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Climate Change Vulnerability and Adaptation in the Intermountain Region

Part 1

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Abstract

The Intermountain Adaptation Partnership (IAP) identified climate change issues relevant to resource management on Federal lands in Nevada, Utah, southern Idaho, eastern California, and western Wyoming, and developed solutions intended to minimize negative effects of climate change and facilitate transition of diverse ecosystems to a warmer climate. U.S. Department of Agriculture Forest Service scientists, Federal resource managers, and stakeholders collaborated over a 2-year period to conduct a state-of-science climate change vulnerability assessment and develop adaptation options for Federal lands. The vulnerability assessment emphasized key resource areas—water, fisheries, vegetation and disturbance, wildlife, recreation, infrastructure, cultural heritage, and ecosystem services—regarded as the most important for ecosystems and human communities.

The earliest and most profound effects of climate change are expected for water resources, the result of declining snowpacks causing higher peak winter streamflows, lower summer flows, and higher stream temperatures. These changes will in turn reduce fish habitat for cold-water fish species, negatively affect riparian vegetation and wildlife, damage roads and other infrastructure, and reduce reliable water supplies for communities. Increased frequency and magnitude of disturbances (drought, insect outbreaks, wildfire) will reduce the area of mature forest, affect wildlife populations (some positively, some negatively), damage infrastructure and cultural resources, degrade the quality of municipal water supplies, and reduce carbon sequestration. Climate change effects on recreation, a major economic driver in the IAP region, will be positive for warm-weather activities and negative for snow-based activities. IAP participants developed adaptation options that can be implemented in planning, project management, monitoring, and restoration as climate-smart responses to altered resource conditions.

Keywords: adaptation, climate change, ecological disturbance, Intermountain Adaptation Partnership, resilience, science-management partnership, vulnerability assessment

Front cover photo: Fall colors and reflection on a pond in Lamoille Canyon, Ruby Mountains District, Humboldt-Toiyabe National Forest, NV, photo by Susan Elliott, U.S. Forest Service.

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Summary

The Intermountain Adaptation Partnership (IAP) is a science-management partnership with a wide variety of participants across the U.S. Department of Agriculture, Forest Service Intermountain Region, which spans Nevada, Utah, southern Idaho, eastern California, and western Wyoming. The partnership includes the Forest Service Intermountain Region, and Pacific Northwest and Rocky Mountain Research Stations; National Park Service Climate Change Response Program; North Central Climate Science Center; Desert, Great Basin, Great Northern, and Southern Rockies Landscape Conservation Cooperatives; the University of Washington; Native American tribes; and dozens of other stakeholder organizations. These organizations and other IAP participants worked together over 2 years to identify climate change issues relevant to resource management on Forest Service and National Park Service lands in the IAP region, and to find solutions that could help to minimize the negative effects of climate change and facilitate the transition of ecosystems to a warmer climate. The IAP provided education, conducted a climate change vulnerability assessment, and developed adaptation options for managing resources of the 12 national forests (Ashley, Boise, Bridger-Teton, Caribou-Targhee, Dixie, Fishlake, Humboldt-Toiyabe, Manti-La Sal, Payette, Salmon-Challis, Sawtooth, Uinta-Wasatch-Cache [plus Curlew National Grassland]) and 22 National Park Service units in the IAP region.

The IAP region is characterized by high ecological diversity. Vegetation types include mixed conifer forest, dry ponderosa pine forest, subalpine forest, sagebrush, grasslands, alpine tundra, and wetlands. Ecosystems in the IAP region produce water, fish, timber, wildlife, recreation opportunities, livestock grazing, and other ecosystem services, providing a socioeconomic foundation based on natural resources. The geographic and ecological diversity of the region, especially on Federal lands, contributes significantly to the economic sustainability of human communities, linking Federal resource management with local livelihoods.

The effects of climate change on each resource area in the IAP region are synthesized from the available scientific literature and analyses and are based on available climate change projections (Chapter 3). Highlights of the vulnerability assessment and adaptation options for each resource area are summarized next.

Water and Soil Resources

Climate Change Effects

Lower snowpack and increased drought will result in lower base flows, reduced soil moisture, wetland loss, riparian area reduction or loss, and more frequent and possibly more severe wildfire. April 1 snow water equivalent and mean snow residence time are sensitive to temperature and precipitation variations. Warmer (usually lower elevation) snowpacks are more sensitive to temperature variations, whereas colder (usually higher elevation) snowpacks are more sensitive to precipitation. Warmer locations will experience more runoff in winter months and early spring, whereas colder locations will experience more runoff in late spring and early summer. In both cases, future peakflows will be higher and more frequent.

Lower snowpacks will cause significantly lower streamflow in summer, and reduce the rate of recharge of water supply in some basins. Annual water yields, which are affected by annual precipitation totals (heavily influenced by winter and spring precipitation in the western part of the region) and summer evapotranspiration, will generally be lower. Although declining snowpacks will occur throughout the region, snowpacks at higher elevations (Uinta Mountains, Teton and Wind River Ranges, and some central Idaho ranges) may not change much through the late 21st century. Carbon content in soils will decrease in areas where decomposition rate and wildfire frequency increase, and soil erosion will be accelerated by intense fires.

Adaptation Options

Primary adaptation strategies focus on expanding water conservation; increasing water storage, managing for highly functioning riparian areas, wetlands, and groundwater-dependent ecosystems; and developing policies for water rights. Adaptation tactics include: (1) using drought-tolerant plants for landscaping, managing livestock water improvements efficiently, and educating the public about water resource issues and conservation; (2) decommissioning and improving road systems, improving grazing management practices, and promoting and establishing American beaver populations; (3) managing vegetation to reduce forest density and hazardous fuels; (4) modifying dam and reservoir operation to improve water storage, and improving streamflow and runoff forecasts; and (5) maintaining and protecting soil cover and cryptobiotic crusts, using grazing management systems that promote healthy root systems in plants, and promoting native plant species diversity.

Fish and Other Aquatic Species

Climate Change Effects

A combination of higher stream temperature, low streamflow in summer, and higher peakflow at other times of the year will create a significant stress complex for cold-water fish species. Habitats that provide the restrictive thermal requirements of juvenile bull trout are rare, and little evidence exists for flexibility in habitat use. The length of connected habitat needed to support a bull trout population varies with local conditions, but current estimates suggest a minimum of 20 to 30 miles contingent on water temperature, nonnative species presence, and local geomorphic characteristics. Juvenile cutthroat trout occupy a broader thermal and stream size niche than bull trout. They also appear to persist in smaller habitat patches. Nonetheless, they require cold-water habitat patches exceeding 3 to 6 miles. Increased frequency and extent of extreme events will be especially stressful for bull trout and cutthroat trout, except at higher elevations, where habitat will remain favorable. Both species may in some cases be able to adjust their life histories to accommodate altered habitat, although the potential for this adaptive capacity is unknown. From the mid- to late-21st century, the vast majority of suitable cold-water fish habitat will be on Federal lands.

