and Braswell, 2010, 2011; Proistosescu et al., 2018). When tested within ESMs, regression-based feedbacks have been found to be only weakly correlated with values of ECS (Chung et al., 2010), although cloudy-sky TOA radiation fluxes have been found to be moderately correlated with ECS at ENSO time scales within CMIP5 models (Lutsko and Takahashi, 2018).

Finding such correlations within models requires simulations that span multiple centuries, suggesting that the satellite record may not be of sufficient length to produce robust feedback estimates. However, correlations between regression-based feedbacks and long-term feedbacks have been found to be higher when focused on specific processes or regions, such as for the cloud- or water-vapour feedbacks (Section 7.4.2; Dessler, 2013; Zhou et al., 2015). Assessing the global radiative feedback in terms of the more stable relationship between tropospheric temperature and TOA radiation offers another potential avenue for constraining ECS. The 'emergent constraints' on ECS based on variability in the TOA energy budget are assessed in Section 7.5.4.1.

7.5.2.4 Estimates of ECS Based on the Climate Response to Volcanic Eruptions

A number of studies consider the observed climate response to volcanic eruptions over the 20th century (Section 3.3.1 and Cross-Chapter Box 4.1; Knutti et al., 2017). However, the direct constraint on ECS is weak, particularly at the high end, because the temperature response to short-term forcing depends only weakly on radiative feedbacks and because it can take decades of a sustained forcing before the magnitude of temperature changes reflects differences in ECS across models (Geoffroy et al., 2013b; Merlis et al., 2014). It is also a challenge to separate the response to volcanic eruptions from internal climate variability in the years that follow them (Wigley et al., 2005). Based on ESM simulations, radiative feedbacks governing the global surface temperature response to volcanic eruptions can be substantially different than those governing long-term global warming (Merlis et al., 2014; Marvel et al., 2016; Ceppi and Gregory, 2019). Estimates based on the response to volcanic eruptions agree with other lines of evidence (Knutti et al., 2017), but they do not constitute a direct estimate of ECS (*high confidence*). The 'emergent constraints' on ECS based on climate variability, including volcanic eruptions, are summarized in Section 7.5.4.1.

7.5.2.5 Assessment of ECS and TCR Based on the Instrumental Record

Evidence from the instrumental temperature record, including estimates using global energy budget changes (Section 7.5.2.1), climate emulators (Section 7.5.2.2), variability in the TOA radiation budget (Section 7.5.2.3), and the climate response to volcanic eruptions (Section 7.5.2.4) produce median ECS estimates that range between 2.5°C and 3.5°C, but a best estimate value cannot be given owing to a strong dependence on assumptions about how radiative feedbacks will change in the future. However, there is *robust evidence* and *high agreement* across the lines of evidence that ECS is *extremely likely* greater than 1.6°C (*high confidence*). There is *robust evidence* and *medium agreement* across the lines of evidence that ECS is *very likely* greater than 1.8°C and *likely* greater than 2.2°C (*high confidence*). These ranges of ECS correspond to estimates based on historical global energy budget constraints (Section 7.5.2.1) under the assumption of no feedback dependence on evolving SST patterns (i.e., $\alpha' = 0$) and thus represent an underestimate of the true ECS ranges that can be inferred from this line of evidence (*high confidence*). Historical global energy budget changes do not provide constraints on the upper bound of ECS, while the studies assessed in Section 7.5.2.3 based on climate variability provide *low confidence* in its value owing to *limited evidence*.

Global energy budget constraints indicate a central estimate (median) TCR value of 1.9°C and that TCR is *likely* in the range 1.5 to 2.3 °C and *very likely* in the range 1.3 to 2.7 °C (*high confidence*). Studies that constrain TCR based on the instrumental temperature record used in conjunction with ESM simulations are summarized in Section 7.5.4.3.

7.5.3 Estimates of ECS Based on Paleoclimate Data

Estimates of ECS based on paleoclimate data are complementary to, and largely independent from, estimates based on process-based studies (Section 7.5.1) and the instrumental record (Section 7.5.2). The strengths of using paleoclimate data to estimate ECS include: (i) the estimates are based on observations of a real-world Earth system response to a forcing, in contrast to using estimates from process-based modelling studies or directly from models; (ii) the forcings are often relatively large (similar in magnitude to a CO_2 doubling or more), in contrast to data from the instrumental record; (iii) the forcing often changes relatively slowly so the system is close to equilibrium; as such, all individual feedback parameters, α_x, are included, and complications associated with accounting for ocean heat uptake are reduced or eliminated, in contrast to the instrumental record. However, there can be relatively large uncertainties on estimates of both the paleo forcing and paleo global surface temperature response, and care must be taken to account for long-term feedbacks associated with ice sheets (Section 7.4.2.6), which often play an important role in the paleoclimate response to forcing, but which are not included in the definition of ECS. Furthermore, the state-dependence of feedbacks (Section 7.4.3) means that climate sensitivity during Earth's past may not be the same as it is today, which should be accounted for when interpreting paleoclimate estimates of ECS.

AR5 stated that data and modelling of the Last Glacial Maximum (LGM; Cross-Chapter Box 2.1) indicated that it was *very unlikely* that ECS lay outside the range 1°C–6°C (Masson-Delmotte et al., 2013). Furthermore, AR5 reported that climate records of the last 65 million years indicated an ECS 95% confidence interval of 1.1 to 7.0 °C.

Compared with AR5, there are now improved constraints on estimates of ECS from paleoclimate evidence. The strengthened understanding and improved lines of evidence come in part from the use of high-resolution paleoclimate data across multiple glacial–interglacial cycles, taking into account state-dependence (Section 7.4.3; von der Heydt et al., 2014; Köhler et al., 2015, 2017, 2018; Friedrich et al., 2016; Snyder, 2019; Stap et al., 2019) and better constrained pre-ice-core estimates of atmospheric CO_2 concentrations (Martínez-Botí et al., 2015; Anagnostou et al., 2016, 2020; de la Vega et al., 2020) and surface temperature (Hollis et al., 2019; Inglis et al., 2020; McClymont et al., 2020).

Overall, the paleoclimate lines of evidence regarding climate sensitivity can be broadly categorized into two types: estimates of radiative forcing and temperature response from paleo proxy measurements, and emergent constraints on paleoclimate model simulations. This section focuses on the first type only; the second type (emergent constraints) are discussed in Section 7.5.4.

In order to provide estimates of ECS, evidence from the paleoclimate record can be used to estimate forcing (ΔF) and global surface temperature response (ΔT) in Equation 7.1, Box 7.1, under the assumption that the system is in equilibrium (i.e., $\Delta N = 0$). However, there are complicating factors when using the paleoclimate record in this way, and these challenges and uncertainties are somewhat specific to the time period being considered.

7.5.3.1 Estimates of ECS from the Last Glacial Maximum

The LGM (Cross-Chapter Box 2.1) has been used to provide estimates of ECS (see Table 7.11 for estimates since AR5; Sherwood et al., 2020; Tierney et al., 2020b). The major forcings and feedback processes that led to the cold climate at that time (e.g., CO_2, non-CO_2 greenhouse gases, and ice sheets) are relatively well-known (Section 5.1), orbital forcing relative to pre-industrial was negligible, and there are relatively high spatial resolution and well-dated paleoclimate temperature data available for this time period (Section 2.3.1). Uncertainties in deriving global surface temperature from the LGM proxy data arise partly from uncertainties in the calibration from the paleoclimate data to local annual mean surface temperature, and partly from uncertainties in the conversion of the local temperatures to an annual mean global surface temperature. Overall, the global mean LGM cooling relative to pre-industrial is assessed to be *very likely* from 5 to 7 °C (Section 2.3.1). The LGM climate is often assumed to be in full equilibrium with the forcing, such that ΔN in Equation 7.1, Box 7.1, is zero. A calculation of sensitivity using solely CO_2 forcing, and assuming that the LGM ice sheets were in equilibrium with that forcing, would give an Earth System Sensitivity (ESS) rather than an ECS (see Box 7.1). In order to calculate an ECS, which is defined here to include all feedback processes except ice sheets, the approach of Rohling et al. (2012) can be used. This approach introduces an additional forcing term in Equation 7.1, Box 7.1, that quantifies the resulting forcing associated with the ice-sheet feedback (primarily an estimate of the radiative forcing associated with the change in surface albedo). However, differences between studies as to which processes are considered as forcings (for example, some studies also include vegetation and/or aerosols, such as dust, as forcings), means that published estimates are not always directly comparable. Additional uncertainty arises from the magnitude of the ice-sheet forcing itself (Stap et al., 2019; Zhu and Poulsen, 2021), which is often estimated using ESMs. Furthermore, the ECS at the LGM may differ from that of today due to state-dependence (Section 7.4.3). Here, only studies that report values of ECS that have accounted for the long-term feedbacks associated with ice sheets, and therefore most closely estimate ECS as defined in this chapter, are assessed here (Table 7.11).

7.5.3.2 Estimates of ECS from Glacial–Interglacial Cycles

Since AR5, several studies have extended the Rohling et al. (2012) approach (described above for the LGM) to the glacial–interglacial cycles of the last approximately 1 to 2 million years (von der Heydt et al., 2014; Köhler et al., 2015, 2017, 2018; Friedrich et al., 2016; Royer, 2016; Snyder, 2019; Stap et al., 2019; Friedrich and Timmermann, 2020; see Table 7.11). Compared to the LGM, uncertainties in the derived ECS from these periods are in general greater, due to greater uncertainty in global surface temperature (due to fewer individual sites with proxy temperature records), ice-sheet forcing (due to a lack of detailed ice-sheet reconstructions), and CO_2 forcing (for those studies that include the pre-ice-core period, where CO_2 reconstructions are substantially more uncertain). Furthermore, accounting for varying orbital forcing in the traditional global mean forcing and response energy budget framework (Box 7.1) is challenging (Schmidt et al., 2017b), due to seasonal and latitudinal components of the forcing that, despite a close-to-zero orbital forcing in the global annual mean, can directly result in responses in annual mean global surface temperature (Liu et al., 2014), ice volume (Abe-Ouchi et al., 2013), and feedback processes such as those associated with methane (Singarayer et al., 2011). In addition, for time periods in which the forcing relative to the modern era is small (interglacials), the inferred ECS has relatively large uncertainties because the forcing and temperature response (ΔF and ΔT in Equation 7.1, Box 7.1) are both close to zero.

7.5.3.3 Estimates of ECS from Warm Periods of the Pre-Quaternary

In the pre-Quaternary (prior to about 2.5 million years ago), the forcings and response are generally of the same sign and similar magnitude as future projections of climate change (Burke et al., 2018; Tierney et al., 2020a). Similar uncertainties as for the LGM apply, but in this case a major uncertainty relates to the forcing, because prior to the ice-core record there are only indirect estimates of CO_2 concentration. However, advances in pre-ice-core CO_2 reconstruction (e.g., Foster and Rae, 2016; Super et al., 2018; Witkowski et al., 2018) mean that the estimates of pre-Quaternary CO_2 have less uncertainty than at the time of AR5, and these time periods can now contribute to an assessment of climate sensitivity (Table 7.11). The mid-Pliocene Warm Period (MPWP; Cross-Chapter Box 2.1 and Cross-Chapter Box 2.4) has been targeted for constraints on ECS (Martínez-Botí et al., 2015; Sherwood et al., 2020), due to the fact that CO_2 concentrations were relatively high at this time (350–425 ppm) and because the MPWP is sufficiently recent that topography and continental configuration are similar to modern-day. As such, a comparison of the MPWP with the pre-industrial climate provides probably the closest natural geological analogue for the modern day that is useful for assessing constraints on ECS, despite the effects of different geographies not being negligible (global surface temperature patterns; ocean circulation). Furthermore, the global surface temperature of the MPWP was such that non-linearities in feedbacks (Section 7.4.3) were relatively modest. Within the MPWP, the KM5c interglacial has been identified as a particularly useful time period for assessing ECS (Haywood et al., 2013, 2016b) because Earth's orbit during that time was very similar to that of the modern day.

Further back in time, in the Early Eocene (Cross-Chapter Box 2.1), uncertainties in forcing and temperature change become larger, but the signals are generally larger too (Anagnostou et al., 2016, 2020;

Shaffer et al., 2016; Inglis et al., 2020). Caution must be applied when estimating ECS from these time periods, due to differing continental position and topography/bathymetry (Farnsworth et al., 2019), and due to temperature-dependence of feedbacks (Section 7.4.3). On even longer time scales of the last 500 million years (Royer, 2016) the temperature and CO_2 measurements are generally asynchronous, presenting challenges in using this information for assessments of ECS.

7.5.3.4 Synthesis of ECS Based on Paleo Radiative Forcing and Temperature

The lines of evidence directly constraining ECS from paleoclimates are summarized in Table 7.11. Although some of the estimates in Table 7.11 are not independent because they use similar proxy records to each other (e.g., von der Heydt et al., 2014; Köhler et al., 2015, 2017; Stap et al., 2019), there are still multiple independent lines of paleoclimate evidence regarding ECS, from differing past time periods: LGM (Sherwood et al., 2020; Tierney et al., 2020b); glacial–interglacial (Royer, 2016; Köhler et al., 2017; Snyder, 2019; Friedrich and Timmermann, 2020); Pliocene (Martínez-Botí et al., 2015; Sherwood et al., 2020); and the Eocene (Anagnostou et al., 2016, 2020; Shaffer et al., 2016; Inglis et al., 2020), with differing proxies for estimating forcing (e.g., CO_2 from ice cores or boron isotopes) and response (e.g., global surface temperature from $\delta^{18}O$, Mg/Ca or Antarctic δD). Furthermore, although different studies have uncertainty estimates that account for differing sources of uncertainty, some studies (Snyder, 2019; Inglis et al., 2020; Sherwood et al., 2020; Tierney et al., 2020b) do consider many of the uncertainties discussed in Sections 7.5.3.1–7.5.3.3. All the studies based on glacial–interglacial cycles account for some aspects of the state-dependence of climate sensitivity (Section 7.4.3) by considering only the warm phases of the Pleistocene, although what constitutes a warm phase is defined differently across the studies.

Table 7.11 | Estimates of equilibrium climate sensitivity (ECS) derived from paleoclimates; from AR5 (above double lines) and from post-AR5 studies (below double lines). Many studies provide an estimate of ECS that includes only CO_2 and the ice-sheet feedback as forcings, providing an estimate of $S_{[CO2,LI]}$ using the notation of Rohling et al. (2012), which is equivalent to our definition of ECS (Box 7.1). However, some studies provide estimates of other types of sensitivity (column 4). Different studies (column 1) focus on different time periods (column 2) and use a variety of different paleoclimate proxies and models (column 3) to give a best estimate (column 5) and/or a range (column 5). The published ranges given account for varying sources of uncertainty (column 6). See Cross-Chapter Box 2.1 for definition of time periods. All temperature values in column 5 are shown to a precision of 1 decimal place.

(1) Study	(2) Time Period (kyr = thousand years; Myr = million years; Ma = million years ago)	(3) Proxies/Models Used for CO_2, Temperature (T) and Global Scaling (GS)	(4) Climate Sensitivity Classification According to Rohling et al. (2012)	(5) Published Best Estimate of ECS [and/or Range]	(6) Range Accounts For:
AR5 (Masson-Delmotte et al., 2013)	LGM (Last Glacial Maximum)	Assessment of multiple lines of evidence	S^a = ECS[a]	[*very likely* >1.0; *very unlikely* >6.0°C]	Multiple sources of uncertainty
AR5 (Masson-Delmotte et al., 2013)	Cenozoic (last 65 Myr)	Assessment of multiple lines of evidence	$S_{[CO2,LI]}$	[95% range: 1.1°C to 7.0°C]	Multiple sources of uncertainty
Tierney et al. (2020b)	LGM	CO_2: ice core T: multi-proxy	$S_{[CO2,LI,CH4,N2O]}$	3.8°C [68% range: 3.3°C to 4.3°C]	Multiple sources of uncertainty
Sherwood et al. (2020)	LGM	CO_2: ice core T: multiple lines of evidence	$S_{[CO2,LI,CH4,N2O,dust,VG]}$	maximum likelihood [likelihood of 1.0]: 2.6°C [*likely* range depends on chosen prior; likelihood of 0.6: 1.6°C to 4.4°C]	Multiple sources of uncertainty
von der Heydt et al. (2014)	Warm states of glacial–interglacial cycles of last 800 kyr	CO_2: ice core T: ice core δD, benthic $\delta^{18}O$ GS: Schneider von Deimling et al. (2006); Annan and Hargreaves (2013)	$S_{[CO2,LI]}$	3.5°C [range: 3.1°C to 5.4°C][b]	Varying LGM global mean temperatures used for scaling
Köhler et al. (2015)	Warm states of glacial–interglacial cycles of last 2 Myr	CO_2: ice core alkenones and boron isotopes T: benthic $\delta^{18}O$ GS: PMIP LGM and PlioMIP MPWP	$S_{[CO2,LI]}$	5.7°C [68% range: 3.7°C to 8.1°C][b]	Temporal variability in records
Köhler et al. (2017)	Warm states of glacial–interglacial cycles of last 2 Myr	CO_2: boron isotopes T: benthic $\delta^{18}O$ GS: PMIP LGM and PlioMIP MPWP	$S_{[CO2,LI]}$	5.6°C [16th to 84th percentile: 3.6°C to 8.1°C][b]	Temporal variability in records
Köhler et al. (2018)	Warm states of glacial–interglacial cycles of last 800 kyr, excluding those for which CO_2 and T diverge	CO_2: ice cores T: benthic $\delta^{18}O$, alkenone, Mg/Ca, MAT, and faunal SST GS: PMIP3 LGM	$S_{[CO2,LI]}$	[range: 3.0°C to 5.9°C][b]	Varying temperature reconstructions
Stap et al. (2019)	States of glacial–interglacial cycles of last 800 kyr for which forcing is zero compared with modern, excluding those for which CO_2 and T diverge	CO_2: ice cores T: benthic $\delta^{18}O$ GS: PMIP LGM and PlioMIP MPWP	$S_{[CO2,LI]}$	[range: 6.1°C to 11.0°C][b]	Varying efficacies of ice-sheet forcing

7

(1) Study	(2) Time Period (kyr = thousand years; Myr = million years; Ma = million years ago)	(3) Proxies/Models Used for CO_2, Temperature (T) and Global Scaling (GS)	(4) Climate Sensitivity Classification According to Rohling et al. (2012)	(5) Published Best Estimate of ECS [and/or Range]	(6) Range Accounts For:
Friedrich et al. (2016)	Warm states of glacial–interglacial cycles of last 780 kyr	CO_2: ice cores T: alkenone, Mg/Ca, MAT, and faunal SST GS: PMIP3 LGM	$S_{[GHG,LI,AE]}$	4.9°C [*Likely* range: 4.3°C to 5.4°C][b]	Varying LGM global mean temperatures, aerosol forcing
Friedrich and Timmermann (2020)	Last glacial–interglacial cycle	CO_2: ice cores T: alkenone, Mg/Ca, MAT	$S_{[GHG,LI,AE]}$	4.2°C [range: 3.4°C to 6.2°C][b]	Varying aerosol forcings
Snyder (2019)	Interglacial periods and intermediateglacial climates of last 800 kyr	CO_2: ice cores T: alkenone, Mg/Ca, species assemblages GS: PMIP models	$S_{[GHG,LI,AE,VG]}$	3.1°C [67% range: 2.6°C to 3.7°C][b]	Multiple sources of uncertainty
Royer (2016)	Glacial–interglacial cycles of the Pliocene (3.4 to 2.9 Ma)	CO_2: boron isotopes T: benthic $\delta^{18}O$	$S_{[CO2,LI]}$	10.2°C [68% range: 8.1°C to 12.3°C]	Temporal variability in records
Martínez-Botí et al. (2015)	Pliocene	CO_2: boron isotopes T: benthic $\delta^{18}O$	$S_{[CO2,LI]}$	3.7°C [68% range: 3.0°C to 4.4°C][b]	Pliocene sea level, temporal variability in records
Sherwood et al. (2020)	Pliocene	CO_2: boron isotopes T: multiple lines of evidence	$S_{[CO2,\ LI,N2O,CH4,VG]}$	maximum likelihood [likelihood of 1.0]: 3.2°C [*likely* range depends on chosen prior; likelihood of 0.6: 1.8°C to 5.2°C]	Multiple sources of uncertainty
Anagnostou et al. (2016)	Early Eocene	CO_2: boron isotopes T: various terrestrial MAT, Mg/Ca, TEX, $\delta^{18}O$ SST	$S_{[CO2,LI]}$	3.6°C [66% range: 2.1°C to 4.6°C]	Varying calibrations for temperature and CO_2
Anagnostou et al. (2020)	Late Eocene (41.2 to 33.9 Ma)	CO_2: boron isotopes T: one SST record GS: CESM1	$S_{[CO2,LI]}$	3.0°C [68% range: 1.9°C to 4.1°C]	Temporal variability in records
Shaffer et al. (2016)	Pre-PETM (Paleocene–Eocene Thermal Maximum)	CO_2: mineralogical, carbon cycling, and isotope constraints T: various terrestrial MAT, Mg/Ca, TEX, $\delta^{18}O$ SST	$S_{[GHG,AE,VG,LI]}$	[range: 3.3°C to 5.6°C]	Varying calibration of temperature and CO_2
Inglis et al. (2020)	Mean of EECO (Early Eocene Climatic Optimum), PETM, and latest Paleocene	CO_2: boron isotopes T: multiproxy SST and SAT GS: EoMIP models	$S_{[CO2,LI,\ VG,AE]}$	3.7°C [*likely* range: 2.2°C to 5.3°C]	Multiple sources of uncertainty

[a] S^a in this table denotes a classification of climate sensitivity following Rohling et al. (2012).

[b] Although our assessed value of ERF due to CO_2 doubling is 3.93 W m^{-2} (Section 7.3.2.1), for these studies the best estimate and range of temperature is calculated from the published estimate of sensitivity in units of °C (W m^{-2})$^{-1}$ using an ERF of 3.7 W m^{-2}, for consistency with the typical value used in the studies to estimate the paleo CO_2 forcing.

None of the post-AR5 studies in Table 7.11 have an estimated lower range for ECS below 1.6°C. As such, based solely on the paleoclimate record, it is assessed to be *very likely* that ECS is greater than 1.5°C (*high confidence*).

In general, it is the studies based on the warm periods of the glacial–interglacial cycles (Section 7.5.3.2) that give the largest values of ECS. Given the large uncertainties associated with estimating the magnitude of the ice-sheet forcing during these intervals (Stap et al., 2019), and other uncertainties discussed in Section 7.5.3.2, in particular the direct effect of orbital forcing on estimates of ECS, there is only *low confidence* in estimates from the studies based on glacial–interglacial periods. This *low confidence* also results from the temperature-dependence of the net feedback parameter, α, resulting from several of these studies (Figure 7.10), that is hard to reconcile with the other lines of evidence for α, including proxy estimates from warmer paleoclimates (Section 7.4.3.2). A central estimate of ECS, derived from the LGM (Section 7.5.3.1) and warm periods of the pre-Quaternary (Section 7.5.3.3), that takes into account some of the interdependencies between the different studies, can be obtained by averaging across studies within each of these two time periods, and then averaging across the two time periods; this results in a central estimate of 3.4°C. This approach of focussing on the LGM and warm climates was also taken by Sherwood et al. (2020) in their assessment of ECS from paleoclimates. An alternative method is to average across all studies, from all periods, that have considered multiple sources of uncertainty (Table 7.11); this approach leads to a similar central estimate of 3.3°C. Overall, we assess *medium confidence* for a central estimate of 3.3°C to 3.4°C.

There is more variation in the upper bounds of ECS than in the lower bounds. Estimates of ECS from pre-Quaternary warm periods have an average upper range of 4.9°C, and from the LGM of 4.4°C; taking into account the independence of the estimates from these two time periods, and accounting for state-dependence (Section 7.4.3) and other uncertainties discussed in Section 7.5.3, the paleoclimate record on its own indicates that ECS is *likely* less than 4.5°C. Given the higher values from many glacial–interglacial studies, this value has only *medium confidence*. Despite the large variation in individual studies at the extreme upper end, all except two studies (both of which are from glacial–interglacial time periods associated with *low confidence*) have central estimates that are below 6°C; overall we assess that it is *extremely likely* that ECS is below 8°C (*high confidence*).

7.5.4 Estimates of ECS and TCR Based on Emergent Constraints

ESMs exhibit substantial spread in ECS and TCR (Section 7.5.7). Numerous studies have leveraged this spread in order to narrow estimates of Earth's climate sensitivity by employing methods known as 'emergent constraints' (Section 1.5.4). These methods establish a relationship between an observable and either ECS or TCR based on an ensemble of models, and combine this information with observations to constrain the probability distribution of ECS or TCR. Most studies of this kind have clearly benefitted from the international efforts to coordinate the CMIP and other multi-model ensembles.

A number of considerations must be taken into account when assessing the diverse literature on ECS and TCR emergent constraints. For instance, it is important to have physical and theoretical bases for the connection between the observable and modelled ECS or TCR since in model ensembles thousands of relationships that pass statistical significance can be found simply by chance (Caldwell et al., 2014). It is also important that the underlying model ensemble does not exhibit a shared bias that influences the simulation of the observable quantity on which the emergent constraint is based. Also, correctly accounting for uncertainties in both the observable (including measurement uncertainty and natural variability) and the emergent constraint statistical relationship can be challenging, in particular in cases where the latter is not expected to be linear (Annan et al., 2020). A number of proposed emergent constraints leverage variations in modelled ECS arising from tropical low-clouds, which was the dominant source of inter-model spread in the CMIP5 ensemble used in most emergent constraint studies. Since ECS is dependent on the sum of individual feedbacks (Section 7.5.1) these studies implicitly assume that all other feedback processes in models are unbiased and should therefore rather be thought of as constraints on tropical low-cloud feedback (Klein and Hall, 2015; Qu et al., 2018; Schlund et al., 2020). The following sections go through a range of emergent constraints and assess their strengths and limitations.

