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08 November 2021

USDA Forest Service
Pacific Southwest Regional Office, Ecosystem Planning
1323 Club Drive
Vallejo, CA 94592
https://cara.ecosystem-management.org/Public//CommentInput?Project=60950

Subject: Scoping Comments, R5 Post-Disturbance Hazardous Tree Management Project

Greetings,

Thank you for the opportunity to comment on the appropriate scope for assessing hazardous-tree management in Forest Service lands affected by recent large fires in California. For reasons identified below, I believe it's appropriate that the Pacific Southwest Region assume responsibility for a coordinated approach to hazard-tree management in California. However, the scope of that undertaking requires a coordinated partnership arrangement with the individual national forests on which the project elements would be implemented, as well as incorporating the perspectives of relevant stakeholders. In general, the proposed project addresses a need for which Region 5 management is appropriate, but the proposed project does not address most of the forested landscapes affected by large wildfires in the last few years. The Region also needs to provide coordinated leadership for a programmatic response to the effects of climate change and increased wildfire within these landscapes, as described in the following pages.

I. Coordination of NEPA Assessments

This letter reflects and amplifies on comments regarding the scope and subsequent content of the Environmental Assessment (EA) issued by the Mendocino National Forest (MNF) for the proposed Plaskett-Keller Project, major elements of which involve roadside and campground hazard-tree removal in response to the August Complex. The MNF also has other projects underway that involve roadside hazard tree removals, including the Hammerhorn Project and the 4Beetles Project for the August Complex and the Northshore Restoration Project for the Ranch Fire. The Region 5 (R5) scoping notice does not indicate whether the proposed R5 Hazardous Tree Management Project (project) replaces and supersedes the MNF Plaskett-Keller Project and other projects on the MNF, or whether it's to be considered as a separate project <u>in addition to</u> the MNF Plaskett-Keller Project and others. Accordingly, this scoping comment incorporates by reference all scoping comments and EA comments that I sent to the MNF with respect to the Plaskett-Keller Project as if fully set forth herein (all comments are included in the public record for that project; also see discussion below).

Other national forests in northwestern California affected by the August Complex have also initiated individual projects to begin their own recovery processes, and the same consideration is likely to occur in those cases (see additional discussion re the four Klamath Ecoregion national forests below), if not also for the six Sierra Nevada national forests affected by fires in their own landscapes.

While this letter addresses the proposed R5 Hazardous Tree Management Project, it cannot address the multitude of specific environmental concerns that exist within the many thousands of miles of roads and trails covered by the project, or the dozens of trailheads and campgrounds. The Forest Service (FS) needs to clarify whether the proposed region-wide project is intended to serve as a programmatic 'umbrella' for hazardous-tree management projects throughout the Region with respect to assessments required by the National Environmental Policy Act (NEPA) and other federal laws and regulations. If so, the Regional Office needs to clarify the relationship between the R5 programmatic assessment and any/all subsequent projects by individual national forests enacted to implement the regional program:

- Is the R5 intention that implementing projects carried out by the individual national forests (identified only generally in the scoping description and maps) are to be addressed by project-specific assessments per NEPA requirements, tiered to this regional NEPA assessment, INCLUDING the identification of more-specific measures to address potential environment effects for each project, WITH opportunities for public review and comment?
- Is the R5 intention that projects by each national forest to implement the proposed region-wide program NOT prepare subsequent project-specific assessments, instead relying on the programmatic assessment and the measures identified in the scoping documents and in any subsequent R5 programmatic NEPA assessment, WITHOUT additional project-specific opportunities for public review?

A brief consideration of the range of ecosystem variability affected by recent large fires across the ten (when the Modoc NF is included) national forests covered by the proposed program implicates a wide range of variation in project elements and natural vegetation patterns. That brief consideration suggests that there's too much variability for the forests identified in the proposal to adequately address, in one assessment conducted in a brief window of time, the range of site-specific conditions that will occur among the many projects developed by ten national forests throughout the highly diverse landscape that is California. On this basis alone it appears to me that NEPA mandates a programmatic approach by R5, tiered to a project-specific assessment for each implementation project proposed by each national forest. Given the region-wide scope of the program, it seems unlikely that the Region can address the effects of the proposal with a NEPA assessment less extensive than an Environmental Impact Statement (EIS).

The R5 scoping documents identify the proposed project as applicable only to hazardous-tree removal operations along roadways and near public-use facilities like campgrounds, trailheads, and FS buildings. It appears to me that having the Region assume responsibility for developing a coherent approach to hazard-tree management in recently burned forestlands throughout the Region is both appropriate and desirable. Such a 'standard' approach lends itself to a programmatic environmental assessment, to which individual national forests and ranger districts can tier projects proposed to implement the strategy.

[I understand the evaluation procedures proposed for identifying trees to be treated, as well as the identified marking guidelines, and agree with the Region's conclusion that the methodology for identifying hazardous trees identified in the scoping documents is valid and appropriate. It appears to me that the project might benefit from including additional variables identified in individual national forest projects for use in identifying hazardous trees in different locations, such as traveled roadways vs high-use campgrounds. The Plaskett-Keller Project proposed by the Mendocino NF adopted a variable *probability of mortality* for use in selecting trees for removal depending on location, an approach that I believe might result in less controversy with stakeholders; the Region should consult with the MNF for further consideration.]

II. Use of Forest LRMP Elements Requires Validation

I concur with the R5 hazard-tree project proposal to incorporate as 'mitigation measures' any design features and Best Management Practices (BMPs) developed for dealing with watershed conditions, riparian areas, cultural resources, scenic and recreational resources, and geological resources from adopted LRMPs, subject to their *consistency with existing regulatory policies and scientific standards* in use among relevant regulatory and trustee agencies for those resources in California. However, measures identified in the scoping documents are unlikely to be the only 'mitigation measures' needed across all the treated landscapes in the subject national forests, and thus constitute a 'minimum set' of measures required to implement the proposal. Site-specific concerns undoubtedly exist, or will arise, that require additional measures to minimize or offset effects of the proposed treatments. These additional measures must be identified by specialists and stakeholders on a site- or project-specific basis by each forest in implementing the proposed project on landscapes with the forest.

Other concerns resulting from reliance on existing LRMPs for topics typically included in FS environmental assessment documents include:

- Measures to avoid or offset wildlife habitat impacts for 'special status' species clearly must be consistent with the requirements of applicable federal and state laws, whether or not those are identified in the R5 proposal.
- A reference condition for ecological communities and habitat types within forested landscapes known generally as 'natural (or 'historic') range of variation,' often-cited in Forest Service planning contexts, fails to address changes that are already being observed because of climate change and increased fires, and should *NOT* be identified as a goal of national forest management (see Attachment A for further information). Instead, the overriding goal for managing our forests is achieving ecologically resilient landscapes.
- Reliance on or incorporation of outmoded management concepts identified in many existing LRMPs (e.g., 'management indicator species' or 'optimum snag population') should be minimized. Instead, wildlife assessments must be based on current NFMA requirements to address habitat structure, composition, and connectivity at landscape scales.

While the proposed project is not identified as a 'salvage' project, live trees will undoubtedly occur in areas to be treated, and the largest and/or oldest of these 'green' trees (and the largest snags) should be retained as forest legacy elements to maintain ecological integrity in the treated landscapes. In 'dry forest' regions, the proposed project should strive to create or support the development of an 'ICO' stand structure (individual large trees, clumps of trees, and open areas) in treated stands (see Attachment A for additional information).

III. Assessments Require the Use of Best Available Current Science

The hazard-tree project's narrow focus does not adequately address a larger and extremely important issue for national forest landscape management in an era of climate change and increased fires: the increased probability of subsequent wildfire that was the subject addressed in the Coppoletta et al (2020) JFSP report cited in the scoping documents. The underlying issue is fundamentally the accumulation of fuels throughout entire landscapes, including burned parts of the landscapes. The 'fuels' within these landscapes that need to be considered include any natural advance regeneration of conifers, the well-known ingrowth of shrubs and/or hardwoods resulting from sprouting and/or germination from an abundant seed-bank, and the effects of accumulating ground fuels as burned conifer fall. Any planting carried out to replace large areas of burned conifers also contributes to these accumulated fuels. Long-term ecosystem management in California forests can't be planned or executed without attending to all these fuels.

As Coppoletta and her colleagues have noted, evidence is accumulating that this climate change-driven dynamic has a significant potential to alter conditions in our national forest landscapes, potentially leading to type-conversions to non-forest. This is a Region-wide issue that requires a coherent strategy for adapting to changing conditions; essentially, we need a 'planning' framework for a Region-wide strategy, requiring that every national forest incorporate climate-change adaptation into its Land and Resource Management Plan (LRMP), including forest-specific Standards & Guidelines tailored to conditions on each forest. The primary focus of the LRMPs must be increasing and maintaining the sustainability and ecological integrity of the forested landscapes, as identified in the National Forest Management Act (NFMA) regulations in 36 CFR §219. The Region has already identified [in the *Bioregional Assessment of Northwest Forests* (see below)] the importance of developing such a revised planning focus for the 'dry' forests in the Klamath ecoregion, but the need is no less dire for the other national forests in California.

While an existing specification in Forest Service regulations implementing the NFMA (36 CFR §219.15) directs that all national forests base decisions about proposed projects on the content of an adopted LRMP, current Forest Service NFMA regulations explicitly direct that FS decision-makers base their decisions on the 'best available science' (36 CFR §219.3, quoted here for reference):

> "**36 CFR §219.3 Role of science in planning.** The responsible official shall use the best available scientific information to inform the planning process required by this subpart. In doing so, the responsible official shall determine what information is the most accurate, reliable, and relevant to the issues being considered. The responsible official shall document how the best available scientific information was used to inform the assessment, the plan decision, and the monitoring program as required in §§ 219.6(a)(3) and 219.14(a)(4). Such documentation must: Identify what information was determined to be the best available scientific information, explain the basis for that determination, and explain how the information was applied to the issues considered."

When the adopted LRMPs are not consistent with current 'best available science,' an internal conflict is created that must be resolved by having the appropriate Region 5 decisionmakers direct national forests to follow the current science rather than what's in the outdated LRMPs.

Moreover, even the current Trump-era CEQ regulations for implementing NEPA (40 CFR §1500 *et seq.*) direct that federal agencies incorporate current science into the NEPA process when developing and approving projects:

> **"40 CFR §1501.2 Apply NEPA early in the process.**
>
> "(a) Agencies should integrate the NEPA process with other planning and authorization processes at the earliest reasonable time to ensure that agencies consider environmental impacts in their planning and decisions, to avoid delays later in the process, and to head off potential conflicts.
>
> "(b) Each agency shall:
>
>> "(1) Comply with the mandate of section 102(2)(A) of NEPA to utilize a systematic, interdisciplinary approach which will ensure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision making which may have an impact on man's environment, as specified by § 1507.2(a) of this chapter." …

The scoping notice indicates explicitly that the individual forests, when implementing the proposed R5 hazard-tree project, incorporate elements from their existing LRMPs (see below). However, for many of these forests the LRMPs are based upon, and specifically direct that projects be implemented consistently with, science and technical approaches developed between the 1960s and the early 1990s. For example, the MNF's current LRMP was adopted in 1995, incorporating amendments necessitated at that time by the then-recent adoption by the Forest Service of the Northwest Forest Plan (NWFP), addressing the then-understood ecological needs of the Northern Spotted Owl (NSO) and several aquatic species listed under the federal Endangered Species Act (ESA). [The LRMPs of all four national forests in northwestern California (the Klamath ecoregion forests, identified in the scoping notice as the 'northern zone' forests) were adopted in the mid-90s, based upon the same science and the same set of mandates, and all four LRMPs suffer from similar misapplications of outdated information.]

The scoping notice does not require that the implementation of the proposed R5 project by these forests incorporate an understanding of current science relevant for management and decision-making developed by the Forest Service itself. In July 2020, the Forest Service regional offices for California (Region 5) and Washington and Oregon (Region 6) issued a document entitled the '*Bioregional Assessment of Northwest Forests'* (*BioA*)[1] for public review. The *BioA* accompanies the 2018 *Science Synthesis*[2] as a document on which the in-progress forest plan revisions for each of 19 national forests in Washington, Oregon, and northwestern California are to be based. The *Science Synthesis* and the *BioA* are thus identified *by the Forest Service* as the current scientific basis to be used in FS decision-making within the NWFP region.

Given the formal endorsement of the science in these published Forest Service summaries by the R5 and R6 offices, the conclusion is inescapable that the Klamath ecoregion forests should incorporate the contents of the *Science Synthesis* and the *BioA* as the science on which the R5 hazard-tree management project must be based in order to comply with current NEPA regulations, as well as in meeting the NFMA directive for information used in decision-making in 36 CFR §219.3. The LRMPs of the three northern Sierra Nevada forests included in the R5 project were also adopted in the late 20th Century, at about the same time as the Klamath ecoregion forests' LRMPs, and were largely based on the same or very similar science. Elements in all these LRMPs *may* be consistent with current best available science, but the LRMP Standards & Guidelines in the adopted LRMPs cannot be concluded to be consistent with current scientific understanding unless and until each standard and guideline is independently verified by comparison with practices that are consistent with current science (particularly, for the Klamath ecoregion forests, with the understanding reflected in the *Science Synthesis* and the *BioA*).

IV. Regional Assessment Must Differentiate Ecologically Different Forest Types Within the Region and Incorporate Effects of Climate Change and Increased Fire

The forests in the Klamath ecoregion are ecologically similar to forests in the Sierra Nevada, but there are regional differences in temperature and moisture gradients, substrate conditions, plant community composition, and forest structure that must be considered in addressing management requirements such as wildlife habitat requirements. For the Klamath ecoregion forests, a consideration of differences among forested ecosystems hosting the NSO across R5 (and R6)

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[1] The *BioA* is available at URL: https://www.fs.usda.gov/detail/r6/landmanagement/planning/?cid=fseprd677501.

[2] The three volumes of the Science Synthesis can be downloaded from URL: https://www.fs.fed.us/outernet/pnw/publications/gtr966/index.shtml. In addition, a separate Executive Summary document for the synthesis is also available for download from that URL.

emerges clearly from considering the altered understanding of the ecology of the Northern Spotted Owl reflected in the US Fish & Wildlife Service (USWFS, FWS) 2011 NSO Recovery Plan.[3]

At the time the Recovery Plan was adopted, the FWS already understood that the forested ecosystems occupied by the NSO differed throughout the owl's range (the history of this science through the first decade of the century is summarized in the Recovery Plan; an additional decade's worth of NSO-relevant science is covered in the *Science Synthesis*). The 2011 NSO Recovery Plan identified a focus on 'dry forests,' a different habitat type standing alongside the 'moist forests' that had been the model for 'old growth' NSO habitat when the NWFP (and consequently the mid-90s Klamath ecoregion LRMPs) was adopted. 'Dry' and 'moist' forests differ in several significant ways, and have developed under substantially different 'disturbance regimes,' particularly different 'fire regimes.' 'Dry forests' are also frequently characterized as 'frequent-fire forests,' owing to the general relationship that exists between frequent low- or mixed-severity fires and the more open structure exhibited by these landscapes.

Characteristics of 'dry' 'frequent-fire' forests, and their relationships to forest management, are discussed in detail in the *Science Synthesis* and the *BioA* (and in the scoping comments I provided to the MNF for the Plaskett-Keller Project). Those documents recognize, as does the FWS NSO Recovery Plan, that ecosystem composition, structure, and dynamic processes in 'dry forests' are different from the composition, structure, and dynamic processes in the 'moist forests' on which the original NWFP was based, and that current and future management of 'dry' forests require a fundamentally different approach.

[For purposes of summarizing a number of important ecological processes occurring in the 'dry forests' in the Klamath ecoregion, a summary of ecological relationships and management considerations initially submitted to the national forests in the Klamath ecoregion is attached and incorporated fully into this scoping comment (Attachment A: *Climate Change & Fire Adaptation in Northwestern California National Forest Landscapes*, dated March 2021). The summary reflects ecological processes that occur in all California forested landscapes, but is explicitly directed to ecological processes important for the Klamath ecoregion, including the Siskiyou region in southwestern Oregon. The degrees of similarity and difference between Klamath ecoregion landscapes and those in the central and southern Sierra Nevada are not unimportant, either scientifically or for management purposes, but a full characterization vastly exceeds the scope of this comment. Attachment A also incorporates extensive consideration of adapting Klamath ecoregion forested landscapes to the effects of increased fire and climate change; these elements are directly relevant to the scope of the R5 hazard-tree project, and should be addressed as a central element in the Region's approach.]

For the 'frequent-fire' forests, the significance of post-fire fuels on subsequent wildfire fire severity [the specific focus of the Coppoletta et al (2020) JFSP report identified in the scoping documents] is clearly a necessary element to be considered in planning for the future. Relationships among snags, downed logs and other coarse woody debris, and future fires are fundamentally an important management issue raised when relying on the outdated LRMPs in the northern California forests, which assumed that low- and mid-elevation conifer forests were all 'moist

[3] USDI Fish and Wildlife Service. 2011. Revised Recovery Plan for the Northern Spotted Owl (*Strix occidentalis caurina*). Portland, OR. xvi + 258 pp. See URL: https://www.fws.gov/oregonfwo/Species/Data/NorthernSpottedOwl/Recovery/Library/Documents/RevisedNSORecPlan2011.pdf.

forest' with abundant coarse woody debris and abundant snags, in addition to dense, multistoried canopies. The outdated LRMPs consequently include Standards & Guidelines intended to retain abundant snags and coarse woody debris, which is directly contrary to the actual management approaches needed for 'dry' 'frequent-fire' forests.

For example, the MNF LRMP includes direction to provide 5-20 tons per acre of coarse woody debris, based on directions in the 1996 NWFP for wildlife habitat in what are now known to be 'moist' forests. In NEPA assessments for fire-recovery projects after the 2018 Ranch Fire, fuels-management staff on the MNF identified the low end of the range (ca 5 tons/acre) as potentially consistent with managing the forest under warming climate and intensified fire regimes, although even 5 tons/acre was identified as being a higher loading than is desirable if the intent were to maintain fuels consistent with an increased fire regime.[4]

Such conflicts are clearly not desirable if the goal is to achieve long-term landscape sustainability in a time of warming climate and increasing fire. The direction provided by the existing MNF LRMP is not even consistent with the array of stand structures that are now considered to be ecologically typical of natural variability in 'old-growth' 'frequent-fire' forests, which have been identified as having generally been more open, typically with large, fire-resistant conifers in a matrix of grasses, shrubs, and/or hardwoods [see Reilly & Spies (2015), cited in Attachment A, and other discussion in Attachment A].

Recent scientific investigations of National Forest landscapes throughout the western United States (including the *Science Synthesis* and the *BioA*) support an overarching conclusion regarding adaptations for climate change and increased fire, particularly in overly dense 'dry' 'frequent- fire' forests: stand densities need to be reduced, then subsequently maintained at lower densities, to create ecological conditions that are more resilient in a hotter, dryer climate. It appears to me that Region 5 should explicitly identify reducing stand densities as a significant objective for *every* project enacted as part of the fire and fuels management program, including this one.

Attachment A (intentionally) doesn't address potential 'turnover thresholds' or 'tipping points' for fire and fuel dynamics in forested landscapes. However, evidence from recent large, high-severity fires has begun to indicate that 'tipping points' may be important in determining future landscape compositions in western forested landscapes.[5] The essential considerations in this model for future fires include these elements:

(i) Increased climate warming will lead to increasing future vapor pressure deficit/Climate Water Deficit, which will have an unavoidable effect in increasing the likelihood of fire in future landscapes, including an increased fire frequency and an expanding area burned each year;

(ii) An increased fire frequency and area burned will reduce the volume of fuels in forested landscapes; eventually the reduced availability of fuels will result in fuels-limited landscapes and a reduction in further burning;

(iii) Fuels limitation occurs because increased fire results in significant alterations in the dominant vegetation in the affected landscapes, with reduced tree cover and increased

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[4] See the documentation prepared by the Upper Lake Ranger District for the North Shore Restoration Project at URL; https://www.fs.usda.gov/project/?project=55716).

[5] Numerous authors have included these considerations as caveats in their published work. Perhaps the best expression of these concerns is in McKenzie & Littell (2017), "Climate change and the eco-hydrology of fire: Will area burned increase in a warming western USA?" *Ecological Applications* 27:26; https://doi.org/10.1002/eap.1420.

dominance by shrubs and hardwoods, and a potential conversion of forests to shrublands, or even conversions from forests and shrublands to grasslands.

The national forests in California should consider the implications of the above dynamic as an alternative future. Increased fire frequency will clearly favor a potential conversion of more densely forested landscapes to open forests, or to shrublands. The evolutionary history of California's vegetation exhibits an 'alternative stable state' coexistence dynamic involving conifers, hardwoods, shrubs, and grasslands, distributed throughout the regional landscapes in a 'shifting mosaic' pattern through time (as summarized in Attachment A).