Rocky Mountain tailed frogs have long generation times and low fecundity, so increased summer droughts and wildfires, as well as extreme floods and postfire debris flows may threaten some populations. Sensitivities are similar for Idaho giant salamanders. Western pearlshell mussels have a broad geographic range, which reduces their vulnerability, although lower streamflow and higher stream temperatures are expected to be stressful in some locations. Springsnails are expected to be highly vulnerable because they require particular hydrological conditions, specific and stable temperature regimes, and perennial flows. Yosemite toads, already in decline, will be sensitive to reduced duration of ephemeral ponds for breeding in spring. Sierra Nevada yellow-legged frogs will be sensitive to less reliable availability of perennial water bodies needed for multiyear metamorphosis and maturation.

Adaptation Options

Primary adaptation strategies focus on increasing resilience of native fish species by restoring structure and function of streams, riparian areas, and wetlands; monitoring for invasive species and eliminating or controlling invasive populations; understanding and managing for community-level patterns and processes; and conducting biodiversity surveys to describe current baseline conditions and manage for changes in the distribution of fish and other aquatic species. Adaptation tactics include reconnecting floodplains and side channels to improve hyporheic and base flow conditions, ensuring that passage for aquatic organisms is effective, accelerating restoration in riparian areas, maintaining or restoring American beaver populations, managing livestock grazing to restore ecological function of riparian vegetation, removing nonnative fish species, maintaining or increasing habitat connectivity, and increasing the resilience of forests to wildfire.

Vegetation and Ecological Disturbances

Climate Change Effects

Increased temperature is expected to cause a gradual change in the distribution and abundance of dominant plant species. Increased ecological disturbance, driven by higher temperatures, is expected to cause near-term effects on vegetation structure and age classes, and will facilitate long-term changes in dominant vegetation. In forest ecosystems, native and non-native insects are expected to be significant stressors in a warmer climate; in fact, this appears to be already occurring. In all vegetation types, an increase in the frequency and extent of wildfire will be a significant stressor, especially where large fuel accumulations exist. Nonnative plant species will likely continue to expand in most vegetation types, especially in rangelands, potentially displacing native species and altering fire regimes. A combination of these and other stressors (stress complexes), exacerbated by climate, may accelerate the rate of change in vegetation assemblages, and reduce productivity and carbon storage in most systems. Riparian areas may be especially sensitive as a warming climate causes hydrological regimes to change, reducing the timing and amount of water available in summer. Climate change effects on specific forest types include:

- Subalpine pine forest—Most subalpine tree species will be moderately affected by a warmer climate, although bristlecone pine could undergo stress in the driest locations. Whitebark pine will be vulnerable because it is already stressed from white pine blister rust and mountain pine beetles. If wildfire increases, crown fires may quickly eliminate mature trees across the landscape.

- Subalpine spruce-fir forest—This forest type will be moderately vulnerable. Subalpine fir and Engelmann spruce may have increased growth in a longer growing season. Bark beetles will be a stressor for Engelmann spruce. If wildfire increases, crown fires may quickly eliminate mature trees across the landscape. Quaking aspen will be minimally affected by a warmer climate.

- Mesic mixed conifer forest—Late-seral forests will be susceptible to wildfire, especially where fuel loads are high. Douglas-fir, ponderosa pine, and Jeffrey pine, which have high fire tolerance, may become more common, and late-seral species less common. Growth rates of most species will decrease. Lodgepole pine and quaking aspen will persist, perhaps with increased stress from insects and pathogens.

- Dry mixed conifer forest—Most species in mixed conifer forest (ponderosa pine, Gambel oak, quaking aspen) can cope with dry soils and wildfire. Growth of less drought-tolerant species (Douglas-fir, white fir) will decrease. With increased fire frequency, early-seral species will become more common, and late-seral species less common.

- Aspen mixed conifer forest—Increased wildfire frequency and extent will determine future composition and structure of this forest type. Conifers at higher elevations (mostly not fire resistant) will become less common, confined to northern slopes and valley bottoms. Quaking aspen and Gambel oak will attain increasing dominance because of their ability to sprout vigorously after fire, outcompeting species susceptible to drought and fire.

- Persistent aspen forest—Conifers at higher elevation (mostly not fire resistant) will become less common, confined to northern slopes and valley bottoms. Quaking aspen will attain increasing dominance because of its ability to sprout vigorously after fire, outcompeting species susceptible to drought and fire. Douglas-fir will persist in locations with sufficient soil moisture. Overall productivity will probably decrease.

- Montane pine forest—Ponderosa pine will persist in this forest type because it is drought tolerant and fire tolerant, outcompeting other species following wildfire, but will grow more slowly. Limber pine and bristlecone pine will probably persist at higher elevations where fuel loads are low. If insect outbreaks are more prevalent in a warmer climate, they could increase stress in pine species, especially during drought.

- Riparian forest—This is a highly vulnerable forest type because it depends on a reliable water supply. Vegetation dominance may shift to species that are more tolerant of seasonal drought, including ponderosa pine and other deep-rooted conifers. Hardwoods could become less common. Riparian forests associated with small or transient water sources will be especially vulnerable, especially at lower elevations.

Nonforest

In nonforest ecosystems, increasing frequency and duration of drought are expected to drive direct changes on soil moisture, which will reduce the vigor of some species, causing mortality or making (mostly woody species) more susceptible to insects and pathogens. Increasing frequency and extent of wildfire will be a major stressor for species that regenerate slowly following fire, especially non-sprouting vegetation (e.g., most sagebrush species). The dominance of nonnative plant species, especially annual grasses (e.g., cheatgrass), will be enhanced by increasing disturbance and will themselves encourage more frequent fire—a significant change in the ecology of most vegetation assemblages. Although productivity may increase in some grasslands, most other nonforest ecosystems will experience lower productivity. Most native species are expected to persist if they can move to favorable portions of the landscape and are sufficiently competitive. Climate change effects on specific nonforest vegetation include:

- Pinyon-juniper shrublands and woodlands—These woodlands are sensitive to chronic low soil moisture during prolonged droughts (to which pinyon pines are more sensitive than junipers), increased insect outbreaks that follow drought stress, and increased frequency and extent of wildfire. These species will persist across the landscape, although the distribution and abundance of species may change.

- Oak-maple woodlands—Gambel oak and bigtooth maple, the dominant species in these woodlands, are widely distributed and both sprout heavily following wildfire. As a result, their vulnerability is expected to be relatively low, and Gambel oak in particular may become more dominant as wildfire frequency and extent increase across the landscape.