7.5.4.1 Emergent Constraints Using Global or Near-global Surface Temperature Change

Perhaps the simplest class of emergent constraints regress past equilibrium paleoclimate temperature change against modelled ECS to obtain a relationship that can be used to translate a past climate change to ECS. The advantage is that these are constraints on the sum of all feedbacks, and furthermore unlike constraints on the instrumental record they are based on climate states that are at, or close to, equilibrium. So far, these emergent constraints have been limited to the Last Glacial Maximum (LGM; Cross-Chapter Box 2.1) cooling (Hargreaves et al., 2012; Schmidt et al., 2014; Renoult et al., 2020) and warming in the mid-Pliocene Warm Period (MPWP; Cross-Chapter Box 2.1 and Cross-Chapter Box 2.4; Hargreaves and Annan, 2016; Renoult et al., 2020) due to the availability of sufficiently large multi-model ensembles for these two cases. The paleoclimate emergent constraints are limited by structural uncertainties in the proxy-based global surface temperature and forcing reconstructions (Section 7.5.3), possible differences in equilibrium sea surface temperature patterns between models and the real world, and a small number of model simulations participating, which has led to divergent results. For example, Hopcroft and Valdes (2015) repeated the study based on the LGM by Hargreaves et al. (2012) using another model ensemble and found that the emergent constraint was not robust, whereas studies using multiple available ensembles retain useful constraints (Schmidt et al., 2014; Renoult et al., 2020). Also, the results are somewhat dependent on the applied statistical methods (Hargreaves and Annan, 2016). However, Renoult et al. (2020) explored this and found 95th percentiles of ECS below 6°C for LGM and Pliocene individually, regardless of statistical approach, and by combining the two estimates the 95th percentile dropped to 4.0°C. The consistency between the cold LGM and warm MPWP emergent constraint estimates increases confidence in these estimates, and further suggests that the dependence of feedback on climate mean state (Section 7.4.3) as represented in PMIP models used in these studies is reasonable.

Various emergent constraint approaches using global warming over the instrumental record have been proposed. These benefit from more accurate data compared with paleoclimates, but suffer from the fact that the climate is not in equilibrium, thereby assuming that ESMs on average accurately depict the ratio of short-term to long-term global warming. Global warming in climate models over 1850 to the present day exhibits no correlation with ECS, which is partly due to a substantial number of models exhibiting compensation between a high climate sensitivity with strong historical aerosol cooling (Kiehl, 2007; Forster et al., 2013; Nijsse et al., 2020). However, the aerosol cooling increased up until the 1970s, when air quality regulations reduced the emissions from Europe and North America whereas other regions saw increases resulting in a subsequently reduced pace of global mean aerosol ERF increase (Section 2.2.8 and Figure 2.10). Energy balance considerations over the 1970–2010 period gave a best estimate ECS of 2.0°C (Bengtsson and Schwartz, 2013), however this estimate did not account for pattern effects. To address this limitation an emergent constraint on 1970–2005 global warming was demonstrated to yield a best estimate ECS of 2.83 [1.72 to 4.12] °C (Jiménez-de-la-Cuesta and Mauritsen, 2019). The study was followed up using CMIP6 models yielding a best estimate ECS of 2.6 [1.5 to 4.0] °C based on 1975–2019 global warming (Nijsse et al., 2020), thereby confirming the emergent constraint. Internal variability and forced or unforced pattern effects may influence the results (Jiménez-de-la-Cuesta and Mauritsen, 2019; Nijsse et al., 2020). For instance the Atlantic Multi-decadal Oscillation changed from negative to positive anomaly, while the Indo-Pacific Oscillation changed less over the 1970–2005 period, potentially leading to high-biased results (Jiménez-de-la-Cuesta and Mauritsen, 2019), whereas during the later period 1975–2019 these anomalies roughly cancel (Nijsse et al., 2020). Pattern effects may have been substantial over these periods (Andrews et al., 2018), however the extent to which TOA radiation anomalies influenced surface temperature may have been dampened by the deep ocean (Hedemann et al., 2017; Newsom et al., 2020). It is therefore deemed *more likely than not* that these estimates based on post-1970s global warming are biased low by internal variability.

A study that developed an emergent constraint based on the response to the Mount Pinatubo 1991 eruption yielded a best estimate of 2.4 [*likely* range 1.7 to 4.1] °C (Bender et al., 2010). When accounting for ENSO variations they found a somewhat higher best estimate of 2.7°C, which is in line with results of later studies that suggest ECS inferred from periods with substantial volcanic activity are low-biased due to strong pattern effects (Gregory et al., 2020) and that the short-term nature of volcanic forcing could exacerbate possible underestimates of modelled pattern effects.

Lagged correlations present in short-term variations in the global surface temperature can be linked to ECS through the fluctuation–dissipation theorem, which is derived from a single heat-reservoir model (Einstein, 1905; Hasselmann, 1976; Schwartz, 2007; Cox et al., 2018a). From this it follows that the memory carried by the heat capacity of the ocean results in low-frequency global temperature variability (red noise) arising from high-frequency (white noise) fluctuations in the radiation balance, for example, caused by weather. Initial attempts to apply the theorem to observations yielded a fairly low median ECS estimate of 1.1°C (Schwartz, 2007), a result that was disputed (Foster et al., 2008; Knutti et al., 2008). Recently it was proposed by Cox et al. (2018a) to use variations in the historical experiments of the CMIP5 climate models as an emergent constraint giving a median ECS estimate of 2.8 [1.6 to 4.0] °C. A particular challenge associated with these approaches is to separate short-term from long-term variability, and slightly arbitrary choices regarding the methodology of separating these in the global surface temperature from long-term signals in the historical record, omission of the more strongly forced period after 1962, as well as input data choices, can lead to median ECS estimates ranging from 2.5°C to 3.5°C (Brown et al., 2018; Po-Chedley et al., 2018a; Rypdal et al., 2018). Calibrating the emergent constraint using CMIP5 modelled internal variability as measured in historical control simulations (Po-Chedley et al., 2018a) will inevitably lead to an overestimated ECS due to externally forced short-term variability present in the historical record (Cox et al., 2018b). Contrary to constraints based on paleoclimates or global warming since the 1970s, when based on CMIP6 models a higher, yet still well-bounded ECS estimate of 3.7 [2.6 to 4.8] °C is obtained (Schlund et al., 2020). A more problematic issue is raised by Annan et al. (2020) who showed that the upper bound on ECS estimated this way is less certain when considering deep-ocean heat uptake. In conclusion, even if not inconsistent, these limitations prevent us from directly using this type of constraint in the assessment.

Short-term variations in the TOA energy budget, observable from satellites, arising from variations in the tropical tropospheric temperature have been linked to ECS through models, either as a range of models consistent with observations (those with ECS values between 2.0°C and 3.9°C; Dessler et al., 2018) or as a formal emergent constraint by deriving further model-based relationships to yield a median of 3.3 [2.4 to 4.5] °C (Dessler and Forster, 2018). There are major challenges associated with short-term variability in the energy budget, in particular how it relates to the long-term forced response of clouds (Colman and Hanson, 2017; Lutsko and Takahashi, 2018). Variations in the surface temperature that are not directly affecting the radiation balance lead to an overestimated ECS when using linear regression techniques where it appears as noise in the independent variable (Proistosescu et al., 2018; Gregory et al., 2020). The latter issue is largely overcome when using the tropospheric mean or mid-tropospheric temperature (Trenberth et al., 2015; Dessler et al., 2018).

7.5.4.2 Emergent Constraints Focused on Cloud Feedbacks and Present-day Climate

A substantial number of emergent constraint studies focus on observables that are related to tropical low-cloud feedback processes (Volodin, 2008; Sherwood et al., 2014; Zhai et al., 2015; Brient and Schneider, 2016; Brient et al., 2016). These studies yield median ECS estimates of 3.5°C–4°C and in many cases indicate low likelihoods of values below 3°C. The approach has attracted attention since most of the spread in climate sensitivity seen in CMIP5, and earlier climate model ensembles, arises from uncertainty in low-cloud feedbacks (Bony and Dufresne, 2005; Wyant et al., 2006; Randall et al., 2007; Vial et al., 2013). Nevertheless, this approach assumes that all other feedback processes are unbiased (Klein and Hall, 2015; Qu et al., 2018; Schlund et al., 2020), for instance the possibly missing negative anvil area feedback or the possibly exaggerated mixed-phase cloud feedback (Section 7.4.2.4). Thus, the subset of emergent constraints that focus on low-level tropical clouds are not necessarily inconsistent with other emergent constraints of ECS. Related emergent constraints that focus on aspects of the tropical circulation and ECS have led to conflicting results (Su et al., 2014; Tian, 2015; Lipat et al., 2017; Webb and Lock, 2020), possibly because these processes are not the dominant factors in causing the inter-model spread (Caldwell et al., 2018).

The fidelity of models in reproducing aspects of temperature variability or the radiation budget has also been proposed as emergent constraints on ECS (Covey et al., 2000; Knutti et al., 2006; Huber et al., 2010; Bender et al., 2012; Brown and Caldeira, 2017; Siler et al., 2018a). Here indices based on spatial or seasonal variability are linked to modelled ECS, and overall the group of emergent constraints yields best estimates of 3.3°C–3.7°C. Nevertheless, the physical relevance of present-day biases to the sum of long-term climate change feedbacks is unclear and therefore these constraints on ECS are not considered reliable.

7.5.4.3 Assessed ECS and TCR Based on Emergent Constraints

The available emergent constraint studies have been divided into two classes: (i) those that are based on global or near-global indices, such as global surface temperature and the TOA energy budget; and (ii) those that are more focussed on physical processes, such as the fidelity of phenomena related to low-level cloud feedbacks or present-day climate biases. The former class is arguably superior in representing ECS, since it is a global surface temperature or energy budget change, whereas the latter class is perhaps best thought of as providing constraints on individual climate feedbacks, for example, the determination that low-level cloud feedbacks are positive. The latter result is consistent with and confirms process-based estimates of low-cloud feedbacks (Section 7.4.2.4), but are potentially biased as a group by missing or biased feedbacks in ESMs and is accordingly not taken into account here. A limiting case here is Dessler and Forster (2018) which is focused on monthly co-variability in the global TOA energy budget with mid-tropospheric temperature, at which time scale the surface-albedo feedback is unlikely to operate, thus implicitly assuming it is unbiased in the model ensemble.

In the first group of emergent constraints there is broad agreement on the best estimate of ECS ranging from 2.4°C–3.3°C. At the lower end, nearly all studies find lower bounds (5th percentiles) around 1.5°C, whereas several studies indicate 95th percentiles as low as 4°C. Considering both classes of studies, none of them yield upper *very likely* bounds above 5°C. Since several of the emergent constraints can be considered nearly independent one could assume that emergent constraints provide very strong evidence on ECS by combining them. Nevertheless, this is not done here because there are sufficient cross-dependencies, as for instance models are re-used in many of the derived emergent constraints, and furthermore the methodology has not yet reached a sufficient level of maturity since systematic biases may not have been accounted for. Uncertainty is therefore conservatively added to reflect these potential issues. This leads to the assessment that ECS inferred from emergent constraints is *very likely* 1.5 to 5 °C with *medium confidence*.

Emergent constraints on TCR with a focus on the instrumental temperature record, though less abundant, have also been proposed. These can be influenced by internal variability and pattern effects, as discussed in Section 7.5.4.1, although the influence is smaller because uncertainty in forced pattern effects correlates between transient historical warming and TCR. In the simplest form Gillett et al. (2012) regressed the response of one model to individual historical forcing components to obtain a tight range of 1.3°C–1.8°C, but later when an ensemble of models was used the range was widened to 0.9°C–2.3°C (Gillett et al., 2013), and updated by Schurer et al. (2018). A related data-assimilation-based approach that accounted also for uncertainty in response patterns gave 1.33°C–2.36°C (Ribes et al., 2021), but is dependent on the choice of prior ensemble distribution (CMIP5 or CMIP6). Another study used the response to the Pinatubo volcanic eruption to obtain a range of 0.8°C–2.3°C (Bender et al., 2010). A tighter range, notably at the lower end, was found in an emergent constraint focusing on the post-1970s warming exploiting the lower spread in aerosol forcing change over this period (Jiménez-de-la-Cuesta and Mauritsen, 2019). Their estimate was 1.67 [1.17 to 2.16] °C. Two studies tested this idea: Tokarska et al. (2020) estimates TCR was 1.60 [0.90 to 2.27] °C based on CMIP6 models, whereas Nijsse et al. (2020) found 1.68 [1.0 to 2.3] °C. In both cases there was a small sensitivity to choice of ensemble, with CMIP6 models yielding slightly lower values and ranges. Combining these studies gives a best estimate of 1.7°C and a *very likely* range of TCR of 1.1 to 2.3 °C with *high confidence*.

7.5.5 Combined Assessment of ECS and TCR

Substantial quantitative progress has been made in interpreting evidence of Earth's climate sensitivity since AR5, through innovation, scrutiny, theoretical advances and a rapidly evolving data base from current, recent and paleo climates. It should be noted that, unlike AR5 and earlier reports, our assessment of ECS is not directly informed by ESM simulations (Section 7.5.6). The assessments of ECS and TCR are focussed on the following lines of evidence: process-understanding; the instrumental record of warming; paleoclimate evidence; and emergent constraints. ESMs remain essential tools for establishing these lines of evidence, for instance, in estimating part of the feedback parameters and radiative forcings, and emergent constraints rely on substantial model spread in ECS and TCR (Section 7.5.6).

A key advance over the AR5 assessment is the broad agreement across multiple lines of evidence. These support a central estimate of ECS close to, or at least not inconsistent with, 3°C. This advance is foremost following improvements in the understanding and quantification of Earth's energy imbalance, the instrumental record of global temperature change, and the strength of anthropogenic radiative forcing. Further

Table 7.12 | Emergent constraint studies used in the assessment of equilibrium climate sensitivity (ECS). These are studies that rely on global or near-global temperature change as the observable.

Study	Emergent Constraint Description	Published Best Estimate and Uncertainty (°C)	Uncertainty Estimate
Bender et al. (2010)	Pinatubo integrated forcing normalized by CMIP3 models' own forcing versus temperature change regressed against ECS	2.4 [1.7 to 4.1]	5–95%
Dessler and Forster (2018)	Emergent constraint on TOA radiation variations linked to mid-tropospheric temperature in CMIP5 models	3.3 [2.4 to 4.5]	17–83%
Hargreaves et al. (2012)	Last Glacial Maximum tropical SSTs in PMIP2 models	2.5 [1.3 to 4.2]	5–95%
Hargreaves and Annan (2016)	Pliocene tropical SSTs in PlioMIP models	[1.9 to 3.7]	5–95%
Jiménez-de-la-Cuesta and Mauritsen (2019)	Post-1970s global warming, 1995–2005 relative to 1970–1989, CMIP5 models	2.83 [1.72 to 4.12]	5–95%
Nijsse et al. (2020)	Post-1970s global warming, 2009–2019 relative to 1975–1985, CMIP6 models	2.6 [1.5 to 4.0]	5–95%
Renoult et al. (2020)	Combined Last Glacial Maximum and Pliocene tropical SSTs in PMIP2, PMIP3, PMIP4, PlioMIP and PlioMIP2 models	2.5 [0.8 to 4.0]	5–95%

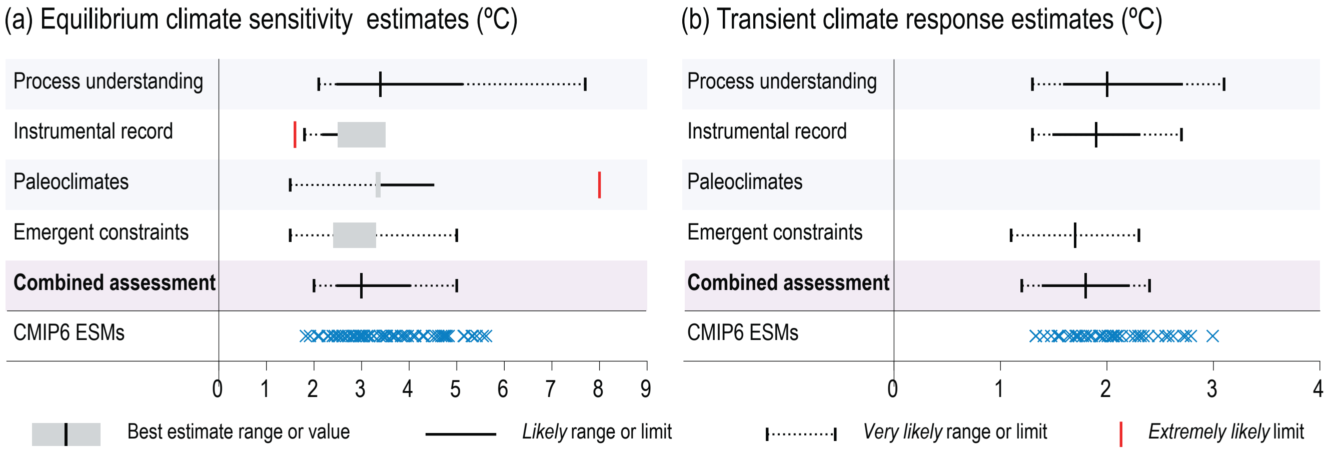


Figure 7.18 | Summary of the equilibrium climate sensitivity (ECS panel (a)) and transient climate response (TCR panel (b)) assessments using different lines of evidence. Assessed ranges are taken from Tables 7.13 and 7.14 for ECS and TCR respectively. Note that for the ECS assessment based on both the instrumental record and paleoclimates, limits (i.e., one-sided distributions) are given, which have twice the probability of being outside the maximum/minimum value at a given end, compared to ranges (i.e., two-tailed distributions) which are given for the other lines of evidence. For example, the *extremely likely* limit of greater than 95% probability corresponds to one side of the *very likely* (5–95%) range. Best estimates are given as either a single number or by a range represented by a grey box. CMIP6 model values are not directly used as a line of evidence but presented on the Figure for comparison. ECS values are taken from Schlund et al. (2020) and TCR values from Meehl et al. (2020); see Supplementary Material 7.SM.4. Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

advances include increased understanding of how the pattern effect influences ECS inferred from historical global warming (Sections 7.4.4 and 7.5.3), improved quantification of paleo climatechange from proxy evidence and a deepened understanding of how feedback mechanisms increase ECS in warmer climate states (Sections 7.4.3, 7.4.4 and 7.5.4), and also an improved quantification of individual cloud feedbacks (Sections 7.4.2 and 7.5.4.2). The assessment findings for ECS and TCR are summarized in Table 7.13 and Table 7.14, respectively, and also visualized in Figure 7.18.

The AR5 assessed ECS to have a *likely* range from 1.5 to 4.5 °C (M. Collins et al., 2013) based on the majority of studies and evidence available at the time. The broader evidence base presented in this Report and the general agreement among different lines of evidence means that they can be combined to yield a narrower range of ECS values. This can be done formally using Bayesian statistics, though such a process is complex and involves formulating likelihoods and priors (Annan and Hargreaves, 2006; Stevens et al., 2016; Sherwood et al., 2020). However, it can be understood that if two lines of independent evidence each give a low probability of an outcome being true, for example, that ECS is less than 2.0°C, then the combined probability that ECS is less than 2.0°C is lower than that of either line of evidence. On the contrary, if one line of evidence is unable to rule out an outcome, but another is able to assign a low probability, then there is a low probability that the outcome is true (Stevens et al., 2016). This general principle applies even when there is some dependency between the lines of evidence (Sherwood et al., 2020), for instance between historical energy budget constraints (Section 7.5.2.1) and those emergent constraints that use the historically observed global warming (Section 7.5.4.1). Even in this case the combined constraint will be closer to the narrowest range associated with the individual lines of evidence.

In the process of providing a combined and self-consistent ECS assessment across all lines of evidence, the above principles were all considered. As in earlier reports, a 0.5°C precision is used. Starting with the *very likely* lower bound, there is broad support for a value of 2.0°C, including process understanding and the instrumental record (Table 7.13). For the *very likely* upper bound, emergent constraints give a value of 5.0°C whereas the three other lines of evidence are individually less tightly constrained. Nevertheless, emergent constraints are a relatively recent field of research, in part taken into account by adding uncertainty to the upper bound (Section 7.5.4.3), and the underlying studies use, to a varying extent, information that is also used in the other three lines of evidence, causing statistical dependencies. However, omitting emergent constraints and statistically combining the remaining lines of evidence likewise yields 95th percentiles close to 5.0°C (Sherwood et al., 2020). Information for the *likely* range is partly missing or one-sided, however it must necessarily reside inside the *very likely* range and is therefore supported by evidence pertaining to both the *likely* and *very likely* ranges. Hence, the upper *likely* bound is assessed to be about halfway between the best estimate and the upper *very likely* bound while the lower *likely* bound is assessed to be about halfway between the best estimate and the lower *very likely* bound. In summary, based on multiple lines of evidence the best estimate of ECS is 3°C, it is *likely* within the range 2.5 to 4 °C and *very likely* within the range 2 to 5 °C. It is *virtually certain* that ECS is larger than 1.5°C. Whereas there is *high confidence* based on mounting evidence that supports the best estimate, *likely* range and *very likely* lower end, a higher ECS than 5°C cannot be ruled out, hence there is *medium confidence* in the upper end of the *very likely* range. Note that the best estimate of ECS made here corresponds to a feedback parameter of –1.3 W m^{-2} °C^{-1} which is slightly more negative than the feedback parameter from process-based evidence alone that is assessed in Section 7.4.2.7.

There has long been a consensus (Charney et al., 1979) supporting an ECS estimate of 1.5°C–4.5°C. In this regard it is worth remembering the many debates challenging an ECS of this magnitude. These started as early as Ångström (1900) criticizing the results of Arrhenius (1896) arguing that the atmosphere was already saturated in infrared absorption such that adding more CO_2 would not lead to warming. The assertion of Ångström was understood half a century later to be incorrect. History has seen a multitude of studies (e.g., Svensmark, 1998; Lindzen et al., 2001; Schwartz, 2007) mostly implying lower ECS than the range assessed as *very likely* here. However, there are also examples of the opposite, such as very large ECS estimates based on the Pleistocene records (Snyder, 2016), which have been shown to be overestimated due to a lack of accounting for orbital forcing and long-term ice-sheet feedbacks (Schmidt et al., 2017b), or suggestions that global climate instabilities may occur in the future (Steffen et al., 2018; Schneider et al., 2019). There is, however, no evidence for unforced instabilities of such magnitude occurring in the paleo-record temperatures of the past 65 million years (Westerhold et al., 2020), possibly short of the Paleocene–Eocene Thermal Maximum (PETM) excursion (Section 5.3.1.1) that occurred at more than 10°C above present-day levels (Anagnostou et al., 2020). Looking back, the resulting debates have led to a deeper understanding, strengthened the consensus, and have been scientifically valuable.

In the climate sciences, there are often good reasons to consider representing deep uncertainty, or what are sometimes referred to as 'unknown unknowns'. This is natural in a field that considers a system that is both complex and at the same time challenging to observe. For instance, since emergent constraints represent a relatively new line of evidence, important feedback mechanisms may be biased in process-level understanding; pattern effects and aerosol cooling may be large; and paleo evidence inherently builds on indirect and incomplete evidence of past climate states, there certainly can be valid reasons to add uncertainty to the ranges assessed on individual lines of evidence. This has indeed been addressed throughout Sections 7.5.1–7.5.4. Since it is neither probable that all lines of evidence assessed here are collectively biased nor is the assessment sensitive to single lines of evidence, deep uncertainty is not considered as necessary to frame the combined assessment of ECS.

The evidence for TCR is less abundant than for ECS, and focuses on the instrumental temperature record (Sections 7.5.2 and 7.5.6), emergent constraints (Section 7.5.4.3) and process understanding (Section 7.5.1). The AR5 assessed a *likely* range for TCR of 1.0 to 2.5 °C. TCR and ECS are related, though, and in any case TCR is less than ECS (see the introduction to Section 7.5). Furthermore, estimates of TCR from the historical record are not as strongly influenced by externally forced surface temperature pattern effects as estimates of ECS are since both historical transient warming and TCR are affected by this phenomenon (Section 7.4.4). A slightly higher weight is given to instrumental record warming and emergent constraints since these are based on observed transient warming, whereas the process-understanding estimate relies on pattern effects and ocean heat uptake efficiency from ESMs to represent the transient dampening effects of the ocean. If these effects are underestimated by ESMs then the resulting TCR would be lower. Given the interdependencies of the other two lines of evidence, a conservative approach to combining them as reflected in the assessment is adopted. Since uncertainty is substantially lower than in AR5 a 0.1°C precision is therefore used here. Otherwise the same methodology for combining the lines of evidence as applied to ECS is used for TCR. Based on process understanding, warming over the instrumental record and emergent constraints, the best estimate TCR is 1.8°C, it is *likely* 1.4 to 2.2 °C and *very likely* 1.2 to 2.4 °C. The assessed ranges are all assigned *high confidence* due to the high level of agreement among the lines of evidence.