As a general comment about this and other management focuses for national forests in California, it seems to me that Region 5 needs to identify *fuels management* as an essential element for *all* individual national forests, and for Region 5 itself. A management program to address climate change and fire must include elements for monitoring fuels accumulations throughout the Region's forests. Future re-treatment of fuels in strategic landscape locations (including locations treated as part of the current program) should be identified as an essential element in managing future fires.[6] Better fire and fuels management is an essential component of Forest Service landscape management in California. The amended National Forest Management Act provides explicit direction to maintain ecosystem functions and services on a landscape basis, which is perhaps the best overriding goal the Region could specify for managing NF landscapes.

Closing

Please incorporate the concerns addressed in this letter and its attached report into the NEPA assessment for the R5 Post-Disturbance Hazardous Tree Management Project. Thank you for your continuing commitment to conserving our public environmental resources. Please feel free to contact me if there are questions.

Sincerely,

Chad Roberts

Chad Roberts
Conservation Ecologist

Attachment A: *Climate Change & Fire Adaptation in Northwestern California National Forest Landscapes*

Copies: Eberlien, Exline, Olson, Shahani, Carlson, McArthur, Smith, Birkey, Butz, Bohlman, Safford

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[6] Perhaps the Region should consider a Region-wide implementation of the 'Potential Operational Delineations' (PODs) concept as a strategy to assist forest managers and stakeholders in developing an adaptive strategy for fire and fuels management: see URL: https://www.fs.usda.gov/rmrs/potential-operational-delineations-pods#:~:text=POD%20is%20an%20acronym%20for,can%20be%20quantified%20and%20summarized.

Attachment A

CLIMATE CHANGE & FIRE ADAPTATION IN NORTHWESTERN CALIFORNIA NATIONAL FOREST LANDSCAPES

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March 2021

A Short Summary

The Klamath ecoregion in northwestern California includes substantial parts of four national forests. Existing planning documents for these forests, including the Northwest Forest Plan (NWFP), will soon be updated, and the plans will be developed pursuant to the 2012 Planning Rule, which directs a planning focus on processes occurring at landscape scales, on ecological processes leading to services from these public lands, and on adapting to the effects of climate change. That planning focus differs in substantive ways from the focus in existing management plans; however, it's the required focus for updating existing plans, and should also be the focus for designing projects to respond to ongoing disturbances in the Klamath ecoregion, particularly fires.

Science summaries prepared for these plan updates show that many landscapes in the four national forests are dominated by 'dry' 'frequent-fire' forests, which were not addressed in the existing NWFP and the existing forest plans. The effects of increased fire and other disturbances, and of the aridity that results from warming climate, will exert significant stresses on existing forest ecosystems, and current management guidance is unlikely to address responses to those changes. New scientific information and better understanding of ecological processes in northwestern California landscapes, summarized in this report, do address many of those questions.

Responding to climate change and fire requires adaptational responses at stand or patch levels. Increased fuels in many mixed-conifer stands in the Klamath ecoregion must be addressed by increased management, including a restoration of fire to forested landscapes, returning its historical occurrence patterns. Resiliency of existing stand structures must be adapted to increased fire and aridity by reducing stand densities. Restoration of a more natural stand structure identified in frequent-fire forests, the individuals/clumps/openings ('ICO') structure, and the intentional retention of large and old trees will increase stand resiliency. Stand compositions in the Klamath ecoregion may shift toward more hardwood dominance with increased fire, because hardwoods and shrubs are ecologically selected vegetation types in the ecoregion. Nonetheless, climate change and more active fire regimes may cause the development of 'no-analog' stand compositions unlike those currently present. This report summarizes many of these effects.

Responding to climate change and fire also requires adaptational responses at landscape levels. Landscapes are large areas that combine many stands, and landscape-level

management must include considerations about the joint status of multiple resources across stands as those resources are affected at the scale of the entire landscape. Landscapes are 'mosaics' of multiple patch or stand types, and landscape-scale responses include shifts in the condition, and even in the locations, of stands through time. Landscape-scale management requires an understanding of how those large-area dynamics occur and how they may be used to plan for the land and address public concerns. This report provides a context for landscape-scale planning and management, which also helps in framing potential management considerations about shifts to 'no-analog' communities that may be better adapted and more resilient to future climates.

Landscape-scale considerations are already a significant part of many conservation planning frameworks, and incorporating scientific concepts developed for conservation purposes helps frame landscape management options. 'Connectivity' is fundamentally a landscape-scale concept that's essential in conservation contexts, and it will help guide development of landscape-scale plans for other resource concerns. In the Klamath ecoregion a fundamental consideration for the future is the relative importance of coniferous trees with respect to increased fire, because the Klamath ecoregion is well understood to include hardwood tree and shrub species that are specifically adapted to frequent-fire ecosystems. Hardwoods, shrublands, and coniferous forests may be 'alternative stable states' in the ecoregion. An increased focus on riparian areas within the ecoregion will enhance both conservation outcomes and landscape-scale management. This report presents information to help shape discussions about these conservation topics in planning contexts that are immediately applicable for plan updates under the 2012 Planning Rule, as well as for agency review processes required to develop and implement management projects in the near term.

This report includes a substantial body of scientific information relevant for climate change and landscape management. It includes numerous citations to and references for the scientific concepts described, providing an avenue for readers to consult recent scientific literature most relevant for the processes underlying the application of the 2012 Planning Rule to national forest landscapes in the Klamath ecoregion.

I. Bioregional Science, Climate Change, and Fire Assessment in the August Complex Region

Northwestern California's four national forests [the Klamath (KNF), Six Rivers (SRNF), Shasta-Trinity (STNF), and Mendocino (MNF)] are the southernmost national forests included in the range of the Northern Spotted Owl (*Strix occidentalis caurina*), and as such their Land and Resource Management Plans (LRMPs) are constrained to be consistent with the requirements of the Northwest Forest Plan (NWFP). The forest LRMPs provide essential guidance for projects to be undertaken by the individual forests, including projects to recover from large-scale disturbance events such as the 2020 August Complex fire and other recent fires in this region. A Forest Service (USFS; FS) process is currently underway to update/revise the NWFP, originally adopted by the FS in 1994, although the update of the NWFP, and the subsequent revision of the four forest LRMPs, is not expected to be completed for several years. In the interim the forests are directed by existing FS regulations to respond to the effects of the August Complex and other major fires according to the standards in their existing LRMPs, amended in the mid-1990s to be consistent with the then-new NWFP.

In July 2020, the Forest Service regional offices for California (Region 5; R5) and Washington and Oregon (Region 6; R6) issued a document entitled the 'Bioregional Assessment of Northwest

Forests' (BioA)[1] for public review. The BioA has a formally identified status in the 'pre-decisional' step of the FS's 'Forest Plan Revision Process' under the 2012 Planning Rule[2] (see the diagram on page 79 of the BioA), where it accompanies the Science Synthesis[3] as a document on which the forest plan revision processes for each of 19 identified national forests in Washington, Oregon, and northwestern California are to be based. Thus, like the Science Synthesis, the BioA is part of a formal process intended to identify public concerns as an element in FS engagement with the public regarding the development of those 19 plans.

As the BioA clearly states, it does not incorporate site-specific results for any national forest. What it does is identify general concepts or approaches that the FS may employ in developing updated LRMPs for the national forests identified in the BioA. Because the 19 individual forests are those covered by the NWFP, the BioA is also a foundational document for the pending revision/update of the NWFP. The update process for the NWFP must either lead or run jointly with the update processes for each of the 19 forest plans, but it's unclear how the processes will interdigitate with one another, and the BioA identifies several alternatives (see the 'Modernization Options' discussion on BioA pp 37-38).

The BioA provides, in a generalized way, a set of strategy alternatives from which the FS could select options to update the NWFP. The potential revisions that could emerge from the alternative approaches in the BioA could significantly alter the framework under which the existing NWFP and the current LRMPs are structured. The substantive content of the BioA reflects options that the conservation community and the federal managers need to consider (and discuss) seriously. Many of the potential changes (and the altered planning process required under the 2012 Planning Rule) also support strategic options that have been identified for adapting national forest landscapes to the effects of climate change, which is an existential concern for the long-term conservation of forests throughout the region.

Incorporating climate change into ongoing management programs represents a fundamental challenge for the Forest Service (as it does for most organizations) in several ways. Perhaps most importantly, for most of its history the FS has been guided by a concept that landscapes were 'stationary' through time, and that management should be based on maintaining or restoring landscape conditions that existed at the time the USFS was established, or even on the conditions that existed prior to the colonization of North America by Europeans (see, e.g., the summary in Joyce et al 2008). However, at the time the Joyce summary was written, it was already clear scientifically that climate change was altering dynamic ecological processes in federal landscapes that would take them beyond the range of known historical conditions, and that alternative management approaches would be required that incorporated effects of altered climate on the landscapes (also see West et al 2009). In the decade since these summary documents were published, a vast amount of scientific work has been directed toward climate change adaptation, but translating the results of that work to on-the-ground management remains a challenge.

Potential effects of climate change on USFS lands and resources can be identified through projections of future climate-related effects, which are inherently uncertain. Modeling results form the basis for projecting climate-change impacts on the planet's ecosystems, the services they provide (Box 1), and the world's population (IPCC 2014). Numerous climate simulations have been developed, which differ in internal dynamics, and different modeling approaches initiated

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[1] https://www.fs.usda.gov/detail/r6/landmanagement/planning/?cid=fseprd677501.

[2] Forest Service Handbook §1909.12 - Land Management Planning Handbook; Forest Service Manual §1900 - Planning; 36 CFR §219 - Planning. URL: https://www.fs.usda.gov/detail/planningrule/home/?cid=stelprdb5403924.

[3] https://www.fs.fed.us/outernet/pnw/publications/gtr966/index.shtml.

with identical starting conditions may yield a range of projected future conditions (detailed discussions of climate modeling are beyond the scope of this summary).

Climate exerts a major influence in the evolution of plant and animal species; variations in temperature and moisture patterns are particularly important. Ecological research has long documented the importance of moisture gradients in California for vegetation, with both precipitation and species richness declining from north to south in this Mediterranean region, and from the coast toward the Sierra Nevada (Richerson & Lum 1980; Hawkins et al 2003). Fluctuations in precipitation are related to coupled ocean-atmosphere systems that vary over periods of a few months [e.g., the Madden-Julian Oscillation (MJO)] to a few years [e.g., the El Niño Southern Oscillation (ENSO)] to several decades [e.g., the Pacific Decadal Oscillation (PDO)].[4] These coupled ocean-atmosphere and climatic variations are linked to dynamic processes in vegetation growth and fire occurrence and severity in California (Trouet et al 2006; Skinner et al 2009, 2018; Wahl et al 2019). Vegetation in northwestern California's mountains is a significant element underlying the designation of California as a global biodiversity hotspot; the climate and geological composition of the region support high endemism in numerous plant families, including conifers (Stebbins and Major 1965; Raven and Axelrod 1978; Briles et al 2008; also see Section VI below).

Box 1. Ecosystem Services

The Millennium Ecosystem Assessment (2005) identified four categories of ecosystem services, 'the benefits people obtain from ecosystems.'

Provisioning Services

Provisioning services address benefits that people receive directly from nature, including food, water, timber, and fiber, among others.

Regulating Services

Regulating services address ecosystem controls on climate, floods, disease, wastes, and water quality, among others.

Cultural Services

Cultural services reflect how nature affects people, including effects on their aesthetic, spiritual, educational, and recreational well-being.

Supporting Services

Supporting services underlie all the categories above, reflecting ecosystem processes such as nutrient cycling, soil formation, and primary production, among others.

The assessment noted that 'people are integral parts of ecosystems and that a dynamic interaction exists between them and other parts of ecosystems, with the changing human condition driving, both directly and indirectly, changes in ecosystems and thereby causing changes in human well-being.'

The MNF, for example, has been addressed in two recent climate-change related assessments (Butz et al 2015; Reilly et al 2018), incorporated here by reference. Both assessments incorporate climate model projections of continued increases in ambient air temperature, which are judged by the authors as likely to depart known historical ranges of conditions by the mid-21st Century; observed nighttime low temperatures in the MNF region already show statistically significant increases since the mid-20th Century (Butz et al 2015). Both assessments recognize that climate-model projections of regional precipitation vary from slight overall decreases to slight increases; all projections are largely consistent, however, in indicating that there is likely to be less snow in the

[4] Precipitation patterns and atmospheric moisture demands are primary influences in starting and ending the longer-term water shortages generally known as *droughts*, and both altered atmospheric circulation patterns and warmer air temperatures can exacerbate drought conditions (see, e.g., URL https://scijinks.gov/what-causes-a-drought/). However, conditions perceived as droughts are related to an *expectation* of water availability based largely on historical experiences, a non-physical factor that's not included in either ocean-atmosphere models or climate models. Climate change can clearly affect drought severity through its effect on vapor pressure deficit, but climate change *per se* is not a primary cause of drought.

future, and that an altered future climate has a significant potential to include both more intense winter storms with consequent effects on runoff events, and more intense localized water deficit conditions (see sections III and IV below regarding *climate water deficit*, a pervasive consequence of climate change).

The ambient Mediterranean climate (cool, wet minters and warm, dry summers) in northwestern California interacts with other factors (including but not limited to elevation, localized moisture availability, soil composition, and long-term California Indian land management practices) to influence recurring vegetation patterns in California. One of the most significant of those factors is fire, resulting in patterns that include fire-return frequency, fire intensity/severity, and plant reproductive strategies. Characterized as *fire regimes*, these evolved relationships are reflected in the dominant vegetation patterns in California's landscapes [summaries of factors shaping fire regimes in California are provided in Sugihara et al (2018); Collins et al (2018); Oddi (2018); other chapters in van Wagtendonk et al (2018) summarize relevant understanding about fire regimes in forests in different California ecoregions]. These fire regime and vegetation patterns (together with other underlying ecological relationships) are major contributing factors to the genesis of geographic *ecoregions* (Griffith et al 2016), which are defined to reflect intrinsic patterns in the underlying biophysical factors and ecological interactions, and in the resulting landscapes; that is, fire regimes have been (and remain) a significant factor shaping California's landscapes.

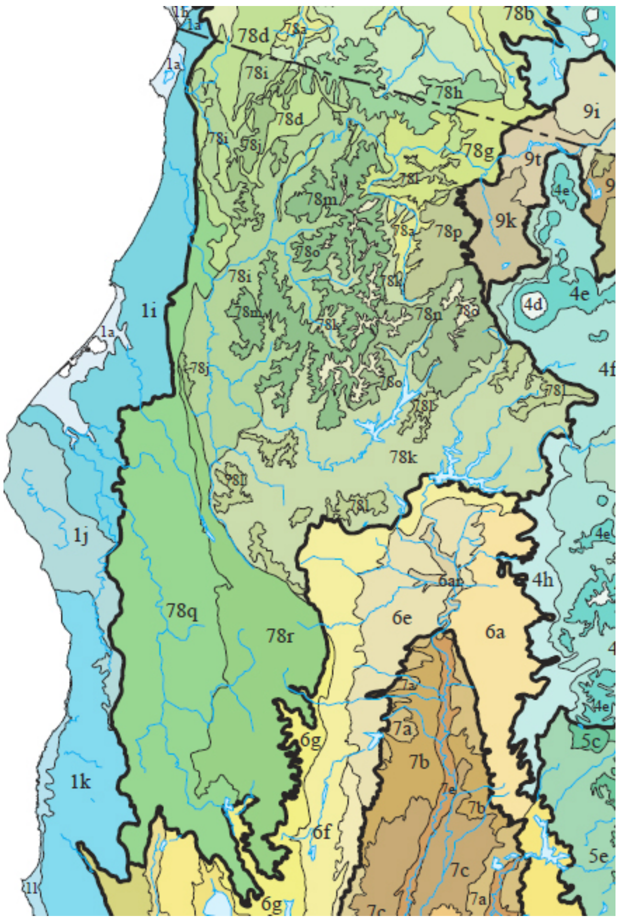

Figure 1. 'The Klamath Mountains/California High North Coast Range Ecoregion *encompasses the highly dissected ridges, foothills, and valleys of the Klamath and Siskiyou Mountains. It extends south into California to include the mixed conifer and montane hardwood forests that occur on mostly mesic soils in the North Coast Range mountains. … The ecoregion's diverse flora, a mosaic of both northern Californian and Pacific Northwestern conifers and hardwoods, is rich in endemic and relic species. The mild, subhumid climate of this ecoregion is characterized by a lengthy summer drought.' (Ecoregion 78 map and text excerpted from Griffith et al 2016.)*

Most of the landscapes within the four NW California national forests are included within the '*Klamath Mountains/High North Coast Range*' ecoregion (Griffith et al 2016; Figure 1). This ecoregion encompasses the geologically defined Klamath Mountains (including the Siskiyou region in southwestern Oregon) together with conifer-dominated forested landscapes in the interior northern Coast Range (i.e., not including the coastal ecoregion dominated by cooler and wetter landscapes, including redwood forests). The Klamath ecoregion generally incorporates forested landscapes above 3000 feet in elevation, with higher elevations generally 4000 to more than 7000 feet; the highest peaks in the Klamath River basin reach elevations above 9,000 feet. The ecoregion incorporates a wide range of geological substrates, soils, aspects, and other underlying physical variables, but the ecological communities are similar throughout the ecoregion, from Snow Mountain in the Mendocino NF Coast Range to the Trinity Alps and the Kalmiopsis region in southwestern Oregon.[5]

A significant thread throughout the Bioregional Assessment is the identification of ecological differences in the forested landscapes covered by the NWFP that were not recognized in the quarter-century since the NWFP was formulated. The most significant regional difference overall is the existence of 'dry forests' in the eastern portions of the plan area, and the four NW California national forests are among the most significantly affected by the prior omission. As synopsized in the BioA, these inland forested landscapes developed and continue to exist under significantly different moisture, temperature, and fire regimes than occur in 'moist forests' closer to the Pacific Ocean. In the original NWFP, the conditions in the 'moist' forests were effectively presumed to exist in all forested landscapes in the region. An abundance of scientific evidence has accrued supporting the distinctions among forests that have developed under differing fire regimes, as summarized in the various chapters in van Wagtendonk et al (2018), and in hundreds of individual scientific publications covering forests throughout the western US from recent decades.

The ecological patterns underlying the 'dry'/'moist' differentiation are described more fully in the Science Synthesis than in the BioA. However, the Synthesis (and therefore the BioA) describes plant associations in California using a classification framework developed for Region 6 that doesn't translate well to vegetation categories normally used in California.[6] Much of the forested landscape in northwestern California is identified in the BioA (see BioA page 23) as 'Douglas-fir' forest or 'White Fir-Grand Fir' forest, grading into 'Tanoak' forest on the coastal side and 'Ponderosa Pine' forest near the Central Valley.

Numerous summaries exist for vegetation patterns in NW California (e.g., Küchler 1977; Sawyer 2006; Griffith et al 2016), and the variability in these forest types is amplified in site descriptions included in hundreds of published and unpublished research reports. The following summary represents a generalized description of the major vegetation types in the region, intended primarily to provide background for the discussions in this synthesis.

In northwestern California, 'dry' forests generally include many of the mid-elevation forests typically identified as 'mixed conifer' and 'yellow pine' forest in California. Dominant conifer species in mixed-conifer forests include Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), ponderosa pine (*Pinus ponderosa*), and sugar pine (*P. lambertiana*). Incense cedar (*Calocedrus decurrens*) varies locally in abundance. Black oak (*Quercus kelloggii*) is frequently a co-dominant species in mixed-conifer forests. Jeffery pine (*P. jeffreyi*) often occurs in mixed-conifer (and yellow pine) stands on mafic substrates. In northwestern California canyon live oak (*Q. chrysolepis*) and madrone (*Arbutus menziesii*) are frequently important hardwood species in 'dry' mixed-conifer forests. In addition, Oregon white oak (also known as Garry oak, *Q. garryana*) may be a dominant hardwood in successional patches following fires, and is more common in northern parts of the Klamath ecoregion. Forests at low elevations on the west side of the Klamath ecoregion include "dry' subareas of 'mixed-evergreen' forests, typically including Douglas-fir, tanoak (*Notholithocarpus densiflorus*), madrone, canyon live oak, and other hardwood species.

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[5] Some historical ecological treatments limit the Klamath Mountains ecoregion (aka the 'Klamath-Siskiyou region') to the geological region identified as the Klamath Mountains, placing the forested landscapes of the inner northern Coast Range in other ecoregions. The Griffith et al (2016) classification places all the higher-elevation forested landscapes in northwestern California into the same ecoregion, based on their ecological similarities. As will be evident from considerations of 'dry' 'frequent-fire' forests in this summary, the Griffith et al (2016) classification generally reflects the ecological patterns in NW California.