- Mountain mahogany woodlands—These woodlands, which are dominated by curl-leaf mountain mahogany, are expected to be moderately vulnerable. This species is slow-growing and does not sprout following wildfire, so regeneration of disturbed sites may be slow, especially where nonnative species are common. However, mountain mahogany is capable of growing on low-fertility soils, so it will continue to be competitive with other species.

- Mountain big sagebrush shrublands—Vulnerability varies from moderate to high because of the broad elevation range at which mountain big sagebrush occurs, and because of the wide range in current conditions. Livestock grazing, expansion of pinyon pine and juniper species, altered wildfire regimes, and nonnative invasive species are significant stressors. These factors may be exacerbated by a warmer climate, especially in drier habitats.

- Dry big sagebrush shrublands—Vulnerability is high, as evidenced by significant mortality that occurred during recent drought. Conditions suitable for seedling establishment are infrequent under current climatic conditions and are likely to become less frequent in a warmer climate. Lower elevations of the Great Basin are especially vulnerable, whereas sagebrush in wetter locations may be able to persist.
- Sprouting sagebrush shrublands—Warmer, drier climate will negatively affect the vigor and abundance of sprouting sagebrush species, which are adapted to more mesic conditions. These species can sprout following wildfire, but seed viability is short and unreliability of spring soil moisture will make them susceptible to prolonged droughts. Overall vulnerability is moderate, and regeneration will be critical to long-term persistence across the landscape.
- Dwarf sagebrush shrublands—All low-growing sagebrush species are likely to be negatively affected by higher temperatures and increased periods of drought. Seed viability is short and their dependence on spring soil moisture will make them susceptible to prolonged droughts and to altered timing and amount of spring moisture. Increased wildfire frequency, coupled with drought, could inhibit regeneration on drier sites.
- Mountain, blackbrush, and salt desert shrublands—These shrublands have low to moderate vulnerability, depending on their location relative to soil moisture availability. Many of these shrublands have relatively high species diversity—some are well-adapted to periodic drought and some may be able to migrate to higher elevations. Salt desert communities at lower elevations may be vulnerable to drought and are intolerant of wildfire.
- Alpine communities—The composition and distribution of alpine ecosystems will be affected by decreasing snowpack, altering plant vigor and regeneration. Specific effects will depend on vulnerability thresholds of diverse species and the rate and magnitude of changes over time. Some species may be able to persist or migrate to suitable habitat, but the lower extent of some communities will be compromised by tree establishment.
- Mountain grasslands—The vulnerability of cool-season grass-dominated communities is moderate to high. Warm-season grasses are favored by higher temperatures, providing an opportunity for spread into mountain grasslands from lower-elevation and more southern locations. Increased wildfire frequency will facilitate more nonnative invasive species, decreasing the dominance and vigor of natives.
- Subalpine forb communities—Higher temperatures and increasing drought make this vegetation type highly vulnerable in many locations. Although some subalpine forb communities may be able to move higher in elevation, shallow soil profiles may support only lower-growing species. Tall forb communities at the highest elevations on plateaus (e.g., Wasatch Plateau) are particularly vulnerable.
- Riparian and wetland communities—Most of these communities are highly vulnerable, especially those at lower elevations where soil conditions are already affected by periodic drought. Reduced summer streamflow and groundwater will create significant stress for some dominant plant species, although high species diversity in many locations ensures some long-term persistence, perhaps with lower functionality.

Adaptation Options

Primary adaptation strategies for forest vegetation focus on promoting disturbance-resilient species, maintaining low tree densities, promoting species and genetic diversity, promoting diversity of forest structure, and increasing knowledge about climate change effects for agency land managers and stakeholders. Tactics include conducting thinning treatments, favoring disturbance-resilient species in thinnings, planting potential microsites with a mixture of species, collecting seed for postfire reforestation, and reducing density through prescribed fire and managed wildfire. Maintaining and restoring stream channels, and protecting vegetation through appropriate livestock management can be applied in riparian areas.

Primary adaptation strategies for nonforest vegetation focus on restoring resilience to and maintaining healthy and intact woodlands, shrublands, and grasslands, increasing management actions to prevent invasive species, and maintaining and restoring natural habitat. Tactics include using mechanical treatments, prescribed fire, using integrated weed management, implementing fuels reduction projects, using ecologically based invasive plant management, implementing livestock management that reduces damage to native perennial species, and maintaining or improving native plant cover, vigor, and species richness.

Terrestrial Animals

Climate Change Effects

The effects of climate change on terrestrial animal species are expected to be highly variable, depending on habitat conditions in specific locations and on the flexibility of animal life histories to accommodate altered conditions. Flammulated owl, wolverine, and greater sage-grouse are expected to be the most vulnerable to population declines, whereas Utah prairie dog and American three-toed woodpecker will be the least vulnerable. Most species will exhibit some sensitivity to altered phenology, habitat, and physiology. Species restricted to high elevations or surface water habitats will generally be vulnerable. Following are possible climate change effects on species of conservation concern.

- Black rosy finch—An alpine specialist, this species will suffer loss of habitat associated with shrinking snowfields and glaciers and possibly encroaching tree establishment, although it does have the capacity to migrate to other locations.

- Flammulated owl—Wildfire and insects will increase early-seral forest structure over time, conditions detrimental for this species, which prefers mature, open ponderosa pine and other semiarid forests with brushy understories.

- Greater sage-grouse—Degraded habitat caused by wildfire-induced mortality of mature sagebrush, in combination with increased dominance of pinyon-juniper woodlands, invasive annual species, and possible effects of West Nile virus will be significant challenges to this species.

- White-headed woodpecker—As long as sufficient mature coniferous forest habitat with pines as a seed source and dead trees for nesting remain, this species will be relatively resilient to a warmer climate because it can move readily to more favorable locations.

- American pika—This species will be vulnerable on isolated mountaintops and at low elevations where it is near its physiological tolerance. Populations in the southern Great Basin are the most vulnerable in the IAP region, but populations in other locations may be fairly resilient.

- Bighorn sheep—Different parts of the region, and thus different subspecies, will be subject to different population dynamics. Populations in the most arid, low-elevation locations and without access to dependable springs and forage will be most vulnerable.

- Canada lynx—This species will be vulnerable to reduced snowpack and prey availability (especially snowshoe hares), although interactions among climate, wildfire, and insect outbreaks may reduce late-seral forest habitat preferred for breeding.

- Fisher—The extent, quality, and connectivity of habitat for this species will probably decrease as increasing wildfire reduces late-seral forest habitat, although fishers can readily move from unfavorable to favorable habitat.

- Fringed myotis—This species could undergo some stress if water sources become less common or more transient, although its mobility and migratory nature allow it to respond to changing conditions.