Table 7.13 | Summary of equilibrium climate sensitivity (ECS) assessment.

Equilibrium Climate Sensitivity (ECS)	Central Value	*Likely*	*Very likely*	*Extremely likely*
Process understanding (Section 7.5.1)	3.4°C	2.5°C to 5.1°C	2.1°C to 7.7°C	–
Warming over instrumental record (Section 7.5.2)	2.5°C to 3.5°C	>2.2°C	>1.8°C	>1.6°C
Paleoclimates (Section 7.5.3)	3.3°C to 3.4°C	<4.5°C	>1.5°C	<8°C
Emergent constraints (Section 7.5.4)	2.4°C to 3.3°C	–	1.5°C to 5.0°C	–
Combined assessment	3°C	2.5°C to 4.0°C	2.0°C to 5.0°C	–

Table 7.14 | Summary of TCR assessment.

Transient Climate Response (TCR)	Central Value	*Likely* Range	*Very likely* Range
Process understanding (Section 7.5.1)	2.0°C	1.6°C to 2.7°C	1.3°C to 3.1°C
Warming over instrumental record (Section 7.5.2)	1.9°C	1.5°C to 2.3°C	1.3°C to 2.7°C
Emergent constraints (Section 7.5.4)	1.7°C	–	1.1°C to 2.3°C
Combined assessment	1.8°C	1.4°C to 2.2°C	1.2°C to 2.4°C

7.5.6 Considerations on the ECS and TCR in Global Climate Models and Their Role in the Assessment

Coupled climate models, such as those participating in CMIP, have long played a central role in assessments of ECS and TCR. In reports up to and including the IPCC Third Assessment Report (TAR), climate sensitivities derived directly from ESMs were the primary line of evidence. However, since AR4, historical warming and paleoclimate information provided useful additional evidence and it was noted that assessments based on models alone were problematic (Knutti, 2010). As new lines of evidence have evolved, in AR6 various numerical models are used where they are considered accurate, or in some cases the only available source of information, and thereby support all four lines of evidence (Sections 7.5.1–7.5.4). However, AR6 differs from previous IPCC reports in excluding direct estimates of ECS and TCR from ESMs in the assessed ranges (Section 7.5.5), following several recent studies (Annan and Hargreaves, 2006; Stevens et al., 2016; Sherwood et al., 2020). The purpose of this section is to explain why this approach has been taken and to provide a perspective on the interpretation of the climate sensitivities exhibited in CMIP6 models.

The primary consideration that led to excluding ECS and TCR directly derived from ESMs is that information from these models is incorporated in the lines of evidence used in the assessment: ESMs are partly used to estimate historical and paleoclimate ERFs (Sections 7.5.2 and 7.5.3); to convert from local to global mean paleo temperatures (Section 7.5.3); to estimate how feedbacks change with SST patterns (Section 7.4.4.3); and to establish emergent constraints on ECS (Section 7.5.4). They are also used as important evidence in the process understanding estimates of the temperature, water vapour, albedo, biogeophysical, and non-CO_2 biogeochemical feedbacks, whereas other evidence is primarily used for cloud feedbacks where the climate model evidence is weak (Section 7.4.2). One perspective on this is that the process understanding line of evidence builds on and replaces ESM estimates.

The ECS of a model is the net result of the model's effective radiative forcing from a doubling of CO_2 and the sum of the individual feedbacks and their interactions. It is well known that most of the model spread in ECS arises from cloud feedbacks, and particularly the response of low-level clouds (Bony and Dufresne, 2005; Zelinka et al., 2020). Since these clouds are small-scale and shallow, their representation in climate models is mostly determined by sub-grid-scale parametrizations. It is sometimes assumed that parametrization improvements will eventually lead to convergence in model response and therefore a decrease in the model spread of ECS. However, despite decades of model development, increases in model resolution and advances in parametrization schemes, there has been no systematic convergence in model estimates of ECS. In fact, the overall inter-model spread in ECS for CMIP6 is larger than for CMIP5; ECS and TCR values are given for CMIP6 models in Supplementary Material 7.SM.4 based on Schlund et al. (2020) for ECS and Meehl et al. (2020) for TCR (see also Figure 7.18 and FAQ 7.3). The upward shift does not apply to all models traceable to specific modelling centres, but a substantial subset of models have seen an increase in ECS between the two model generations. The increased ECS values, as discussed in Section 7.4.2.8, are partly due to shortwave cloud feedbacks (Flynn and Mauritsen, 2020) and it appears that in some models extra-tropical clouds with mixed ice and liquid phases are central to the behaviour (Zelinka et al., 2020), probably borne out of a recent focus on biases in these types of clouds (McCoy et al., 2016; Tan et al., 2016). These biases have recently been reduced in many ESMs, guided by process understanding from laboratory experiments, field measurements and satellite observations (Lohmann and Neubauer, 2018; Bodas-Salcedo et al., 2019; Gettelman et al., 2019). However, this and other known model biases are already factored into the process-level assessment of cloud feedback (Section 7.4.2.4), and furthermore the emergent constraints used here focus on global surface temperature change and are therefore less susceptible to shared model biases in individual feedback parameters than emergent constraints that focus on specific physical processes (Section 7.5.4). The high values of ECS and TCR in some CMIP6 models lead to higher levels of surface warming than CMIP5 simulations and also the AR6 projections based on the assessed ranges of ECS, TCR and ERF (Box 4.1 and FAQ 7.3; Forster et al., 2020).

It is generally difficult to determine which information enters the formulation and development of parametrizations used in ESMs. Climate models frequently share code components, and in some cases entire sub-model systems are shared and slightly modified. Therefore, models cannot be considered independent developments, but rather families of models with interdependencies (Knutti et al., 2013). It is therefore difficult to interpret the collection of models (Knutti, 2010), and it cannot be ruled out that there are common limitations and therefore systematic biases to model ensembles that are reflected in the distribution of ECS as derived from them. Although ESMs are typically well-documented, in ways that increasingly include information on critical decisions regarding tuning (Mauritsen et al., 2012; Hourdin et al., 2017; Schmidt et al., 2017a; Mauritsen and Roeckner, 2020), the full history of development decisions could involve both process-understanding and sometimes also other information such as historical warming. As outlying or poorly performing models emerge from the development process, they can become re-tuned, reconfigured or discarded and so might not see publication (Hourdin et al., 2017; Mauritsen and Roeckner, 2020). In the process of addressing such issues, modelling groups may, whether intentionally or not, modify the modelled ECS.

It is problematic and not obviously constructive to provide weights for, or rule out, individual CMIP6 model ensemble members based solely on their ECS and TCR values. Rather these models must be tested in a like-with-like way against observational evidence. Based on the currently published CMIP6 models we provide such an analysis, marking models with ECS above and below the assessed *very likely* range (Figure 7.19). In the long-term historical warming (Figure 7.19a) both low- and high-ECS models are able to match the observed warming, presumably in part as a result of compensating aerosol cooling (Kiehl, 2007; Forster et al., 2013; Wang et al., 2021). In several cases of high ECS models that apply strong aerosol cooling it is found to result in surface warming and ocean heat uptake evolutions that are inconsistent with observations (Golaz et al., 2019; Andrews et al., 2020; Winton et al., 2020). Modelled warming since the 1970s is less influenced by compensation between climate sensitivity and aerosol cooling (Jiménez-de-la-Cuesta and Mauritsen, 2019; Nijsse et al., 2020) resulting in the high-ECS models in general warming more than observed, whereas low-sensitivity models mostly perform better (Figure 7.19b); a result that may also have been influenced by temporary pattern effects (Sections 7.4.4 and 7.5.4). Paleoclimates are not influenced by such transient pattern effects, but are limited by structural uncertainties in the proxy-based temperature and forcing reconstructions as well as possible differences in equilibrium sea surface temperature patterns between models and the real world (Section 7.5.4). Across the LGM, MPWP and EECO (Figure 7.19c–e), the few high-ECS models that simulated these cases were outside the observed *very likely* ranges (see also Feng et al., 2020; Renoult et al., 2020; Zhu et al., 2020). Also the low-ECS model is either outside or on the edge of the observed *very likely* ranges.

As a result of the above considerations, in this Report projections of global surface temperature are produced using climate model emulators that are constrained by the assessments of ECS, TCR and ERF. In reports up to and including AR5, ESM values of ECS did not fully encompass the assessed *very likely* range of ECS, raising the possibility that past multi-model ensembles underestimated the uncertainty in climate change projections that existed at the times of those reports (e.g., Knutti, 2010). However, due to an increase in the modelled ECS

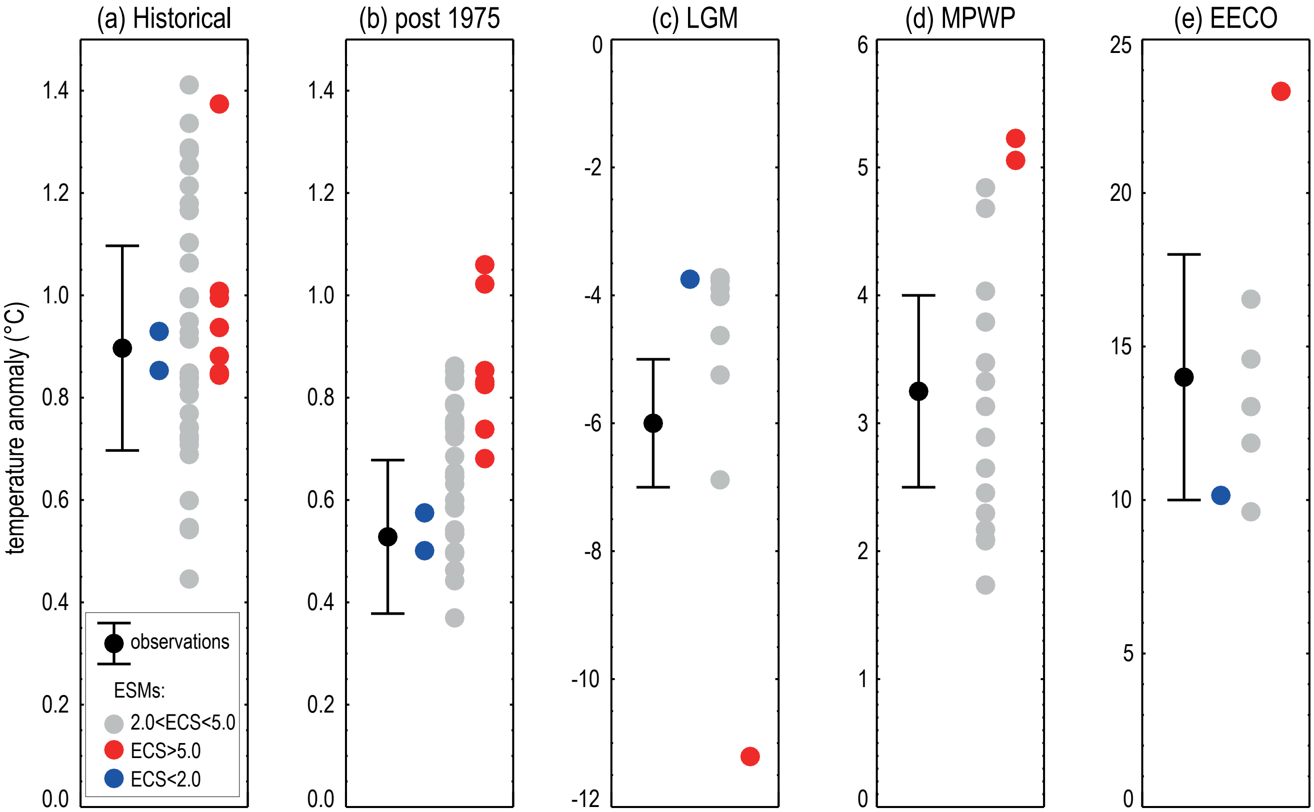


Figure 7.19 | Global mean temperature anomaly in models and observations from five time periods. (a) Historical (CMIP6 models); **(b)** post-1975 (CMIP6 models); **(c)** Last Glacial Maximum (LGM; Cross-Chapter Box 2.1; PMIP4 models; Kageyama et al., 2021; Zhu et al., 2021); **(d)** mid-Pliocene Warm Period (MPWP; Cross-Chapter Box 2.4; PlioMIP models; Haywood et al., 2020; Zhang et al., 2021); **(e)** Early Eocene Climatic Optimum (EECO; Cross-Chapter Box 2.1; DeepMIP models; Zhu et al., 2020; Lunt et al., 2021). Grey circles show models with ECS in the assessed *very likely* range; models in red have an ECS greater than the assessed *very likely* range (>5°C); models in blue have an ECS lower than the assessed *very likely* range (<2°C). Black ranges show the assessed temperature anomaly derived from observations (Section 2.3). The historical anomaly in models and observations is calculated as the difference between 2005–2014 and 1850–1900, and the post-1975 anomaly is calculated as the difference between 2005–2014 and 1975–1984. For the LGM, MPWP and EECO, temperature anomalies are compared with pre-industrial (equivalent to CMIP6 simulation 'piControl'). All model simulations of the MPWP and LGM were carried out with atmospheric CO_2 concentrations of 400 and 190 ppm respectively. However, CO_2 during the EECO is relatively more uncertain, and model simulations were carried out at either 1120ppm or 1680 ppm (except for the one high-ECS EECO simulation which was carried out at 840 ppm; Zhu et al., 2020). The one low-ECS EECO simulation was carried out at 1680 ppm. Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

spread and a decrease in the assessed ECS spread based on improved knowledge in multiple lines of evidence, the CMIP6 ensemble encompasses the *very likely* range of ECS [2 to 5] °C assessed in Section 7.5.5. Models outside of this range are useful for establishing emergent constraints on ECS and TCR and provide useful examples of 'tail risk' (Sutton, 2018), producing dynamically consistent realizations of future climate change to inform impact studies and risk assessments.

In summary, the distribution of CMIP6 models have higher average ECS and TCR values than the CMIP5 generation of models and the assessed values of ECS and TCR in Section 7.5.5. The high ECS and TCR values can in some CMIP6 models be traced to improved representation of extratropical cloud feedbacks (*medium confidence*). The ranges of ECS and TCR from the CMIP6 models are not considered robust samples of possible values and the models are not considered a separate line of evidence for ECS and TCR. Solely based on its ECS or TCR values an individual ESM cannot be ruled out as implausible, though some models with high (greater than 5°C) and low (less than 2°C) ECS are less consistent with past climate change (*high confidence*). High climate sensitivity in models leads to generally higher projected warming in CMIP6 compared to both CMIP5 and that assessed based on multiple lines of evidence (Sections 4.3.1 and 4.3.4, and FAQ 7.3).

7.5.7 Processes Underlying Uncertainty in the Global Temperature Response to Forcing

While the magnitude of global warming by the end of the 21st century is dominated by future GHG emissions, the uncertainty in warming for a given ERF change is dominated by the uncertainty in ECS and TCR (Section 4.3.4). The proportion of variation explained by ECS and TCR varies with scenario and the time period considered, but within CMIP5 models around 60–90% of the globally averaged projected surface warming range in 2100 can be explained by the model range of these metrics (Grose et al., 2018). Uncertainty in the long-term global surface temperature change can further be understood in terms of the processes affecting the global TOA energy budget, namely the ERF, the radiative feedbacks which govern the efficiency of radiative energy loss to space with surface warming, and the increase in the global energy inventory (dominated by ocean heat uptake) which reduces the transient surface warming. A variety of studies

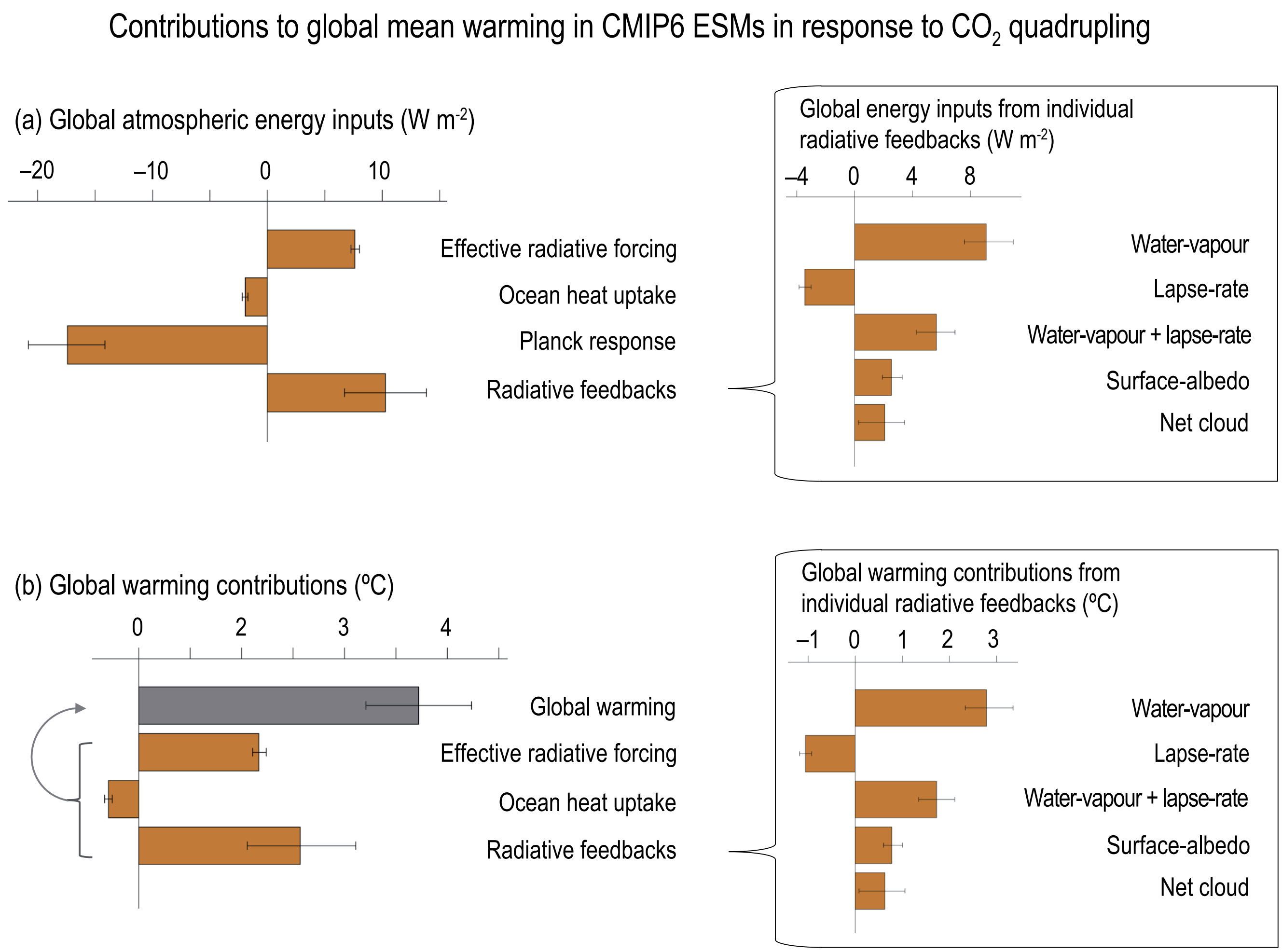


Figure 7.20 | Contributions of effective radiative forcing, ocean heat uptake and radiative feedbacks to global atmospheric energy input and near-surface air temperature change at year 100 of *abrupt4xCO2* simulations of CMIP6 models. (a) The energy flux to the global atmosphere associated with the effective CO_2 forcing, global ocean heat uptake, Planck response, and radiative feedbacks, which together sum to zero. The inset shows energy input from individual feedbacks, summing to the total feedback energy input. **(b)** Contributions to net global warming are calculated by dividing the energy inputs by the *magnitude* of the global Planck response (3.2 W m^{-2} $°C^{-1}$), with the contributions from radiative forcing, ocean heat uptake, and radiative feedbacks (orange bars) summing to the value of net warming (grey bar). The inset shows warming contributions associated with individual feedbacks, summing to the total feedback contribution. Uncertainties show the interquartile range (25th and 75th percentiles) across models. Radiative kernel methods (see Section 7.4.1) were used to decompose the net energy input from radiative feedbacks into contributions from changes in atmospheric water vapour, lapse rate, clouds, and surface albedo (Zelinka et al. (2020) using the Huang et al. (2017) radiative kernel). The CMIP6 models included are those analysed by Zelinka et al. (2020) and the warming contribution analysis is based on that of Goosse et al. (2018). Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

evaluate the effect of each of these processes on surface changes within coupled ESM simulations by diagnosing so-called 'warming contributions' (Dufresne and Bony, 2008; Crook et al., 2011; Feldl and Roe, 2013; Vial et al., 2013; Pithan and Mauritsen, 2014; Goosse et al., 2018). By construction, the individual warming contributions sum to the total global surface warming (Figure 7.20b). For long-term warming in response to CO_2 forcing in CMIP5 models, the energy added to the climate system by radiative feedbacks is larger than the ERF of CO_2 (Figure 7.20a), implying that feedbacks more than double the magnitude of global warming (Figure 7.20b). Radiative kernel methods (see Section 7.4.1) can be used to decompose the net energy input from radiative feedbacks into its components. The water-vapour, cloud and surface-albedo feedbacks enhance global warming, while the lapse-rate feedback reduces global warming. Ocean heat uptake reduces the rate of global surface warming by sequestering heat at depth away from the ocean surface. Section 7.4.4.1 shows the warming contributions from these factors at the regional scale.

Differences in projected transient global warming across ESMs are dominated by differences in their radiative feedbacks, while differences in ocean heat uptake and radiative forcing play secondary roles (Figure 7.20b; Vial et al., 2013). The uncertainty in projected global surface temperature change associated with inter-model differences in cloud feedbacks is the largest source of uncertainty in CMIP5 and CMIP6 models (Figure 7.20b), just as they were for CMIP3 models (Dufresne and Bony, 2008). Extending this energy budget analysis to equilibrium surface warming suggests that about 70% of the inter-model differences in ECS arises from uncertainty in cloud feedbacks, with the largest contribution to that spread coming from shortwave low-cloud feedbacks (Vial et al., 2013; Zelinka et al., 2020).

Interactions between different feedbacks within the coupled climate system pose a challenge to our ability to understand global warming and its uncertainty based on energy budget diagnostics (Section 7.4.2). For example, water-vapour and lapse-rate feedbacks are correlated (Held and Soden, 2006) owing to their joint dependence on the spatial pattern of warming (Po-Chedley et al., 2018b). Moreover, feedbacks are not independent of ocean heat uptake because the uptake and transport of heat by the ocean influences the SST pattern on which global feedbacks depend (Section 7.4.4.3). However, alternative decompositions of warming contributions that better account for correlations between feedbacks produce similar results (Caldwell et al., 2016). The key role of radiative feedbacks in governing the magnitude of global warming is also supported by the high correlation between radiative feedbacks (or ECS) and transient 21st-century warming within ESMs (Grose et al., 2018).

Another approach to evaluating the roles of forcing, feedbacks and ocean heat uptake in projected warming employs idealized energy balance models that emulate the response of ESMs, and which preserve the interactions between system components. One such emulator, used in Section 7.5.1.2, resolves the heat capacity of both the surface components of the climate system and the deep ocean (Held et al., 2010; Geoffroy et al., 2013a, b; Kostov et al., 2014; Armour, 2017). Using this emulator, Geoffroy et al. (2012) find that: under an idealized 1% per year increase in atmospheric CO_2, radiative feedbacks constitute the greatest source of uncertainty (about 60% of variance) in transient warming beyond several decades; ERF uncertainty plays a secondary but important role in warming uncertainty (about 20% of variance) that diminishes beyond several decades; and ocean heat uptake processes play a minor role in warming uncertainty (less than 10% of variance) at all time scales.

More computationally intensive approaches evaluate how the climate response depends on perturbations to key parameter or structural choices within ESMs. Large 'perturbed parameter ensembles', wherein a range of parameter settings associated with cloud physics are explored within atmospheric ESMs, produce a wide range of ECS due to changes in cloud feedbacks, but often produce unrealistic climate states (Joshi et al., 2010). Rowlands et al. (2012) generated an ESM perturbed-physics ensemble of several thousand members by perturbing model parameters associated with radiative forcing, cloud feedbacks and ocean vertical diffusivity (an important parameter for ocean heat uptake). After constraining the ensemble to have a reasonable climatology and to match the observed historical surface warming, they found a wide range of projected warming by the year 2050 under the SRES A1B scenario (1.4°C–3°C relative to the 1961–1990 average) that is dominated by differences in cloud feedbacks. The finding that cloud feedbacks are the largest source of spread in the net radiative feedback has since been confirmed in perturbed parameter ensemble studies using several different ESMs (Gettelman et al., 2012; Tomassini et al., 2015; Kamae et al., 2016b; Rostron et al., 2020; Tsushima et al., 2020). By swapping out different versions of the atmospheric or oceanic components in a coupled ESM, Winton et al. (2013) found that TCR and ECS depend on which atmospheric component was used (using two versions with different atmospheric physics), but that only TCR is sensitive to which oceanic component of the model was used (using two versions with different vertical coordinate systems, among other differences); TCR and ECS changed by 0.4°C and 1.4°C, respectively, when the atmospheric model component was changed, while TCR and ECS changed by 0.3°C and less than 0.05°C, respectively, when the oceanic model component was changed. By perturbing ocean vertical diffusivities over a wide range, Watanabe et al. (2020) found that TCR changed by 0.16°C within the model MIROC5.2 while Krasting et al. (2018) found that ECS changed by about 0.6°C within the model GFDL-ESM2G, with this difference linked to different radiative feedbacks associated with different spatial patterns of sea surface warming (Section 7.4.4.3). By comparing simulations of CMIP6 models with and without the effects of CO_2 on vegetation, Zarakas et al. (2020) find a physiological contribution to TCR of 0.12°C (range 0.02°C–0.29°C across models) owing to physiological adjustments to the CO_2 ERF (Section 7.3.2.1).