[6] The Science Synthesis presents a crosswalk to the CALVEG classification developed for USFS Region 5, but I suspect that many California readers will not find the crosswalk particularly helpful.

These Klamath ecoregion forest types occur along gradients of increasing elevation and decreasing precipitation, from west to east, from the ‘moist’ coastal forests in which redwood (*Sequoia sempervirens*) is the dominant species, to ‘mixed-evergreen’ forest, to ‘mixed-conifer’ forest. At elevations above the mixed-conifer zone, forests generally exhibit a different fire regime than occurs in the mixed-conifer forests, with less-frequent but more severe fires; species like red fir (*A. magnifica*), western white pine (*P. monticola*), and mountain hemlock (*Tsuga mertensiana*) replace the mid-elevation conifers.

Because each of the dominant plant species is responding to its own set of required environmental conditions, local composition varies, and the forest types typically occur in a patchy mosaic. The north-facing side of a ridge (the north ‘*aspect*’) may support dense conifer-dominated forest, while the south aspect of the same ridge may be an open ponderosa pine forest, a black oak woodland, a chaparral-covered slope, or grassland/savanna. Klamath ecoregion mixed-conifer ‘dry’ forests frequently include a shrubby understory, which generally is continuous at lower elevations with mixed chaparral, and the shrubby understory typically grades into montane chaparral at higher elevations.

Forest conservationists and land managers in different parts of northwestern California will recognize that there is substantial local variation in these forests throughout the region, and the general characterization above only serves as a framework for the variability in the ‘dry’ forests in the region. In a general sense, ‘dry forests’ in NW California occur in the eastern/inland parts of the area covered by the NWFP, where landscapes have developed with less rain/snow and higher summer temperatures than those closer to the coast. These landscapes, in consequence, also tend to have a different ecological relationship with fire (i.e., exist in a different fire regime) than do the coastal forests.

In the BioA, the ‘frequent-fire dependent forests’ are identified as having a fire regime dominated by fires with ‘historical’ fire-return intervals (see Section II) less than 50 years, and most inland forests evolved with fire-return intervals much less than 25 years. The overriding ecological consequence of more-frequent fires is forested landscapes that contain less residual biomass, in the form of snags, down logs, and complex vegetation structure, than do the coastal ‘moist forest’ landscapes. Given the significance of vegetation structural complexity for the original focus of the NWFP, managing the ‘dry’ ‘frequent-fire dependent’ inland forests presents a fundamental landscape management challenge under the existing NWFP and forest LRMPs.

The Mendocino NF, the southernmost national forest covered by the Northwest Forest Plan, represents one endpoint in a continuum of fire regimes in the NWFP forests. The MNF is functionally a transitional landscape between the Klamath Mountains ecoregion that dominates higher-elevation northwestern California and southwestern Oregon and the *Central California Coastal and Foothill Mountains* ecoregion to the south. Owing to similar ecological and climatic drivers, in the southern part of the MNF the two ecoregions share many lower-elevation species and biological community types in similar landscape contexts; the same shrub species that dominate mixed chaparral compose the understory in substantial areas of mixed-conifer forest. Higher elevations in the MNF are dominated by the same coniferous (and some deciduous) tree species shared with other high-elevation landscapes in northwestern California and southwestern Oregon. As indicated above, similar gradients in fire regime and dominant species affect the transition zone to ‘moist’ forests on the western side of the ‘dry’ forests.

The BioA (correctly in my judgement) identifies the MNF as virtually all dominated by "dry' 'frequent-fire dependent' forests (Figure 2; see BioA page 56). Other NW California national forests respond to increasing moisture gradients with slightly increased percentages of other forest types (Figure 2). The BioA identifies the overarching dominance of 'frequent-fire dependent' landscapes in much of the region as having significant implications for the NWFP and LRMP updates, and the BioA correctly identifies (in Table 5-1, page 68) 'climate change' and 'disturbance restoration' as high-priority management concerns for the MNF (designations shared with 'dry' forests in the other three NW California forests and the Rogue-Siskiyou NF)[7]. Forest ecologists have generally concluded that climate change will increase the significance of fire in all western forest landscapes during the 21st Century and beyond (e.g., Stephens et al 2020). These landscapes require a management emphasis that restores and recognizes appropriate roles for fire and regular disturbance.

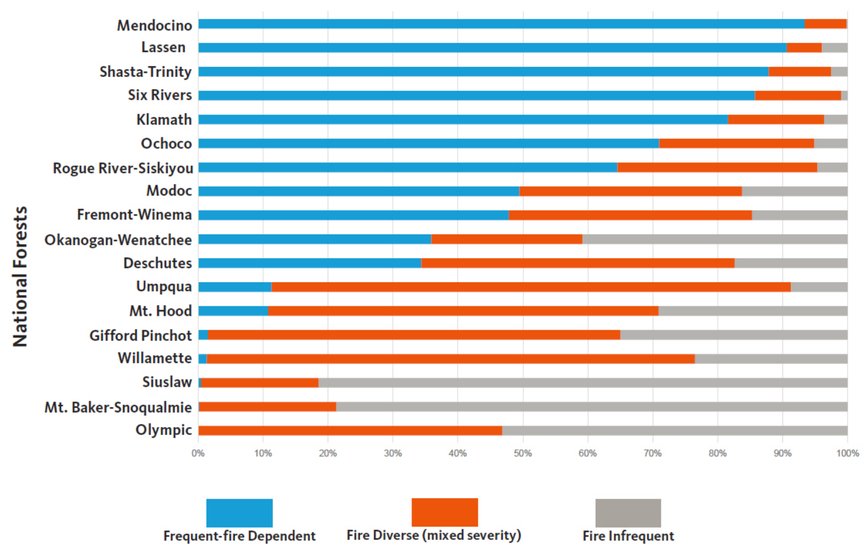

Figure 2. The BioA includes this figure (as Fig 4-4) identifying generalized fire regimes for national forests covered by the NWFP. The northwestern California forests all exhibit at least 80% landscape dominance by 'frequent-fire dependent' forests, which are not currently addressed by the NWFP or the individual forest LRMPs. The NWFP needs to identify the management strategy that the FS will use to address climate change, habitat values, increased fire, and fuels management in these forested landscapes.

II. Fire Regimes Shape Species and Ecological Communities in the Klamath Ecoregion

<u>*Conifer-Dominated Vegetation Types*</u>. Most mid-elevation forested landscapes in the Klamath Mountains and northern California Coast Range are dominated by ecological communities identified in the preceding quarter-century as 'dry forests,' as summarized in the Science Synthesis and the BioA (Spies et al 2018, 2019). Dry mixed-conifer forests in northwestern California are generally understood to have exhibited a *frequent-fire, mixed-severity regime* prior to the 20th Century (Halofsky et al 2011; Perry et al 2011; Hessburg et al 2016; Skinner et al 2018; Stephens et al 2018a, 2018b; Spies et al 2019).[8] A mixed-severity regime is also the dominant natural fire regime for mixed-conifer forests throughout the southern Cascades and the Sierra Nevada (Mallek

[7] BioA Table 5-1 identifies 'large, high-severity fire impacts' as high-priority concerns for the Six Rivers and Rogue-Siskiyou national forests, but as low-priority concerns for the Mendocino, Klamath, and Shasta-Trinity NFs. Based on recent fire occurrences (including the 2018 Ranch Fire, the 2020 August Complex and Red Salmon Complex, and other recent fires) and the projections of future fire resulting from climate change, large, high-severity fire impacts should also be identified as a major concern for all national forests in northwestern California.

[8] The heat energy released in a fire is identified by fire scientists as its *intensity*, which is generally related to the availability of fuels, but may also reflect factors such as ambient weather and even slope. The biological effect of a fire (usually in terms of the percentage of mortality, the degree of biomass loss, or similar indicators) is identified as its *severity*.

et al 2013; Safford and Stevens 2017); there are, however, ecological differences among the mixed-conifer forests in NW California, the inland Cascades, and the Sierra Nevada that must be considered when applying insights from one region to other regions.

For example, within the coniferous forests in the Klamath ecoregion in NW California, Douglas-fir exhibits a larger ecological amplitude than in the Sierra Nevada and southern Cascades, or in other regions of North America (Sawyer & Thornburgh 1977; Sawyer et al 1977; Uchytil 1991; Taylor & Skinner 1998, 2003; Tepley et al 2017; Skinner et al 2018).[9] Douglas-fir in mid-elevation forests in northwestern California has been shown to be adapted to frequent fires, an adaptation pattern that includes germinating under established shrub or hardwood canopies and tolerating competition until trees can grow through and overtop the shrub or hardwood canopy (Sawyer et al 1977; Hunter & Barbour 2001; Taylor & Skinner 2003; Shatford et al 2007; Tepley et al 2017; Skinner et al 2018; Stephens et al 2018b). Douglas-fir regeneration success is greatest in the years immediately following a fire and declines through time; in addition, regeneration declines with distance from a living-tree seed source and with increasing climate water deficit (Tepley et al 2017; Meyer et al 2021)

Mixed-conifer forests in the eastern Klamath ecoregion, including all four NW California national forests, evolved with a *fire return interval* typically less than 25 years (often significantly less, particularly in areas influenced for millennia by California Indian management); this has been characterized as a *very-frequent fire, low-severity regime* (Halofsky et al 2011; Spies et al 2018, 2019). The frequent fires tended to maintain low levels of accumulated fuel in these forested landscapes by removing shrubs and smaller trees, while the dominant tree species (particularly large ponderosa pines and Douglas-firs) were relatively resistant to low-intensity fire. The only conifer taxon in this region known to sprout if top-killed by fire is California-nutmeg (*Torreya californica*), although knobcone pine (*P. attenuata*) and several native cypresses (*Hesperocyparis* species) are serotinous (i.e., with cones that open and shed seeds after a fire). Dominant hardwood species [particularly black oak, madrone, and canyon live oak, but also bigleaf maple (*Acer macrophyllum*)] show adaptations to resist being killed by low-intensity fire (e.g., thick bark in black oak) and abundant sprouting by top-killed trees.

The relative historical lack of accumulated fuels supported low-severity or mixed-severity fires (i.e., fire with few to moderate impacts on the biological structure of the forest) in ‘dry’ mixed-conifer forests, in which most large trees were not killed in most fires, although many (or most) shrubs and small trees in the forest understory were eliminated (Taylor & Skinner 2003; Halofsky et al 2011; Perry et al 2011; Hessburg et al 2016; Spies et al 2018). That is, the recurring fires removed much of the surface-level and ladder fuels that would have increased the heat energy released in canopy (or crown) fires that caused high mortality levels. The ongoing interactions of low- or mixed-severity fire with the composition and structure of the mixed-conifer forests composed the primary dynamic of the ‘mixed-severity fire regimes’ that maintained most of the mid-elevation ‘dry’ mixed-conifer and ponderosa pine forests in California. The identified source of most wildfires during the pre-EuroAmerican history of California and the western US was lightning (Swetnam et al 2016), although studies (e.g., Skinner et al 2009) have indicated that California Indian land management practices were associated with locally increased fire frequencies in some forested areas, such as lower elevations in the Mendocino NF.

[9] Some ecologists working in these Klamath ecoregion forests have concluded that they are unique in the United States, perhaps worldwide. “(I)t is readily apparent that, although the Klamath Mts. maintain many species in common with other western mountain areas, local populations are not ecologically equivalent to those of the Sierra Nevada or the Cascades. Additionally, the roles played by some environmental factors may be unique. For example, the fire ecology of the Klamath region seems to be intermediate between that of the Pacific Northwest and the Sierra Nevada, and therefore distinctive.” (Sawyer & Thornburgh 1977:730).

Management directions for federal forested landscapes in the 20th Century to suppress all fires altered the natural fire occurrence patterns in these forests, particularly in the period after WWII, reducing the role of frequent fires in preventing fuel accumulations that resulted from the increased growth of shrubs and smaller shade-tolerant trees in these landscapes (Restaino & Safford 2018; Stephens et al 2018a; North et al 2019; Richter et al 2019). Forested federal lands in California experienced decades of 'missed' fires, which has been characterized as a 'positive' *fire return interval departure* (FRID), showing significantly less fire than occurred during the pre-suppression era (Safford & Van de Water 2014; Figure 3).

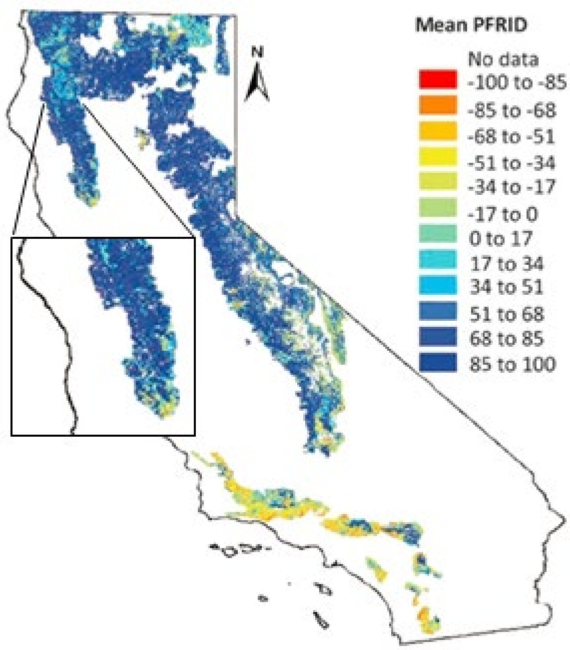

Figure 3. Average Percent Fire Return Interval Departures (PFRID) for National Forests in California. Negative PFRID measures (warm colors) identify places where the current fire return interval (FRI) is shorter than the pre-settlement FRI (fires are more common). Positive PFRID (cool colors) identify places where current FRI is longer than the pre-settlement FRI (less fire or missed fires.) Modified from Safford & Van de Water (2014).

The National Forests in southern California show a strongly negative average Percent Fire Return Interval Departure (PFRID; indicating that fires are much more frequent than historically), a direct consequence of high human activity in and near national forest lands in southern California and the resulting influence of humans on fire ignitions. The southern end of the Mendocino NF also shows a negative PFRID (Figure 3), likely reflecting a high local incidence of fire ignitions resulting from human land uses in the Clear Lake region. The August Complex was not caused directly by human activity, but developed areas near Lake Pillsbury, Ruth Lake, and Highway 36 increased the complexity of fire response in those areas, and the updated NWFP and the individual forest LRMPs should consider the implications of increasing human populations in these areas as a source of potential ignitions.

In recent years the importance of unusual ('extreme') weather conditions or events in creating conditions in which fires escape containment has become clear throughout California (Jin et al 2014; Keeley & Syphard 2019). Late summer and autumn atmospheric circulation patterns the western US typically create conditions with high atmospheric pressure in the interior western US and lower pressure over the eastern Pacific, a context in which strong 'foehn' winds bring dry air from the northeast over much of California, which dry further and warm by 'katabatic' compression (widely identified as 'Santa Ana winds' in Southern California and 'Diablo winds' in the San Francisco Bay region). These winds are essential elements in many of the largest wildfires in recent years. However, data clearly indicate that there are many occurrences of similar wind events each year that are not associated with large wildland fires; the distinction is that significant, damaging wildfires are associated with ignitions, and the ignition sources are nearly always human-caused or human-related (including powerlines; see Keeley & Syphard 2019 for an overview). The degree to which climate change might alter the occurrence of these 'foehn winds' is uncertain, as they're a consequence of atmospheric patterns that may be relatively unaffected by climate change, although the increased fuel dryness that clearly will result from a warmer atmosphere could result in greater fire intensity and/or in a greater dominance of fine fuels in regional landscapes.

Box 2. Designations in Climate Change Projections.

Climate-change assessments both contribute to and are led by scientific research. Scientific climate-change assessments generally incorporate one of the frameworks developed by the International Panel on Climate Change (IPCC). The Third and Fourth IPCC Climate Assessments were based on several emissions pathways originally published by the IPCC in 2000 [the *Special Report on Emissions Scenarios* (SRES)]. For example, SRES A2 was a high-growth scenario that projected high greenhouse gas (GHG) emissions through the 21st Century. The Fifth IPCC Assessment (2014) incorporated a different set of emissions scenarios, the *Representative Concentration Pathways* (RCPs), with emissions-reduction strategies incorporated into the GHG emissions scenarios. RCP 8.5 is a high-emissions scenario that closely resembles SRES A2. Detailed discussion of the IPCC assessment methodology exceeds the scope of this summary.

Describing in detail the effects of altered climate on the distribution and composition of plant 'communities' is beyond the scope of this summary. As noted in Section I, plant species respond to altered environmental conditions individualistically, not as groups of species, although species with similar niche requirements may respond similarly. Climate-change projections for individual plant species and for larger groups of species show that climate change may, for most species, result in shifts toward cooler and/or moister environments (generally expressed as 'poleward and up'), although range shifts may be toward more microclimatically favorable locations, such as toward the coast or even toward favorable moisture conditions at lower elevations (Parmesan & Yohe 2003; Loarie et al 2008; Ackerly et al 2010; Beier 2012; McLaughlin et al 2017). However, individualistic responses by different species indicate that future vegetation alliances should be expected to differ from current species groups to varying but unknown degrees as a consequence of climate change.

<u>*Fuels Management is a Priority Concern in 'Dry' 'Frequent-Fire' Forested Landscapes.*</u> Fire regimes and fuels management are issues of overriding concern for the NWFP update (and forest LRMP updates). The BioA identifies (page 71) fuels management as an issue of great planning concern for the northwestern California national forests, because of its functional relationship with the historically recent under-representation of fire in these landscapes. 'Fuels' in this context is a term that includes all combustible biomass, including live and dead standing trees, down logs and branches, litter and duff, and vegetation from the ground to the canopy that can burn in a fire. The BioA and the Science Synthesis, if anything, understate the importance of fuels management as a planning issue for these dry forests, which evolved with short fire-return intervals.

Current interpretations of dynamic ecological processes in frequent-fire landscapes in California (and in the southwestern US; see Reynolds et al 2013) emphasize that periodic fires in these landscapes in pre-EuroAmerican times removed most accumulated fuels, and most fires shaping the evolution of these landscapes were low- or mixed-severity fires. Under such dynamics, mid-elevation 'dry' forested landscapes characteristically developed a general structure composed of (i) large individual trees, (ii) clumps of trees of various sizes, and (iii) intervening 'open' areas lacking trees [an '*ICO*' structure (Figure 4; see section IV for additional explication); Larson & Churchill 2012; Kane et al 2019]. Stated a different way, most frequent-fire forests in California (including those in the Sierra Nevada and other mountainous areas south as far as northern Baja California) exhibited an ICO structure under natural fire regimes, where periodic low- and mixed-severity fires removed much of the fuels that accumulated between fires, creating stands with a few relatively large trees that would resist being killed by those fires. Over time, periodic fires created landscapes in which the periodic fires maintained the dominant forest structure in those landscapes.

Fuels management is clearly an essential consideration in planning for stands in a climate-altered future, because of expected climate change-driven future increases in fire occurrence (Figure 5).

Figure 4. A mixed-conifer stand in Yosemite National Park in which fires have not been suppressed, exhibiting a stand structure of individual trees, tree clumps, and open areas. This ICO structure is considered by many forest ecologists to be the natural stand structure in most 'frequent-fire' forests in the western US. From Larson & Churchill (2012).

Accumulated surface fuels are concerns when an essential element in successful adaptation to future fire regimes includes an intentional use of prescribed and/or 'managed' wildfire (e.g., the 2019 East Fire in the Yolla Bolly Wilderness) to reduce future fuel loads, because the existing fuel loads must be reduced before prescribed fire can be used (e.g., Mallek et al 2013; Richter et al 2019; White & Long 2019). Accumulated fuels can support high-intensity fires in treated stands, with 100% mortality of above-ground vegetation. If such fires occur before trees in future stands (either conifers or hardwoods) reach reproductive maturity, the effect may result in a conversion of such stands to grasslands and other non-forested ecosystems (Tepley et al 2017). *Climate-adaptation strategies for the August Complex recovery program must address fuels by including actions to reduce current and future fuels loading.* This likely should include removing standing conifer snags resulting from the August Complex whenever doing so is consistent with short-term and long-term management objectives, including maintaining appropriate habitat conditions for desired wildlife. In addition, programs to reduce shrub dominance in future stands will likely be necessary if those stands are to be protected from high-intensity surface fires that would consume regenerating stands before trees in the stand have grown large enough to resist being killed, a substantial concern identified for conifer forests in the Klamath ecoregion (e.g., Tepley et al 2017; Meyer et al 2021).