- Northern Idaho ground squirrel—Increased vegetative productivity may benefit this species, although loss of snowpack, drought, disease, and nonclimatic factors (overgrazing, land development) may be significant stressors.

- Sierra Nevada red fox—With populations that are mostly small and isolated, this species may be affected by drought, wildfire, and insects that alter vegetation, and especially by reduced snowpack, which promotes higher populations of coyotes, a competitor for limited prey.
- Townsend's big-eared bat—This species uses a variety of habitats, conferring some resilience, although increasing wildfires and nonnative grasses could degrade habitats and reduce prey availability. Declining snowpack may also reduce the number and duration of water sources.
- Utah prairie dog—This species may be fairly resilient to a warmer climate, although population declines have been observed during prolonged periods of drought, which affects food and water availability.
- Wolverine—This species, already low in numbers, could be significantly affected by declining snowpack in its preferred high-elevation forest and alpine habitats, and possibly by altered vegetation composition over time.
- Boreal toad—Subject to recent population declines, this species is sensitive to water balance, so altered timing and duration of water availability could be stressors. The harmful chytrid fungus may or may not be affected by climate change, and trampling of riparian areas by livestock is locally damaging.
- Columbia spotted frog—Historical declines of this species may be exacerbated by alteration and fragmentation of aquatic habitats. Drought, warmer temperatures, and reduced snowpack will potentially alter breeding habitat, although spotted frogs will probably be resilient in areas with reliable water sources.
- Great Basin spadefoot—This species may be fairly resilient to a warmer climate because it occurs in a variety of vegetation types, has a flexible breeding season, and has high reproductive rates. Populations in the southern portion of its range and where it relies on ephemeral ponds may be more vulnerable.
- Prairie rattlesnake—This species has low fecundity, long generation times, and low dispersal, making it vulnerable to additional climate stresses such as wildfires and flooding. It will probably be more resilient in areas with sufficient microhabitats and low habitat fragmentation.

Adaptation Options

Primary adaptation strategies focus on improving riparian habitat through restoration, encouraging healthy beaver populations, retaining mature forest structure where possible, reducing nonnative plant species, maintaining quaking aspen habitat, and maintaining connectivity of habitat patches across the landscape. Adaptation tactics include removing hazardous fuels to reduce wildfire intensities, minimizing impacts from livestock grazing, using prescribed fire and conifer removal to promote aspen stands, removing cheatgrass and other invasive species from sagebrush systems, and minimizing impacts of recreation on species sensitive to human disturbance.

Outdoor Recreation

Climate Change Effects

Summer recreation (hiking, camping, bicycling) will benefit from a longer period of suitable weather without snow, especially during the spring and fall shoulder seasons. **Snow-based recreation** (downhill skiing, cross-country skiing, snowmobiling) will be negatively affected by a warmer climate because of less snow and more transient snowpacks. Ski areas and other facilities at lower elevations will be especially vulnerable. **Hunting and fishing** may be affected somewhat by a warmer climate, depending on specific location and activity. Hunting will be sensitive to temperature during the allotted hunting season and timing and amount of snow. Fishing will be sensitive to streamflows and stream temperatures associated with target species; if summer flows are very low, some streams may be closed to fishing. **Water-based recreation** (swimming, boating, rafting) will be sensitive to lower water levels. **Gathering forest products** for recreational and personal use (e.g., huckleberries, mushrooms) will be somewhat sensitive to the climatic conditions that support the distribution and abundance of target species, and to extreme temperatures and increased occurrence of extreme events (e.g., flooding, landslides).

Adaptation Options

Recreation participants are highly adaptable to changing conditions, although Federal agencies are not very flexible in modifying management. Primary adaptation strategies focus on transitioning management to shorter winter recreation seasons, providing sustainable recreation opportunities, increasing management flexibility and facilitating transitions to meet user demand and expectations, and managing recreation sites to mitigate risks to public safety and infrastructure. Adaptation tactics include collecting data on changing use patterns and demands, maintaining current infrastructure and expanding facilities in areas where concentrated use increases, educating the public about changing resource conditions, varying the permit season for rafting to adapt to changes in peak flow and duration, and determining which recreation sites are at risk from increased hazards.

Infrastructure

Climate Change Effects

Vulnerability of infrastructure can be assessed at three levels: (1) documentation of the type and quantity of infrastructure, (2) examination of infrastructure investments at the regional level, and (3) evaluation of infrastructure at local or smaller scales. Infrastructure risk can be proactively addressed by identifying assets that have a high likelihood of being affected by future climatic conditions and significant consequences if changes do occur. Roads and other infrastructure that are near or beyond their design life are at considerable risk to damage from flooding and geomorphic disturbance (e.g., debris slides). If road damage increases as expected, it will have a profound impact on access to Federal lands and on repair costs. Trails and developed recreation sites may also be sensitive to increased flooding and chronic surface flow, especially in floodplains. Buildings and dams represent large investments, and some may be at risk to an increased frequency of extreme events (wildfire, flooding).

Adaptation Options

Primary adaptation strategies focus on maintaining an accurate inventory of at-risk infrastructure components (e.g., buildings, roads), increasing resilience of the transportation system to increased disturbances (especially flooding), and ensuring that design standards are durable under the new conditions imposed by a warmer climate. Adaptation tactics include improving roads and drainage systems to survive higher peakflows and more flooding, conducting risk assessments of vulnerable roads and infrastructure, decommissioning roads where appropriate, documenting seasonal traffic patterns, emphasizing potential increases in extreme storm events when evaluating infrastructure inventory, fireproofing of buildings, and coordinating with partners whenever possible.

Cultural Resources

Climate Change Effects

Some aspects of climate change may exacerbate damage and loss of cultural resources, which are threatened by natural biophysical factors as well as human behaviors such as vandalism and illegal artifact digging. Increasing wildfire, flooding, melting of snowfields, and erosion can quickly displace or destroy artifacts before they have been identified and examined, potentially leading to the loss of thousands of items. In addition, large disturbances can change the condition of vegetation, streams, and other landscape features valued by Native Americans.

Adaptation Options

Adaptation strategies and tactics to protect cultural resources include improving inventories of the location of cultural resources, suppressing wildfires to protect specific sites, implementing fuels treatments in dry forests to reduce wildfire intensity, implementing protection strategies (e.g., stabilization, armoring, fireproofing) in areas prone to disturbances, monitoring areas affected by flooding and debris flows in mountain canyon and foothill areas, and applying vegetation management treatments designed to protect “first food” resources.