There is *robust evidence* and *high agreement* across a diverse range of modelling approaches and thus *high confidence* that radiative feedbacks are the largest source of uncertainty in projected global warming out to 2100 under increasing or stable emissions scenarios, and that cloud feedbacks in particular are the dominant source of that uncertainty. Uncertainty in radiative forcing plays an important but generally secondary role. Uncertainty in global ocean heat uptake plays a lesser role in global warming uncertainty, but ocean circulation could play an important role through its effect on sea surface warming patterns which in turn project onto radiative feedbacks through the pattern effect (Section 7.4.4.3).

The spread in historical surface warming across CMIP5 ESMs shows a weak correlation with inter-model differences in radiative feedback or ocean heat uptake processes but a high correlation with inter-model differences in radiative forcing owing to large variations in aerosol forcing across models (Forster et al., 2013). Likewise, the spread in projected 21st-century warming across ESMs depends strongly on which emissions scenario is employed (Section 4.3.1; Hawkins and Sutton, 2012). Strong emissions reductions would remove aerosol forcing (Section 6.7.2) and this could dominate the uncertainty in near-term warming projections (Armour and Roe, 2011; Mauritsen and Pincus, 2017; Schwartz, 2018; Smith et al., 2019). On post-2100 time scales carbon cycle uncertainty such as that related to permafrost thawing could become increasingly important, especially under high-emissions scenarios (Figure 5.30).

In summary, there is *high confidence* that cloud feedbacks are the dominant source of uncertainty for late 21st-century projections of transient global warming under increasing or stable emissions scenarios, whereas uncertainty is dominated by aerosol ERF in strong mitigation scenarios. Global ocean heat uptake is a smaller source of uncertainty in long-term surface warming (*high confidence*).

7.6 Metrics to Evaluate Emissions

Emissions metrics are used to compare the relative effect of emissions of different gases over time in terms of radiative forcing, global surface temperature or other climate effects. They are introduced in Chapter 1 (Box 1.3). Chapter 8 of AR5 (Myhre et al., 2013b) comprehensively discussed different emissions metrics so this section focuses on updates since that report. Section 7.6.1 updates the physical assessment. Section 7.6.2 assesses developments in the comparison of emissions of short- and long-lived gases. Box 7.3 assesses physical aspects of emissions metric use within climate policy.

7.6.1 Physical Description of Metrics

This section discusses metrics that relate emissions to physical changes in the climate system. Other metrics, for instance relating to economic costs or 'damage' are discussed in WGIII, Chapter 2. The same Chapter also assesses literature examining the extent to which different physical metrics are linked to cost–benefit and cost-effectiveness metrics. One metric, the 100-year global warming potentials (GWP-100), has extensively been employed in climate policy to report emissions of different GHGs on the same scale. Other physical metrics exist, and these are discussed in this section.

Emissions metrics can be quantified as the magnitude of the effect a unit mass of emission of a species has on a key measure of climate change. This section focuses on physical measures such as the radiative forcing, GSAT change, global average precipitation change, and global mean sea level rise (Myhre et al., 2013b; Sterner et al., 2014; Shine et al., 2015). When used to represent a climate effect, the metrics are referred to as absolute metrics and expressed in units of 'effect per kg' (e.g., absolute global warming potentials, AGWP or absolute global temperature-change potentials, AGTP). More commonly, these are compared with a reference species (almost always CO_2 in kg (CO_2)), to give a dimensionless factor (written as e.g., global warming potentials (GWP) or global temperature-change potential (GTP)). The unit mass is usually taken as a 1 kg instantaneous 'pulse' (Myhre et al., 2013b), but can also refer to a 'step' in emissions rate of 1 kg yr^{-1}.

There is a cause–effect chain that links human activity to emissions, then from emissions to radiative forcing, climate response and climate impacts (Fuglestvedt et al., 2003). Each step in the causal chain requires an inference or modelling framework that maps causes to effects. Emissions metrics map from emissions of some compound to somewhere further down the cause-and-effect chain, radiative forcing (e.g., GWP) or temperature (e.g., GTP) or other effects (such as sea level rise or socio-economic impacts). While variables later in the chain have greater policy or societal relevance, they are also subject to greater uncertainty because each step in the chain includes more modelling systems, each of which brings its own uncertainty (Figure 1.15; Balcombe et al., 2018).

Since AR5, understanding of the radiative effects of emitted compounds has continued to evolve and these changes are assessed in Section 7.6.1.1. Metrics relating to precipitation and sea level have also been quantified (Section 7.6.1.2). Understanding of how emissions metrics are affected by the carbon cycle response to temperature has improved. This allows the carbon cycle response to temperature to be more fully included in the emissions metrics presented here (Section 7.6.1.3). There have also been developments in approaches for comparing short-lived GHGs to CO_2 in the context of mitigation and global surface temperature change (Section 7.6.1.4). Emissions metrics for selected key compounds are presented in Section 7.6.1.5.

7.6.1.1 Radiative Properties and Lifetimes

The radiative properties and lifetimes of compounds are the fundamental component of all emissions metrics. Since AR5, there have been advances in the understanding of the radiative properties of various compounds (see Sections 7.3.1, 7.3.2 and 7.3.3), and hence their effective radiative efficiencies (ERFs per unit change in concentration). For CO_2, CH_4 and N_2O, better accounting of the spectral properties of these gases has led to re-evaluation of their stratospheric-temperature-adjusted radiative forcing (SARF) radiative efficiencies and their dependence on the background gas concentrations (Section 7.3.2). For CO_2, CH_4, N_2O, CFC-11 and CFC-12 the tropospheric adjustments (Sections 7.3.1 and 7.3.2) are assessed to make a non-zero contribution to ERF. There is insufficient evidence to include tropospheric adjustments for other halogenated compounds. The re-evaluated effective radiative efficiency for CO_2 will affect all emissions metrics relative to CO_2.

The effective radiative efficiencies (including adjustments from Section 7.3.2) for 2019 background concentrations for CO_2, CH_4 and N_2O are assessed to be 1.33×10^{-5}, 3.89×10^{-4} and 3.19×10^{-3} W m^{-2} ppb^{-1} respectively (see Table 7.15 for uncertainties), compared to AR5 assessments of 1.37×10^{-5}, 3.63×10^{-4} and 3.00×10^{-3} W m^{-2} ppb^{-1}. For CO_2, increases due to the adjustments do not quite balance the decreases due to the increasing background concentration. For CH_4, increases due to the re-evaluated radiative properties more than offset the decreases due to the increasing background concentration. For N_2O the addition of tropospheric adjustments increases the effective radiative efficiency. Radiative efficiencies of halogenated species have been revised slightly (Section 7.3.2.4) and for CFCs include tropospheric adjustments.

The perturbation lifetimes of CH_4 (Section 6.3.1). and N_2O (Section 5.2.3.1) have been slightly revised since AR5 to be 11.8 ± 1.8 years and 109 ± 10 years, respectively (Table 7.15). The lifetimes of halogenated compounds have also been slightly revised (Hodnebrog et al., 2020a).

Although there has been greater understanding since AR5 of the carbon cycle responses to CO_2 emissions (Sections 5.4 and 5.5), there has been no new quantification of the response of the carbon cycle to an instantaneous pulse of CO_2 emission since Joos et al. (2013).

7.6.1.2 Physical Indicators

The basis of all the emissions metrics is the time profile of effective radiative forcing (ERF) following the emission of a particular compound. The emissions metrics are then built up by relating the forcing to the desired physical indicators. These forcing–response relationships can either be generated from emulators (Cross-Chapter Box 7.1; Tanaka et al., 2013; Gasser et al., 2017b), or from analytical expressions based on parametric equations (response functions) derived from more complex models (Myhre et al., 2013b).

To illustrate the analytical approach, the ERF time evolution following a pulse of emission can be considered an absolute global forcing potential (AGFP; similar to the 'Instantaneous Climate Impact' of Edwards and Trancik, 2014). This can be transformed into an absolute global temperature-change potential (AGTP) by combining the radiative forcing with a global surface temperature response function. This temperature response is typically derived from a two-layer energy balance emulator (Supplementary Material 7.SM.5; Myhre et al., 2013b). For further physical indicators further response functions are needed based on the radiative forcing or temperature, for instance. Sterner et al. (2014) used an upwelling-diffusiveenergy balance model to derive the thermosteric component of sea level rise as response functions to radiative forcing or global surface temperature. A metric for precipitation combines both the radiative forcing (AGFP) and temperature (AGTP) responses to derive an absolute global precipitation potential (AGPP; Shine et al., 2015). The equations relating these metrics are given in Supplementary Material 7.SM.5.

The physical emissions metrics described above are functions of time since typically the physical effects reach a peak and then decrease in the period after a pulse emission as the concentrations of the emitted compound decay. The value of the metrics can therefore be strongly dependent on the time horizon of interest. All relative metrics (GWP, GTP etc.) are also affected by the time dependence of the CO_2 metrics in the denominator. Instantaneous or endpoint metrics quantify the change (e.g., in radiative forcing, global surface temperature, global mean sea level) at a particular time after the emission. These can be appropriate when the goal is to not exceed a fixed target such as a temperature or global mean sea level rise at a specific time. Emissions metrics can also be integrated from the time of emission. The most common of these is the absolute global warming potential (AGWP), which is the integral of the AGFP. The physical effect is then in units of forcing-years, degree-years or metre-years for forcing, temperature, or sea level rise, respectively. These can be appropriate for trying to reduce the overall damage potential when the effect depends on how long the change occurs for, not just how large the change is. The integrated metrics still depend on the time horizon, though for the shorter-lived compounds this dependence is somewhat smoothed by the integration. The integrated version of a metric is often denoted as iAGxx, although the integral of the forcing-based metric (iAGFP) is known as the AGWP. Both the endpoint and integrated absolute metrics for non-CO_2 species can be divided by the equivalent for CO_2 to give relative emissions metrics (e.g., GWP (=iGFP), GTP, iGTP).

Each step from radiative forcing to global surface temperature to sea level rise introduces longer time scales and therefore prolongs further the contributions to climate change of short-lived GHGs (Myhre et al., 2013b). Thus, short-lived GHGs become more important (relative to CO_2) for sea level rise than for temperature or radiative forcing (Zickfeld et al., 2017). Integrated metrics include the effects of a pulse emission from the time of emission up to the time horizon, whereas endpoint metrics only include the effects that persist out to the time horizon. Because the largest effects of short-lived GHGs occur shortly after their emission and decline towards the end of the time period, short-lived GHGs have relatively higher integrated metrics than their corresponding endpoint metrics (Peters et al., 2011; Levasseur et al., 2016).

For species perturbations that lead to a strong regional variation in forcing pattern, the regional temperature response can be different to that for CO_2. Regional equivalents to the global metrics can be derived by replacing the global surface temperature response function with a regional response matrix relating forcing changes in one region to temperature changes in another (W.J. Collins et al., 2013; Aamaas et al., 2017; Lund et al., 2017).

For the research discussed above, metrics for several physical variables can be constructed that are linear functions of radiative forcing. Similar metrics could be devised for other climate variables provided they can be related by response functions to radiative forcing or global surface temperature change. The radiative forcing does not increase linearly with emissions for any species, but the non-linearities (for instance changes in CO_2 radiative efficiency) are small compared to other uncertainties.

7.6.1.3 Carbon Cycle Responses and Other Indirect Contributions

The effect of a compound on climate is not limited to its direct radiative forcing. Compounds can perturb the carbon cycle affecting atmospheric CO_2 concentrations. Chemical reactions from emitted compounds can produce or destroy other GHGs or aerosols.

Any agent that warms the surface perturbs the terrestrial and oceanic carbon fluxes (Sections 5.4.3 and 5.4.4), typically causing a net flux of CO_2 into the atmosphere and hence further warming. This aspect is already included in the carbon cycle models that are used to generate the radiative effects of a pulse of CO_2 (Joos et al., 2013), but was neglected for non-CO_2 compounds in the conventional metrics so this introduces an inconsistency and bias in the metric values (Gillett and Matthews, 2010; MacDougall et al., 2015; Tokarska et al., 2018). A simplistic account of the carbon cycle response was tentatively included in AR5 based on a single study (W.J. Collins et al., 2013). Since AR5 this understanding has been revised (Gasser et al., 2017b; Sterner and Johansson, 2017) using simple parametrized carbon cycle models to derive the change in CO_2 surface flux for a unit temperature pulse as an impulse response function to temperature. In W.J. Collins et al. (2013) this response function was assumed to be simply a delta function, whereas the newer studies include a more complete functional form accounting for subsequent re-uptake of CO_2 after the removal of the temperature increase. Accounting for re-uptake has the effect of reducing the carbon-cycle responses associated with the metrics compared to AR5, particularly at large time horizons. The increase in any metric due to the carbon cycle response can be derived from the convolution of the global surface temperature response with the CO_2 flux response to temperature and the equivalent metric for CO_2 (Equation 7.SM.5.5 in the Supplementary Material). Including this response also increases the duration of the effect of short-lived GHGs on climate (Fu et al., 2020). An alternative way of accounting for the carbon cycle temperature response would be to incorporate it into the temperature response function (the response functions used here and given in Supplementary Material 7.SM.5.2 do not explicitly do this). If this were done, the correction could be excluded from both the CO_2 and non-CO_2 forcing responses as, in Hodnebrog et al. (2020a).

Including the carbon cycle response for non-CO_2 treats CO_2 and non-CO_2 compounds consistently and therefore we assess that its inclusion more accurately represents the climate effects of non-CO_2

species. There is *high confidence* in the methodology of using carbon cycle models for calculating the carbon cycle response. The magnitude of the carbon cycle response contributions to the emissions metrics varies by a factor of two between Sterner and Johansson (2017) and Gasser et al. (2017b). The central values are taken from Gasser et al. (2017b) as the OSCAR 2.2 model used is based on parameters derived from CMIP5 models, and the climate–carbon feedback magnitude is therefore similar to the CMIP5 multi-model mean (Arora et al., 2013; Lade et al., 2018). As values have only been calculated in two simple parametrized carbon cycle models the uncertainty is assessed to be ±100%. Due to there being few studies and a factor of two difference between them, there is *low confidence* that the magnitude of the carbon cycle response is within the higher end of this uncertainty range, but *high confidence* that the sign is positive. Carbon cycle responses are included in all the metrics presented in Table 7.15 and Supplementary Table 7.SM.7. The carbon cycle contribution is lower than in AR5, but there is *high confidence* in the need for its inclusion and the method by which it is quantified.

Emissions of non-CO_2 species can affect the carbon cycle in other ways: emissions of ozone precursors can reduce the carbon uptake by plants (W.J. Collins et al., 2013); emissions of reactive nitrogen species can fertilize plants and hence increase the carbon uptake (Zaehle et al., 2015); and emissions of aerosols or their precursors can affect the utilisation of light by plants (Cohan et al., 2002; Mercado et al., 2009; Mahowald et al., 2017; see Section 6.4.4 for further discussion). There is *robust evidence* that these processes occur and are important, but *insufficient evidence* to determine the magnitude of their contributions to emissions metrics. Ideally, emissions metrics should include all indirect effects to be consistent, but limits to our knowledge restrict how much can be included in practice.

Indirect contributions from chemical production or destruction of other GHGs are quantified in Chapter 6 (Section 6.4). For methane (CH_4), AR5 (Myhre et al., 2013b) assessed that the contributions from effects on ozone and stratospheric water vapour add 50% ± 30% and 15% ± 11% to the emissions-based ERF, which were equivalent to $1.8 \pm 0.7 \times 10^{-4}$ and $0.5 \pm 0.4 \times 10^{-4}$ W m^{-2} ppb $(CH_4)^{-1}$. In AR6 the radiative efficiency formulation is preferred as it is independent of the assumed radiative efficiency for methane. The assessed contributions to the radiative efficiency for methane due to ozone are $1.4 \pm 0.7 \times 10^{-4}$ W m^{-2} ppb $(CH_4)^{-1}$, based on 0.14 W m^{-2} forcing from a 1023 ppb (1850–2014) methane change (Thornhill et al., 2021b). The contribution from stratospheric water vapour is $0.4 \pm 0.4 \times 10^{-4}$ W m^{-2} ppb $(CH_4)^{-1}$, based on 0.05 W m^{-2} forcing from a 1137 ppb (1750–2019) methane change (Section 7.3.2.6). Nitrous oxide (N_2O) depletes upper stratospheric ozone (a positive forcing) and reduces the methane lifetime. In AR5 the methane lifetime effect was assessed to reduce methane concentrations by 0.36 ppb per ppb increase in N_2O, with no assessment of the effective radiative forcing from ozone. This is now increased to –1.7 ppb methane per ppb N_2O (based on a methane lifetime decrease of 4% ± 4% for a 55 ppb increase in N_2O (Thornhill et al., 2021b) and a radiative efficiency of $5.5 \pm 0.4 \times 10^{-4}$ W m^{-2} ppb $(N_2O)^{-1}$ through ozone (Thornhill et al., 2021b)). In summary, GWPs and GTPs for methane and nitrous oxide are slightly lower than in AR5 (*medium confidence*) due to revisions in their lifetimes and updates to their indirect chemical effects.

Methane can also affect the oxidation pathways of aerosol formation (Shindell et al., 2009) but the available literature is insufficient to make a robust assessment of this. Hydrocarbon and molecular hydrogen oxidation also leads to tropospheric ozone production and change in methane lifetime (Collins et al., 2002; Hodnebrog et al., 2018). For reactive species the emissions metrics can depend on where the emissions occur, and the season of emission (Aamaas et al., 2016; Lund et al., 2017; Persad and Caldeira, 2018). The AR5 included a contribution to the emissions metrics for ozone-depleting substances (ODSs) from the loss of stratospheric ozone. The assessment of ERFs from ODSs in Chapter 6 (Section 6.4.2) suggests the quantification of these terms may be more uncertain than the formulation in AR5 so these are not included here.

Oxidation of methane leads ultimately to the net production of atmospheric CO_2 (Boucher et al., 2009). This yield is less than 100% (on a molar basis) due to uptake by soils and some of the reaction products (mainly formaldehyde) being directly removed from the atmosphere before being completely oxidized. Estimates of the yield are 61% (Boucher et al., 2009) and 88% (Shindell et al., 2017), so the assessed range is 50–100% with a central value of 75% (*low confidence*). For methane and hydrocarbons from fossil sources, this will lead to additional fossil CO_2 in the atmosphere whereas for biogenic sources of methane or hydrocarbons, this replaces CO_2 that has been recently removed from the atmosphere. Since the ratio of molar masses is 2.75, 1 kg of methane generates 2.1 ± 0.7 kgCO_2 for a 75% yield. For biogenic methane the soil uptake and removal of partially oxidized products is equivalent to a sink of atmospheric CO_2 of 0.7 ± 0.7 kg per kg methane. The contributions of this oxidation effect to the methane metric values allow for the time delay in the oxidation of methane. Methane from fossil fuel sources has therefore slightly higher emissions metric values than those from biogenic sources (*high confidence*). The CO_2 can already be included in carbon emissions totals (Muñoz and Schmidt, 2016) so care needs to be taken when applying the fossil correction to avoid double counting.

7.6.1.4 Comparing Long-lived with Short-lived Greenhouse Gases

Since AR5 there have been developments in how to account for the different behaviours of short-lived and long-lived compounds. Pulse-based emissions metrics for short-lived GHGs with lifetimes less than 20 years are very sensitive to the choice of time horizon (e.g., Pierrehumbert, 2014). Global surface temperature changes following a pulse of CO_2 emission are roughly constant in time (the principle behind TCRE; Section 5.5.1 and Figure 7.21b) whereas the temperature change following a pulse of short-lived GHG emission declines with time. In contrast to a one-off pulse, a step change in short-lived GHG emissions that is maintained indefinitely causes a concentration increase that eventually equilibrates to a steady state in a way that is more comparable to a pulse of CO_2. Similarly the resulting change in global surface temperature from a step change in short-lived GHGs (Figure 7.21a) after a few decades increases only slowly (due to accumulation of heat in the deep ocean) and hence its effects are more similar to a pulse of CO_2 (Smith et al., 2012; Lauder et al., 2013; Allen et al., 2016, 2018b). The different time dependence of short-lived and long-lived compounds can be accounted for exactly with the CO_2 forcing equivalent metric (Wigley, 1998; Allen et al., 2018b; Jenkins et al., 2018) that produces a CO_2 emissions time profile such that the radiative forcing matches the time evolution of that from the non-CO_2 emissions. But other metric approaches can approximate this exact approach.

The similarity in behaviour of step changes in short-lived GHG emissions and pulses of CO_2 emissions has recently been used to formulate new emissions metric concepts (Collins et al., 2020). For short-lived GHGs, these new concepts use a step change in the rate of emissions, in contrast to an instantaneous pulse in a given year that is typically used (e.g., Myhre et al., 2013b). Metrics for step emissions changes are denoted here by a superscript ‘^{S}’ (e.g., $AGTP_X^S$ is the absolute global surface temperature-change potential from a unit step change in emissions of species “X”). These can be derived by integrating the more standard pulse emission changes up to the time horizon. The response to a step emissions change is therefore equivalent to the integrated response to a pulse emission ($AGTP_X^S = iAGTP_X$); and the radiative forcing response to a step emissions change $AGFP_X^S$ is equivalent to the integrated forcing response $iAGFP_X$ which is the AGWP. The step metric for short-lived GHGs can then be compared with the pulse metric for CO_2 in a ratio $AGTP_X^S/AGTP_{CO2}$ (Collins et al., 2020). This is referred to as a combined GTP (CGTP) in Collins et al. (2020), and has units of years (the standard GTP is dimensionless). This CGTP shows less variation with time than the standard GTP (comparing Figure 7.21c with Figure 7.21d) and provides a scaling for comparing a change in emissions rate (in kg yr^{-1}) of short-lived GHGs with a pulse emission or change in cumulative CO_2 emissions (in kg). Cumulative CO_2 equivalent emissions are given by CGTP × emissions rate of short-lived GHGs. The CGTP can be calculated for any species, but it is least dependent on the chosen time horizon for species with lifetimes less than half the time horizon of the metric (Collins et al., 2020). Pulse-step metrics can therefore be useful where time dependence of pulse metrics, like GWP or GTP, complicates their use (see Box 7.3).