Accumulated fuels in 'dry' mixed-conifer forest stands may be exemplified by abundant small trees of shade-tolerant conifer species (e.g., white fir), continuous fuels from ground level to the canopies of the larger trees, and/or abundant down material such as fallen dead stems; these conditions have resulted, in many cases, from as much as a century of fire suppression in these landscapes. Accumulated fuels can result from past disturbances such as high-severity wildfires, insect or disease outbreaks, intense droughts, or adverse weather events in which the dead trees subsequently become fuels for future fires (e.g., Metz et al 2011; Stephens et al 2018; Wayman & Safford *in press*).[10] In addition, many forest management activities (including logging, which often results in the accumulation of substantial fuels as slash and cull material) increase potential fire impacts in the residual forests. How accumulated fuels should be managed has become a sometimes-contentious issue, particularly when the accumulated fuels result from prior fires (i.e., 'salvage logging'), but in terms of creating and maintaining future forest resiliency the need to

[10] The 2018 Ranch Fire on the MNF provides a good example of this effect. The 1996 Fork Fire on the Upper Lake Ranger District burned within the footprint of the Ranch Fire. Some of the burned forest stands that were identified as important for habitat purposes following the Fork Fire were left without fuels-reduction treatments, and the accumulated fuels created conditions during the Ranch Fire that incinerated several small ('100-acre') Late Successional Reserves (LSRs), obliterating both the desired habitat conditions and the LSR designations.

reduce fuels loading in order to be able to reintroduce fire to these landscapes is a conservation issue of great concern.

Various 'tools' are available to managers to address fuels in these forests, including multiple kinds of thinning projects, commercial timber sales, salvage logging after disturbances, mastication, and/or selective fuels-reduction projects conducted to create or maintain desired habitat conditions (e.g., oak woodlands). It's clearly necessary to address habitat conditions needed by sensitive wildlife species and to meet other management goals (such as recreation, visual effects, and Native American priorities), and the NWFP and LRMP updates must include appropriate standards and guidelines to protect these resources. However, it's also necessary to maintain the availability of all the 'tools' that can be used for fuels reduction if we expect to be able to prepare those landscapes to address climate change and the future effects of enhanced drought and increased numbers, sizes, and intensities of fires.

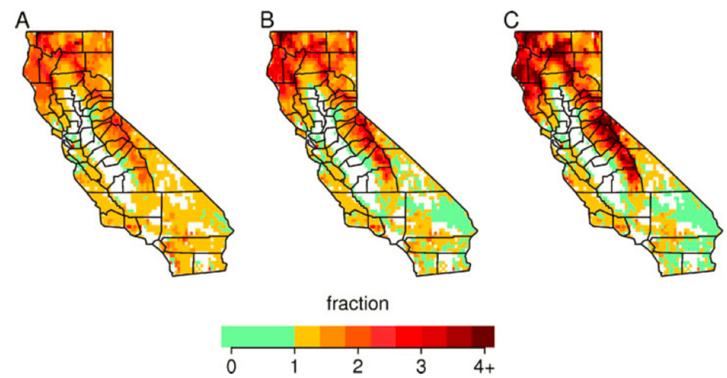

Figure 5. Predicted burned area in the last third of the 21st Century as a multiple of burned area in the last third of the 20th Century. Model results are shown for three Global Climate Models (A to C) under an SRES A2 climate scenario (very similar to the RCP 8.5 scenario in IPCC 2014; see Box 2), with high population growth, high sprawl, and a high threshold housing density. Fire regimes are assumed to be unchanged. A value of '1' indicates that burned area is unchanged, while '4+' indicates that burned area is 400% or more of late 20th Century reference conditions (i.e., a 300+% increase). From Westerling et al (2011).

It should be noted that some conifer species in the Klamath ecoregion may be increased in range covered and in local abundance with increased fires, including knobcone pine and several uncommon cypress species, which are serotinous species that release seeds from their cones following fire. These traits are adaptations for surviving in frequent-fire environments, essentially representing the same kinds of adaptive responses shown by many hardwood and shrub species, and the traits likely would favor an increased prevalence of these species in future landscapes with more fire. This is particularly true for knobcone pine, as the southern Klamath ecoregion is the geographic center of the natural range of knobcone pine (Reilly et al 2019), suggesting that this species is likely to be a co-dominant species in many future plant associations in the southern part of the ecoregion under future fire regimes.

In summary, the BioA and the Science Synthesis summarize a future with fires in western US forested landscapes that are more frequent, larger in area, and more severe. The BioA and the Synthesis consider strategies to increase the ability of forested landscapes to become 'resilient' to those effects by adapting altered stand composition or structure. A science-based strategy to restore resilience involves recreating the 'mixed-severity' fire regimes and natural stand structures (such as the ICO structure) that shaped the evolution of these forests, essentially by reintroducing periodic fire (as managed wildfire or as prescribed fires) (Perry et al 2011; Hessburg et al 2016; North et al 2019). This strategy incorporates results from numerous research studies in 'dry' western forests that concluded that restoring fire to these landscapes is a necessary element for their management, in conjunction with prior reductions in the currently accumulated fuels.

Non-Conifer Vegetation Types. While some studies have addressed potential effects on individual hardwood species (particularly oaks), projections of potential climate-change consequences for hardwood-dominated plant associations in the western US are still uncommon. Some recent studies have identified low-elevation landscapes that are expected to be under severe ‘climate stress’ as the century unwinds, including oak woodlands in the Coast Range and those around the Central Valley (Thorne et al 2016, 2017). Projections of climate-change effects on region-scale vegetation in northwestern California suggest future transformations in which some mixed-conifer forests may become conifer-hardwood community types or hardwood-dominated communities, a climate-change-induced transformation (Lenihan et al 2008; McIntyre et al 2015; Shafer et al 2015); such projections have also been made for increased hardwood dominance in current mixed-conifer stands in the Sierra Nevada (e.g., Liang et al 2017). However, most of these projections have not incorporated significant changes in fire regimes, which could further alter ecosystem processes toward shrub- or grass-dominated ecosystem types.

Specific projections of range shifts by dominant oak species [blue oak (*Quercus douglasii*) and valley oak (*Q. lobata*) at low elevations and black oak and Oregon white oak in mid-elevation landscapes] suggest significant alterations in the future ranges of these species, potentially including a complete loss of blue oak woodlands from much of the Central Valley and surrounding regions (Shafer et al 2001; Kueppers et al 2005; Hannah et al 2012; Barbour & Kueppers 2012; Figure 6). A recent study of blue oak mortality in Sequoia National Park resulting from the 2012-2016 drought (Das et al 2019, red star in Figure 6) indicated mortality in blue oaks (all ages combined) > 25%, consistent with projected effects of climate-change on California’s vegetation (e.g., Thorne et al 2016, 2017).

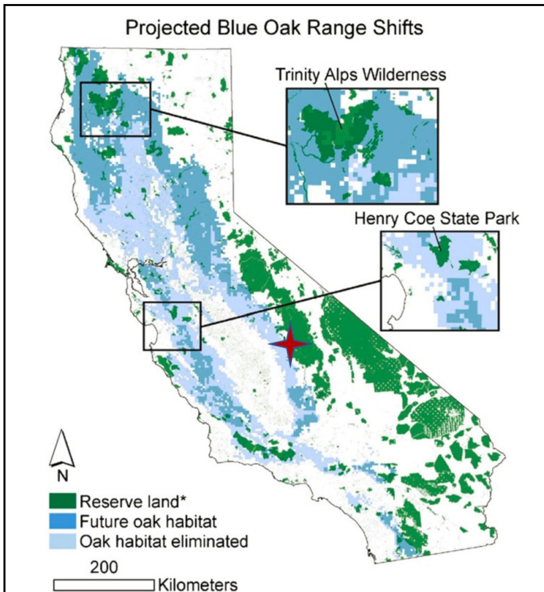

Figure 6. Projected/modeled range shift for blue oak, based on an SRES A1B emissions scenario (see Box 2) and blue oak ecological niche parameters. Projected range shift from Barbour & Kueppers (2012), based on Kueppers et al (2005). Red star indicates the location of blue oak woodlands in Sequoia National Park studied by Das et al (2019).

Some oak species dominant in low-elevation woodlands and savannas (e.g., blue oak and valley oak) have relatively thick, fire-resistant bark and are resistant to being killed by low-intensity surface fires (Plumb 1980; Horney et al 2002; Fry 2008). Black oak, whether part of mixed-conifer forests or in woodlands and savannas, exhibits a similar adaptation pattern and responds vigorously to available light and moisture following fire (Cocking et al 2012; Nemens et al 2018; Skinner et al 2018). Other oak species, particularly thin-barked live oaks, are readily top-killed by surface fires of even moderate intensity. However, most oak species, and many other hardwoods, readily sprout if top-killed, and species that resist top-kill may regenerate leaves soon after a fire. Numerous reports suggest that most hardwoods found in the Klamath ecoregion exhibit adaptations to frequent-fire regimes, in which fire return intervals are sufficiently long to allow individuals to reach reproductive age between subsequent events.

Studies have indicated that typical historical fire return intervals in shrublands near mixed-conifer forests in the southern Cascades and northern Sierra Nevada were longer than those in adjacent conifer forests (e.g., Nagel & Taylor 2005; Airey-Lauvaux et al 2016); a similar evolutionary pattern likely exists in northwestern California. In southwestern Oregon (in the Klamath ecoregion, dominated by the many of the same species as in ‘mixed chaparral’ in NW California), shrublands can be a self-replacing ecosystem that may not experience fire for a century or more (Duren & Muir 2010; Airey-Lauvaux et al 2016). Scientists who study shrubland ecosystems (e.g., Keeley 2002; Halsey and Keeley 2016) have cautioned that shrublands in northern California may exhibit dynamic relationships that are different from the better-studied chaparral dynamics in southern California. Studies carried out in forested landscapes in northwestern California and southwestern Oregon (e.g., Odion et al 2010; Tepley et al 2017) have shown that recurring fire may have an effect of creating 'alternative stable states,' with both conifer-dominated and hardwood- and shrub-dominated communities that may not change for long periods.

Dominant plant species in shrublands (including various associations often identified as 'chaparral') typically exhibit traits (e.g., sprouting from burls, or germinating from long-lived seeds in soil seedbanks) that are adaptations for recovering from fire (Keeley & Zedler 1978); many species also show traits that indicate adaptations to burn very hot when a fire occurs, indicating that recurring fire has been an evolutionarily significant element in the fire regimes sustaining these shrublands. However, a fire return interval shorter than the period required to allow the dominant shrub species to reach reproductive age often leads to a type conversion to grass-dominated communities, which subsequently tend to be maintained by frequently recurring fires. Studies have shown that fires (or fuel-reduction treatments in lieu of fires) in shrublands may lead to colonization (and to dominance) by exotic plant species that may predispose the communities to future fire (Potts & Stephens 2009; Halsey & Keeley 2016).

As a general summary, species in the hardwood tree- and shrub-dominated vegetation types in the Klamath Mountains ecoregion clearly demonstrate adaptations for surviving and reproducing in habitats that are regularly burned, although perhaps at a lower frequency than in nearby conifer-dominated forests. The prevalence of shrubs in the understories of many mid-elevation conifer stands represents a 'pre-colonization' of these stands by shrubs, and indicates a high potential for stand conversions from forest to shrubland if fire-return intervals in conifer stands are reduced by climate change, representing a potential 'tipping point' into regional shrubland and hardwood dominance driven by increased aridity and fire (Tepley et al 2017). However, fires that recur at intervals shorter than the generation time of the dominant hardwoods and shrubs are likely to be associated with conversions of these vegetation types, such as from hardwood woodlands to shrublands and shrublands to grasslands. In addition, increased fire frequency may be associated with increased colonization of these vegetation types by exotic plant species.

III. Some Climate Science Concepts for Planners

Science Principles Relating to Climate Adaptation. Maintaining ecosystem functions and services from national forest lands requires identifying and implementing measures to adapt to climate-related changes in these landscapes. Climate is a primary factor in the evolution of plant and animal species; every native (and most naturalized) species in the Klamath ecoregion has experienced numerous changes in ambient climate during its evolutionary history, and this exposure shaped the species' tolerance of (or requirements for) the ecological conditions in which it occurs today. Climate itself has been variable, on multiple scales, during the periods in which California plant species evolved (Box 3). As current climate conditions are altered, each species will adapt its occurrence pattern to the new ambient conditions in order to experience, to the degree possible, conditions like those in its evolutionary past. Most often this will involve some geographic range shifts, although most species retain enough genetic flexibility to accommodate altered climatic conditions to some degree, and some may respond to changing environments by evolving new genetic variations better adapted to the new ecological conditions. Ecological and evolutionary responses to changing environments are the subjects of thousands of scientific studies; summarizing this work is beyond the scope of this synthesis.

Box 3. Climate Facts

From an evolutionary perspective, climate is a primary driver of change in plant and animal species. The following climate conditions and processes have affected ecosystems in California landscapes today (all statements in italics are quoted from Millar 2014). See text and Figure 7 for additional information.

"*Climates have been changing constantly through the history of life on Earth; this includes dramatic changes throughout the periods of evolutionary history of species we manage today*.

"Climates are expressed at hierarchic levels, with interannual regimes nested in decadal modes, nested within multicentury modes, and these are nested within even longer-term multimillennial cycles.

"*Different physical mechanisms drive modes at the different scales. While these are quasi-independent, drivers interact*. *Climate at any one moment in history is expressed as the cumulative effect of all modes acting together. Ecosystems respond at all scales of climate variability and change*."

Most plant and animal species in California today evolved within the past few million years, although ancestral lineages for most California plant species originated in North America before the early Miocene Period (i.e., by 25 million years ago). During the evolutionary history of California lineages (or 'clades'), global temperatures and precipitation patterns fluctuated significantly, exposing California lineages to a vast range of local climate conditions (Figure 7). Many California plant lineages were shaped to a significant degree by the development of seasonal climates, which are considered to have resulted from changes in Pacific Ocean circulation patterns and ocean-atmosphere coupling primarily within the last 15 million years, and particularly from the development of summer-dry Mediterranean-type climate in California within the last 5 million years (Ackerly 2004; Rundel et al 2016, 2018).

The climate variations summarized in Figure 7 were expressed as long-term cyclic changes that resulted from the interactions of primary physical factors (e.g., orbital variations and the inclination of the Earth's axis) with shorter-term variability resulting from changes in the sun's internal thermonuclear dynamics, and from changes in physical responses in the Earth's energy-transport systems. The short-term cycles in Earth's processes (periodicity of decades to centuries) are nested with cycles that operate over periods of thousands of years, which are in turn nested within orbitally driven cycles of multiple tens of thousands of years. Dynamics occurring at all these scales affected the evolution of species in California today, because adaptations developed in response to one periodicity are carried over into processes of adapting to other periodicities, both longer and shorter. Unless adaptive traits are actively counterselected by subsequent environmental conditions, some genetic ability to respond to these ranges of conditions often remains within

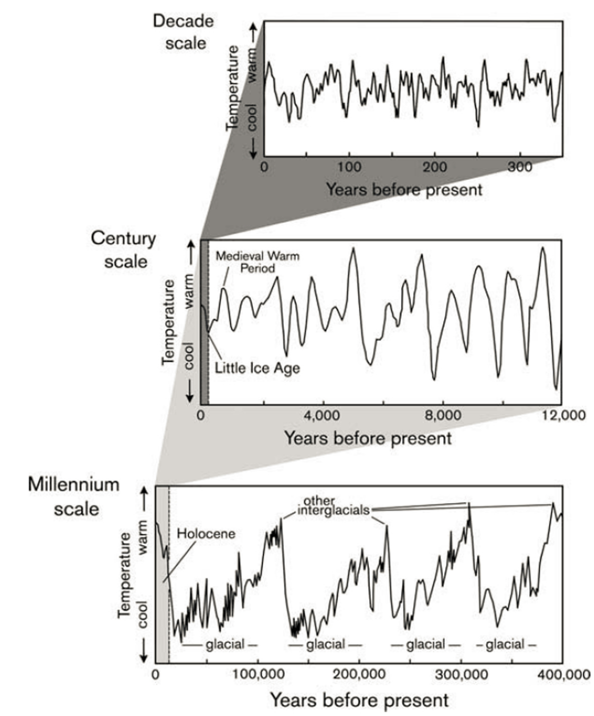

Figure 7. Representations of global temperature cycles showing the nested nature of climate modes at different temporal scales. Top: Multidecadal cycles are related to ocean circulation and sea temperatures. Middle: Century cycles result from variability in solar activity. Bottom: Millennial cycles result from variations in several aspects of Earth's orbit relative to the sun. These and other cycles interact continually and, in combination, result in ongoing changes in earth's natural climate system. (Source: Millar 2014)

each species' genome rather than being lost, which may affect the species' subsequent responses to varying climate.

A dominant effect of changing climate is an unavoidable change (or more correctly, an avalanche of unavoidable changes) in the ecological communities in each landscape. Prior climate-driven ecological changes are well documented in North America's geological record (Figure 8).

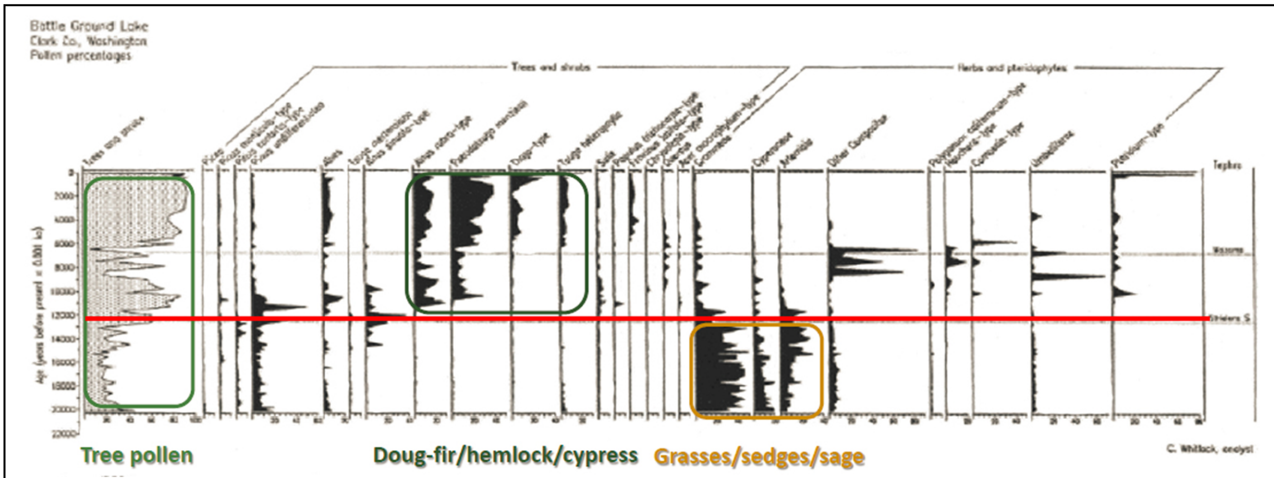

Figure 8. Pollen profiles from sediments in Battle Ground Lake (SW Washington state) from the last glacial maximum to the present illustrate periods of vegetation stability and periods of rapid vegetation change. Between approximately 17,000 and 12,000 years before the present, global temperatures increased approximately 8ºC, the transition from the end-Pleistocene climate to conditions more typical of today's climate in the region (red line at 12,000 years indicates the onset of the 'Holocene'). During this interval ecosystems in the lake basin underwent a significant transition from shrub-steppe vegetation (grasses, sedges, and sagebrush) to conifer-dominated forests (Douglas-fir, western redcedar, western hemlock, and red alder). Adapted from Whitlock (1992).

Paleoecological assessments of vegetation and wildlife patterns from the late Pleistocene to the present (e.g., Overpeck et al 1992; Whitlock 1992; Graham et al 1996; Davis & Shaw 2001; Briles et al 2008; Millar 2014) documented vast ecological transformations in ecological communities in western North America as a consequence of climate warming with an extent similar to what's projected for the late 21st Century with RCP8.5 (IPCC 2014).[11] The short-term internal ecosystem dynamics that led to these transformations can never be known with certainty, but there's no reason to expect that they differed substantially from the ecological processes observed in today's landscapes, particularly those related to altered moisture regimes and altered fire regimes.