Ecosystem Services

Climate Change Effects

Ecosystem services provided to human communities from Federal lands will be affected by climate change in several ways:

- Timber and related products and services—Reduced growth rates in primary timber species will have a minimal effect on harvestable wood volume, although increased wildfires and insect outbreaks can reduce harvestable timber supply. Economic forces and policies will continue to dominate the wood products industry and employment, regardless of climate change.

- Grazing forage for domestic livestock and wildlife—Productivity may increase in some rangelands and decrease in others, so effects will vary spatially. Increased dominance of nonnative species (e.g., cheatgrass) will reduce range quality and support more frequent wildfires. Local erosion and encroaching urbanization will reduce the amount of available forage, regardless of climate change.

- Water quantity and quality—Declining snowpack will alter hydrological regimes annually and seasonally. Water yield is expected to decrease significantly by the 2040s and considerably more by the 2080s. The most sensitive watersheds are those already impaired or at risk, based on vegetation and soil conditions. Water quality may be affected by algal blooms and by erosion following wildfires.

- Ecosystem carbon—Ecosystems will increasingly be affected by disturbances (drought, wildfires, insects) that will remove living and dead vegetation, and, in turn, reduce carbon sequestration. If fires are as frequent as expected, forests may rarely attain a mature stand structure at lower elevations, thus limiting potential carbon sequestration.

- Pollination—Altered temperature and precipitation may lead to variable flowering phenology, which could reduce pollination by native insects such as bumblebees, and reduce native plant reproduction. Increased drought and extreme temperatures may impact pollinators already under stress from insecticides and increased dominance by nonnative plants.

Adaptation Options

Adaptation strategies for ecosystem services focus on availability and quality of forage for livestock, availability and quality of water, and habitat for pollinators. Adaptation strategies for grazing focus on increasing resilience of rangeland vegetation, primarily through nonnative species control and prevention. Adaptation tactics include flexibility in timing, duration, and intensity of authorized grazing as a tactic to prevent ecosystem degradation under changing conditions, as well as a more collaborative approach to grazing management.

Adaptation strategies for water focus on timing of water availability and quality of water delivered beyond Federal lands, assessments of potential climate change effects on municipal water supplies, and identifying potential vulnerabilities to help facilitate adaptive actions. Adaptation tactics include reducing hazardous fuels in dry forests to reduce the risk of crown fires, reducing other types of disturbances (e.g., off-road vehicles, unregulated livestock grazing), and using road management practices that reduce erosion.

Adaptation strategies for pollinators focus on improving pollinator habitat by increasing native vegetation and by applying pollinator-friendly best management. Adaptation tactics include establishing a reserve of native seed mixes for pollinator-friendly plants, implementing revegetation with plants beneficial to both pollinators and wildlife, and creating guidelines that would help managers incorporate pollinator services in planning, project analysis, and decisionmaking.

Conclusions

The IAP facilitated the most comprehensive effort on climate change assessment and adaptation in the United States, including participants from stakeholder organizations interested in a broad range of resource issues. It achieved specific elements of national climate change strategies for the U.S. Forest Service and National Park Service, providing a scientific foundation for resource management, planning, and ecological restoration in the IAP region. The large number of adaptation strategies and tactics, many of which are a component of current management practice, provides a pathway for slowing the rate of deleterious change in resource conditions. Rapid implementation of adaptation as a component of sustainable resource management will help to maintain critical structure and function of terrestrial and aquatic ecosystems in the IAP region. Long-term monitoring will help to detect potential climate change effects on natural resources, and evaluate the effectiveness of adaptation options that have been implemented.

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Figure 1.1—Project area for the Intermountain Adaptation Partnership.

Chapter 1: Introduction

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Introduction

The Intermountain Adaptation Partnership (IAP) is a science-management partnership with a wide variety of participants across the U.S. Department of Agriculture Forest Service (USFS) Intermountain Region, which spans Nevada, Utah, southern Idaho, eastern California, and western Wyoming. This USFS region is the largest in the Nation, representing nearly 17 percent of all National Forest System lands. The partnership includes the USFS Intermountain Region and the USFS Pacific Northwest and Rocky Mountain Research Stations, National Park Service (NPS) Climate Change Response Program, U.S. Fish and Wildlife Service, North Central Climate Science Center, the Desert, Great Basin, Great Northern, and Southern Rockies Landscape Conservation Cooperatives, the University of Washington, Native American tribes, and dozens of other stakeholder organizations (fig. 1.1, box 1.1). Initiated in 2015, the IAP is a collaborative project with the goals of increasing climate change awareness, assessing vulnerability, and developing science-based adaptation options to reduce adverse effects of climate change and ease the transition to new climate states and conditions (see http://adaptationpartners.org/iap). Developed in response to proactive climate change strategies of the USFS (USDA FS 2008,

Box 1.1—Intermountain Adaptation Partnership Participating Organizations

- Backcountry Hunters and Anglers
- Boise State University
- Bureau of Land Management (BLM)
- Colorado State University
- Cooperative Institute for Research in Environmental Sciences
- Deseret News
- Desert Landscape Conservation Cooperative
- Eastern Idaho Public Health
- EcoAdapt
- Grand Canyon Trust
- Great Basin Landscape Conservation Cooperative
- Great Northern Landscape Conservation Cooperative
- Henry's Fork Foundation
- Idaho Army National Guard
- Idaho Bureau of Homeland Security
- Idaho Department of Fish and Game
- Idaho National Guard
- Idaho Power Company
- Institute of Outdoor Recreation and Tourism
- Inter-Tribal Council of Nevada
- McGinnis and Associates
- National Oceanic and Atmospheric Administration
- National Park Service
- National Weather Service
- Natural Resources Conservation Service
- Nevada Department of Wildlife
- Nez Perce Tribe
- North Central Climate Science Center
- Northwest Watershed Research Center
- Southern Rockies Landscape Conservation Cooperative
- Trout Unlimited
- U.S. Fish and Wildlife Service
- U.S. Forest Service
- U.S. Forest Service Intermountain Region
- U.S. Forest Service Pacific Northwest and Rocky Mountain Research Stations
- University of Nevada, Reno
- University of Utah
- University of Washington
- Utah Division of Forestry, Fire and State Lands
- Utah State University
- Utah's Hogle Zoo
- Weber State University
- Western Water Assessment
- Wild Utah Project
- Yerington Paiute Tribe
- Yomba Shoshone Tribe

2010a,b), and building on previous efforts in national forests (Halofsky and Peterson 2017; Halofsky et al. 2011, 2018, in press; Littell et al. 2012; Raymond et al. 2013, 2014; Rice et al. 2012; Swanston et al. 2011, 2016), the partnership brings together resource managers, research scientists, and stakeholders to plan for climate change in the Intermountain Region.