For a stable global warming from non-CO_2 climate agents (gas or aerosol) their effective radiative forcing needs to gradually decrease (Tanaka and O’Neill, 2018). Cain et al. (2019) find this decrease to be around 0.3% yr^{-1} for the climate response function in AR5 (Myhre et al., 2013b). To account for this, a quantity referred to as GWP* has been defined that combines emissions (pulse) and changes in emissions levels (step) approaches (Cain et al., 2019;

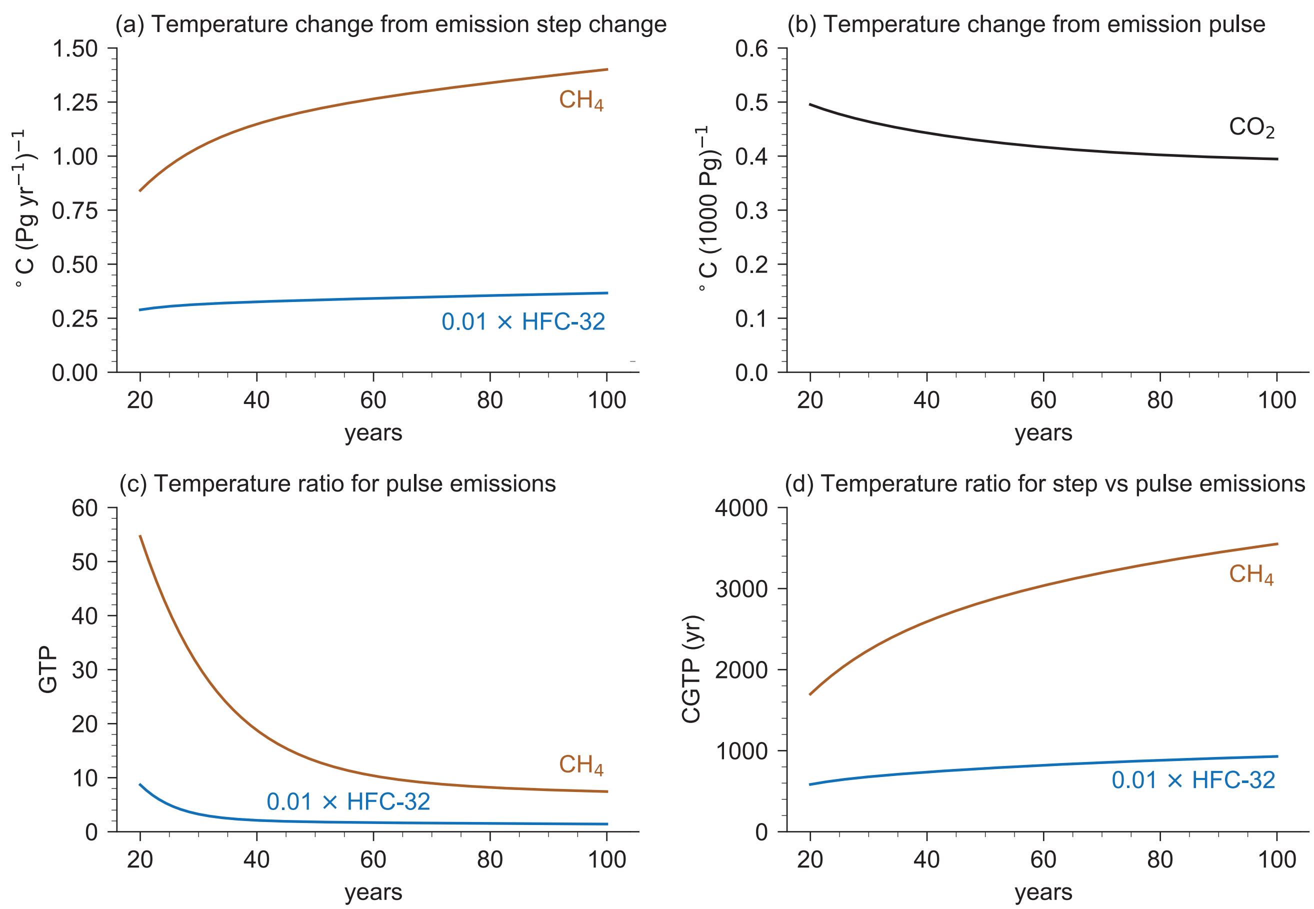


Figure 7.21 | Emissions metrics for two short-lived greenhouse gases: HFC-32 and methane (CH_4; lifetimes of 5.4 and 11.8 years). The temperature response function comes from Supplementary Material 7.SM.5.2. Values for non-CO_2 species include the carbon cycle response (Section 7.6.1.3). Results for HFC-32 have been divided by 100 to show on the same scale. **(a)** Temperature response to a step change in short-lived greenhouse gas emissions. **(b)** Temperature response to a pulse CO_2 emission. **(c)** Conventional GTP metrics (pulse vs pulse). **(d)** Combined GTP metric (step versus pulse). Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

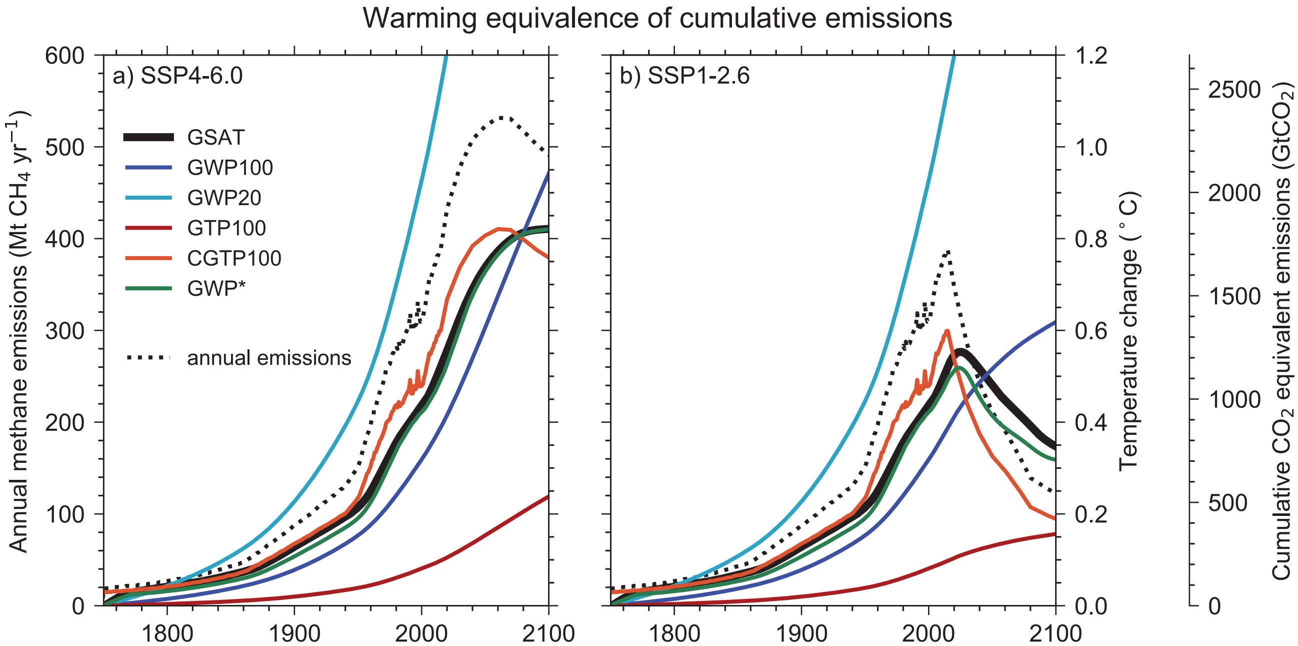


Figure 7.22 | Explores how cumulative carbon dioxide equivalent emissions estimated for methane vary under different emissions metric choices and how estimates of the global surface air temperature (GSAT) change deduced from these cumulative emissions compare to the actual temperature response computed with the two-layer emulator (solid black lines). Panels **(a)** and **(b)** show the SSP4-6.0 and SSP1-2.6 scenarios respectively. The panels show annual methane emissions as the dotted lines (left axis) from 1750 to 2100. The solid lines can be read as either estimates of GSAT change or estimates of the cumulative carbon dioxide equivalent emissions. This is because they are related by a constant factor, the TCRE. Thus, values can be read using either of the right-hand axes. Emissions metric values are taken from Table 7.15. The GWP* calculation is given in Section 7.6.1.4. The two-layer emulator has been calibrated to the central values of the Report's assessment (see Supplementary Material 7.SM.5.2). Further details on data sources and processing are available in the chapter data table (Table 7.SM.14).

Smith et al., 2021).[2] The emissions component accounts for the need for emissions to decrease to deliver a stable warming. The step (sometimes referred to as flow or rate) term in GWP* accounts for the change in global surface temperature that arises from a change in short-lived GHG emissions rate, as in CGTP, but here approximated by the change in emissions over the previous 20 years.

Cumulative CO_2 emissions and GWP*-based cumulative CO_2 equivalent GHG emissions multiplied by TCRE closely approximate the global warming associated with emissions time series (of CO_2 and GHG, respectively) from the start of the time series (Lynch et al., 2020). Both the CGTP and GWP* convert short-lived GHG emissions rate changes into cumulative CO_2 equivalent emissions, hence scaling these by TCRE gives a direct conversion from short-lived GHG emissions to global surface temperature change. By comparison expressing methane emissions as CO_2 equivalent emissions using GWP-100 overstates the effect of constant methane emissions on global surface temperature by a factor of 3–4 (Lynch et al., 2020, their Figure 5), while understating the effect of any new methane emission source by a factor of 4–5 over the 20 years following the introduction of the new source (Lynch et al., 2020, their Figure 4).

Figure 7.22 explores how cumulative CO_2 equivalent emissions estimated for methane vary under different emissions metric choices and how estimates of the global surface air temperature (GSAT) change deduced from these cumulative emissions compare to the actual temperature response computed with the two-layer emulator. Note that GWP and GTP metrics were not designed for use under a cumulative carbon dioxide equivalent emissions framework (Shine et al., 1990, 2005), even if they sometimes are (e.g., Cui et al., 2017; Howard et al., 2018) and analysing them in this way can give useful insights into their physical properties. Using these standard metrics under such frameworks, the cumulative CO_2 equivalent emissions associated with methane emissions would continue to rise if methane emissions were substantially reduced but remained above zero. In reality, a decline in methane emissions to a smaller but still positive value could cause a declining warming. GSAT changes estimated with cumulative CO_2 equivalent emissions computed with GWP-20 matches the warming trend for a few decades but quickly overestimates the response. Cumulative emissions using GWP-100 perform well when emissions are increasing but not when they are stable or decreasing. Cumulative emissions using GTP-100 consistently underestimate the warming. Cumulative emissions using either CGTP or GWP* approaches can more closely match the GSAT evolution (Allen et al., 2018b; Cain et al., 2019; Collins et al., 2020; Lynch et al., 2020).

In summary, new emissions metric approaches such as GWP* and CGTP are designed to relate emissions changes in short-lived GHGs to emissions of CO_2 as they better account for the different physical behaviours of short- and long-lived gases. Through scaling the corresponding cumulative CO_2 equivalent emissions by the TCRE, the GSAT response from emissions over time of an aggregated set of

2 To calculate CO_2 equivalent emissions under GWP*, the short-lived greenhouse gas emissions are multiplied by GWP-100 × 0.28 and added to the net emissions increase or decrease over the previous 20 years multiplied by GWP-100 × 4.24 (Smith et al., 2021).

gases can be estimated. Using either these new approaches, or treating short- and long-lived GHG emissions pathways separately, can improve the quantification of the contribution of emissions to global warming within a cumulative emissions framework, compared to approaches that aggregate emissions of GHGs using standard CO_2 equivalent emissions metrics. As discussed in Box 7.3, there is *high confidence* that multi-gas emissions pathways with the same time-dependence of aggregated CO_2 equivalent emissions estimated from standard approaches, such as weighting emissions by their GWP-100 values, rarely lead to the same estimated temperature outcomes.

7.6.1.5 Emissions Metrics by Compounds

Emissions metrics for selected compounds are presented in Table 7.15, with further compounds presented in the Supplementary Material, Table 7.SM.7. The evolution of the CO_2 concentrations in response to a pulse emission is as in AR5 (Joos et al., 2013; Myhre et al., 2013b), the perturbation lifetimes for CH_4 and N_2O are from Section 7.6.1.1. The lifetimes and radiative efficiencies for halogenated compounds are taken from Hodnebrog et al. (2020a). Combined metrics (CGTPs) are presented for compounds with lifetimes less than 20 years. Note that CGTP has units of years and is applied to a change in emissions rate rather than a change in emissions amount. Changes since AR5 are due to changes in radiative properties and lifetimes (Section 7.6.1.1), and indirect contributions (Section 7.6.1.3). Table 7.15 also gives overall emissions uncertainties in the emissions metrics due to uncertainties in radiative efficiencies, lifetimes and the climate response function (Supplementary Material, Tables 7.SM.8 to 7.SM.13).

Following their introduction in AR5 the assessed metrics now routinely include the carbon cycle response for non-CO_2 gases (Section 7.6.1.3). As assessed in this earlier section, the carbon cycle contribution is lower than in AR5. Contributions to CO_2 formation are included for methane depending on whether or not the source originates from fossil carbon, thus methane from fossil fuel sources has slightly higher emissions metric values than that from non-fossil sources.

Table 7.15 | Emissions metrics for selected species: global warming potential (GWP), global temperature-change potential (GTP). All values include carbon cycle responses as described in Section 7.6.1.3. Combined GTPs (CGTPs) are shown only for species with a lifetime less than 20 years (Section 7.6.1.4). Note CGTP has units of years and is applied to a change in emissions rate rather than a change in emissions amount. The radiative efficiencies are as described in Section 7.3.2 and include tropospheric adjustments where assessed to be non-zero in Section 7.6.1.1. The climate response function is from Supplementary Material 7.SM.5.2. Uncertainty calculations are presented in Supplementary Tables 7.SM.8 to 7.SM.13. Chemical effects of CH_4 and N_2O are included (Section 7.6.1.3). Contributions from stratospheric ozone depletion to halogenated species metrics are not included. Supplementary Table 7.SM.7 presents the full table.

Species	Lifetime (Years)	Radiative Efficiency ($W m^{-2} ppb^{-1}$)	GWP-20	GWP-100	GWP-500	GTP-50	GTP-100	CGTP-50 (years)	CGTP-100 (years)
CO_2	Multiple	$1.33 \pm 0.16 \times 10^{-5}$	1.	1.000	1.000	1.000	1.000		
CH_4-fossil	11.8 ± 1.8	$5.7 \pm 1.4 \times 10^{-4}$	82.5 ± 25.8	29.8 ± 11	10.0 ± 3.8	13.2 ± 6.1	7.5 ± 2.9	2823 ± 1060	3531 ± 1385
CH_4-non fossil	11.8 ± 1.8	$5.7 \pm 1.4 \times 10^{-4}$	79.7 ± 25.8	27.0 ± 11	7.2 ± 3.8	10.4 ± 6.1	4.7 ± 2.9	2675 ± 1057	3228 ± 1364
N_2O	109 ± 10	$2.8 \pm 1.1 \times 10^{-3}$	273 ± 118	273 ± 130	130 ± 64	290 ± 140	233 ± 110		
HFC-32	5.4 ± 1.1	$1.1 \pm 0.2 \times 10^{-1}$	2693 ± 842	771 ± 292	220 ± 87	181 ± 83	142 ± 51	78,175 ± 29,402	92,888 ± 36,534
HFC-134a	14.0 ± 2.8	$1.67 \pm 0.32 \times 10^{-1}$	4144 ± 1160	1526 ± 577	436 ± 173	733 ± 410	306 ± 119	146,670 ± 53,318	181,408 ± 71,365
CFC-11	52.0 ± 10.4	$2.91 \pm 0.65 \times 10^{-1}$	8321 ± 2419	6226 ± 2297	2093 ± 865	6351 ± 2342	3536 ± 1511		
PFC-14	50,000	$9.89 \pm 0.19 \times 10^{-2}$	5301 ± 1395	7380 ± 2430	10,587 ± 3692	7660 ± 2464	9055 ± 3128		

Box 7.3 | Physical Considerations in Emissions Metric Choice

Following AR5, this Report does not recommend an emissions metric because the appropriateness of the choice depends on the purposes for which gases or forcing agents are being compared. Emissions metrics can facilitate the comparison of effects of emissions in support of policy goals. They do not define policy goals or targets but can support the evaluation and implementation of choices within multi-component policies (e.g., they can help prioritize which emissions to abate). The choice of metric will depend on which aspects of climate change are most important to a particular application or stakeholder and over which time horizons. Different international and national climate policy goals may lead to different conclusions about what is the most suitable emissions metric (Myhre et al., 2013b).

Global warming potentials (GWP) and global temperature-change potentials (GTP) give the relative effect of pulse emissions, that is, how much more energy is trapped (GWP) or how much warmer (GTP) the climate would be when unit emissions of different compounds are compared (Section 7.6.1.2). Consequently, these metrics provide information on how much energy accumulation (GWP) or how much global warming (GTP) could be avoided (over a given time period, or at a given future point in time) by avoiding the emission of a unit of a short-lived greenhouse gas compared to avoiding a unit of CO_2. By contrast, the new metric approaches of combined GTP (CGTP) and GWP* closely approximate the additional effect on climate from a time series of short-lived GHG emissions, and can be used to compare this to the effect on temperature from the emission or removal of a unit of CO_2 (Section 7.6.1.4; Allen et al., 2018b; Collins et al., 2020).

Box 7.3 (continued)

If global surface temperature stabilization goals are considered, cumulative CO_2 equivalent emissions computed with the GWP-100 emissions metric would continue to rise when short-lived GHG emissions are reduced but remain above zero (Figure 7.22b). Such a rise would not match the expected global surface temperature stabilization or potential decline in warming that comes from a reduction in emissions of short-lived greenhouse gases (Pierrehumbert, 2014; Allen et al., 2018b; Cain et al., 2019; Collins et al., 2020; Lynch et al., 2020, 2021). This is relevant to net zero GHG emissions goals (Section 7.6.2 and Box 1.4).

When individual gases are treated separately in climate model emulators (Cross-Chapter Box 7.1), or weighted and aggregated using an emissions metric approach (such as CGTP or GWP*) which translate the distinct behaviour from cumulative emissions of short-lived gases, ambiguity in the future warming trajectory of a given emissions scenario can be substantially reduced (Cain et al., 2019; Denison et al., 2019; Collins et al., 2020; Lynch et al., 2021). The degree of ambiguity varies with the emissions scenario. For mitigation pathways that limit warming to 2°C with an even chance, the ambiguity arising from using GWP-100 as sole constraint on emissions of a mix of greenhouse gases (without considering their economic implications or feasibility) could be as much as 0.17°C, which represents about one-fifth of the remaining global warming in those pathways (Denison et al., 2019). If the evolution of the individual GHGs is not known, this can make it difficult to evaluate how a given global multi-gas emissions pathway specified only in CO_2 equivalent emissions would achieve (or not) global surface temperature goals. This is potentially an issue as Nationally Determined Contributions frequently make commitments in terms of GWP-100-based CO_2 equivalent emissions at 2030 without specifying individual gases (Denison et al., 2019). Clear and transparent representation of the global warming implications of future emissions pathways including Nationally Determined Contributions could be achieved either by their detailing pathways for multiple gases or by detailing a pathway of cumulative carbon dioxide equivalent emissions approach aggregated across GHGs evaluated by either GWP* or CGTP metric approaches (Cain et al., 2019; Collins et al., 2020; Lynch et al., 2021). It should be noted that although the Paris Agreement Rulebook asks countries to report emissions of individual GHGs separately for the global stocktake (Decision 18/CMA.1, annex, paragraph 38), which can allow the current effects of their emissions on global surface temperature to be accurately estimated, estimates of future warming are potentially ambiguous where emissions are aggregated using GWP-100 or other pulse metrics.

Although there is significant history of using single-basket approaches, supported by emissions metrics such as GWP-100, in climate policies such as the Kyoto Protocol, multi-basket approaches also have many precedents in environmental management, including the Montreal Protocol (Daniel et al., 2012). Further assessment of the performance of physical and economics-based metrics in the context of climate change mitigation is provided in the contribution of Working Group III to AR6.

7.6.2 Applications of Emissions Metrics

One prominent use of emissions metrics is for comparison of efforts measured against climate change goals or targets. One of the most commonly discussed goals is in Article 2 of the Paris Agreement which aims to limit the risks and impacts of climate change by setting temperature goals. In addition, the Paris Agreement has important provisions which relate to how the goals are to be achieved, including making emissions reductions in a manner that does not threaten food production (Article 2), an early emissions peaking target, and the aim to 'achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century' (Article 4). Article 4 also contains important context regarding international equity, sustainable development, and poverty reduction. Furthermore, the United Nations Framework Convention on Climate Change (UNFCCC) sets out as its ultimate objective, the 'stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.'

How the interpretation of the Paris Agreement and the meaning of 'net zero' emissions, reflects on the appropriate choice of metric is an active area of research (Schleussner et al., 2016, 2019; Fuglestvedt et al., 2018; Collins et al., 2020). Several possible scientific interpretations of the Article 2 and 4 goals can be devised, and these, along with emissions metric choice, have implications both for when a balance in GHG emissions, net zero CO_2 emissions or net zero GHG emissions are achieved, and for their meaning in terms of temperature outcome (Fuglestvedt et al., 2018; Rogelj et al., 2018; Wigley, 2018). In AR6 net zero GHG emissions is defined as the condition in which metric-weighted anthropogenic GHG emissions are balanced by metric-weighted anthropogenic GHG removals over a specified period (see Box 1.4 and Appendix VII: Glossary). The quantification of net zero GHG emissions depends on the GHG emissions metric chosen to compare emissions and removals of different gases, as well as the time horizon chosen for that metric. As the choice of emissions metric affects the quantification of net zero GHG emissions, it therefore affects the resulting temperature outcome after net zero emissions are achieved (Lauder et al., 2013; Rogelj et al., 2015; Fuglestvedt et al., 2018; Schleussner et al., 2019). Schleussner et al. (2019) note that declining temperatures may be a desirable outcome of net zero. Rogelj and Schleussner (2019) also point out that the use of physical metrics raises questions of equity and fairness between developed and developing countries.

Based on SR1.5 (Allen et al., 2018a), there is *high confidence* that achieving net zero CO_2 emissions and declining non-CO_2 radiative forcing would halt human-induced warming. Based on (Bowerman et al., 2013; Pierrehumbert, 2014; Fuglestvedt et al., 2018; Tanaka and O'Neill, 2018; Schleussner et al., 2019) there is also *high confidence* that reaching net zero GHG emissions as quantified by GWP-100 typically leads to reductions from peak global surface temperature after net zero GHGs emissions are achieved, depending on the relative sequencing of mitigation of short-lived and long-lived species. If both short- and long-lived species are mitigated together, then temperatures peak and decline. If mitigation of short-lived species occurs much earlier than that of long-lived species, then temperatures stabilize very near peak values, rather than decline. Temperature targets can be met even with positive net GHG emissions based on GWP-100 (Tanaka and O'Neill, 2018). As demonstrated by Allen et al. (2018b), Cain et al. (2019), Schleussner et al. (2019) and Collins et al. (2020) reaching net zero GHG emissions when quantified using the new emissions metric approaches such as CGTP or GWP* would lead to an approximately similar temperature evolution as achieving net zero CO_2. Hence, net zero CO_2 and net zero GHG, quantified using these new approaches, would both lead to approximately stable contributions to temperature change after net zero emissions are achieved (*high confidence*).

Comparisons with emissions or global surface temperature stabilization goals are not the only role for emissions metrics. Other important roles include those in pricing approaches where policymakers choose to compare short-lived and long-lived climate forcers (e.g., Manne and Richels, 2001), and in life cycle analyses (e.g., Hellweg and Milà i Canals, 2014). Several papers have reviewed the issue of metric choice for life cycle analyses, noting that analysts should be aware of the challenges and value judgements inherent in attempting to aggregate the effects of forcing agents with different time scales onto a common scale (e.g., Mallapragada and Mignone, 2017) and recommend aligning metric choice with policy goals as well as testing sensitivities of results to metric choice (Cherubini et al., 2016). Furthermore, life cycle analyses approaches which are sensitive to choice of emissions metric benefit from careful communication of the reasons for the sensitivity (Levasseur et al., 2016).

Frequently Asked Questions

FAQ 7.1 | What Is the Earth's Energy Budget, and What Does It Tell Us About Climate Change?

The Earth's energy budget describes the flow of energy within the climate system. Since at least 1970 there has been a persistent imbalance in the energy flows that has led to excess energy being absorbed by the climate system. By measuring and understanding these energy flows and the role that human activities play in changing them, we are better able to understand the causes of climate change and project future climate change more accurately.

Our planet receives vast amounts of energy every day in the form of sunlight. Around a third of the sunlight is reflected back to space by clouds, by tiny particles called *aerosols*, and by bright surfaces such as snow and ice. The rest is absorbed by the ocean, land, ice and atmosphere. The planet then emits energy back out to space in the form of thermal radiation. In a world that was not warming or cooling, these energy flows would balance. Human activity has caused an imbalance in these energy flows.

We measure the influence of various human and natural factors on the energy flows at the top of our atmosphere in terms of *radiative forcings*, where a positive radiative forcing has a warming effect and a negative radiative forcing has a cooling effect. In response to these forcings, the Earth system will either warm or cool, so as to restore balance through changes in the amount of outgoing thermal radiation (the warmer the Earth, the more radiation it emits). Changes in Earth's temperature in turn lead to additional changes in the climate system (known as *climate feedbacks*) that either amplify or dampen the original effect. For example, Arctic sea ice has been melting as the Earth warms, reducing the amount of reflected sunlight and adding to the initial warming (an amplifying feedback). The most uncertain of those climate feedbacks are clouds, as they respond to warming in complex ways that affect both the emission of thermal radiation and the reflection of sunlight. However, we are now more confident that cloud changes, taken together, will amplify climate warming (see FAQ 7.2).

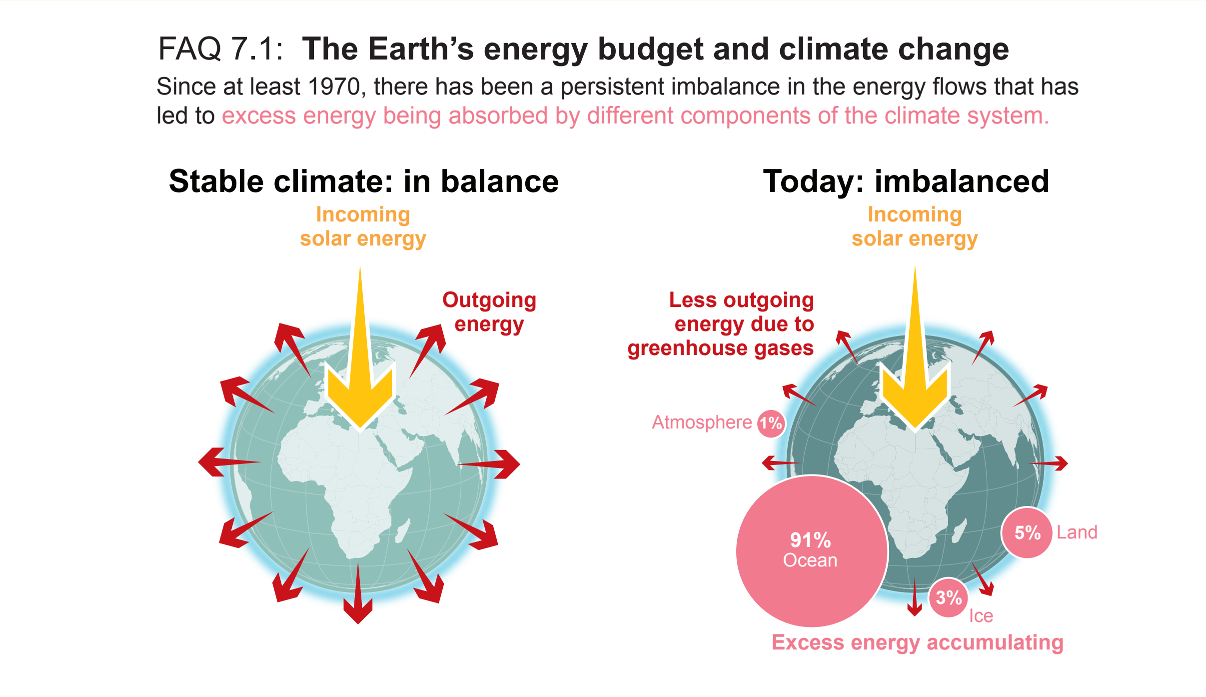
Human activities have unbalanced these energy flows in two main ways. First, increases in greenhouse gas levels have led to more of the emitted thermal radiation being absorbed by the atmosphere, instead of being released to space. Second, increases in pollutants have increased the amount of aerosols such as sulphates in the atmosphere (see FAQ 6.1). This has led to more incoming sunlight being reflected away, by the aerosols themselves and through the formation of more cloud drops, which increases the reflectivity of clouds (see FAQ 7.2).