Increased ambient air temperature results in the atmosphere's increased ability to hold more water vapor (an increased atmospheric 'vapor pressure deficit'), which the atmosphere gets by increasing the evaporation rate from soil and through increased vegetation evapotranspiration. This effect is generally identified as *'Climate Water Deficit'* (CWD), which reflects an atmospheric water demand that exceeds readily available moisture. Defined empirically when actual evapotranspiration exceeds potential evapotranspiration (PET<AET), such conditions typically exist in California wildlands in summer and early fall (see Stephenson 1998 for a full explication of the dynamic process and its effect on dominant vegetation types). Computing CWD is complicated, but measures of CWD are now readily available from several climate data

[11] The RCP8.5 projection included a likely increase in global mean temperature by 2100 of about 3°C (5°F), although the increase varies geographically, being greater at higher latitudes. Current sampling indicates, however, that the actual progressions of GHG emissions and global mean temperature are increasing faster than the RCP8.5 scenario projection. The IPCC will produce a new global climate-change assessment in the next year or two, and the upper range of projected temperatures is likely to be higher for most of the planet.

repositories for most locations in the western US. In essence, warmer air is 'a bigger sponge,' pulling more moisture out of the substrate and the vegetation. Increased CWD results in accelerated fuel drying and increased ignition probability from natural sources (i.e., lightning), and has been identified as a primary contributing factor in the altered fire regimes and increased wildfire occurrences in national forest landscapes during the 21st Century, when compared to those of the late 20th Century (Bachelet et al 2007; Westerling & Bryant 2008; Allen et al 2010, 2015; Westerling et al 2011; Liang et al 2017; Restaino & Safford 2018; Westerling 2018; Keyser & Westerling 2019; Martinuzzi et al 2019; Wahl et al 2019).

The contribution of CWD to climate-change stress for western US forests in the 21st Century has also been widely identified by forest ecologists (McKenzie et al 2004; van Mantgem et al 2009; Allen et al 2010, 2015; Abatzoglou & Williams 2016; Tepley et al 2017; Restaino & Safford 2018; Hessburg et al 2019; Wahl et al 2019). Increased CWD is an unavoidable consequence of climate change, which depends solely on physical processes, and the primary driver of those processes is increased air temperature, a consequence of climate change that is irrefutably established (Figure 9). Recent climate-change assessments for California, based on widely used global climate models, improved hydrological assessment methodology, and now-standardized methods for computing CWD, demonstrate an uneven increase in CWD, with lower elevations throughout California experiencing greater atmospheric drying (Thorne et al 2015, 2016), although localized conditions (e.g., increasing CWD with upper slope positions and western and/or southern aspect) affect CWD on a landscape scale in northern California forestlands (JH Thorne, *in seminar* 2021).

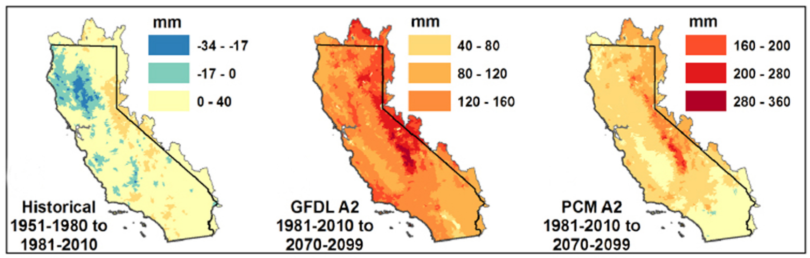

Figure 9. Projected increases in Climate Water Deficit in California during the 21st Century, calculated from SRES A2 scenarios projected by two global climate models (see Box 2). The GFDL model projects a hotter and dryer future than does the PCM model, resulting in a greater CWD in California wildlands. It's instructive to compare these results with the projected increases in future fires shown in Figure 5. (Excerpted from Figure 2 in Thorne et al 2015.)

Increased CWD results in increased competition among trees in a stand for water and nutrients, reduced tree growth and increased competitive mortality, reduced resistance to and increased mortality from insects and diseases, and similar effects (Abatzoglou & Williams 2016; Schoennagel et al 2017; Crockett & Westerling 2018; Restaino & Safford 2018; Vose et al 2018; Fettig et al 2019). The combination of altered fire regimes (particularly the positive FRID indicating 'missed fires' in mixed-conifer forests) and altered climate (increased temperatures, intensified CWD, and altered precipitation patterns) increases the likelihood of altered ecological communities and landscape patterns for California wildlands. For example, increased CWD was identified as a fundamental cause of excessive tree mortality in the Sierra Nevada during the 2014-2017 drought, both directly and as a major factor underlying deaths of weakened trees because of bark beetle attacks (Young et al 2017; Fettig et al 2019). Region-wide studies (e.g., van Mantgem et al 2013) have indicated that increased climatic stress results in increased tree mortality across the gradient of wildfire energy release because of stress effects on tree physiology. In the Klamath ecoregion increased CWD has been identified as a potential cause of large-scale conversions of mixed-conifer forest to hardwood- and shrub-dominated landscapes (Tepley et al 2017). *The update processes for the NWFP and the forest LRMPs in NW California must incorporate measures to accommodate the effects of increased CWD, which are not presently addressed by* *either the NWFP or the individual LRMPs. Planning for major programs (such as the August Complex recovery) must also incorporate the effects of CWD, anticipating the incorporation of this primary management concern in the LRMP*s.

Development of Ecologically Novel Communities. Changing climate does not affect every plant or wildlife species in any community in the same way or to the same degree. Based on both observed changes in historical communities and expectations from ecological science, the effect of climate change on local plant and wildlife communities may include both a shift in the places where communities are found within landscapes and a dissociation of existing communities, with the formation of 'novel' or 'no-analog' communities of plants and animals (Whitlock 1992; Jackson & Overpeck 2000; Skinner 2007; Williams & Jackson 2007; Millar 2014). Simulations of future landscape patterns in the inner northern Coast Range and Sierra Nevada, based on climate change, fire regime change, or both, have projected decreased conifer-dominated forest area in both regions and increased 'mixed woodlands' dominated by one or more oak species and other hardwoods (Lenihan et al 2008; McIntyre et al 2015; Shafer et al 2015; Liang et al 2017).

Historically, the post-fire recovery of forested landscapes has been focused on 'restoring' the same or closely similar ecological communities that were present prior to the fire (e.g., Beschta et al 2004). However, the likely emergence of 'no-analog' communities under future climates raises substantive scientific concerns for focusing landscape recovery on re-establishing predisturbance conditions following fire and other major disturbances, particularly with respect to the continued provision of ecological services (Dawson et al 2011; Hurteau et al 2014). Given current scientific understanding, successful ecological restoration following disturbance can no longer be presumed to be (as was the case for most of the last quarter of the 20th Century) a process intended simply to return parts of a landscape to some prior condition. Ecosystem recovery under climate change requires anticipating the future and incorporating elements that address the dynamic environmental changes that are likely to occur (Joyce et al 2008; Hobbs et al 2009; Jackson & Hobbs 2009).

In response to these changed perceptions, a synthesis perspective has emerged: *ecological recovery incorporating traditional restoration as a primary focus is only appropriate if ecosystem dynamics can be managed within the range of historical variation*; when it's clear that some ecosystem processes are no longer within their historical ranges (i.e., when 'new' ecological conditions occur, or are anticipated), then recovery projects must focus on establishing 'hybrid' or 'novel' ecosystems adapted to the altered conditions (Hobbs et al 2014; Millar & Stephenson 2015).

'Novel' (or 'no-analog') ecological communities reflect changes in the composition, structure, and/or functioning of 'old' communities, and may be primarily altered mixes of 'old' species from different communities. However, a widely expected effect of climate change is a shift toward communities composed of some 'old' species and some 'new' species, sometimes termed 'hybrid' communities. Some 'new' species favored by climate change may be 'invasive' species that can alter ecosystem properties or functions, a scientific topic already the subject of a vast literature, a review of which exceeds the scope of this summary [but see Poland et al (2021) for a recent treatment]. It seems clear that climate-change adaptation in national forest landscapes in NW California should include attention to the potential effects of invasive species. What isn't clear, however, is what criteria should be established to identify 'invasiveness,' given that species assemblages that provide desired future ecological services may depend on the characteristics of some of the 'new' species. It's clearly not appropriate to identify a species as 'invasive' simply because it's 'new' to a future community, since future communities may include many 'new' species; a test of species' impacts on ecological functions would appear to be necessary.

Functionally, future ecosystems should be established and maintained to provide the ecological services (and the ecological functions that produce those services) that managers and/or the public desire from them (expressed in the conceptual framework established in the 2005 Millennium Ecosystem Assessment; see Box 1). Moreover, the currently adopted FS planning regulations (the 2012 Planning Rule) specifically identify the delivery of desired ecosystem services as a preferred outcome of forest LRMPs. The question of what future ecosystem compositions will be needed the Klamath ecoregion to maintain desired ecosystem functions does not have a simple answer, and in fact does not have just one answer; numerous alternative communities might be 'assembled,' but no simple guidebook exists to describe how best to identify the 'best' composition or structure of future communities. Such outcomes may not be available by attempting to 'restore' the same ecological communities to the project area landscape that were present before the August Complex. The recovery program could benefit from having a degree of flexibility to implement varied 'adaptive management' approaches in the burned landscape based on site-specific considerations about what's likely to happen in different locations. Developing detailed prescriptions for every site in the August Complex footprint at the inception of the recovery process seems inherently unrealistic.

IV. Climate-Change Adaptation at the Stand Level in Forested Systems

Strategies to Incorporate Climate Change into Forest Management. Forest ecologists working in various regions in the United States have identified ecological characteristics and processes that can be incorporated into the recovery program for the August Complex to guide site-specific prescriptions that address climate-change effects and help guide a transition to forests of the future (Millar et al 2007; Stephens et al 2010; Dawson et al 2011; Peterson et al 2011; Millar & Stephenson 2015; Swanston et al 2016; Restaino & Safford 2018; Hessburg et al 2019; Richter et al 2019; White & Long 2019). The expected effects of altered climate on forested landscapes result from the same physical and biological processes that shaped current forests, but which are expected to exceed the range of historical conditions (Millar 2014). Forested ecosystems will undergo adaptive transitions to accommodate future conditions, even without management intervention, but more desirable future outcomes could be obtained through appropriate management.

Millar et al (2007, likely the most widely cited climate-adaptation reference in forest ecology) lay out a three-part strategy for responding to climate-change effects: (*i*) '*resistance*,' forestalling impacts and protecting highly valued resources; (*ii*) '*resilience*,' improving the capacity of ecosystems to return to desired conditions after disturbance; and (*iii*) '*response,*' facilitating a transition of ecosystems from current to new conditions (identified by some authors as '*realignment'* or as '*transition'*). Occasionally one or more additional steps are included, but the general sequence (identified in some recent USFS publications under the inclusive term '*climate-change resilience*') fundamentally includes the following three elements:

- Stabilize existing stands through management practices that reduce the effects of shorter-term climate changes. Examples may include increasing the level of fuels management to reduce potential future fire severity, or reducing stand density to allow existing vegetation to resist the effects of increased vapor pressure deficits/CWD.
- Incorporate management practices to prepare forest stands to respond adaptively to climate changes that can be anticipated in a longer-term future. Examples may include reducing stand density from current high stocking levels to a lower level that's expected to be compatible with future projected future CWD, or altering stand composition to favor existing species (such as hardwoods in the Klamath ecoregion) better adapted to expected future conditions.
- Plan for and implement management actions that address future conditions that may be outside the range of those in existing forests. Examples may include planting new species that don't occur in the region now, planting existing species in more favorable locations (e.g., uphill or on north-aspect slopes), introducing genetic variation to existing species from other

populations better adapted to a warmer and dryer future climate, or intentionally changing stand structure to protect desired ecological locations and functions (e.g., creating denser riparian stands in cooler, moister valley locations to increase stream shading and protect water quality and instream habitat conditions).

Clearly this strategy (and other similar strategies) represents a gradient in responding to changes that occur over time, and responses from each phase will overlap with those for the next. The key elements are identifying probable future conditions, then incorporating management elements that address how those conditions are likely to affect desired ecological functions in future stands and the ecological services that those functions will support. Uncertainty is embedded throughout this planning process, but FS managers already plan for uncertain future conditions; the difference is that climate change is certain to introduce conditions outside the range currently addressed by most current management plans. Recent FS technical publications (e.g., Peterson et al 2011; Swanston et al 2016) recommend processes that are adapted from current FS operations, and the Swanston et al (2016) report[12] is supported by an active FS research team that can assist local FS staff in local applications. *Addressing the effects of climate change on national forest landscapes in northwestern California is an essential part of the update processes for the Northwest Forest Plan and the LRMPs for the individual forests, and it will clearly be counterproductive not to incorporate climate-adaptation into the planning process for the August Complex recovery program and its derivative projects.* It's not the purpose of this synthesis to identify a specific climate-adaptation approach for northwestern California national forests, but this is a task that the Forest Service (as a whole and by individual forests) is required to do.

Planning and implementing plans and programs (such as the August Complex recovery program) for FS lands require assessment with respect to the requirements in an adopted forest LRMP and (in northwestern California) to the requirements of the NWFP. The NWFP currently identifies management targets for *composition*, *structure*, and *function* as elements in implementing the NWFP conservation strategy.[13] The 2012 Planning Rule emphasizes a requirement that plans address the connections among forest composition, structure, and ecological processes and the ecological services provided by national forest landscapes; up to the present time, however, the FS has provided only limited guidance to FS managers about how to address ecological services in FS programs (e.g., Deal et al 2017).[14] The 2012 Planning Rule also mandates that FS planning efforts (for programs as well as forest plans) address the effects of climate change on national forest landscapes. In effect, these requirements place FS managers in northwestern California in the difficult position of having to develop responses based on plan policies that are already known to be out of step with current science and which are therefore being revised, while the updated planning documents that will be based on the current science are still in development. A prudent strategy in such conditions is to base proposed project actions on the updated science and the pending altered planning framework instead of on currently adopted plans.

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[12] See URL: https://www.nrs.fs.fed.us/pubs/52760.

[13] These terms refer to ecological community traits related to the identities and relative abundances of (primarily plant) species (the *composition*), the ways the species are arrayed in physical space (the *structure*), and the ecological dynamics or *processes* (the *functions*) of forest stands. The original term '*function'* was intended in the NWFP to address ecological processes occurring in forested landscapes, in conjunction with focuses on community composition and structure. Since the publication of the Millennium Assessment (2005), however, the term 'function' has largely been superseded in forest planning discussions by 'ecological *process*,' as the focus on ecological functions has been captured by the broader meaning as the processes that support and deliver ecosystem services.

[14] See URL https://www.fs.fed.us/ecosystemservices/ for the current USDA Forest Service 'Ecosystem Services' website. Additional information is available at URL: https://www.fs.usda.gov/ccrc/topics/ecosystem-services.

Box 4. Ecosystems: Complex, Adaptive, Self-Organizing Systems

The term 'ecosystem,' a concept referring to the union of biotic and physiochemical elements in a given location, was introduced to science in the 1930s. The concept grew throughout the rest of the 20th Century, with trophic dynamics, population growth and regulation, nutrient cycling, and other subfields being combined within an ever-enlarging framework. By the early 1970s the concept had incorporated elements of the post-WWII cybernetic revolution, and the concept of an ecological 'system' was born, in which information within the system influenced the state of the system and its behavior. An influential paper (Odum 1969) popularly fused ecological dynamics with ideas about system 'succession' and the internalization of control. A less widely-read but (eventually) more influential paper (Holling 1973) parsed questions of ecosystem behavior in terms relevant in the 21st Century, including 'resistance' to change, 'resilience' following disturbance, and the meaning of ecosystem 'stability.'

An outgrowth of the critical assessment of 'system' concepts was the development of 'hierarchy theory,' which identified 'nestedness' within biological systems. A highly influential monograph (O'Neill et al 1986) established the concept of differing response rates for different levels of organization, including ecosystems. For example, physiological reactions occur in seconds to hours, annual plants live and die in months, population demographics for larger plants and many animals are years to decades, and 'succession' is a landscape-level process that occurs on the scale of decades to centuries. This structured concept enabled ecologists to focus critically on the processes that affected ecological systems, realizing that levels of biological organization too distant from the ecosystem level of organization were not affecting the system's dynamics.

In the 1980s and 1990s, ecologists (e.g., Pickett & Cadenasso 1995; Forman 1995; many others) expanded the compass of the ecosystem concept, identifying landscapes as a distinct level of organization that included multiple ecosystems. By the early 2000s conceptual papers (e.g., Levin 2005) solidified an understanding (motivated in part by the 'Gaia Hypothesis' of James Lovelock and other 'deep ecologists' and in part by mathematical modelers who had tried to identify criteria for 'domains of stability' in ecological systems) that ecosystems were 'self-organizing' systems. Ecosystems were 'adaptive,' and not 'determinative;' they became complex only if the dynamic interactions of their component populations were interactively stable and if the environment itself were stable enough to allow the system's component populations and the environment to stabilize. Significant, uncontrolled population fluctuations or significant environmental disturbances could prevent development of complex ecosystems. The systems were 'adaptive' in the sense that component species could evolve traits less disruptive, or well-adapted new species could colonize, leading to greater ecosystem 'stability'.

These concepts of ecosystems as complex, adaptive, and self-organizing 'systems' were also applied to forests (e.g., Drever et al 2006), in the sense of asking whether viewing a forest in system terms provided insights into the dynamics of real forested landscapes. As the awareness of the effects of climate change (and other human-driven disturbances) has become central in resource management, forest ecologists have adopted the conceptualization of forest ecosystems as complex, adaptive systems to help adapt our management of forested landscapes to these changes (e.g., Messier et al 2014).

Managing National Forest Landscapes as Self-Organizing Complex Adaptive Systems. Both the NWFP and the 2012 Planning Rule address national forest landscapes from a perspective enriched in ecosystem science (the landscape focus in the 2012 Planning Rule essentially *requires* a focus on ecosystem processes; see the following section). Ecosystems are classically defined as a collection of interacting biotic organisms and the physicochemical environment in which they occur, although current conceptions of ecosystems are much more detailed and nuanced (Box 4). 'Ecosystem-based management' (or simply 'ecosystem management')[15] incorporates many disciplinary subject areas and procedures, but its fundamental principle is that *multiple processes are involved in the managed landscapes and ecosystem-based management must attend to multiple objectives and interactions*, rather than focusing on managing for single species or for narrow quantitative outputs (such as board feet of logs). The intent of the 2012 Planning Rule in adopting an ecosystem-based focus is emphasized clearly in the definitions in 36 CFR § 219.19.

While this synthesis can't be a treatise on principles of ecosystem-based management, the following example helps to illustrate how interpreting landscapes in ecosystem terms can help managers incorporate climate-change and ecosystem-services considerations into managing FS landscapes in northwestern California. As a general property of ecosystems, the level of 'services' provided is a function of the complexity of an ecosystem (there are exceptions!), and more-complex ecosystems generally provide more services, or a higher quality of services, than less-complex ecosystems. That is, ecosystem complexity (assessed by monitoring through time, such characteristics as tree species composition and structural layering in designated stands or the ratio of exotic to native species in a meadow) can be a proxy for ecosystem services such as wildlife habitat, carbon sequestration, erosion protection, and recreation/aesthetic value. The trends in such monitoring data are indicators of ecosystem functions that are altered by climate change, providing managers with evidence that adaptive actions may be necessary (as well as their success).

Consider the example circumstances portrayed in Figure 10. In the trajectory in the upper panel, managers do not respond to increasing tree mortality (determined to be related to long-term CWD, beetle attack, and root disease, say). The reduced stand conditions indicate decreased ecosystem complexity, which in turn is a valid indicator of decreased ecosystem functions and the related ecosystem services (which are the indicators on which the 2012 Planning Rule directs that managers focus). In the trajectory in the upper panel, a new (and different) ecosystem will be gradually assembled from natural colonization or by intentional species introductions, and the provision of ecological services will recover, although possibly to a reduced degree.

The contrasting strategy in the lower panel in Figure 10 includes responding to the initiation of increased mortality (interpreted to be an indication of climate-related ecosystem stress) at an earlier stage, before the ecosystem is altered to the degree in the upper panel. In this example the response could include the intentional introduction over time of one or more species better adapted to anticipated future climate conditions (an example of the 'transition' phase of the adaptation sequence described previously). As changing climate removed less-adapted species from the original ecosystem, the introduced better-adapted species would maintain some of the ecosystem complexity present in the original stands, and these ecosystems would continue to provide desired ecological functions and services. Although the degree of services provided could be less than from the original stands, the decline would be less than in the example in the upper panel (although the ecosystem complexity could actually be enhanced by the transition, and the output of services could increase as well).

The contrast between the panels in Figure 10 illustrates that climate-change adaptation need not require significant technical expertise not normally available to FS managers, but it does require a mind-set attuned to what monitoring data mean. In the Figure 10 example, the management response to the change in complexity needs to begin by the second step in the sequence, when actions to increase the 'resistance' of the existing stands could help, or potentially when

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[15] See URL: https://www.fs.usda.gov/about-agency/emc for the USDA Forest Service website for Ecosystem Management Coordination.

management approaches such as stand density reduction could increase the 'resilience' of the ecosystem to further complexity loss. In the Figure 10 lower panel, managers opted to implement a 'transition' to a 'new' ecosystem better adapted to altered conditions, a response that would clearly require an expectation about what those forests can (or must) be like in the future to deliver the ecological functions that result in the desired services. Such ecosystems may be different from what they were like in the past or even what they're like now. This is, however, the real key to climate-change adaptation. What will future forests need to be like to provide ecosystem services like clean water or habitat for birds, given that the future may not sustain the same plant species in the same places, and certainly not in the same mixtures, that we see on our landscapes now?