This effort directly addressed goals identified in the USFS Intermountain Region Strategic Framework for FY 2017–2020 (USDA FS 2016) and the USFS Strategic Plan, FY 2015–2020 (USDA FS 2015). These main strategic goals are to: (1) sustain our Nation's forests and grasslands, (2) deliver benefits to the public, (3) apply knowledge globally, and (4) excel as a high-performing agency. These goals aim the USFS toward success in the agency's mission "to sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations." Finally, this assessment strives to provide options and solutions to a complex challenge in a way inspired by Gifford Pinchot, the first Chief of the USFS: for "the greatest good of the greatest number in the long run," (USDA FS 2007).

Climate Change Response in the Forest Service and National Park Service

Climate change is an agency-wide priority for the USFS, which has issued direction to administrative units for responding to climate change (USDA FS 2008) (table 1.1). In 2010, the USFS provided specific direction to the National Forest System in the form of the National Roadmap for Responding to Climate Change (USDA FS 2010a) and the Performance Scorecard for Implementing the USFS Climate Change Strategy (USDA FS 2010b). The goal of the USFS climate change strategy is to "ensure our national forests and private working lands are conserved, restored, and made more resilient to climate change, while enhancing our water resources," (USDA FS 2010a, p. 2). To achieve this goal, starting in fiscal year (FY) 2011, each national forest and grassland began using a 10-point scorecard system to report accomplishments on 10 elements in 4 dimensions: (1) increasing organizational capacity, (2) partnerships, engagement, and education, (3) adaptation, and (4) mitigation and sustainable consumption. The scorecard elements can be found in box 1.2. From FY 2011 to FY 2016, progress toward accomplishing elements of the scorecard was required to be reported annually by each national forest and national grassland. All units were expected to accomplish 7 of 10 criteria, with at least one "yes" in each dimension, and in FY 2016, all units in the Intermountain Region were successful in this endeavor. As of FY 2017, the USFS is actively developing a new reporting model.

Similarly, the NPS Climate Change Response Strategy provides direction for addressing the impacts of climate change on NPS lands (NPS 2010) (table 1.2). The strategy has four components to guide NPS actions: science, adaptation, mitigation, and communication. The science component involves conducting and synthesizing research at various scales, monitoring trends and conditions, and delivering information to resource managers and partners. It also provides the scientific basis for adaptation, mitigation, and communication. Adaptation involves developing capacity within the agency to assess climate change scenarios and risks and implementing actions to better manage natural and cultural resources and infrastructure for a changing climate. Mitigation efforts focus on reducing the agency carbon footprint and enhancing carbon sequestration. Finally, the strategy requires the NPS to take advantage of agency capacity for education and interpretation to communicate the effects of climate change to NPS employees and to the public. Park rangers and other employees are encouraged to engage visitors about climate change because national parks are visible examples of how climate change can affect natural and cultural resources. The similarity of USFS and NPS climate response strategies facilitated coordination between the two agencies.

The IAP built on previous Adaptation Partners (www.adaptationpartners.org) efforts in ecosystem-based management and ecological restoration to address climate change and put these efforts in a broader regional context in the Intermountain Region. Starting in 2008, Halofsky et al. (2011) conducted a climate change assessment for Olympic National Forest and Olympic National Park (1.55 million acres), a science-management collaboration initiated to develop climate adaptation strategies. In 2010, the North Cascadia Adaptation Partnership (Raymond et al. 2014) began a similar effort with an expanded geographic scope of two national forests and two national parks. These organizations worked with stakeholders over 2 years to identify climate change issues relevant to resource management in the North Cascades to assist in the transition of diverse ecosystems of the region to a warmer climate. The North Cascadia Adaptation Partnership provided education, conducted a climate change vulnerability assessment, and developed adaptation options for the Federal agencies that manage nearly 6 million acres in north-central Washington. In 2013, the USFS Pacific Northwest Research Station, Pacific Northwest Region, and Malheur, Umatilla, and Wallowa-Whitman National Forests (5.29 million acres in Oregon and Washington) initiated the Blue Mountains Adaptation Partnership (Halofsky and Peterson 2017). Formed in 2015, the South Central Oregon Adaptation Partnership (Halofsky et al. in press) brought together the Deschutes National Forest, Fremont-Winema National Forest, Ochoco National Forest, Crooked River National Grassland, the USFS Pacific Northwest Region, USFS Pacific Northwest and Rocky Mountain Research Stations, Crater Lake National Park, and the University of Washington to conduct a similar climate change assessment, covering 5 million acres. In the largest effort to date in the western United States, the Northern Rockies Adaptation

Table 1.1—U.S. Forest Service policies related to climate change.

Policy	Description
Forest Service Strategic Framework for Responding to Climate Change (USDA FS 2008)	Developed in 2008, the Strategic Framework is based on seven strategic goals in three broad categories: foundational, structural, and action. The seven goals are science, education, policy, alliances, adaptation, mitigation, and sustainable operations. Like the challenges themselves, the goals are interconnected; actions that achieve one goal tend to help meet other goals. The key is to coordinate approaches to each goal as complementary parts of a coherent response to climate change. All seven goals are ultimately designed to achieve the same end (the USFS mission): to ensure that Americans continue to benefit from ecosystem services from national forests and grasslands.
USDA 2010-2015 Strategic Plan (USDA FS 2010c)	In June 2010, the U.S. Department of Agriculture released the Strategic Plan that guides its agencies toward achieving several goals including Strategic Goal 2—Ensure our national forests and private working lands are conserved, restored, and made more resilient to climate change, while enhancing our water resources. This goal has several objectives. Objective 2.2 is to lead efforts to mitigate and adapt to climate change. The performance measures under this objective seek to reduce greenhouse gas emissions by the U.S. agricultural sector, increase the amount of carbon sequestered on U.S. lands, and bring all national forests into compliance with a climate change adaptation and mitigation strategy. The USFS response to this goal includes the National Roadmap for Responding to Climate Change and Performance Scorecard (Roadmap).
National Roadmap for Responding to Climate Change (USDA FS 2010a)	Developed in 2011, the Roadmap integrates land management, outreach, and sustainable operations accounting. It focuses on three kinds of activities: assessing current risks, vulnerabilities, policies, and gaps in knowledge; engaging partners in seeking solutions and learning from as well as educating the public and employees on climate change issues; and managing for resilience in ecosystems and human communities through adaptation, mitigation, and sustainable consumption strategies.
Climate Change Performance Scorecard (USDA FS 2010b)	To implement the Roadmap, starting in 2011, each national forest and grassland began using a 10-point scorecard to report accomplishments and plans for improvement on 10 questions in four dimensions: organizational capacity, engagement, adaptation, and mitigation. By 2015, each is expected to answer "yes" to at least seven of the scorecard questions, with at least one "yes" in each dimension. The goal is to create a balanced approach to climate change that includes managing forests and grasslands to adapt to changing conditions, mitigating climate change, building partnerships across boundaries, and preparing employees to understand and apply emerging science.
2012 Planning Rule (USDA FS 2012)	The 2012 Planning Rule is based on a planning framework that will facilitate adaptation to changing conditions and improvement in management based on new information and monitoring. There are specific requirements for addressing climate change in each phase of the planning framework, including in the assessment and monitoring phases, and in developing, revising, or amending plans. The 2012 Planning Rule emphasizes restoring the function, structure, composition, and connectivity of ecosystems and watersheds to adapt to the effects of a changing climate and other ecosystem drivers and stressors, such as wildfire and insect outbreaks. A baseline assessment of carbon stocks required in assessment and monitoring will check for measureable changes in the plan area related to climate change and other stressors. Requirements of the Roadmap and Scorecard and requirements of the 2012 Planning Rule are mutually supportive and provide a framework for responding to changing conditions over time.