Altogether, the global energy flow imbalance since the 1970s has been just over half a watt per square metre of the Earth's surface. This sounds small, but because the imbalance is persistent and because Earth's surface is large, this adds up to about 25 times the total amount of primary energy consumed by human society, compared over 1971 to 2018. Compared to the IPCC Fifth Assessment Report (AR5), we are now better able to quantify and track these energy flows from multiple lines of evidence, including satellite data, direct measurements of ocean temperatures, and a wide variety of other Earth system observations (see FAQ 1.1). We also have a better understanding of the processes contributing to this imbalance, including the complex interactions between aerosols, clouds and radiation.

Research has shown that the excess energy since the 1970s has mainly gone into warming the ocean (91%), followed by the warming of land (5%) and the melting of ice sheets and glaciers (3%). The atmosphere has warmed substantially since 1970, but because it is comprised of thin gases it has absorbed only 1% of the excess energy (FAQ 7.1, Figure 1). As the ocean has absorbed the vast majority of the excess energy, especially within its top two kilometres, the deep ocean is expected to continue to warm and expand for centuries to millennia, leading to long-term sea level rise – even if atmospheric greenhouse gas levels were to decline (see FAQ 5.3). This is in addition to the sea level rise expected from melting ice sheets and glaciers.

Understanding the Earth's energy budget al.o helps to narrow uncertainty in future projections of climate. By testing climate models against what we know about the Earth's energy budget, we can make more confident projections of surface temperature changes we might expect this century and beyond.

FAQ 7.1 (continued)



FAQ 7.1, Figure 1 | The Earth's energy budget compares the flows of incoming and outgoing energy that are relevant for the climate system. Since at least the 1970s, less energy is flowing out than is flowing in, which leads to excess energy being absorbed by the ocean, land, ice and atmosphere, with the ocean absorbing 91%.

Frequently Asked Questions

FAQ 7.2 | What Is the Role of Clouds in a Warming Climate?

One of the biggest challenges in climate science has been to predict how clouds will change in a warming world and whether those changes will amplify or partially offset the warming caused by increasing concentrations of greenhouse gases and other human activities. Scientists have made significant progress over the past decade and are now more confident that changes in clouds will amplify, rather than offset, global warming in the future.

Clouds cover roughly two-thirds of the Earth's surface. They consist of small droplets and/or ice crystals, which form when water vapour condenses or deposits around tiny particles called *aerosols* (such as salt, dust, or smoke). Clouds play a critical role in the Earth's *energy budget* at the top of our atmosphere and therefore influence Earth's surface temperature (see FAQ 7.1). The interactions between clouds and the climate are complex and varied. Clouds at low altitudes tend to reflect incoming solar energy back to space, creating a cooling effect by preventing this energy from reaching and warming the Earth. On the other hand, higher clouds tend to trap (i.e., absorb and then emit at a lower temperature) some of the energy leaving the Earth, leading to a warming effect. On average, clouds reflect back more incoming energy than the amount of outgoing energy they trap, resulting in an overall net cooling effect on the present climate. Human activities since the pre-industrial era have altered this climate effect of clouds in two different ways: by changing the abundance of the aerosol particles in the atmosphere and by warming the Earth's surface, primarily as a result of increases in greenhouse gas emissions.

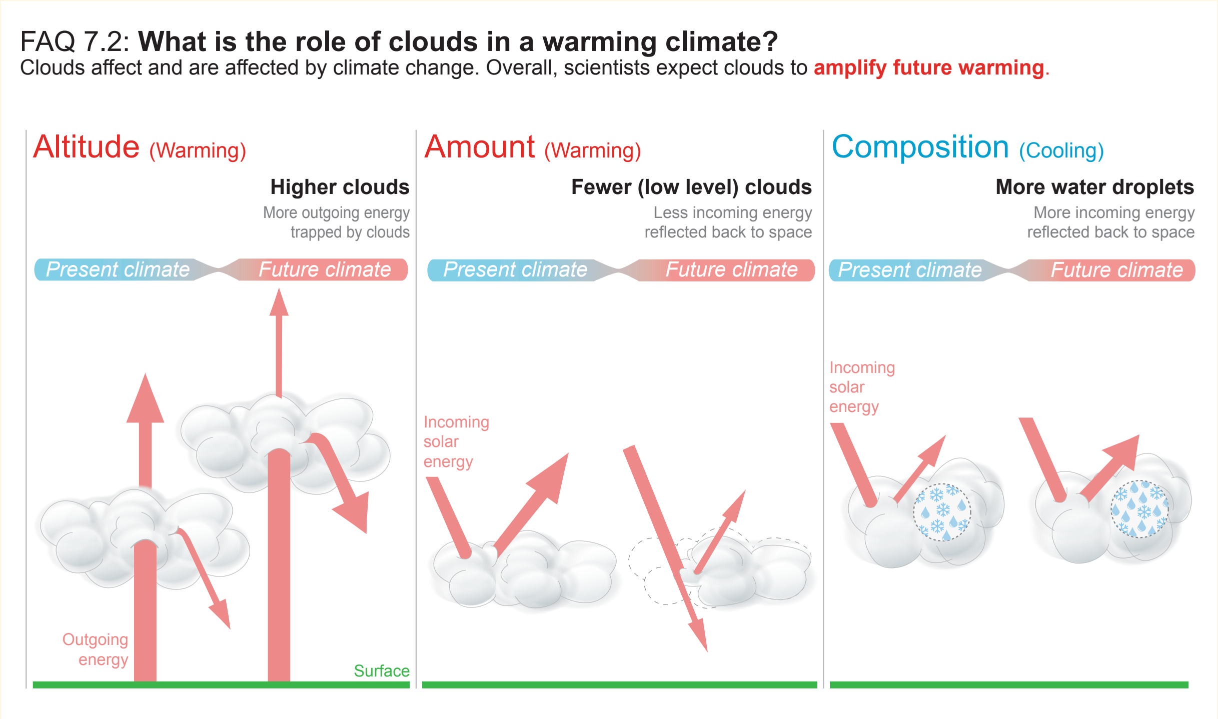
The concentration of aerosols in the atmosphere has markedly increased since the pre-industrial era, and this has had two important effects on clouds. First, clouds now reflect more incoming energy because cloud droplets have become more numerous and smaller. Second, smaller droplets may delay rain formation, thereby making the clouds last longer, although this effect remains uncertain. Hence, aerosols released by human activities have had a cooling effect, counteracting a considerable portion of the warming caused by increases in greenhouse gases over the last century (see FAQ 3.1). Nevertheless, this cooling effect is expected to diminish in the future, as air pollution policies progress worldwide, reducing the amount of aerosols released into the atmosphere.

Since the pre-industrial period, the Earth's surface and atmosphere have warmed, altering the properties of clouds, such as their altitude, amount and composition (water or ice), thereby affecting the Earth's energy budget and, in turn, changing temperature. This cascading effect of clouds, known as the *cloud feedback,* could either amplify or offset some of the future warming and has long been the biggest source of uncertainty in climate projections. The problem stems from the fact that clouds can change in many ways and that their processes occur on much smaller scales than global climate models can explicitly represent. As a result, global climate models have disagreed on how clouds, particularly over the subtropical ocean, will change in the future and whether the change will amplify or suppress the global warming.

Since the last IPCC Report in 2013 (the Fifth Assessment Report, or AR5), understanding of cloud processes has advanced with better observations, new analysis approaches and explicit high-resolution numerical simulation of clouds. Also, current global climate models simulate cloud behaviour better than previous models, due both to advances in computational capabilities and process understanding. Altogether, this has helped to build a more complete picture of how clouds will change as the climate warms (FAQ 7.2, Figure 1). For example, the amount of low-clouds will reduce over the subtropical ocean, leading to less reflection of incoming solar energy, and the altitude of high-clouds will rise, making them more prone to trapping outgoing energy; both processes have a warming effect. In contrast, clouds in high latitudes will be increasingly made of water droplets rather than ice crystals. This shift from fewer, larger ice crystals to smaller but more numerous water droplets will result in more of the incoming solar energy being reflected back to space and produce a cooling effect. Better understanding of how clouds respond to warming has led to more confidence than before that future changes in clouds will, overall, cause additional warming (i.e., by weakening the current cooling effect of clouds). This is called a *positive net cloud feedback*.

In summary, clouds will amplify rather than suppress the warming of the climate system in the future, as more greenhouse gases and fewer aerosols are released to the atmosphere by human activities.

FAQ 7.2 (continued)



FAQ 7.2, Figure 1 | Interactions between clouds and the climate, today and in a warmer future. Global warming is expected to alter the altitude **(left)** and the amount **(centre)** of clouds, which will amplify warming. On the other hand, cloud composition will change **(right)**, offsetting some of the warming. Overall, clouds are expected to amplify future warming.

7

Frequently Asked Questions

FAQ 7.3 | What Is Equilibrium Climate Sensitivity and How Does It Relate to Future Warming?

For a given future scenario, climate models project a range of changes in global surface temperature. This range is closely related to equilibrium climate sensitivity, or ECS, which measures how climate models respond to a doubling of carbon dioxide in the atmosphere. Models with high climate sensitivity project stronger future warming. Some climate models of the new generation are more sensitive than the range assessed in the IPCC Sixth Assessment Report. This leads to end-of-century global warming in some simulations of up to 2°C–3°C above the current IPCC best estimate. Although these higher warming levels are not expected to occur, high-ECS models are useful for exploring low-likelihood, high-impact futures.

The *equilibrium climate sensitivity* (ECS) is defined as the long-term global warming caused by a doubling of carbon dioxide above its pre-industrial concentration. For a given emissions scenario, much of the uncertainty in projections of future warming can be explained by the uncertainty in ECS (FAQ 7.3, Figure 1). The significance of equilibrium climate sensitivity has long been recognized, and the first estimate was presented by Swedish scientist Svante Arrhenius in 1896.

This Sixth Assessment Report concludes that there is a 90% or more chance (*very likely*) that the ECS is between 2°C and 5°C. This represents a significant reduction in uncertainty compared to the Fifth Assessment Report, which gave a 66% chance (*likely*) of ECS being between 1.5°C and 4.5°C. This reduction in uncertainty has been possible not through a single breakthrough or discovery but instead by combining evidence from many different sources and by better understanding their strengths and weaknesses.

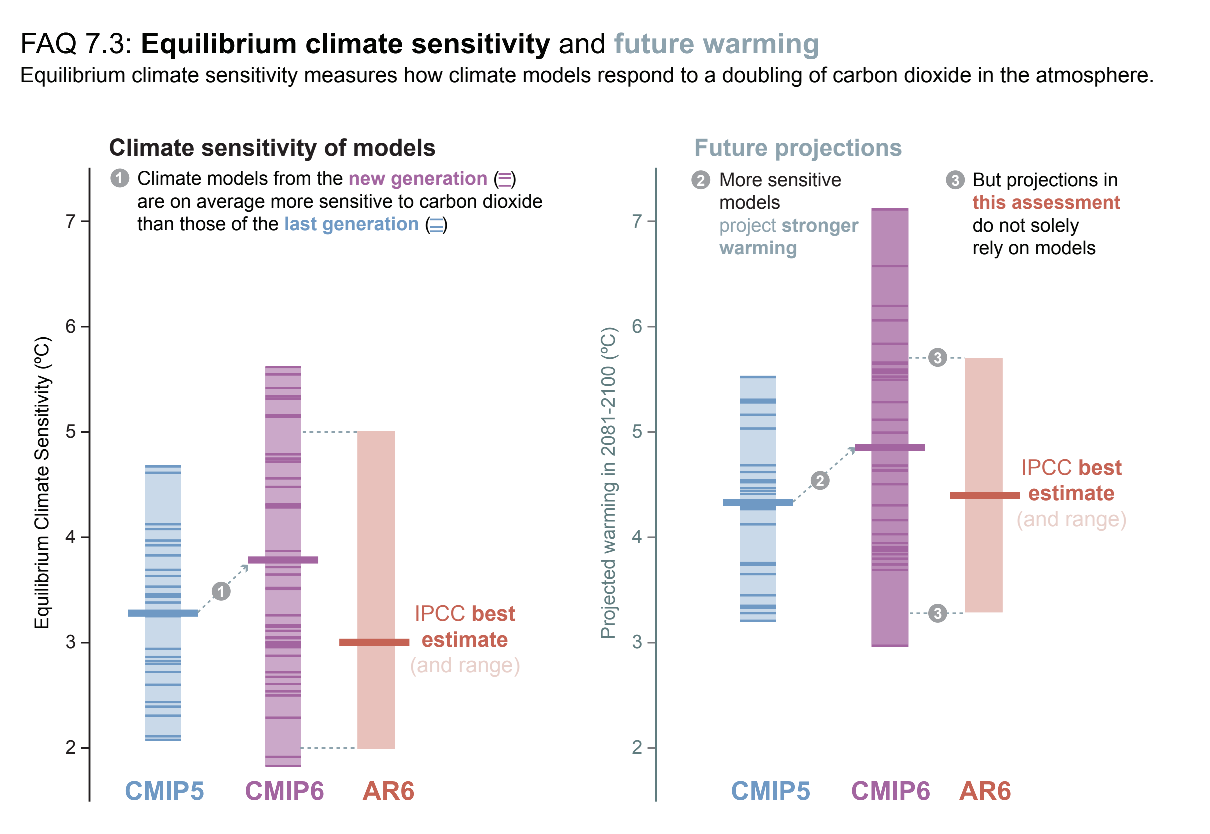
There are four main lines of evidence for ECS.

- The self-reinforcing processes, called *feedback loops*, that amplify or dampen the warming in response to increasing carbon dioxide are now better understood. For example, warming in the Arctic melts sea ice, resulting in more open ocean area, which is darker and therefore absorbs more sunlight, further intensifying the initial warming. It remains challenging to represent realistically all the processes involved in these feedback loops, particularly those related to clouds (see FAQ 7.2). Such identified model errors are now taken into account, and other known, but generally weak, feedback loops that are typically not included in models are now included in the assessment of ECS.
- Historical warming since early industrialisation provides strong evidence that climate sensitivity is not small. Since 1850, the concentrations of carbon dioxide and other greenhouse gases have increased, and as a result the Earth has warmed by about 1.1°C. However, relying on this industrial-era warming to estimate ECS is challenging, partly because some of the warming from greenhouse gases was offset by cooling from aerosol particles and partly because the ocean is still responding to past increases in carbon dioxide.
- Evidence from ancient climates that had reached equilibrium with greenhouse gas concentrations, such as the coldest period of the last ice age around 20,000 years ago, or warmer periods further back in time, provide useful data on the ECS of the climate system (see FAQ 1.3).
- Statistical approaches linking model ECS values with observed changes, such as global warming since the 1970s, provide complementary evidence.

All four lines of evidence rely, to some extent, on climate models, and interpreting the evidence often benefits from model diversity and spread in modelled climate sensitivity. Furthermore, high-sensitivity models can provide important insights into futures that have a low likelihood of occurring but that could result in large impacts. But, unlike in previous assessments, climate models are not considered a line of evidence in their own right in the IPCC Sixth Assessment Report.

The ECS of the latest climate models is, on average, higher than that of the previous generation of models and also higher than this Report's best estimate of 3.0°C. Furthermore, the ECS values in some of the new models are both above and below the 2°C to 5°C *very likely* range, and although such models cannot be ruled out as implausible solely based on their ECS, some simulations display climate change that is inconsistent with the observed changes when tested with ancient climates. A slight mismatch between models and this Report's assessment is only natural because this Report's assessment is largely based on observations and an improved understanding of the climate system.

FAQ 7.3 (continued)



FAQ 7.3, Figure 1 | Equilibrium climate sensitivity and future warming. (left) Equilibrium climate sensitivities for the current generation (Coupled Model Intercomparison Project Phase 6, CMIP6) climate models, and the previous (CMIP5) generation. The assessed range in this Report (AR6) is also shown. **(right)** Climate projections of CMIP5, CMIP6 and AR6 for the very high-emissions scenarios RCP8.5, and SSP5-8.5, respectively. The thick horizontal lines represent the multi-model average and the thin horizontal lines represent the results of individual models. The boxes represent the model ranges for CMIP5 and CMIP6 and the range assessed in AR6.

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Exhibit 19


Incorporating Key Restoration Decisions into Habitat Suitability Models to Forecast SWFL Outcomes
James Tracy
Lisa Markovchick


Photo: halcyonenv.com/swfl


Photo: Lisa Markovchick

SWFL fecundity in decline, linked to defoliation & nest temperatures

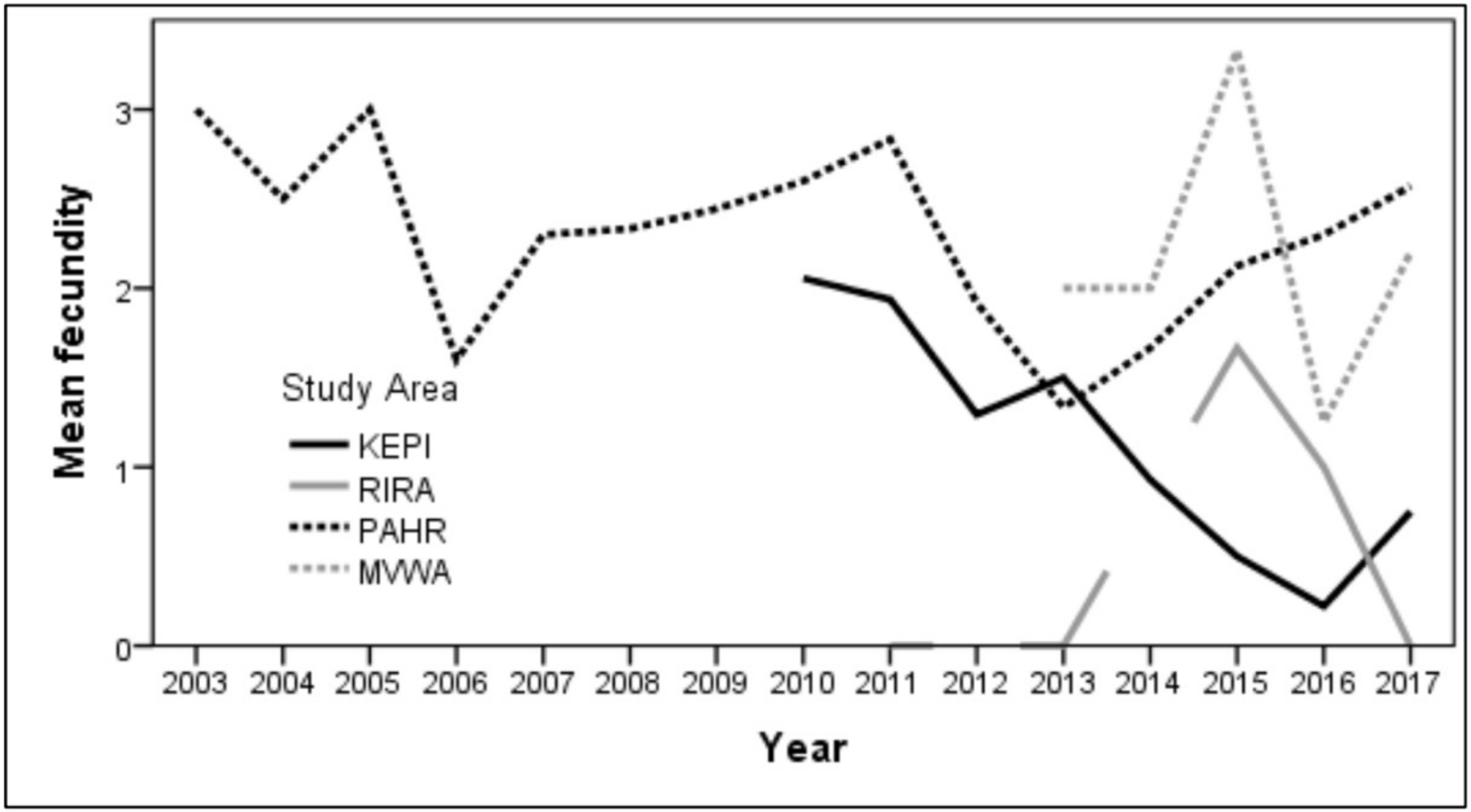
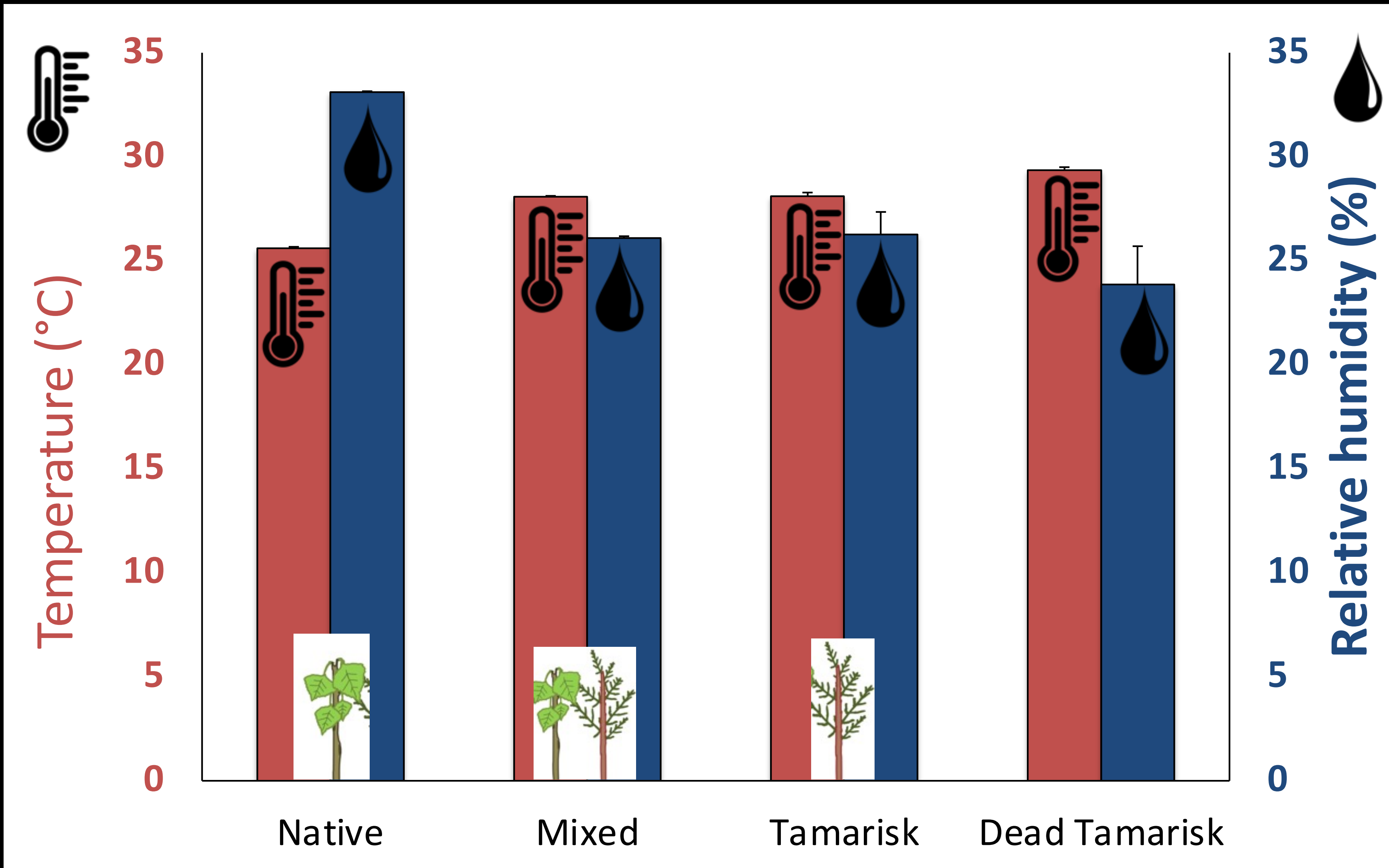


Figure 4-5.—Mean annual fecundity (young produced per female southwestern willow flycatcher) at Key Pittman (KEPI), River Ranch (RIRA), Pahranagat (PAHR), and Meadow Valley Wash (MVWA), 2003–17.