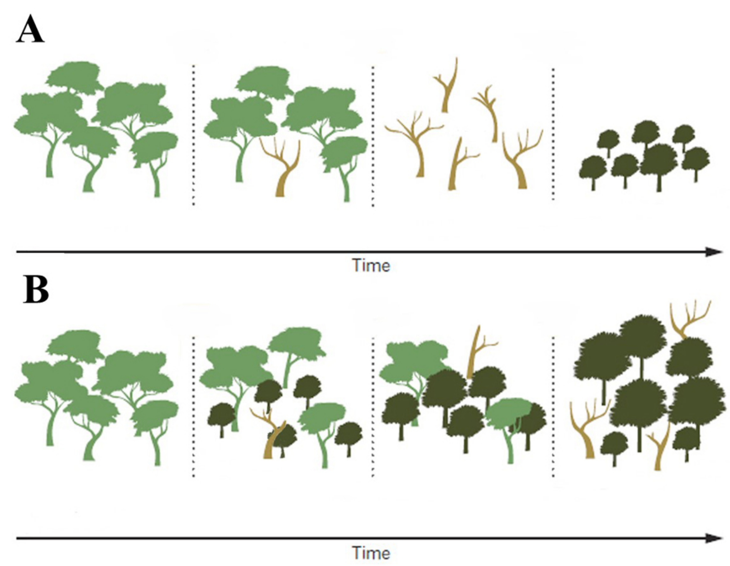

Figure 10. Diagram illustrating how management decisions can improve climate-change adaptation. In sequence A, a response to climate-change effects is not implemented until major changes (e.g., high levels of tree mortality) have occurred. In Sequence B, managers initiate adaptation by introducing climate-adapted species in anticipation of climate-change effects on existing stands and the ecological functions they provide. See text for additional discussion. (Modified from Millar & Stephenson 2015).

A recovery dynamic like that presented in the lower panel in Figure 10 may well be needed for many of the forest areas affected by the August Complex, in which oaks and other hardwood species (e.g., madrone) that are well-adapted to increased moisture stress and fire already occur in the Klamath ecoregion, although not as commonly as in 'moist' conifer forests or in adjoining ecoregions. A potential adaptation strategy for responding to changing climate could emphasize recovery with fire-adapted hardwoods like black oak, canyon live oak, and madrone, species that are already important members in mixed-conifer forests, where high-severity fire patches may functionally restore the former presence of these important landscape elements (White & Long 2019). This strategy could also include introductions into planted forests of oak species currently more common at lower elevations (such as blue oak and valley oak). Appropriate stand-level recovery-project decisions likely would need to incorporate factors like aspect, soil characteristics, and site-specific moisture conditions.

If the updated NWFP continues to focus on composition, structure, and processes in our public landscapes, the effects of climate change on forest ecosystems must be a major scientific focus for the update. Maintaining the *structure* of forest stands may remain a viable planning focus, and selecting species for stand enhancement that maintain stand structure, when possible, would be preferable to selecting replacements that result in significantly altered structure. However, maintaining the current *composition* of forest stands in response to changing climate will undoubtedly prove to be difficult, and potentially counterproductive, as there are substantive reasons to conclude that the species composing future stands may not be the same as those in current stands; a primary adaptive strategy would be to alter the composition strategically to address future (rather than previous) ecological conditions affecting the stands (see discussion below regarding the 'Natural Range of Variability'). Given altered stand composition, the greatest effect of altered climate may be in elevating the importance of maintaining desired ecological *processes*, and a management focus on maintaining ecosystem processes may well be the overriding goal.

Climate-change adaptation will require some level of commitment to a practice generally known as 'adaptive management,' a process in which managers conduct monitoring to identify conditions and trends in the landscapes they manage, based on expected relationships between monitoring results and desired conditions, and then modify management practices when monitoring indicates that it's needed. Adaptive management has been part of the NWFP since its inception; while the 'hypothesis testing' focus in the NWFP was never developed as initially intended, using monitoring results to modify management actions should remain an element in the NWFP, and should be incorporated into the LRMP updates and the August Complex revovery program.

<u>*An Evolutionarily Stable Stand Structure for 'Dry' 'Frequent-Fire' Forests.*</u> Current ecological interpretations of evolutionary dynamics in frequent-fire landscapes (perhaps particularly in California) emphasize that periodic fires in these landscapes in pre-EuroAmerican times removed most accumulated fuels, and an absence of abundant fuels meant that most fires shaping the evolution of those landscapes were low- or mixed-severity fires. Middle-elevation 'dry' forests in these landscapes developed a general structure in which stands developed large individual trees, clumps of trees of various sizes, and intervening 'open' areas lacking trees [the 'ICO' structure described in Section II (Figure 11; Box 5); Larson & Churchill 2012; Kane et al 2019]. Stated a different way, most frequent-fire forests in California (including those in the Sierra Nevada and other mountainous areas south as far as northern Baja California) most likely exhibited a widespread ICO structure under natural fire regimes, where periodic low- and mixed-severity fires removed much of the fuels that accumulated between fires, creating stands with a few relatively large trees that would resist being killed by those fires. That is, periodic fires created landscapes in which periodic fires maintained the dominant forest structure.

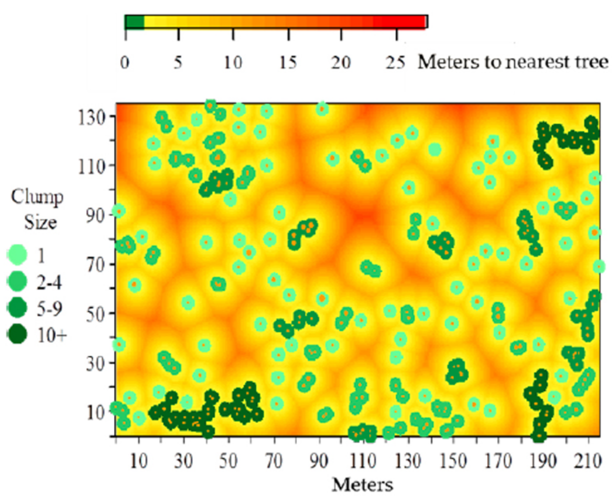

Figure 11. A 'stem map' of a reconstructed forest stand circa 1900 in the Fremont-Winema NF that displays a spatial pattern of individual trees, clumps, and openings (the natural ICO stand structure). Orange dots are tree boles scaled to dbh. All trees are ponderosa pine. Green circles are a fixed 3m (10') crown radius around each tree, showing interlocking crowns and clump formation. Clump size is the number of trees in the clump; larger clumps are shown in darker green. Color ramp and background coloration in the plot indicate distances to nearest tree or gap edge. From Franklin et al (2013).

The BioA and the NWFP Science Synthesis summarize existing climate science as indicating a future with fires in western US forested landscapes that are more frequent, larger in area, and more severe. The BioA and the Synthesis also consider strategies to increase the ability of the forested landscapes to 'resist' the effects of climate change, or to become 'resilient' to those effects, by adapting to altered stand composition or structure. Strategies to restore resilience to 'dry' forests involve recreating the 'mixed-severity' fire regimes and natural stand structures (primarily variations of the ICO structure) that shaped the evolution of these forests, by reintroducing periodic fire (as managed wildfire or as prescribed fires) (Perry et al 2011; Hessburg et al 2016, 2019; North et al 2019).

Box 5. Steps in an ICO Stand Design

The following description of an ICO design process for 'dry' forests in eastern Oregon is excerpted from Part IV of Franklin et al (2013). A similar process is applicable for 'dry' forests in northwestern California. See Franklin et al (2013) for substantial additional information.

"The ICO approach provides quantitative targets for spatial pattern based on historical or contemporary reference sites. Pattern is expressed in terms of the number of individual trees, and small, medium, and large tree clumps to leave in a stand. Instead of marking for a specific range of basal areas, marking crews identify and track the number of clumps they retain while incorporating other leave tree criteria.

"The ICO approach is implemented as follows:

"1. **Identify and mark out skips and large openings**. By focusing on marking clumps, small to medium sized openings (<0.2 acre) generally result automatically. Larger openings often are not created, so prescriptive creation of larger openings is typically necessary if large openings are a treatment objective.

"2. **Determine the appropriate inter-tree distance to define clumps**. The definition of a clump is based on the average distance at which mature/old trees of the dominant leave tree species have clearly interlocking crowns and form contiguous patches of canopy. This distance can vary from 15 to 20', depending on site productivity of the stand. Trees are members of the same clump if they are within this distance of at least one other tree in the clump. Individual trees are those with no neighbors within the distance.

"3. **Obtain reference clump targets**. Reference stands can be reconstructions of historical conditions or contemporary stands with active frequent-fire regimes. Professional judgment can also be used to set and adjust targets for forest types where historical information is difficult to obtain.

"4. **Derive clump percentage targets for specific stand**. Consider the following when setting and adjusting clump targets:

a. Assess the number and clumping levels of live old trees in your stand. The clump percentage targets should accommodate retaining existing old trees. If a high proportion of old trees are in large clumps, choose a higher clumping level.

b. In stands with few old trees, assess any evidence of historical tree patterns (live old trees, old stumps, old snags & downed logs) to determine what the largest clump size was and the approximate percentage of trees in large clumps. These historical conditions can inform what that site supported.

c. Assess the extent to which healthy, young trees of the desired species are clumped. While some inferior trees should be left to make up larger clumps, higher clumping levels may not be possible in some stands.

d. Assess whether the pattern in surrounding stands has been simplified by past thinning. If so, consider a higher clumping level.

"5. **Calculate the stand average TPA target**. The BA or SDI target for the stand, including old trees, should be used and converted to TPA.

"6. **Generate clump targets for the whole unit**.

a. Multiply the target percentages for each clump size by the leave tree TPA target to get the target number of trees per acre for each clump size.

b. Divide each total by the average number of trees for that clump size to derive the target number of clumps per acre.

c. Multiply the clump per acre targets by the total stand acreage to get clump targets for the whole stand. For stands over 20 acres, break up the stand into 10–30 acre sub-units for marking so that marking crews can track clump totals within a reasonable area. Use a road, stream, or other barrier to divide stands up.

"7. **Add leave tree criteria**.

Box 5. Steps in an ICO Stand Design (Continued)

"8. **Mark the stand**. When marking, decide what to do at each tree group or small area (<1/10th acre). Leave or cut tree marking can be used for this method.
   a. Leave all old trees. Where high numbers of old trees exist, most of the clumping targets will be met with the old trees.
   b. For young trees, assess what the tree group naturally looks like and has the potential to become. For example, many trees already appear to be clustered in a clump of a certain size. Widely spaced trees with large crowns often already appear to be individual trees.
   c. Look at what is already marked and check progress towards clump targets.
   d. Look ahead to see what opportunities for clumps of different sizes exist.
   e. Always balance leave-tree criteria with clumping targets. For example, don't try to force clumps by leaving excessive numbers of marginal trees (e.g., > 20% of leave trees with crown ratios below 35%).

"9. **Track during marking**. One person on the crew should track clumps that are marked and periodically report to the crew what clump sizes are needed (e.g., individual trees, small clumps, moderate clumps, large clumps).

"10. **Work with the Stand**. The purpose of this method is not to engineer the target pattern on every acre but to promote a mosaic pattern of individual trees, clumps, and openings within the envelope of historical conditions. The clump targets should not be used as rigid targets but instead as approximate averages to be obtained over the entire unit."

Stand-level Considerations for Climate Change and Fire Adaptation. Stand conditions in forested landscapes that help to provide resiliency to stressors like fire and climate change vary across those landscapes. The variability is related to variations in temperature, soil depth and nutrient content, annual precipitation amount and timing, and other physical and biological parameters. The same factors will affect future forests, although they're likely to be altered, potentially substantially, from the ranges of conditions under which existing stands developed (Millar 2014). Past management policies, particularly fuels management and treatment methodology and the amount and type of biological legacy retention across stand development sequences, will also affect the future resiliency of these stands.

A well-known strategy for managing mixed-conifer forests in the Sierra Nevada is the 'GTR-220' strategy (North et al 2009), in which conditions known to affect plant densities are incorporated into management approaches. Attributes like land slope (steepness), aspect (e.g., facing north), and slope position (e.g., convex upper slope vs. concave lower slope) influence factors like species and tree densities that are incorporated into restoration plans (i.e., ponderosa pine at lower densities for stressed locations like convex upper south-aspect slopes, vs. Douglas-fir at higher densities for concave east-aspect lower slopes with greater soil depth and greater soil moisture). This strategy, though formulated with respect to forests in the Sierra Nevada, also addresses observed effects of prior mixed-severity fires in the Klamath Mountains, where upper slopes, particularly those with southern or western aspects, have historically experienced higher fire severities than did lower slopes and those with northern or eastern aspects (Taylor & Skinner 1998). Approaches to forest planning like the 'GTR-220' strategy harness natural ecosystem processes for management purposes, an approach likely to enhance ecosystem resilience under increased stress from changing climate (West et al 2009; North et al 2019; Figure 12).

Strategies like that shown in Figure 12 are focused on coniferous forests, although the principles apply equally to mixed conifer-hardwood forests and broadleaved woodlands like those in the August Complex region. Reforestation can be demonstrated as successfully with hardwoods as with conifers (White & Long 2019). Climate change will likely drive forest ecosystems in this region toward uncertain future compositions, although many models (e.g., Lenihan et al 2008) suggest that hardwood-dominated forests will be prominent in future landscapes. 'Standard' reforestation practices for conifer forests on National Forests in the region in recent decades have involved planting conifers at closely spaced intervals across varying landscapes, typically at densities significantly higher than are expected to be sustainable through the stand-development and self-thinning processes (often referred to as 'pines in lines,' although the seedlings are not always pines). Planting strategies for the Klamath ecoregion might be better-adapted to future conditions by incorporating other approaches. *Variable-density planting*, for example, incorporates an understanding of ecosystem dynamics such as those recommended by forest scientists in the past decade (Figure 12; see Stephens et al 2010; North et al 2019). It should be noted that variable-density planting and similar approaches are based on incorporating the same ecosystem processes that lead to the characteristics identified in research underlying the ICO strategy.

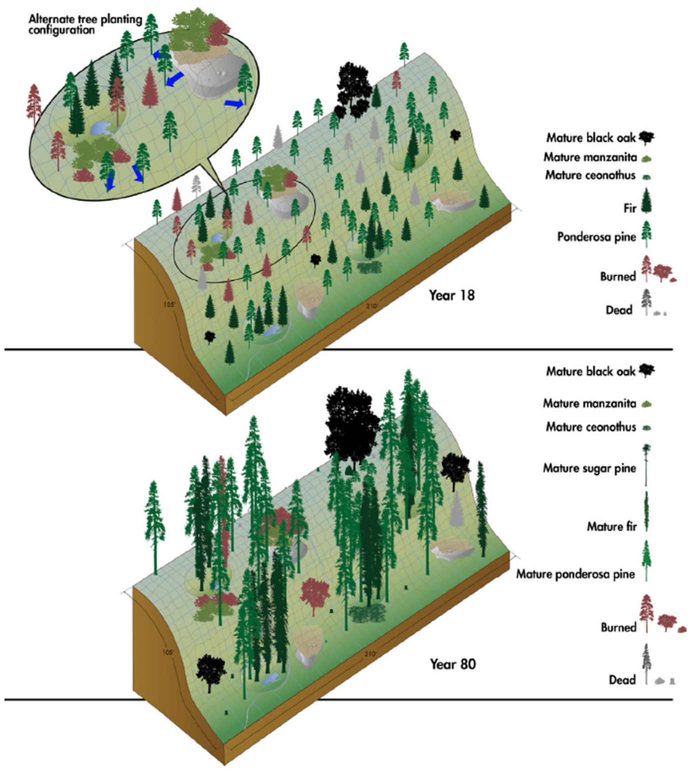

Figure 12. Example reforestation approach combining a regular planting array with variable-density planting configurations adjusted to local conditions. In combination with variable-density thinning and other management approaches, the resulting configuration at 80 years is an ICO-compliant stand. Modified from North et al (2019).

Variable-density strategies adapted to climate change likely should start with understanding the varying ecosystems affected by the August Complex, where planting could incorporate both conifer and the hardwood species that occur in the intermixed vegetation types that dominate northwestern California. Rather than adopting a 'standard' reforestation program for the entire region, the recovery program likely should include sufficient flexibility to enable forest managers to develop reforestation strategies tailored to specific locations, crafted with the understanding that the future will likely be as different from the present as from the more distant past. Diversity in stand conditions is likely to be a desirable hedge against the unknown stressors that will emerge as climate change unwinds.

Variability in stand structure can also be introduced by thinning treatments in stands that survived the August Complex, where thinning is intended to reduce the volume of biomass (the basal area) and/or the number of stems (the density) in a stand to provide a hedge against increased temperature, CWD, and the resulting stand-level stressors. Different thinning approaches may focus on removing small trees, large trees, or a combination of trees of different diameters. Thinning can and probably should occur in combination with prescribed fire. However, prescribed fire without prior thinning may be used to remove smaller stems as a form of density reduction.

Thinning treatments counter the increased moisture deficit resulting from CWD, reducing mortality from competition among the trees in the stand and augmenting the likelihood of survival and increasing the growth rates of the remaining trees. By reducing fuel loading, thinning can substantially reduce the mortality of trees from subsequent fire, and in consequence thinning is widely recommended as a science-supported approach to increase stand resilience to the effects of climate change and wildfire.

Potential benefits from thinning approaches were explored in research in mixed-conifer forests in the Sierra Nevada (e.g., Knapp et al 2013, 2017; other reports not cited here), where *variable-density thinning* and prescribed fire achieved a stand structure that resembled an untreated 'old-growth' control stand nearby. Prescribed fire was judged to be a necessary treatment component in this research, to address the increased coverage of shrubs that were favored by the canopy opening resulting from the thinning. The effect of opening canopies in conifer stands that results in increased shrub growth is a concern described in numerous studies (e.g., McGinnis et al 2010; Collins & Roller 2013; Mallek et al 2013; Coppoletta et al 2016; Stephens et al 2018; Richter et al 2019; many others). Increased shrub growth typically accompanies (and competes with) growth of planted trees and/or natural regeneration following logging, fire, or high mortality because of insects or forest diseases. All these factors can result in a major increase in surface-level fuels, which may be accompanied by an accumulation of fallen dead stems a decade or more following the death of the trees because of fire, insect attack, or disease, a combination that leads to an increased potential for high-severity follow-on fires (e.g., Thompson et al 2007; Hicke et al 2012; Stephens et al 2018).

An important element in forest management prescriptions for 'dry' forests is *legacy retention*, focused primarily on retaining large and/or old trees (Franklin & Johnson 2012; Franklin et al 2013). Forest management that focuses on keeping large trees as legacy elements has an essential effect of adding 'old forest' structure to these landscapes, as was intended in the NWFP. Legacy retention is a significant management element in adapting larger forested landscape regions to climate-change effects (see the following subsection) by maintaining 'old forest' elements across patchy ecosystems. Removing most of the larger and/or older trees is clearly not consistent with restoring 'old forest' structure to 'dry' 'frequent-fire dependent' forests.[16] Legacy retention concepts can be modified for 'dry' forests (e.g., Franklin et al 2013), where creating an ICO structure and retaining large and old trees become primary objectives.

An element identified repeatedly in the BioA with respect to stand-scale restoration should, however, be considered as clearly inapplicable for northwestern forests in the 21st Century. The BioA identifies reestablishing conditions within the 'natural range of variability' (sometimes known as the 'Historical Range of Variation' or HRV) as the principal guidance for future landscape composition, structure, and processes (e.g., Beschta et al 2004). However, as an adaptive focus for forests responding to climate conditions likely to occur outside known historical ranges, historical conditions are not an adaptive scenario that will assure stand composition, structure, and processes that can address an altered future. Because it does not include the potential for establishing communities outside the historical range, returning to the 'natural range of variability' has been rejected by many forest scientists as being an unsuitable response for climate adaptation (e.g., Millar et al 2007; West et al 2009; Stephens et al 2010; Millar 2014; Millar & Stephenson

[16] Research in the 'dry' forests east of the Cascades in Oregon and Washington, which are not within the range of the Northern Spotted Owl and are not covered by the NWFP, has indicated that many of the larger trees in these forests are not necessarily old, and older trees are not necessarily large (Franklin et al 2013; Hessburg et al 2020). Modifications to the 'Eastside Screens' in these forests (Hessburg et al 2020) have emphasized the retention of older trees regardless of their size, and it's likely that similar reasoning should apply for 'dry' 'frequent-fire' forests in the Klamath ecoregion.