Box 1.2—The Forest Service Climate Change Performance Scorecard, 2011

1. **Employee Education.** Are all employees provided with training on the basics of climate change, impacts on forests and grasslands, and the Forest Service response? Are resource specialists made aware of the potential contribution of their own work to climate change response?
2. **Designated Climate Change Coordinators.** Is at least one employee assigned to coordinate climate change activities and be a resource for climate change questions and issues? Is this employee provided with the training, time, and resources to make his/her assignment successful?
3. **Program Guidance.** Does the Unit have written guidance for progressively integrating climate change considerations and activities into Unit-level operations?
4. **Science and Management Partnerships.** Does the Unit actively engage with scientists and scientific organizations to improve its ability to respond to climate change?
5. **Other Partnerships.** Have climate change related considerations and activities been incorporated into existing or new partnerships (other than science partnerships)?
6. **Assessing Vulnerability.** Has the Unit engaged in developing relevant information about the vulnerability of key resources, such as human communities and ecosystem elements, to the impacts of climate change?
7. **Adaptation Actions.** Does the Unit conduct management actions that reduce the vulnerability of resources and places to climate change?
8. **Monitoring.** Is monitoring being conducted to track climate change impacts and the effectiveness of adaptation activities?
9. **Carbon Assessment and Stewardship.** Does the Unit have a baseline assessment of carbon stocks and an assessment of the influence of disturbance and management activities on these stocks? Is the Unit integrating carbon stewardship with the management of other benefits being provided by the Unit?
10. **Sustainable Operations.** Is progress being made toward achieving sustainable operations requirements to reduce the environmental footprint and increase the resilience of agency operations and assets?

Partnership developed a vulnerability assessment and adaptation options for 15 national forests and 3 national parks in Montana, northern Idaho, North Dakota, and parts of South Dakota and Wyoming, covering a total of 183 million acres (Halofsky et al. 2018). The IAP continues these efforts to develop science-based adaptation strategies.

Other efforts have also demonstrated the success of science-management partnerships for increasing climate change awareness among resource managers and adaptation planning on Federal lands. In addition to the Adaptation Partners assessments described earlier, Tahoe National Forest, Inyo National Forest, and Devils Postpile National Monument worked with the USFS Pacific Southwest Research Station to develop climate change vulnerability assessments (Littell et al. 2012) and the Climate Project Screening Tool (Morelli et al. 2012) in order to incorporate adaptation into project planning. In response to requests from Shoshone National Forest in northern Wyoming, the Rocky Mountain Research Station synthesized information on past climate, future climate projections, and potential effects of climate change on the multiple ecosystems within the forest (Rice et al. 2012).

In the largest effort to date in the eastern United States, the USFS Northern Research Station, in collaboration with Chequamegon-Nicolet National Forest in northern Wisconsin and numerous other partners, conducted a vulnerability assessment for natural resources (Swanston et al. 2011) and developed adaptation options (Swanston et al. 2016). Another USFS science-management partnership assessed the vulnerability of watersheds to climate change (Furniss et al. 2013). These watershed vulnerability assessments, conducted on 11 national forests throughout the United States, were locally focused (at a national forest scale) and included water resource values, hydrological reaction to climate change, watershed condition, and landscape sensitivity. The assessments were intended to help national forest managers identify where limited resources could be best invested to increase watershed resilience to climate change. More recently, Butler et al. (2015) conducted a climate change vulnerability assessment and synthesis for forest ecosystems of the Central Appalachians region.

The processes, products, and techniques used for several studies and other climate change efforts on national forests have been compiled in a guidebook for developing adaptation options for national forests (Peterson et al. 2011). The guidebook outlines four key steps to facilitate adaptation in national forests: (1) Become aware of basic climate change science and integrate that understanding with knowledge of local conditions and issues (review), (2) evaluate sensitivity of natural resources to climate change (rank), (3) develop and implement options for adapting resources to climate change (resolve), and (4) monitor the effectiveness of

Table 1.2—National Park Service policies related to climate change.

Policy	Description
National Park Service Climate Change Response Strategy (NPS 2010)	Developed in 2010, the Climate Change Response Strategy is designed to guide management actions and collaboration, from the national to park levels, to address the effects of climate change. The Response Strategy is based on four components: science, mitigation, adaptation, and communication. These components provide a framework for consistent, legal, and appropriate management decisions. The Response Strategy calls for a scientific approach to updating interpretations of previous policy and mandates in order to uphold the mission of the NPS in the face of new conditions created by climate change.
A Call to Action: Preparing for a Second Century of Stewardship and Engagement (NPS 2011)	The Call to Action outlines themes and goals for the second century of stewardship and engagement of the NPS. The plan provides actions for the achievement of each goal before the NPS centennial in 2016. Under the theme of preserving America's special places, the plan sets the goal for management of resources to increase resilience to climate change stressors. Specific actions include revised management objectives, increases in sustainability, and changes in investments.
Green Parks Plan (NPS 2012b)	The Green Parks Plan (GPP) outlines how the NPS will achieve the commitment set in A Call to Action, to "Go Green." An overarching vision and strategy for sustainable management in the future, the GPP is based on nine strategic goals that focus on the effects of park operations on the environment and human welfare. The goals are to continually improve environmental performance; be climate friendly and climate ready; be energy smart; be water wise; develop a green NPS transportation system, buy green and reduce, reuse, and recycle; preserve outdoor values; adopt best practices; and foster sustainability beyond NPS boundaries.
Revisiting Leopold: Resource Stewardship in the National Parks (NPS 2012c)	In August 2012, the NPS released the Revisiting Leopold, intended as an updated interpretation of the guiding document, The Leopold Report (Leopold et al. 1963). Members of the current NPS Science Committee were tasked with revisiting three questions: (1) What should be the goals of resource management in the National Parks? (2) Which policies for resource management are necessary to achieve these goals? (3) Which actions are required to implement these policies? The interpretation presents general principles and guidance for the enlarged scope of all natural and cultural resources of the NPS. The committee stresses that the NPS needs to act quickly on structural changes and long-term investments in management in order to preserve resources through the uncertainties of environmental change.
Climate Change Action Plan 2012-2014 (NPS 2012a)	The 2012 Climate Change Action Plan builds on the 2010 NPS Climate Change Response Strategy to communicate how the NPS can respond to climate change at different geographic scales. The plan outlines parameters for introducing science, adaptation, mitigation, and communication actions to address climate change. The plan also identifies high-priority actions for addressing climate change in NPS operations, and describes how to anticipate and prepare for future changes.

on-the-ground management (observe) and adjust as needed. The IAP is focused on implementation of the principles and practices in the guidebook.