Southwestern Willow Flycatcher Surveys, Demography, and Ecology Along the Lower Colorado River and Tributaries, 2013–2017 Summary Report, May 2019

Mixed, tamarisk & dead tam sites warmer & drier – restoring native veg even more important



Temperature: $F=273.9$, $p<0.00001$

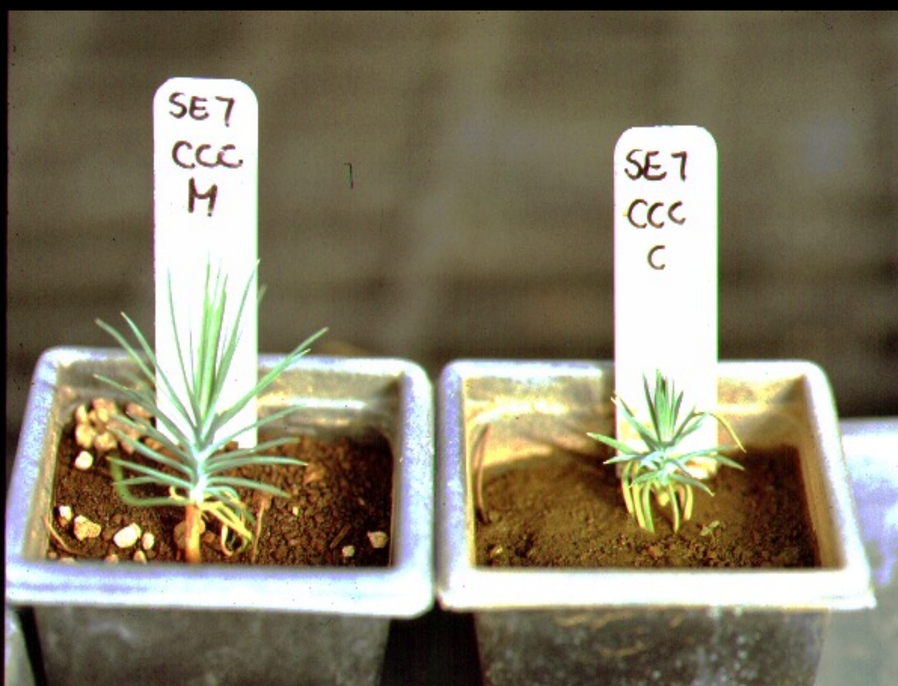
Relative Humidity: $F=590.2$, $p<0.00001$

Data by Sean Mahoney

Mycorrhizal effects on plants

Tons of data in Ag,
growing body of data in ecology

- Boost survival/growth
- Pest control
- Water/drought survival
- Toxicity protection
- continued…



Not negligible impacts:
~25-50%+

Invasive vegetation reduces mycorrhizas

- Spotted knapweed
  (Mummey & Rillig 2006)
- Garlic mustard
  (Stinson et al. 2006)
- Canada goldenrod
  (Zhang et al. 2010)
- Italian thistle
  (Vogelsang & Bever 2009)

Spotted Knapweed
Centaurea maculosa

Garlic Mustard
Alliaria petiolata

Italian thistle
Carduus pycnocephalus

Tamarisk-specific field data: Pulliam-Babbitt / SEGA common garden

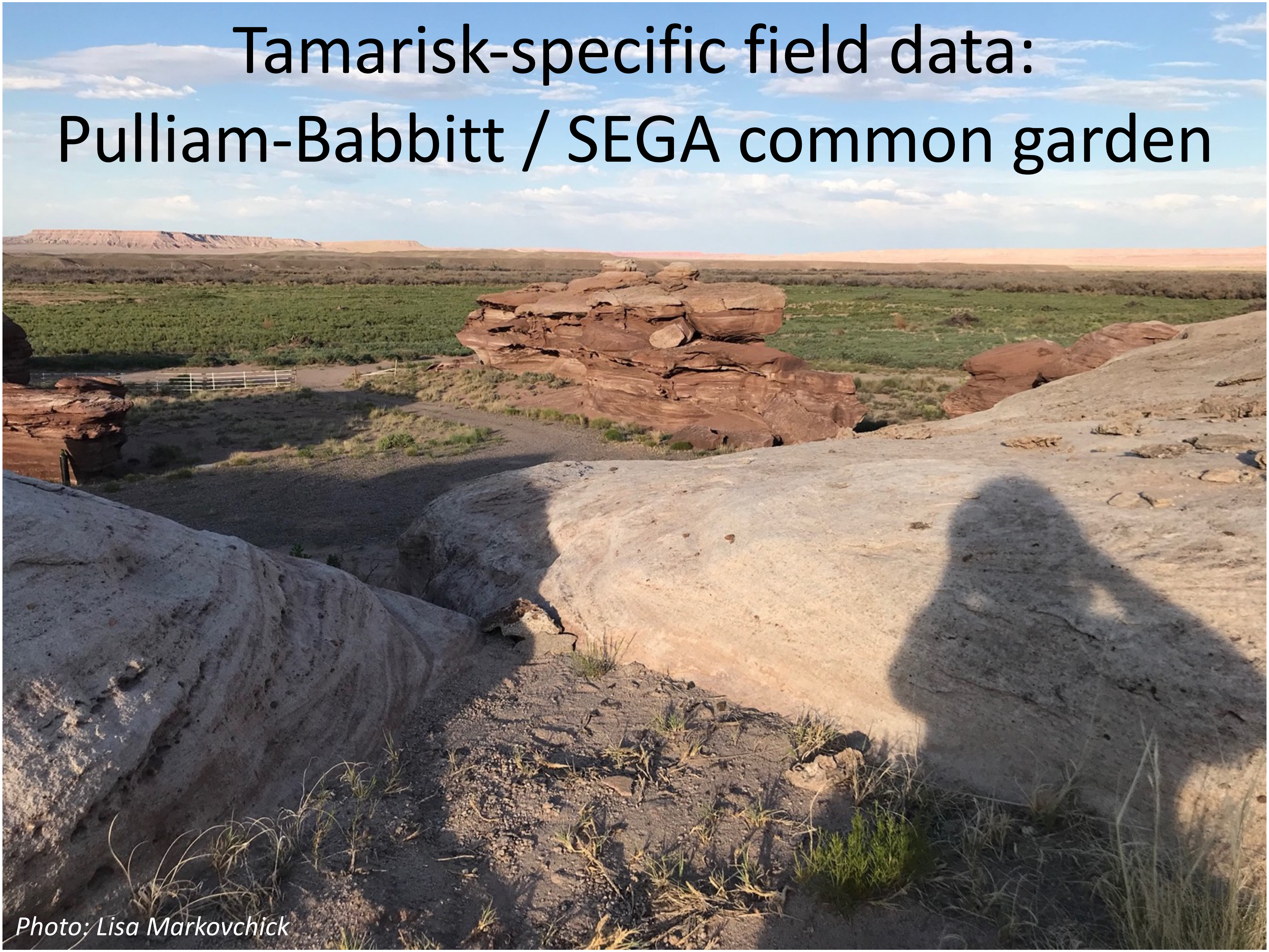


Photo: Lisa Markovchick

Tam legacy reduces cottonwood survival

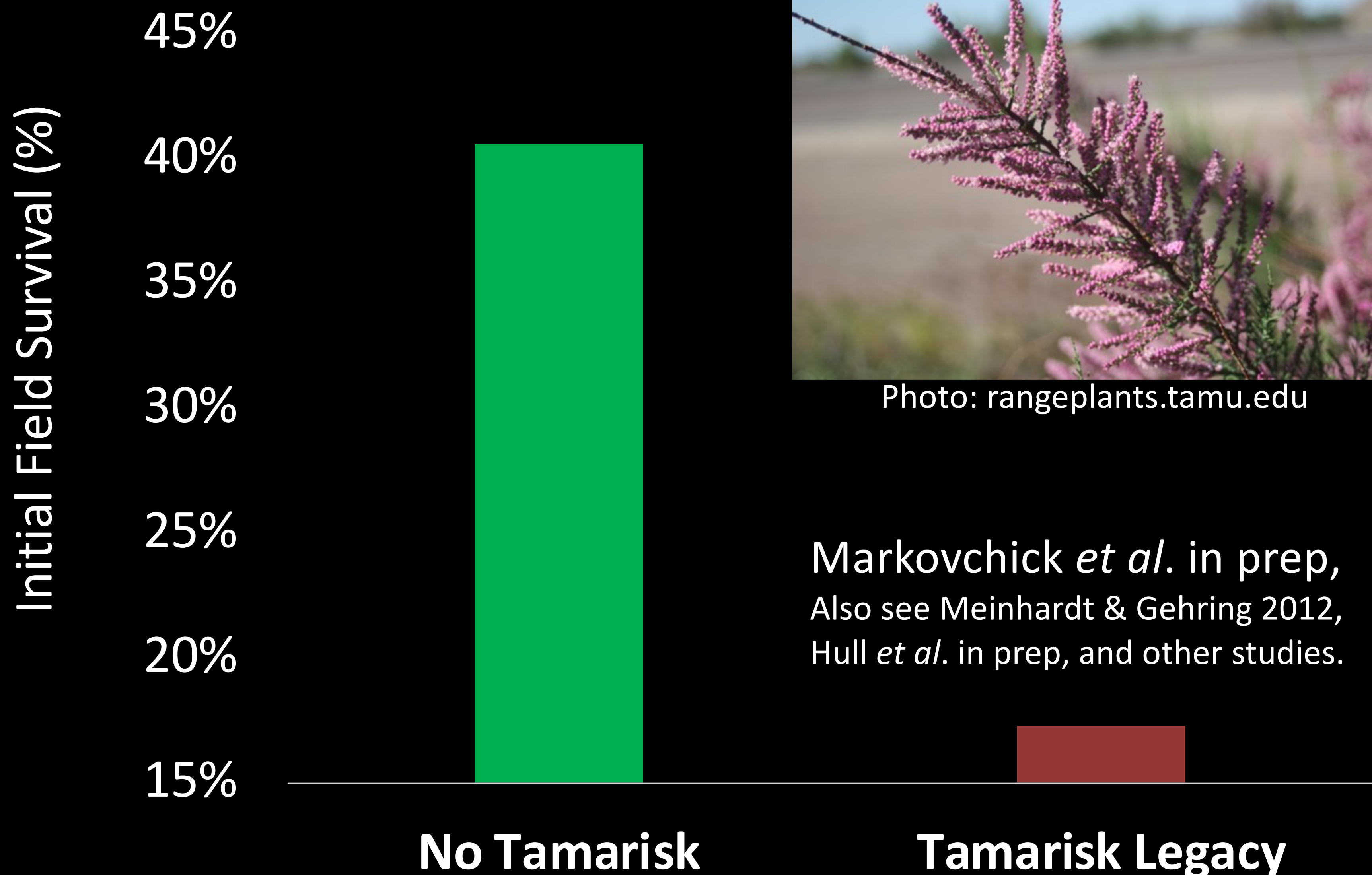
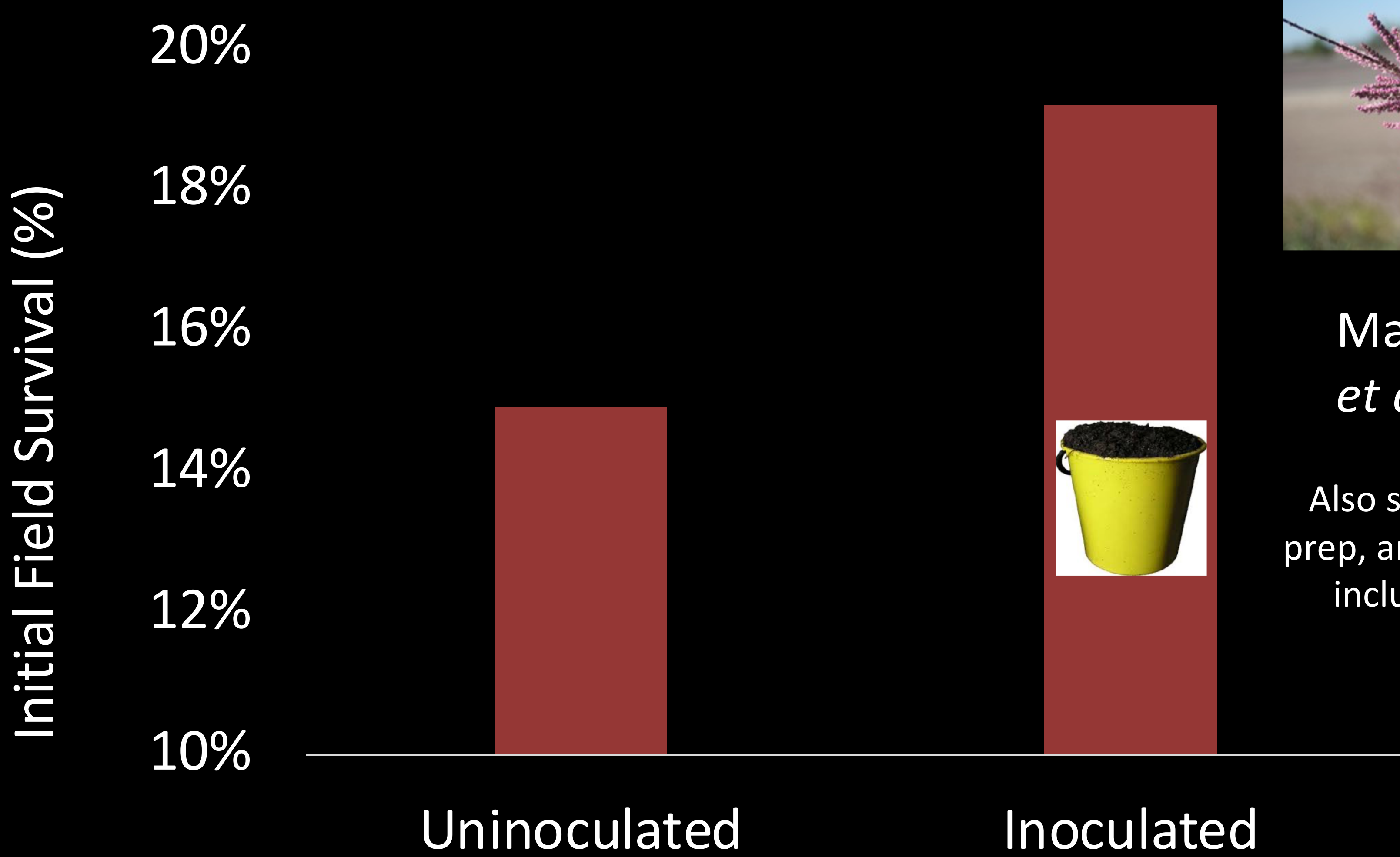


Photo: rangeplants.tamu.edu

Markovchick *et al*. in prep,
Also see Meinhardt & Gehring 2012,
Hull *et al*. in prep, and other studies.

Bars represent total survival proportions in study, thus no error bars are provided.

Inocculation can help counteract reduced survival

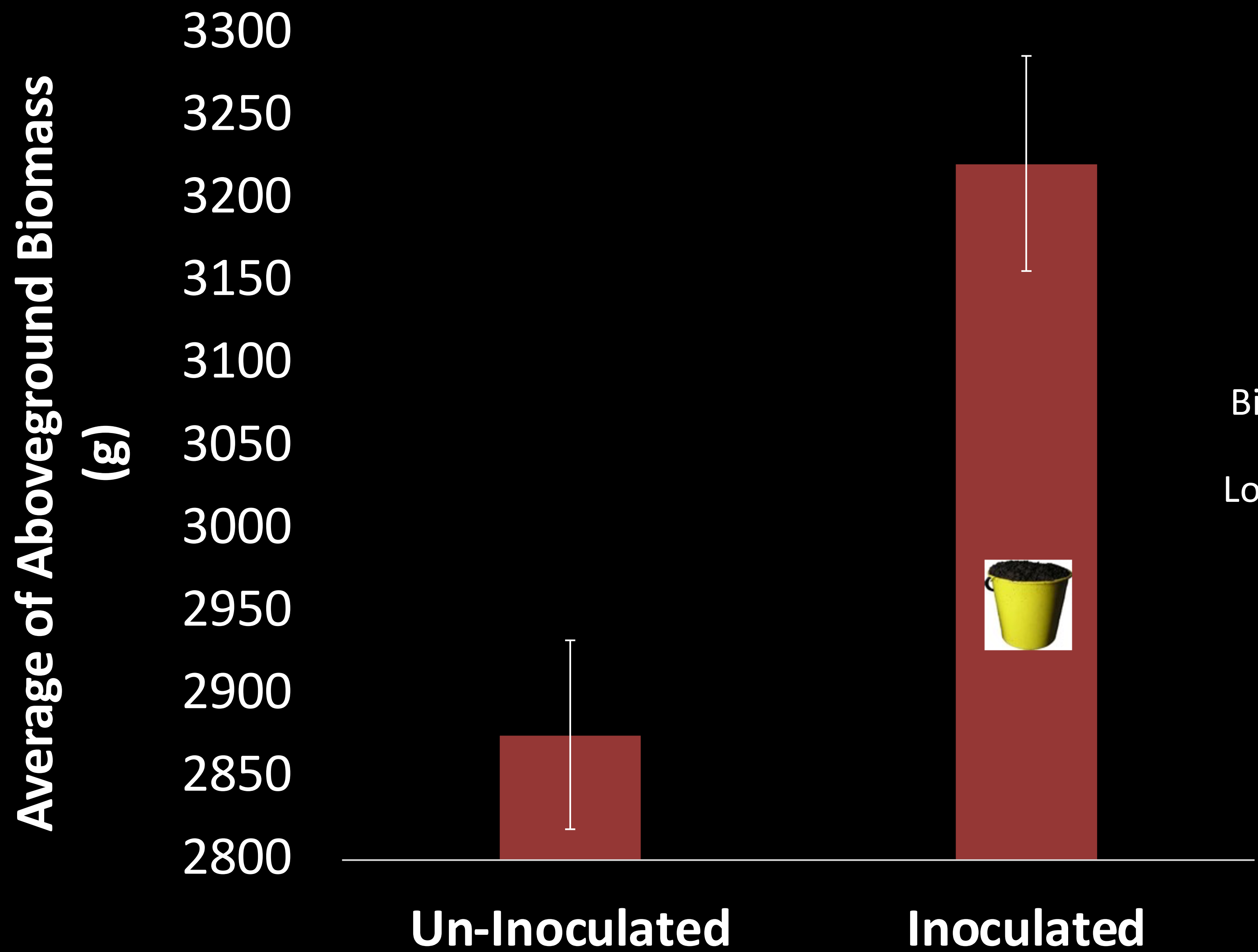


Markovchick *et al*. in prep

Also see Hull *et al*. in prep, and other studies, including willows.

Bars represent total survival proportions in study, thus no error bars are provided.

And increase above-ground biomass



Biomass equations from Lojewski *et al.* 2009

Markovchick *et al*. in prep

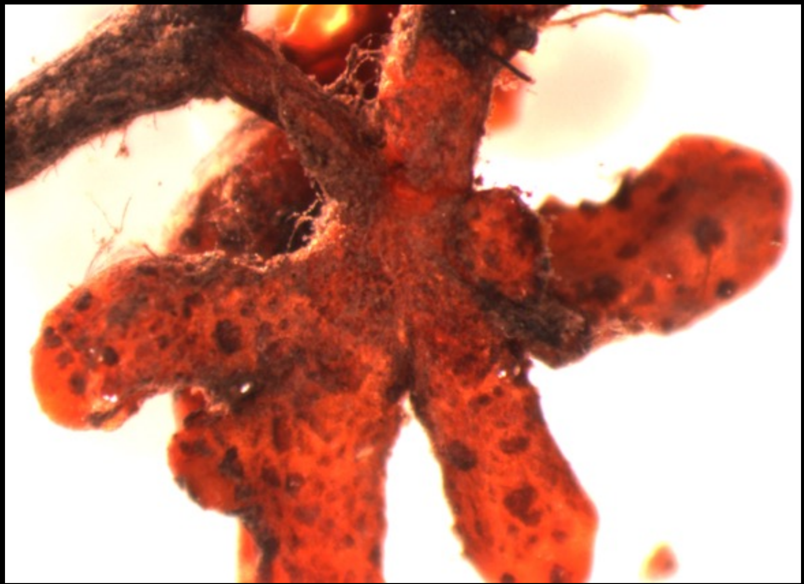
Similar results in Hull *et al*. in prep, and other studies.

Error bars = 2 SE.

Research questions

1) Shouldn't mycorrhizas boost SWFL habitat suitability?

2) Can fine-scale SWFL habitat models discriminate between specific restoration decisions at a site?



Hypotheses

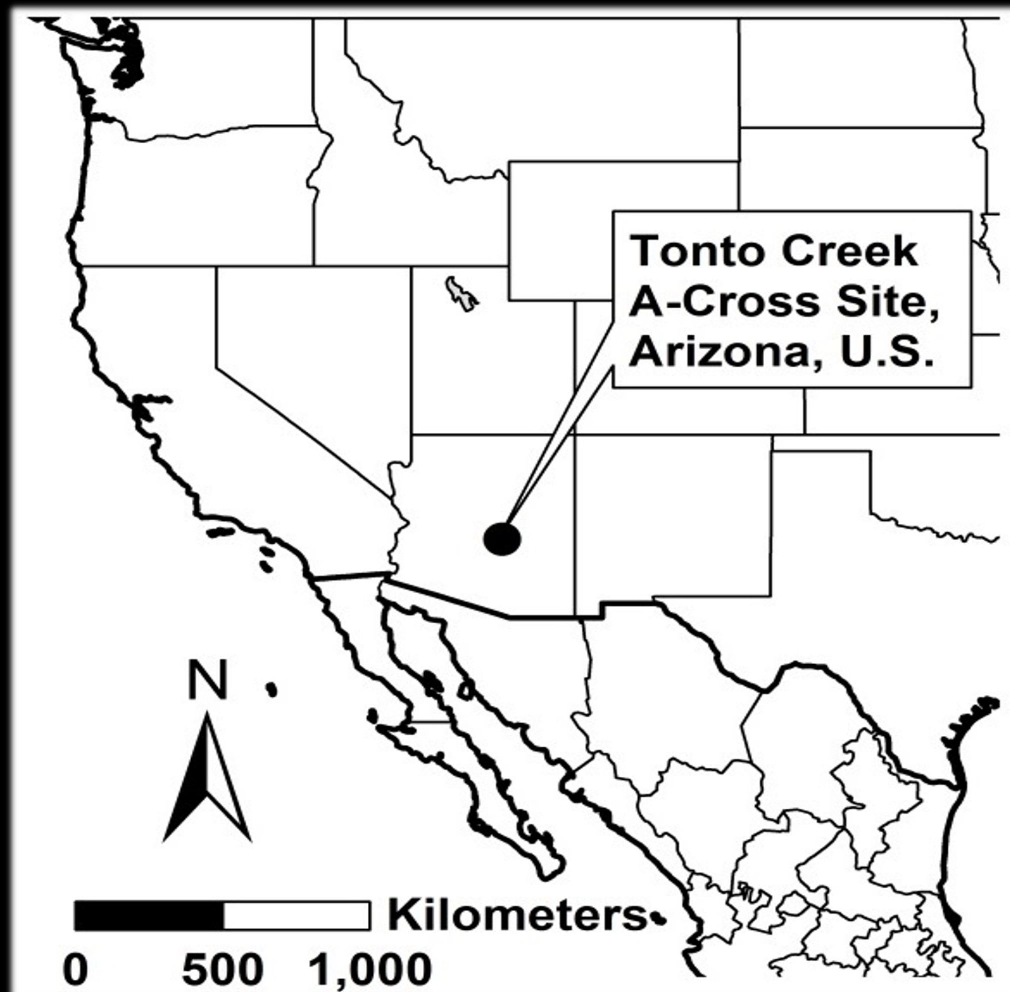
1) Appropriate mycorrhizal inoculations can improve SWFL habitat suitability in tamarisk restoration.

2) Appropriate mycorrhizal inoculations can decrease the time to achieve suitable SWFL habitat.

3) Fine-scale models can discriminate between SWFL outcomes based on key restoration decisions -> to evaluate the importance of specific decisions compared to their cost, ahead of action in the field.