2015). Maintaining or returning to the 'natural range of variability' in northwestern California forests is simply not a credible planning objective for climate change adaptation in the NWFP update, or for any of the LRMP updates.

'Old' Has Different Meanings, and Different Structures, in Different Forests. The context in which the NWFP was developed was a reaction to what was at the time widely recognized as a program to convert 'old' forests to younger, faster-growing plantations. A major outcome of the NWFP development was the general adoption of a 'new' concept, an 'old-growth forest,' something of intrinsic biological value and a desired part of public landscapes. Old-growth forests were to be recognized by having a combination of old and/or large trees, the presence of other legacy features like down logs and snags, and structural characteristics relating to canopy layering and closure percentages. At the time, the plight of the Northern Spotted Owl came to represent a focus for old-forest activism, one result of which was the identification of 'old-growth' Spotted Owl habitat as a central element in the NWFP.

The Science Synthesis and the BioA recognize that the 'dry' 'frequent-fire dependent' forests in the Klamath ecoregion don't provide many of the 'moist forest' conditions the original NWFP stipulated. It should be noted that this recognition addresses a challenge issued by the US Fish & Wildlife Service (FWS) in the Final Recovery Plan for the Northern Spotted Owl (USFWS 2011), in which the FWS formally recognized the ecological pattern difference presented by the 'dry' forests and directed the Forest Service (and the BLM) to develop a management approach that addresses the sustainability of owl habitat in the 'dry' forests. The discussion in the Synthesis and the BioA suggests that the pending plan updates will provide that approach. It's clear, however, that most 'dry' forests lack the capability to provide habitat that consistently conforms to the 'old-growth' concept as defined in the 1990s NWFP, are even less likely to be able to do so in a climate-altered future, and that an alternative set of stand structural objectives are needed for the NWFP and LRMP updates.

Ecological studies in the Pacific Northwest have documented that a range of 'old' forest types exists, differing in different parts of the region (e.g., Reilly & Spies 2015). 'Old-forest' conditions regularly develop through different successional sequences, involving different plant species associations in different locations, with different substrates and different climatic conditions. Each combination may generate stand conditions providing elements of the habitat conditions for wildlife species that respond to 'old-forest' elements, but different forest stands with large and/or old trees don't necessarily conform to the NWFP 'old-growth' concept, although each such forest type does present 'old-tree' habitat attributes. Among these alternatives are 'dry' conditions in which large, old trees will occur, but they occur in stands that lack the closed canopies, multiple canopy layers, and relictual coarse woody debris levels required to satisfy the definitions in the NWFP.

Based on current ecological interpretations, the 'dry' 'old' forests in the ecoregion, with typical 'frequent-fire' adaptations, likely exhibited ICO structures over large areas, as did most mixed-conifer forests in the Sierra Nevada, the Transverse Range, and mountains in southern California and northern Baja California. Scattered large (and old) trees and groups of trees (likely varying regionally in size, species composition, and age) alternated with intervening areas supporting grasses, shrubs of varying ages, and/or hardwoods (mostly oaks). Extensive ecological research within the Klamath ecoregion during the past quarter-century has documented a regional vegetation dynamic in which non-coniferous vegetation occupies significant parts of the regional landscape, where shrublands and hardwoods occupy as much as or more of the landscape than do conifers (in which Douglas-fir is the dominant conifer species in the Klamath ecoregion) (Sawyer & Thornburgh 1977; Taylor & Skinner 2003; Shatford et al 2007; Skinner et al 2009; Halofsky et al 2011; Tepley et al 2017). *Maintaining the legacy provided by large and/or old trees in 'dry'*

Klamath ecoregion landscapes, especially conifers, may be among the more problematical strategies to be developed in updating these plans, particularly conifer stands conforming to the current NWFP 'old-growth' standards, as it's unclear that such stand conditions are compatible with the consequences of climate change and increased fire.

V. Climate-Change Adaptation at Landscape Scales in Forested Systems

Existing localized stand conditions within the Klamath ecoregion vary along multiple physiochemical gradients, including temperature, moisture, and substrate composition. The occurrences of plant and animal species in the ecoregion also vary along gradients, based on individual species' preferences for combinations of physiochemical and ecological conditions. Because these gradients vary separately, the potential combinations of species in different places within the ecoregion also vary, giving rise to a variety of ecosystems within the ecoregion's landscapes. The 2012 Planning Rule directs that planning for and managing Forest Service lands in the ecoregion be based on landscape-scale interactions, and this focus on landscapes is clearly required to play a central role in updating the NWFP and the forest LRMPs. As stated earlier in this synthesis, incorporating a landscape-scale focus into major programs like the August Complex recovery will assure that projects planned for the program (including the currently proposed Plaskett-Keller Project) remain consistent with the updated NWFP and forest LRMPs, and with the insights provided by ecological science over the past quarter-century.

The ecological insights initially incorporated into the Northwest Forest Plan (NWFP) resulted from recognizing that landscape processes, which intrinsically involve land areas larger than forest stands, have been and continue to be essential in the conservation of many varieties of forested ecosystems (e.g., Pickett & Thompson 1978; Franklin & Forman 1987; Forman 1995; Franklin et al 2002; Franklin & Lindenmayer 2009; Puettmann et al 2009; Franklin & Johnson 2012; Turner & Gardner 2015; Spies et al 2018; Franklin et al 2018). Identifying composition, structure, and ecological processes in forest stands distributed throughout northwestern landscapes was a major focus in the NWFP, because local stand conditions were key considerations in the habitat needs of the Northern Spotted Owl. However, an underlying motivation for the sociocultural dynamic that led to the NWFP was the widely recognized impact FS management was having on 'old-growth' forests in Pacific Northwest, and effects on old forests remain a public concern today.

What defines a 'landscape' is to some extent scale-dependent. A landscape can be defined as *the smallest geographical area within which all the elements of an ecological disturbance regime operate*; that is, a landscape may be thought of as the smallest area within which the landscape itself can provide all the elements needed for an entire disturbance/recovery cycle (Pickett & Thompson 1978; Pickett & Cadenasso 1995; Forman 1995; Franklin & Forman 1997; Drever et al 2006; Turner & Gardner 2015). Disturbance events such as large fires can help to define regions in which the elements necessary for recovery from a disturbance are 'internal' within the landscape. While the range of areas within which planning can address such dynamic recovery processes may span a range from 10,000 acres to 50,000 acres or more, planning for a 1,000,000-acre region (the August Complex) is equivalent to planning for an entire national forest, which contains many landscapes. A planning program to recover from a million-acre fire complex is intrinsically likely to burden FS planning capabilities, which characteristically have focused on stand-level conditions associated with much smaller projects.

Landscapes are the context within which many important ecological (e.g., subpopulation extirpations and recolonizations in metapopulation dynamics) and conservation (e.g., habitat connectedness vs. effects of fragmentation; see the following section) processes occur. Landscapes integrate multiple dynamic processes occurring at local scales, such as stand recovery from fire because of natural seed-fall from adjoining parts of the landscape, recolonization of burned stands by small mammals, and the long-term dynamic habitat shifts provided by dead trees for snag-dependent wildlife. Similar dynamics are relevant for climate-change adaptation; for example, landscape-scale climate-change 'resilience' (ecosystem function recovery following disturbance) clearly depends on the landscape's potential to assemble post-disturbance communities from within the landscape that will sustain the continued delivery of ecological services.

Fundamentally, *managing only at the scale of local stands cannot address landscape-scale processes*. To address and satisfy the requirement in the 2012 Planning Rule, the FS must manage within a landscape-scale framework *in addition to* planning for stand-scale dynamics. Landscape resilience within the August Complex footprint depends on developing and implementing management that links together individual stand-level approaches into landscape-level outcomes.

Climate change has already begun to alter conditions in northwestern California, affecting ecosystem dynamics in the forested landscapes covered by the NWFP. A recent summary of many of the potential effects of climate change in the NWFP area addressed these concerns (Reilly et al 2018). Other elements of the Science Synthesis report (e.g., Spies et al 2018) summarized evolving scientific knowledge about landscapes in the NWFP region, including a summary of successional dynamics and disturbance processes for 'dry' 'frequent-fire' conifer-dominated forests in northwestern California. The BioA further amplified the importance of climate change in updating the planning framework for the region. As summarized in the previous section, planning for the effects of altered climate involves considering the dynamics of entire landscapes as well as the processes taking place at the level of stands in the component ecosystems (Franklin & Forman 1987; Forman 1995; Franklin et al 2002; Franklin & Johnson 2012; Turner & Gardner 2015; Franklin et al 2018; Figure 13; Box 6).

It's not possible to know for certain what future conditions will occur in northwestern forests. A strategic approach in those circumstances is to plan in contingent 'no regret' terms; that is, to identify options that will produce benefits at multiple severities of climate change (Peterson et al 2011; Swanston et al 2016). Achieving this can be a difficult task for planners and decision-makers alike, because doing so requires conceptualizing an unknown future, an outcome that's often limited by expecting future conditions to be the same as existing conditions in the managed landscapes, a viewpoint termed a 'climate stationarity' perspective (Safford et al 2012). Some climate scientists and public resource managers have opined that 'stationarity is dead,' but in fact a 'stationarity' framework remains embedded in most current natural resource management plans, where it's likely to be the primary issue that prevents managers from engaging with real climate-change issues.

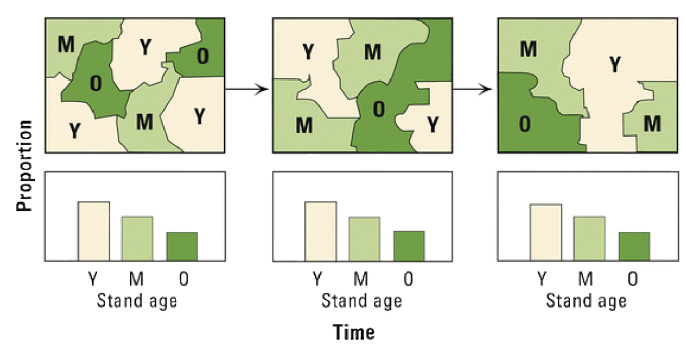

Figure 13. Conceptual dynamic relationships in a 'Shifting-Mosaic Steady State' landscape model. See Box 6 for a description of why the upper panel is widely applicable, while the lower panel has been shown not to apply to most landscapes. Shifting Mosaic: yes; Steady State: not so much. Excerpted from Turner & Gardner (2015).

For example, Hessburg et al (2016:240-241) recommended a 'comprehensive landscape strategy' that clearly assumed a 'static' environment in which the landscape factors that will be important for future climate regimes will be the same factors, in terms of intensities, locations, and rates of change, as those that determined the composition, structure, and processes acting in current landscapes. However, current landscapes developed in climate conditions in the past that may not exist today, and while future landscapes will undoubtedly be affected by the same ecological processes, the details of those processes in the future are unlikely to be the same as those of a century (or even a few decades) ago [as Hessburg et al (2016:235) clearly acknowledged]. In fact, in more recent scientific publications (e.g., Hessburg et al 2019) many of the same authors concluded that the framework for landscape-level planning has changed, and have recognized that ecological conditions in western forested landscapes in the future may not closely resemble those of even the recent past.

Box 6. Perspectives on Landscapes as Dynamic Ecological Systems

The 'subdiscipline' of *landscape ecology* (e.g., Forman 1995) evolved out of discussions in the late 20th Century about the nature and behavior of ecological systems. Many prominent ecologists were engaged over several decades in studying relationships surrounding concepts like 'succession' and 'climax' as they were understood in the context of ecosystem dynamics. Several long-term research projects were established to investigate forested ecosystem dynamics, including the HJ Andrews Experimental Forest within national forest lands in the western Cascades of central Oregon (where Jerry Franklin was a principal investigator for many years), and the Hubbard Brook Ecosystem Study within national forest lands in the White Mountains of New Hampshire.

Many prominent ecologists worked within the Hubbard Brook study; the best known are undoubtedly Herbert Borman and Gene Likens. These authors published a highly influential treatment of forest ecosystem biogeochemistry in the mid-1970s, then followed up with *Pattern and Process in a Forested Ecosystem* at the end of the decade (Borman & Likens 1979). Their research led them to formulate a model of ecosystem dynamics on a landscape scale, known as '*the shifting-mosaic steady state*;' the overarching dynamic in the model is represented in general terms in Figure 13.

In this model, a landscape will include a variety of local ecosystems, which may be thought of as various stages of successional development within the landscape, represented in the figure as 'young,' 'mature,' and 'old.' The shifting-mosaic model posits that the landscape reaches an 'average' or steady-state distribution of stages, but because ecological processes within the landscape (e.g., fire and other disturbances, growth of vegetation according to species traits, and succession from young to old forest) do not stop, the places where each stage occurs shift through time. The result is a landscape in a 'steady-state' condition (as in the lower panel in Figure 13), but with a 'shifting mosaic' of patches/ecosystems of various ages that 'move around the landscape' (the upper panel in Figure 13). In this landscape, disturbances convert 'mature' and 'old' ecosystems back to 'young' ecosystems, which then trend through successional processes back to 'old' ecosystems.

In the decades since *Pattern and Process* was published, it has become clear that landscapes seldom develop a 'steady state' distribution of successional stages. That is, the areas of 'young,' 'mature,' and 'old' stages are not in equilibrium, but occur in a varying combination of areas that add up to the area of the whole landscape. The '*shifting mosaic*' landscape concept is a generally accepted fundamental construct in landscape ecology. Landscapes do exhibit a shifting mosaic of constituent ecosystems through time, in response to internal ecosystem processes like succession and to disturbances like climate change and fire. See Turner and Gardner (2015) for additional explication and Franklin et al (2018) for an application of the construct to practical forest management.

Both climate change and landscape-scale processes are necessary parts of future management in the Klamath ecoregion, although it remains for Forest Service managers and concerned stakeholders to incorporate an appropriate framework into future management plans that achieves that result by, fundamentally, planning at whole-landscape scales. This summary has incorporated some recent guidance from Forest Service research personnel that addresses landscape-based climate-change planning, but it should be clear that much remains to be understood about the required framework. What processes will occur in the ecoregion in 20 years? Will the effects be the same everywhere, or will subregional differences be important? What effects will be important in 80 years? These are not trivial issues, but such questions don't seem to be all that different from long-term forest management considerations that are already part of many silviculture prescriptions. From a practical perspective, such plans also need to incorporate enough implementational flexibility to respond when 'new' findings about climate change and forest ecology emerge from research during the next 20 (80) years.

Some of the evolution of landscape-scale planning for Forest Service lands is well exemplified in recent papers by Paul Hessburg, a landscape ecologist in Region 6, and various colleagues (e.g., Hessburg et al 2015, 2016, 2019, 2020). The following table (Table 1) abstracts and amplifies several guiding principles identified by Hessburg and colleagues for incorporating landscape-scale concerns into Forest Service management programs.

Table 1. Principles for national forest landscape-based planning and management, modified from Hessburg et al (2015) to incorporate general recommendations from Hessburg et al (2019). Developed for ponderosa pine and mixed-conifer landscapes, but useful landscape-scale planning for other forest types.

Principle	Landscape Management Guidance
Regional landscapes function as multi-level, cross-connected, patchwork hierarchies: • Large-scale ecoregional prescriptions are important to reconnecting broad habitat networks and rescaling disturbance processes. • Local landscape prescriptions define objectives for successional patch types, size distributions, and spatial arrangements across the topographic template. • Stand-level prescriptions describe target conditions within successional patches.	Landscape-scale management involves actions at multiple scales, including stand-level prescriptions to develop local patch characteristics, but landscape-scale management involves integrating patterns, processes, and dynamics across ecosystems that include multiple patches and/or stands.
Topography, substrate, moisture regime, and other local conditions provide a natural template for vegetation and disturbance patterns at local stand, successional patch, and tree-neighborhood scales.	Local conditions should guide development of stand characteristics and shape development of local habitat patches, which must be integrated across individual stands into a landscape-scale framework.
Disturbances drive ecosystem change, and changes at the ecosystem scale drive landscape change. Patch size distributions within landscapes emerge from linked interactions among climate, disturbance, topography, and vegetation.	Fire regimes are predominant causes of landscape-scale patterns, and may be altered by climate change. Management practices should anticipate and respond to variations in vegetation patterns that result from changing disturbance regimes, particularly fire. Management must be adapted to accommodate changing climate and disturbance regimes.
Successional patches are 'landscapes within landscapes.' A successional patch may be one or more stands with similar management characteristics.	Stand-level objectives should include tree clump and gap variation based on ecological and habitat requirements and other landscape-scale management objectives.
Widely distributed large, old trees and other legacy elements are critical for maintaining conifer-dominated forested landscapes.	Retaining large and/or old trees, old forest patches, post-disturbance large snags (and down logs in moister forest stands), and other legacy elements of prior forests are essential stand- and landscape-level objectives.
Land allocation, management, and access patterns should be coordinated across boundaries to preserve ecosystem and landscape-scale patterns and processes.	To the extent possible, landscape-scale management should be coordinated across land ownership boundaries, management allocations, and infrastructure (e.g., road networks).

A recent summary paper from the Hessburg laboratory (Hessburg et al 2019) of climate-change effects, wildfires, and forest resiliency across landscapes in the western US included the following:

> "(A) task for current era managers is to *manage for the changes, with uncertainty clearly in mind*. Promoting forest resilience or resistance to wildfires and other disturbances will require planning on an uncertain amount of unbridled and ongoing disturbance. It will necessitate being mindful and inclusive of species-level traits; characteristic patch-level tree clump and gap distributions, tree sizes, densities, and canopy layers; meso-scale seral stage and fuelbed heterogeneity; and broad-scale forest and non-forest patchworks. … This may require preemptively adapting landscapes in areas with anticipated future water deficit, before abrupt changes occur from disturbance- or drought-related mortality events. Examples of preparing landscapes for the coming wildfire and climatic regime changes include reducing forest area, expanding woodland or grassland area, reducing canopy cover and layering, and increasing the areal extent of large trees of fire-tolerant species. In these ways, managers can also better prepare human communities for future uncertainty by reducing the likelihood of abrupt broadscale changes." (emphasis in original)

This conclusion is clearly applicable to forests in the Klamath ecoregion, and is perhaps particularly applicable to the 'dry' 'frequent-fire' forests affected by the August Complex.

VI. Selected Conservation Guidance for Climate Change Adaptation

The existing NWFP and forest LRMPs are based, in part, on conservation priorities previously identified for these landscapes. Future management plans for northwestern California's national forests also should be based, in part, on the current and future conservation values exhibited by these landscapes. The Forest Service is required to address the status of a number of 'sensitive' wildlife and plant species in future planning, a topic specific to those species, not further addressed in this summary. Conservation science still offers substantial guidance for adaptive landscape management that could (and ***should***) be incorporated into future plans.

Studies of climate-change effects on wildlife have shown that local species groups that established in North America during the Pleistocene Epoch fragmented over the following millennia because of habitat changes resulting from warming climate (e.g., Graham 1988; Graham et al 1996). Similar effects may be expected in the future. Recent climate changes have altered wildlife associations in the Sierra Nevada just during the past century (e.g., Moritz et al 2008; Tingley et al 2012). More generally, projections of future ranges of various wildlife species show that existing wildlife 'communities' are likely to fragment, and new associations of species to form, as consequences of habitat alterations and direct changes in the ecological conditions to which wildlife species are adapted (Stralberg et al 2009; Langham et al 2015). Habitat alterations resulting from climate change may, however, have significant implications for management options available for special-status wildlife species in the project area, including the Northern Spotted Owl (see, e.g., Spies et al 2018; Stephens et al 2019), not addressed here.

In general, wildlife species respond (both in terms of preferences for use and in terms of numbers of individuals, reproductive success, so forth) primarily to habitat structure, and the effects on wildlife of fires (or fire suppression and fuels management) and climate change are best understood in terms of alterations in habitat structure. As for plant species, wildlife species respond individualistically to altered environments; altered habitat conditions (including those resulting from wildfire or forest management activities) usually results in altered mixtures of wildlife species (e.g., Thomas et al 1979; Kennedy & Fontaine 2009; Fontaine & Kennedy 2012; Stephens et al 2019). In general, fire-caused habitat alterations increase habitat types preferred by some wildlife species while decreasing the habitats types preferred by other species. Mixed-severity fire regimes, such as those historically typical of mid-elevation mixed-conifer forests in the Klamath ecoregion (see section II), may not affect regional wildlife species richness significantly; larger landscapes typically include most of the different habitat types in the region in a shifting ecosystem mosaic, where each habitat type occurs in different places in the regional mosaic at different times (Pickett & Thompson 1978; Franklin & Lindenmayer 2009; Turner & Gardner 2015; Box 6).