Original fine-scale GIS SWFL Habitat Suitability Index (HSI) model

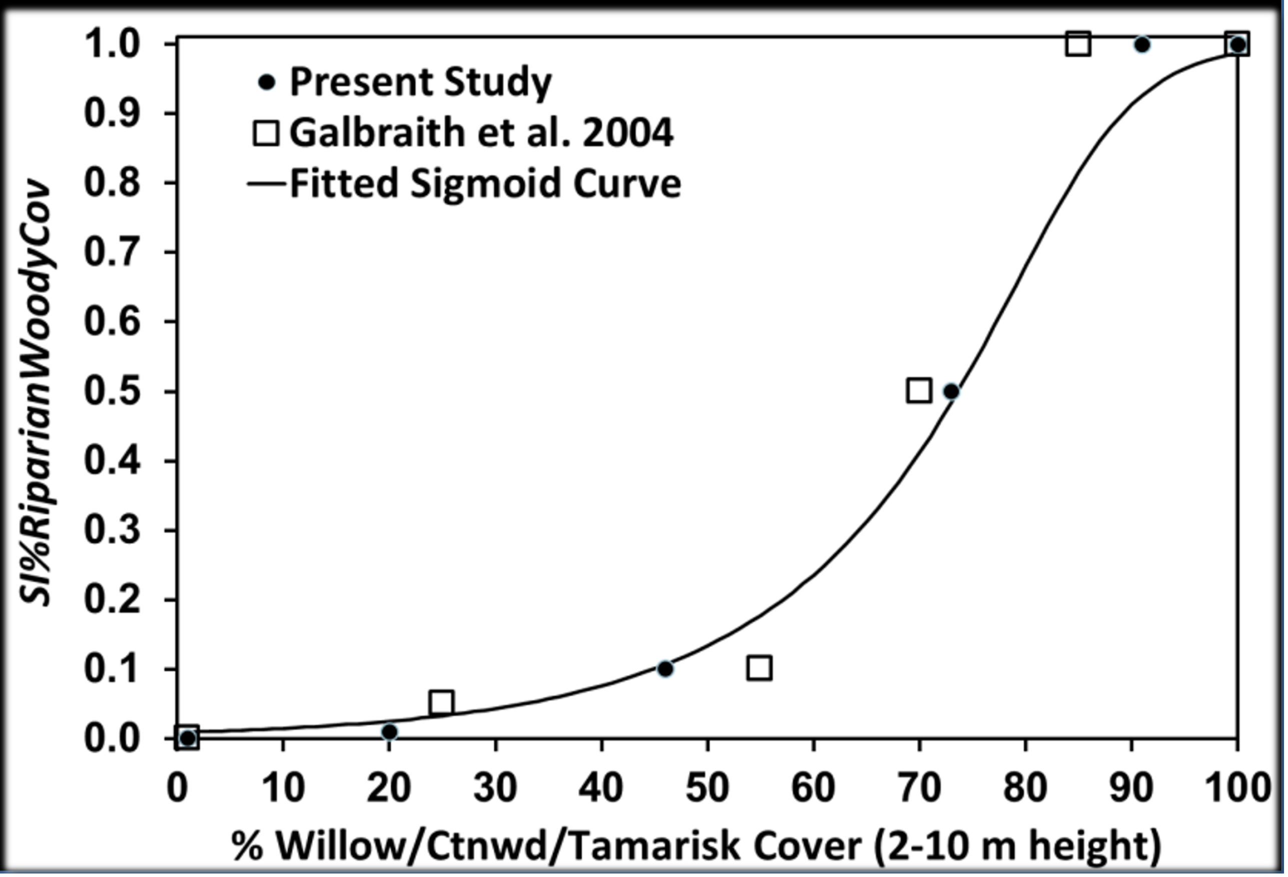
- 1 m resolution
- Tracy *et al*. 2016



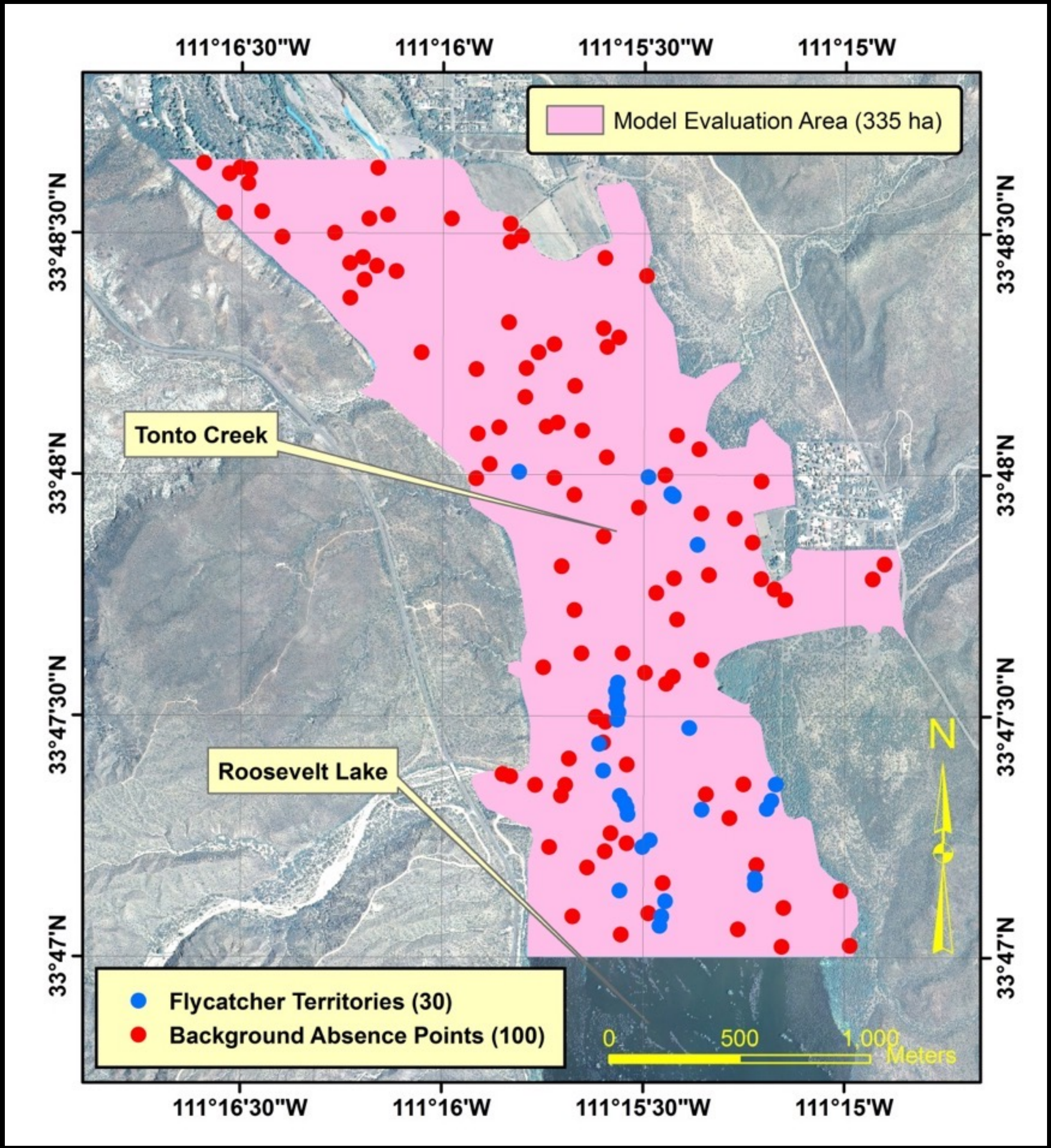
Original HSI model-building steps

- Pull info on habitat suitability from field studies
- Identify factors
- Estimate their relative contributions
- Curve: each variable value & its impact on habitat suitability

(Tracy *et al*. 2016)



Test model predictions verses SWFL field data



(Tracy *et al*. 2016)

Hypotheses

1) Appropriate mycorrhizal inoculations can improve SWFL habitat suitability in tamarisk restoration.

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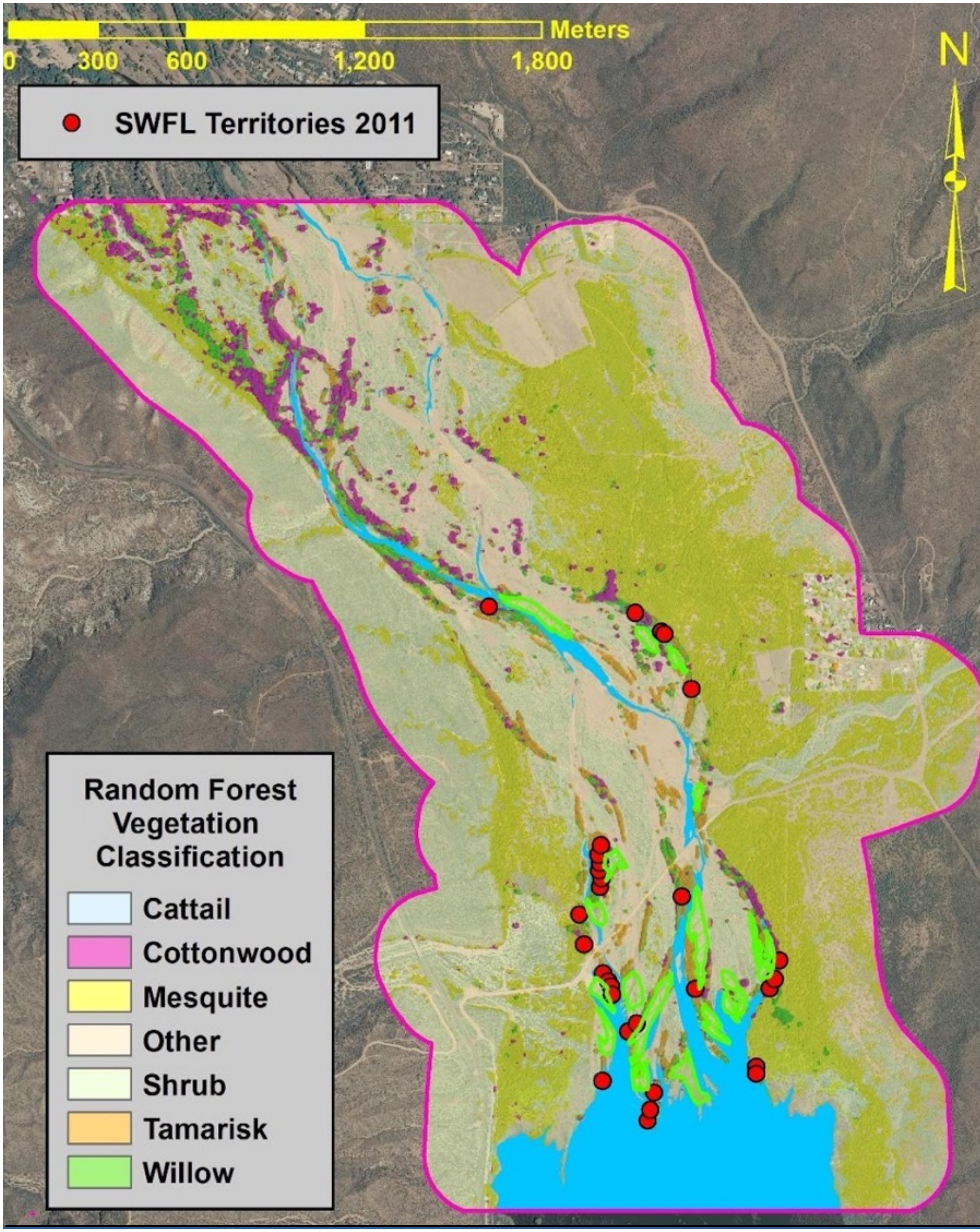
3) Fine-scale models can discriminate between SWFL outcomes based on key restoration decisions -> to evaluate the importance of specific decisions compared to their cost, ahead of action in the field.

Added to Original Fine-Scale GIS Model

*Current results demo minor work over 2 months.
More to come!

We hope you'll ask for what is needed to support restoration projects!



Selected restoration patches near water

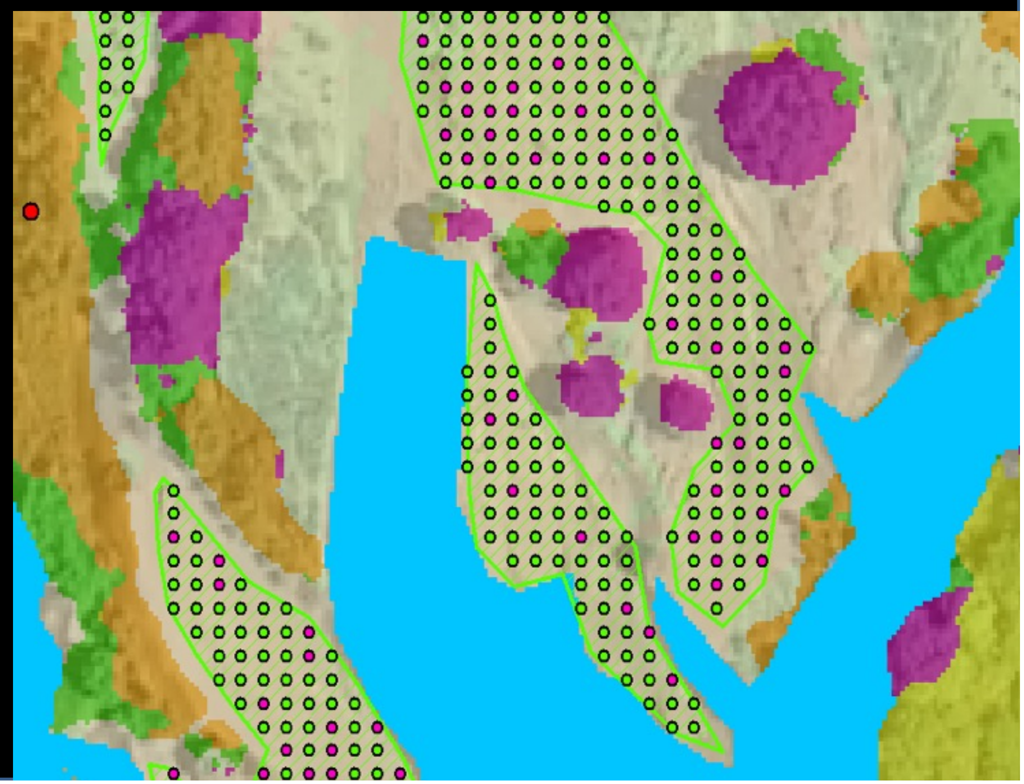
1) Plant installation & SWFL preferences.
2) 2011 water lines used for demo.
3) Future scenarios: sites identified for restoration & hydrological predictions.

Identified plant palette, planting type & plant spacing

Riparian restoration plantings of 2’ deep pots at 3-meter spacings for Tonto Creek A-Cross site, AZ.

Species	Number Plantings	Percent Total
Goodding’s Willow	8,952	98.9%
Fremont Cottonwood	100	1.1%
Total	9,052	100%

- 3 m apart
- 2’ potted plantings



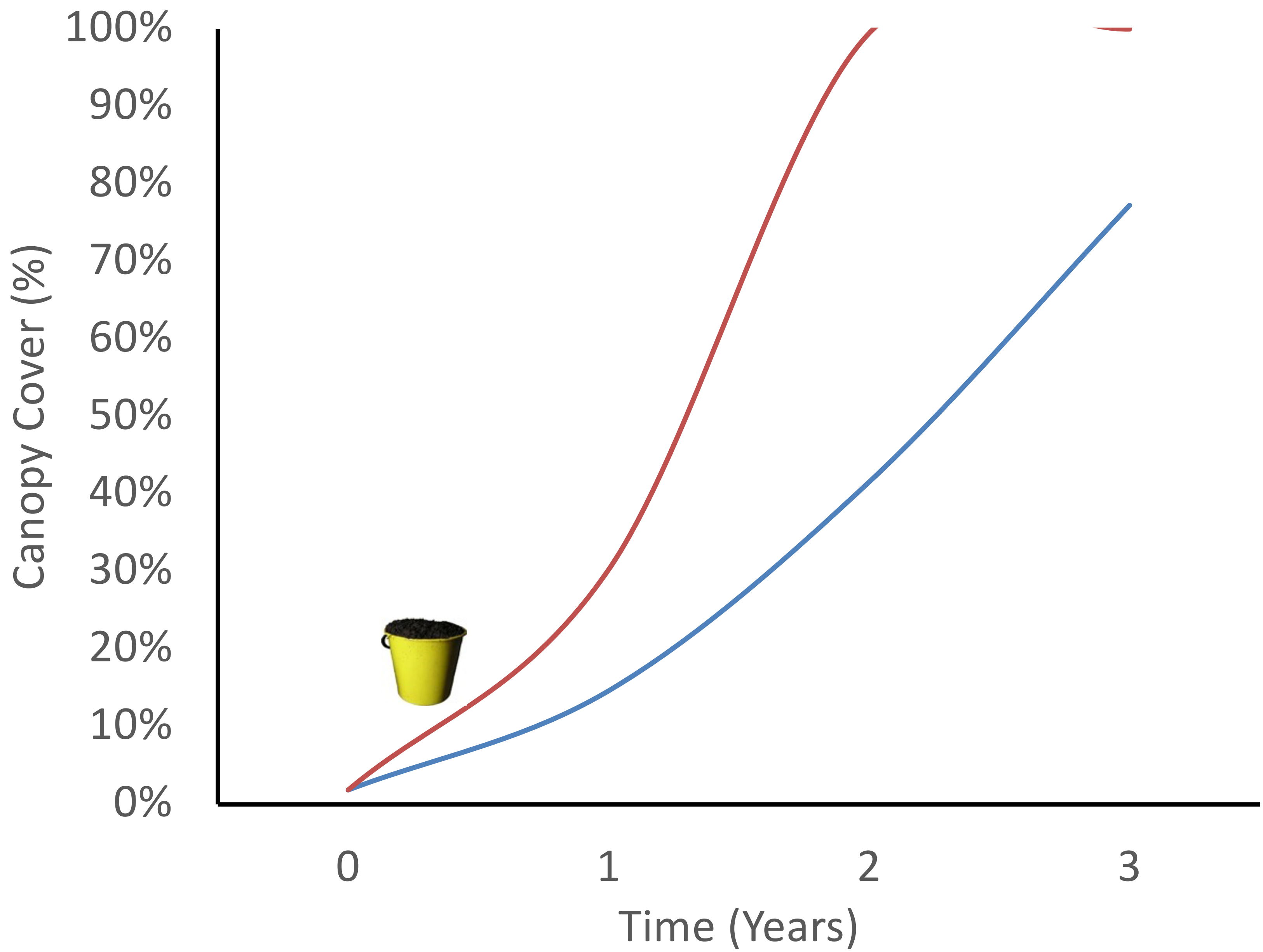
Added survival & growth by species & planting type

Reference	Location	Plant Spp.	Planting Type	Spacing	Duration	Survival
Laub et al. 2019	San Rafael River, Utah, U.S.A.	Fremont cottonwood	2-m-tall trees in 3.8 L pots	no info	1.25 years	35%
Amanda Clements, 2008 - 2010, Presentation	Western CO, Gunnison River	Cottonwood	poles	no info	1 growing season	0%
Amanda Clements, 2008 - 2010, Presentation	Western CO, Gunnison River	Cottonwood	poles	no info	1 growing season	12% yr 1, 0-6% yr 2
McMaster and Chaudhry 2017	Grand Canyon National Park, Colorado River	Salix gooddingii (Gooding's willow)	poles	no info	10 months	40%

Added responses to appropriate mycorrhizal inoculation for each plant species

Reference	Effect	Percent Change	Direction	Time Interval	Context
Meinhardt & Gehring 2012	Cottonwood biomass	33%	+		Greenhouse + Field, biomass results from Greenhouse
Beauchamp et al. 2005	Tamarisk biomass	75%	-	1 growing season (7 mo)	Greenhouse

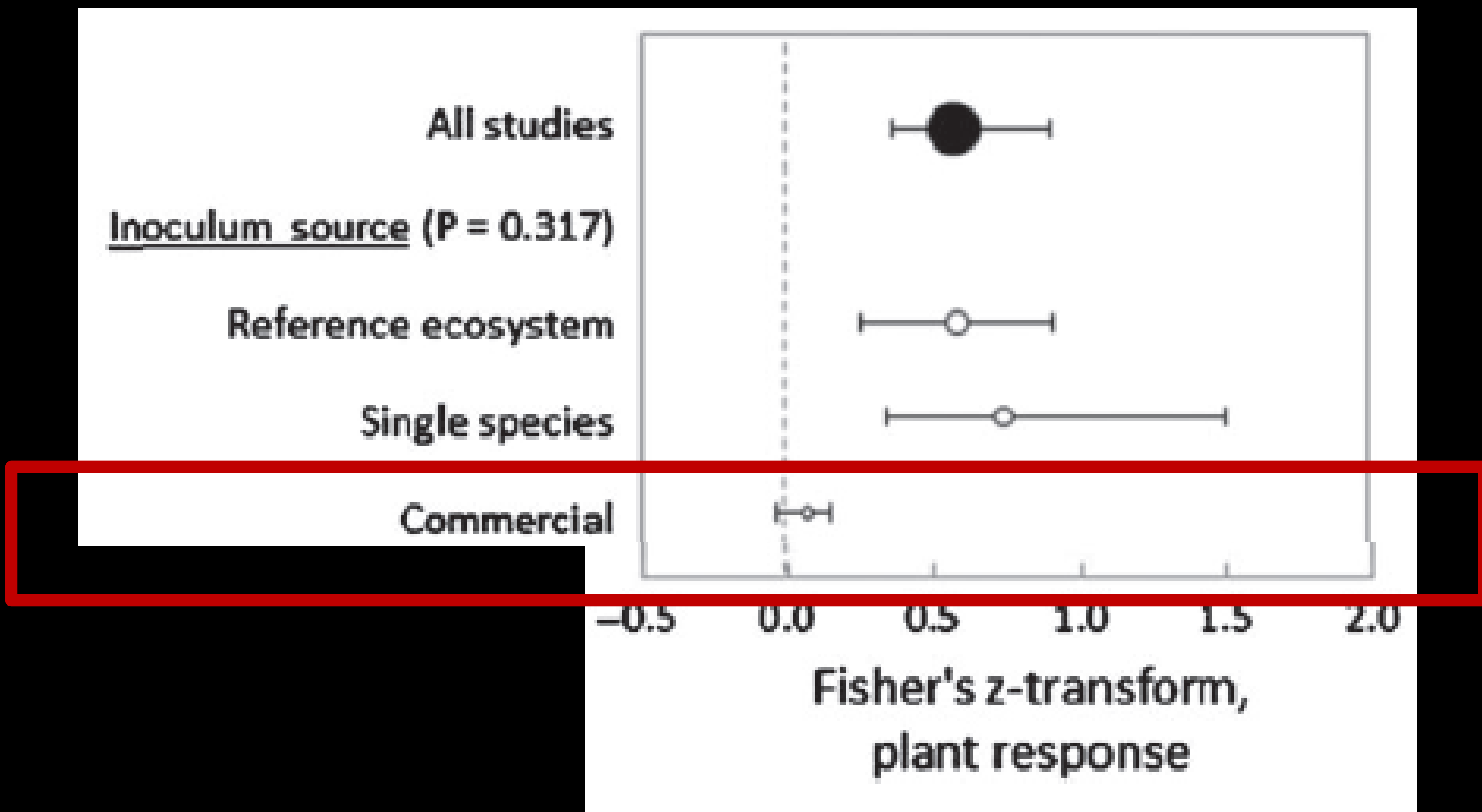
Inoculation increases canopy cover, and faster



Discussion

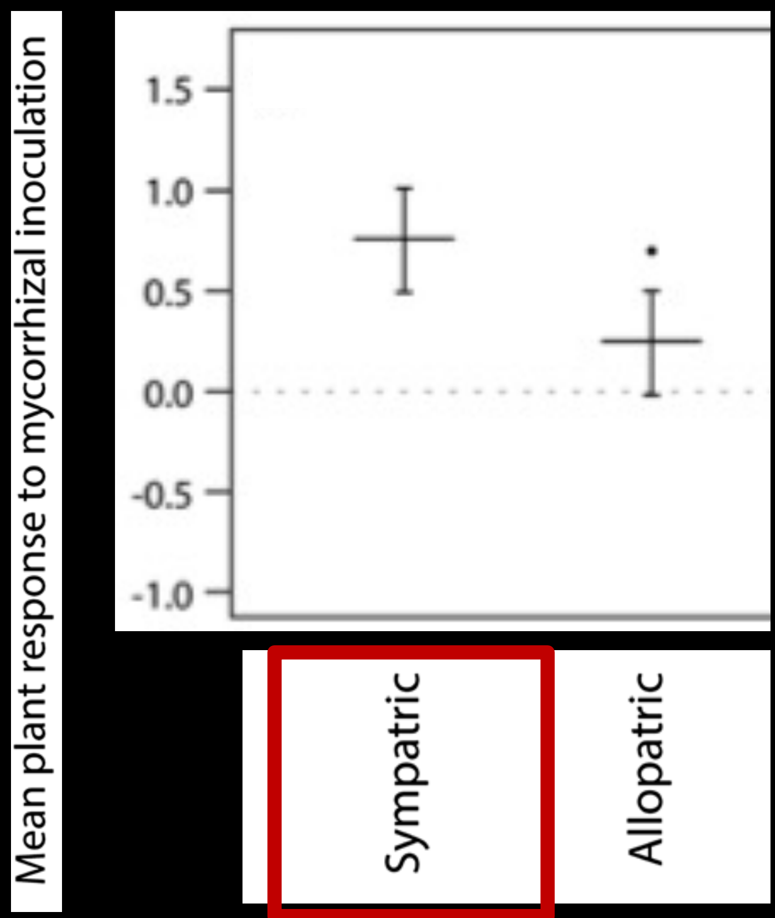
1) What is ”appropriate” mycorrhizal inoculation?

Please do not use commercial inoculum
Neutral to negative effects occur with a poor match between plants, soil, and mycorrhizas



Maltz & Treseder, 2015

“These results … emphasize the importance of routinely considering the origin of plant, soil, and fungal components.”



Rua et al. 2016

Discussion

1) What other factors might affect inoculation outcomes?

- Water availability
- Timing of inoculation
- Other management actions that impact mycorrhizas (e.g. pesticides, fuel management…)

[redacted]

THURSDAY, FEBRUARY 6, 2020

OPTION 3

WORKSHOP | USING MYCORRHIZAL FUNGI IN RESTORATION PROJECTS OF THE SOUTHWESTERN U.S.
WITH NORTHERN ARIZONA UNIVERSITY

8:00 AM ~ 12:00 PM
$20, TRANSPORTATION PROVIDED
MEET IN THE WEST BALLROOM AT 8 AM

[redacted]

Discussion

2) What decisions are practitioners facing at specific sites that should be included in model scenarios?

Nest Steps

1) Refine model specifics
   (e.g. each planting type modeled for comparisons).

2) Add sites under consideration for restoration.

3) Incorporate manager scenarios, to address key decisions.

4) Use model to weight SWFL outcomes vs. cost.

Thank you!

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SWFL photo, 1st slide: S&D Maslowski, nps.gov

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TEXAS A&M UNIVERSITY AGRICULTURE & LIFE SCIENCES

KEL KNOWLEDGE ENGINEERING LABORATORY