Regional Habitat Types Vary in Biological Richness, Less in Significance. In 2003 the California Department of Fish & Wildlife (CDFW) published an '*Atlas of Biodiversity*' that illuminated landscape biodiversity patterns in California (CDFW 2003), based on data compiled by the Jepson Herbarium, the California Native Plant Society, CDFW's Natural Diversity Data Base, and the Wildlife Habitat Relationships database, regarding geographical patterns of occurrence of plants and wildlife. Information compiled for the southern part of the Klamath ecoregion helps illuminate the essential conservation significance of regional habitat types (Table 2). An existing gradient in species richness/biodiversity roughly matches the habitat complexity gradient, from the highly modified agricultural landscapes of the Central Valley to the landscapes dominated by shrubs and deciduous trees in lower mountain elevations, and further to the landscapes dominated by conifers, hardwoods, and understory shrubs in the higher mountains of the Klamath ecoregion.

Table 2. Biological diversity elements for the Klamath Mountains/High North Coast Range ecoregion compared with the Central Valley ecoregion.

Group	Central Valley Agricultural Areas [A]	Conifer-Hardwood Forests and Shrublands	Higher-Elevation Conifer-Dominated Forests
Native Plant Species	719 - 838	1253 - 1704	1409 - 1704
Vegetation Richness [B]	26-35	36 - 63	45 - 82
Amphibian Species	4 - 6	7 - 10	7 - 17
Reptile Species	6 - 18	12 - 25	19 - 25
Bird Species (Summer)	91 - 108 [C]	91 - 127	109 - 162
Bird Species (Winter)	144 - 187	118 - 143	68 - 117
Mammal Species	22 - 39	40 - 47	48 - 73

Notes

A Presumed to include species of riparian habitats.

B Numbers of "Plant Alliances."

C Most breeding birds in agricultural regions are associated with remnants of natural habitat types, rather than with agricultural areas *per se*.

A biologically relevant factor in the Table 2 pattern is that higher-elevation parts of the region include greater variability in 'land facets' (Brost & Beier 2012) and localized climates, resulting in greater subdivision of plant groups into a variety of habitat elements, including native grasslands, oak woodlands, shrublands, and coniferous forests. While conifers adds habitat elements not otherwise present in the region, the presence of oaks provides specific habitat benefits for many species that exceed the contributions of other elements. Oaks are widely identified among the most important habitat elements for wildlife in California; for example, the California Partners in Flight Oak Woodlands Plan (CalPIF 2002) includes the following summary:

> "Oak woodlands have the richest wildlife species abundance of any habitat in California, with over 330 species of birds, mammals, reptiles, and amphibians depending on them at some stage in their life cycle (*references omitted*). Wilson and others (*reference omitted*) suggest that California oak woodlands rank among the top three habitat types in North America for bird richness. Oak woodlands are able to sustain such abundant wildlife primarily because they produce acorns, a high quality and frequently copious food supply (*references omitted*). Oaks also provide important shelter in the form of cavities for nesting (*references omitted*)."

Oregon white oaks are well documented as significant habitat elements for many wildlife species in the Pacific Northwest (e.g., Gucker 2007), and are widely distributed throughout forested parts of the Klamath ecoregion. The frequent inclusion of black oaks in conifer-dominated habitats increases the well-documented value of these habitats for a variety of wildlife species (e.g., Block et al 1994).

Studies in the Klamath ecoregion (e.g., Fontaine et al 2009, Stephens et al 2015) have concluded that breeding bird communities in shrub-dominated habitats include as many species as breeding bird communities in conifer habitats, including species that are associated primarily with shrubby habitats as well as species that have more general preferences. Habitat preferences in bird species develop through evolutionary time, and the current species preferences clearly result from evolution by many species toward shrub-dominated conditions in this ecoregion. The evolutionary and ecological significance of shrublands is further indicated in many California Floristic Province plant families, including the two dominant genera in California shrublands, *Ceanothus* and *Arctostaphylos*, in which the majority of species are shrubs and occur in shrubland plant associations (Raven & Axelrod 1978; Ackerly 2009). Genetic relatedness among California oak species also indicates the significance of shrubland adaptations; many species that occur as trees also have well-established variants that reproduce as shrubs in shrublands. These patterns suggest that oak clades have often developed evolutionarily with 'tree' and 'shrub' branches.[17] Studies in forested landscapes in northwestern California and southwestern Oregon (e.g., Odion et al 2010; Tepley 2017) have shown that recurring fire has apparently had the evolutionarily effect of creating long-term 'alternative stable states' involving shrublands as the alternative state to forestlands in the Klamath ecoregion. From a conservation perspective, shrublands and hardwood-dominated landscapes in northwestern California are clearly no less significant ecologically than those dominated by conifers.

The effects of natural or managed vegetation changes on wildlife in California hardwood woodlands and shrublands are not well documented; studies indicate that habitat values in treated shrubland areas can recover rapidly, although recovery periods differ and may occur to lesser extent for differing treatments (e.g., Fry 2008; Potts & Stephens 2009; Wilkin et al 2017; Newman et al 2018). Effects of fire on wildlife species in oak woodlands and similar hardwood-dominated communities are expected to be mediated largely by changes in habitat composition and structure (Purcell & Stephens 2005), as with wildlife use in other habitat types. Likely effects of climate change on oak woodland and shrubland wildlife include species reassortments and the development of 'no-analog' wildlife communities (Stralberg et al 2009).

Streams and their riparian areas are intrinsically already the most 'connected' habitat elements in most landscapes (Beier 2012; Fremier et al 2015). From biological and physical/hydrological perspectives, *riparian areas* function both as elements of the aquatic ecosystems with which they are associated and as elements in the terrestrial zones in which the aquatic areas lie (National Research Council 2002; it should be noted that within the NRC conception of 'riparian,' all waterbodies, rather than just streams, have riparian ecotones that include both uplands and aquatic elements). Riparian habitats are generally considered to be among the most important habitats for many wildlife species, including fish and aquatic invertebrates. For example, the following summary is provided in the Riparian Habitat Joint Venture Bird Conservation Plan (RHJV 2004):

> "More than 225 species of birds, mammals, reptiles, and amphibians depend on California's riparian habitats. Riparian ecosystems harbor the most diverse bird communities in the arid and semiarid portions of the western United States (*references omitted*). Riparian vegetation is critical to the quality of in-stream habitat and aids significantly in maintaining aquatic life by providing shade,

[17] Many examples of a close relationship between morphologically and taxonomically distinct 'species' suggest a trend within California's geographical boundaries to local differentiation that likely was driven by past climate and fire regimes. For example, scrub oak (*Q. berberidifolia*), a species of California shrublands and probably the most common oak species in the state, is a sister species to Oregon white oak (*Q. garryana*); large scrub oaks can be mistaken easily for small Garry oaks, and *vice versa*. California oak taxonomy is summarized in Hipp et al (2018).

> food, and nutrients that form the basis of the food chain (*references omitted*). Riparian vegetation also supplies in-stream habitat when downed trees and willow mats scour pools and form logjams important for fish, amphibians, and aquatic insects. The National Research Council (2002) concluded that riparian areas perform a disproportionate number of biological and physical functions on a unit area basis and that the restoration of riparian function along America's waterbodies should be a national goal."

As noted by numerous studies in conifer-dominated landscapes (e.g., North et al 2009; Stephens et al 2018a; North et al 2019), lower slopes near streams are places where higher levels of soil moisture favor plant species associated with moister habitats, and these locations often support larger trees and denser or more complex (e.g., multi-layered) forests. These locations are more likely to develop and maintain 'late successional' habitat conditions in the future more like those in 'moist forests' than in the "dry' forests in most of the Klamath ecoregion. There's a suggestion from recent modeling studies that deep river and stream valleys in the Klamath ecoregion may provide climate 'micro-refugia' as the 21st Century unwinds (Thorne et al 2020; JH Thorne *in seminar* 2021). These areas are intrinsically parts of the riparian zones in regional landscapes. Protecting and improving riparian areas within the ecoregion would enhance the connectivity of both terrestrial and aquatic features, in addition to complying with the Aquatic Conservation Strategy (ACS) of the NWFP (Reeves et al 2018). In addition to benefitting instream resources, a well-developed and managed riparian habitat network would sustain landscape connectivity between lower and higher elevations in the August Complex area, supporting local migrations of mobile species and the potential climate-driven colonization of higher-elevation habitats by slower-migrating plant species.

The State of California has adopted an updated State Wildlife Action Plan (SWAP; California Department of Fish & Wildlife 2015), an identification of habitats needed to protect and sustain 'wildlife species of greatest conservation need' in the state. The 2015 SWAP includes an explicit emphasis on climate change in addressing the needs of California wildlife species. The conservation priorities identified in the SWAP for northwestern California ecoregions emphasize riparian areas and oak-containing forests and woodlands. The CDFW Areas of Conservation Emphasis (ACE) project (discussed further below) also identifies riparian areas and oak-dominated habitats as conservation priorities for these ecoregions. Both programs emphasize climate-change adaptation as a priority criterion for actions that implement state and federal wildlife programs, and both incorporate a focus on enhancing connectivity as a priority objective in those actions.

<u>*Habitat Connectivity is a Fundamental Conservation Element at the Landscape Scale*</u>. A basic principle of conservation science is that conserving wildlife and plant species requires maintaining viable populations of each species, and maintaining viable populations requires sufficient suitable habitat. Virtually from its initial conceptualization, this principle was accompanied by the recognition that even where total habitat area might be sufficient for a population, appropriate habitat could be unavailable to a species because it was blocked by unsuitable conditions; that is, the effective habitat area could be substantially lessened by *habitat fragmentation*, a process through which continuous habitat is sequentially reduced in area and the parts isolated from one another. The significance of fragmentation as an adverse effect soon led to the identification of habitat *connectivity* as a primary element in maintaining population viability. Similarly, a lack of connectivity between places where appropriate habitat currently exists and where it's expected to exist in the future is also a climate-change concern, because *habitat alterations resulting from climate change are also potential fragmenting agents* that need to be addressed in land management plans.

Conservation planning has, since its inception in the 1970s, identified the importance of (preferably large) *reserves* as a central focus in landscape-based conservation planning. The concept of *corridors* or *landscape linkages* that combine individual reserves into a *conservation network* has also been an element in conservation science since the 1970s, and the importance of maintaining connectivity in landscapes undergoing climate stress has become evident. Two alternative perspectives have evolved regarding the relevant focus of conservation corridor development (Crooks & Sanjayan 200x). One perspective (a 'fine-filter' approach) posits that corridors ought to be designed to satisfy the habitat requirements of individual 'focal species,' such as those listed pursuant to federal or state endangered species laws. An alternative perspective (a 'coarse-filter' approach) is that connectivity should be based on a representation of habitat types included in entire landscapes, or on the generalized habitat needs of species that are adversely affected by habitat fragmentation. Some conservation scientists opine that course-filter approaches ought to take specific account of physical elements themselves, such as slope position and aspect [often termed a 'land facets' approach; see Beier (2012) and Brost and Beier (2012), including cited references, for additional information]. These alternative approaches often, but not always, provide similar or convergent results (e.g., Brost and Beier 2012).

An alternative perspective has long existed among conservation scientists regarding the 'best' way to ensure landscape connectivity. The conservation 'network' approaches summarized in the previous paragraph are outgrowths of 'island biogeography' theory, wherein elements not included in the reserves and linkages are functionally the same as ocean waters for terrestrial species (that is, the intervening areas provide no habitat value). An alternative conservation perspective is that most landscapes actually demonstrate varying degrees of habitat value in most parts of the landscape [which is often identified as '*matrix*,' meaning the most common and widespread habitat type in the region, a term borrowed from landscape ecology (Forman 1995)], where qualities or characteristics of the matrix are significant factors in the ability of *landscapes* to sustain viable populations of all species in the landscape, including focal species.

The significance of matrix areas has been widely recognized in conservation planning, including planning for forested landscapes (Noss & Daly 2006; Franklin & Lindenmayer 2009; Kennedy et al 2017). When the matrix itself provides essential habitat components, the entire landscape is more functionally 'connected.' In general, most terrestrial landscapes include matrix habitats that vary in a range of habitat conditions, and some current planning approaches include identifying connectivity considerations that take advantage of habitat values within the matrix; one such approach is the 2012 Planning Rule, which specifies that forest plans (including the NWFP and the forest LRMPs) should direct management on a 'coarse-filter' basis to assure that the plans sustain wildlife and plant populations. The implication is that the Forest Service should manage the composition, structure, and ecological processes in national forest landscapes in ways that maintain the complexity and sustainability of all ecosystem components, but the Planning Rule is rather indefinite about how to do that.

The NWFP science synthesis addresses the conservation status of several 'special status' species and species groups in the NWFP plan area, including potential effects of climate change on them and/or their habitats (reviewing the management of these species exceeds the scope of this summary), but the 2018 science synthesis (like the Planning Rule) is less comprehensive in addressing conservation concerns for all species in northwestern California in a more general sense. Conservation within California is, however, a substantive concern for many members of the public, as well as for state conservation agencies such as the CDFW. As the state agency responsible for conservation planning for wildlife and habitat conditions in one of the five 'global biodiversity hotspots' constituting Mediterranean climate regions, the CDFW has developed an extensive conservation planning framework.

The CDFW commissioned an early study of connectivity for the State of California that also addressed connectivity regionally, including northwestern California: the California Essential Habitat Connectivity (CEHC) study (Spencer et al 2010; Figure 14). The CEHC study incorporated minimum patch size requirements (i.e., for potential '*reserve areas*') that essentially assured that most of the national forest lands in Klamath ecoregion were identified as high-value habitat areas, although the marginal areas of most NF patches were excluded because of the effects of habitat alterations and various land use practices outside the patches (termed '*edge effects*'). Since these large areas of federal lands are intrinsically contiguous with other federal lands, most national forest patches are inherently well-linked to other high-value patches, and the CEHC study identified many NF lands in northwestern California as exhibiting high existing connectivity.

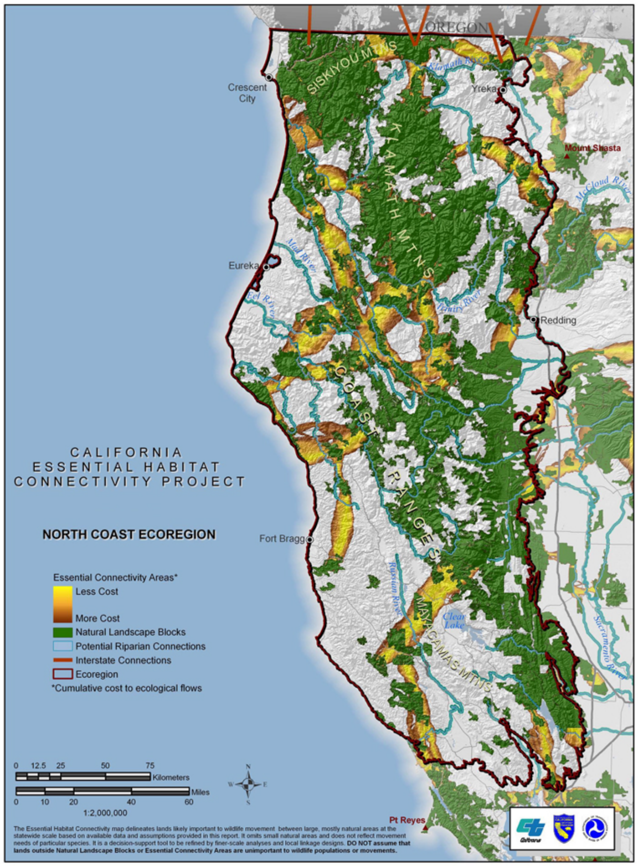

Figure 14. Natural landscape blocks and ecological connectivity areas in North Coast ecoregions, as identified in the CEHC study. Modified from Spencer et al (2010).

Other scientists (e.g., McGuire et al 2016, McRae et al 2016) have conducted assessments in the western US that identify the importance of connectivity for conservation. Assessments for NW California that overlapped with the CEHC study [using different criteria as part of the CDFW's 'Areas of Conservation Emphasis' (ACE) project[18]] also identified intrinsic connectivity in northwestern California as 'high.' Because the ACE project incorporates an explicit focus on climate-change adaptation, it's clear that these identified connectivity ratings reflect CDFW priorities regarding conservation management at the beginning of the 21st Century, with appropriate acquisition, restoration, or enhancement actions within non-federal lands, and providing the State of California's current expectations regarding coordinated management of wildlife habitat for federal lands.

Synthesis: A 'New' Conservation Focus for the Updates of the Northwest Forest Plan and Forest Land and Resource Management Plans, and for August Complex Recovery Projects. The update process for the Northwest Forest Plan builds on additional scientific understanding that has developed since the 1994 NWFP was adopted. It's now clear that much of the forested landscape in the Klamath ecoregion was mischaracterized in the original NWFP, and that a management direction that accommodates increased temperatures, greater aridity and moisture stress, and more fire is required for the next planning cycle. Under current Forest Service planning requirements, future management must incorporate a focus on ecosystems and landscapes, and on how they

[18] See URL: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=170744&inline; 2019 California Terrestrial Habitat Connectivity map. See URL: https://www.wildlife.ca.gov/Data/Analysis/Ace for the ACE3 website. The criteria and methodology used in the connectivity assessments (and other elements in the ACE project) are fully described in documents available on the ACE website.

interact with climate change and fire to produce ecosystem services important for people as well as for the environment itself.

Climate change and its accompanying modifications in ecological processes, particularly fire, are likely to cause (another round of) alterations in landscape compositions in the Klamath ecoregion, as has occurred periodically throughout geological and evolutionary time. While the future is never certain, it's not unreasonable to expect a reduction in the dominance of conifers in many mid-elevation landscapes, with increased importance of hardwood tree species and more (potentially much more) coverage by shrublands. Current understanding of ecological landscape processes indicates that the essential 'connectedness' of these landscapes will play a significant role in the ability of species in the ecoregion to adapt to these changes. It's unclear that all of the species that have been identified in the ecoregion in the past can continue to exist in the region in the future, but the ability of regional landscapes to sustain the extraordinary biodiversity in the Klamath ecoregion depends on how well planning incorporates this 'new' knowledge.

The August Complex recovery program and its individual implementation projects should focus on landscape connectivity through enhancing and maintaining aquatic and riparian areas, which are already considered by many conservation ecologists to be among the most important habitat elements in California landscapes for both aquatic and terrestrial species. Wider watercourse protection areas throughout the region will help protect water quality in a warming climate, as well as providing a core framework for ecoregional connectivity. Stream canyons may provide cooler, moister microrefugia that sustain complex forest structure and the species that respond to it.

In addition to focusing on riparian areas, connectivity enhancement within the August Complex project area should include an increased focus on the presence of hardwoods within the forest matrix, as well as increasing the numbers and areas of hardwood woodland/forest patches. This should be identified as a priority in the August Complex recovery program throughout the fire's footprint. Increased fire will functionally result in a restoration of previously dominant landscape dynamics in the ecoregion (White & Long 2019). Pre-August Complex mixed-conifer stands already exhibited components dominated to varying degrees by black oak, canyon live oak, Oregon white oak, and madrone; these species are already important habitat elements for wildlife, and are resilient to increased fire in the future. Oak woodlands are also culturally significant resources for Californian Indian communities.

As described previously in this synthesis, remaining 'dry' mixed-conifer forests in the region should be restored to a more natural stand structure (the ICO structure), with lower tree densities, more variability in tree spacing, and greater resilience to wildfire effects, which should result in fewer but larger and older conifers (the majority of which are likely to be the regionally favored Douglas-fir). Oak elements within conifer forests should be enhanced. Oak woodlands are individual habitat areas ('islands') for woodland-associated wildlife species, as well as elements in 'stepping-stone' linkages among woodland patches in a coniferous matrix, forming a distributed network of woodland habitats throughout coniferous landscapes. Connectivity within the project area will be functionally enhanced by increasing the representation of hardwoods in areas reforested after the fire by (1) decreasing the distances among woodland patches and by (2) increasing the proportion of hardwoods in the forest matrix; both measures enhance the capability of the landscape to sustain wildlife movements among the distributed habitat areas (see, e.g., Noss & Daly 2006; Beier 2012).

Plans for the Klamath ecoregion, and for projects within it, must reemphasize the originally intended role of 'adaptive management' in the NWFP by increasing the FS commitment to monitoring conditions in FS landscapes. Uncertainty about future conditions must be addressed in management plans by increasing the FS commitment to monitoring what's actually occurring in the landscape, then adjusting management approaches accordingly. Such a commitment to ongoing monitoring is also necessary in implementing projects (such as the currently proposed Plaskett-Keller Project) in the August Complex recovery program.

VII. References

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