The Intermountain Adaptation Partnership Process

The IAP geographic area includes 12 national forests (table 1.3) and 22 NPS units across an ecologically and geographically complex area. The IAP process includes:

- A vulnerability assessment of the effects of climate change on water resources, fisheries, forest and nonforest vegetation, disturbance, wildlife, recreation, infrastructure, cultural resources, and ecosystem services. These resource sectors were selected based on their importance in the region and current management concerns and challenges.
- Development of adaptation options that will help to reduce negative effects of climate change and assist the transition of biological systems and management to a warmer climate.
- Development of an enduring science-management partnership to facilitate ongoing dialogue and activities related to climate change and to other natural resource management challenges and actions.
- Vulnerability assessments typically involve exposure, sensitivity, and adaptive capacity (Parry et al. 2007), where exposure is the degree to which the

Table 1.3—Area of U.S. Forest Service units in the Forest Service Intermountain Region (from USDA FS 2016). The national forests and grassland in the Intermountain Region are organized into 12 administrative units discussed throughout this assessment. The Forest Service Rocky Mountain Research Station manages the Desert Range Experimental Station. The "Other" category refers to areas located within National Forest System boundaries that are not Federally owned or administered by the Forest Service.

	Number of units	National Forest System	Other	Total
		Acres		
National forest	18	31,784,550	2,330,896	34,115,446
National grassland	1	47,544	27,240	74,784
Research and experimental area	1	55,510	0	55,510
Regional totals	20	31,887,604	2,358,136	34,245,740

system is exposed to changes in climate, sensitivity is an inherent quality of the system that indicates the degree to which it could be affected by climate change, and adaptive capacity is the ability of a system to respond and adjust to the exogenous influence of climate. Vulnerability assessments can be both qualitative and quantitative and focus on whole systems or individual species or resources (Glick et al. 2011). Several tools and databases are available for systematically assessing sensitivity of species (e.g., Case and Lawler 2016; Luce et al. 2014; Potter and Crane 2010).

We used scientific literature and expert knowledge to assess exposure, sensitivity, and adaptive capacity to identify key vulnerabilities for the selected resource areas. The assessment process took place over 2 years and involved monthly phone meetings for each of the resource-specific assessment teams. Each assessment team refined key questions that the assessment needed to address, chose values and key ecosystem attributes to assess, and determined which climate change effects models best informed the assessment. In some cases, assessment teams conducted spatial analyses or ran and interpreted models, selected criteria by which to evaluate model outputs, and developed maps of model output and resource sensitivities. To the greatest extent possible, teams focused on effects and projections specific to the region and used the finest scale projections that are scientifically valid.

By working collaboratively with scientists and resource managers and focusing on a specific region, the goal of IAP was to provide the scientific foundation for integrating climate change in planning, ecological restoration, and project management (Peterson et al. 2011; Raymond et al. 2013, 2014; Swanston et al. 2016). After identifying key vulnerabilities for each resource sector, scientists, land managers, and other stakeholders (box 1.1) convened five 2-day workshops in May and early June 2016 in Ogden, Utah (Uinta and Wasatch Front subregion), Boise, Idaho (Middle Rockies subregion), Salt Lake City, Utah (Plateaus subregion), Reno, Nevada (Great Basin region), and Idaho Falls, Idaho (Southern Greater Yellowstone subregion) to present and discuss the vulnerability assessment, and to elicit adaptation options from resource managers.

During these workshops, scientists and resource specialists presented information on climate change effects and current management practices for each of the resources. Facilitated dialogue was used to identify key sensitivities and adaptation options. Participants identified strategies (general approaches) and tactics (on-the-ground actions) for adapting resources and management practices to climate change, as well as opportunities for implementing these adaptation actions in projects, management plans, partnerships, and policies. Participants generally focused on adaptation options that can be implemented given our current scientific understanding of climate change effects, but they also identified research and monitoring that would benefit future efforts to assess vulnerability and guide management practices. Information from the assessment was also downscaled to identify the most significant vulnerabilities to climate change for priority resources in each subregion where appropriate. Facilitators captured information generated during the workshops with worksheets adapted from Swanston et al. (2016). Initial results from the workshops were augmented with continued dialogue with Federal agency resource specialists.

This publication contains a chapter on expected climatological changes in the IAP region, and one chapter for each of the resource sectors covered in the vulnerability assessment (water resources, fisheries, forest and nonforest vegetation, disturbance, wildlife, recreation, infrastructure, cultural resources, and ecosystem services). Each of the resource chapters includes a review of climate change effects, sensitivities, and current management practices. An additional chapter summarizes adaptation strategies and tactics that were compiled at the workshops (see Appendix 1 for author affiliations).

Resource managers and other decisionmakers can use this publication in several ways. First, the vulnerability assessment will provide information on climate change effects needed for national forest and national park planning, projects, conservation strategies, restoration, monitoring, and environmental effects analyses. Second, climate change sensitivities and adaptation options developed at the broad scale provide the scientific foundation for finer scale assessments, adaptation planning, and resource monitoring. We expect that over time, and as needs and funding align, appropriate adaptation options will be incorporated into plans and programs of Federal management units. Third, we anticipate that resource specialists will apply this assessment to incorporate climate-smart resource management and planning in land management throughout the region.

Adaptation planning is an ongoing and iterative process. Implementation may occur at critical times in the planning process, such as when managers revise USFS land management plans and other planning documents, or after the occurrence of extreme events and ecological disturbances (e.g., wildfire). We focus on adaptation options for the USFS and NPS, but information in this publication can be used by other land management agencies as well. Just as the IAP process has been adapted from previous vulnerability assessments and adaptation planning, it can be further adapted by other national forests and organizations, thus propagating climate-smart management across larger landscapes.

Toward an All-Lands Approach to Climate Change Adaptation

The USFS and NPS climate change strategies identify the need to build partnerships and work across jurisdictional boundaries when planning for adaptation. This concept of responding to the challenge of climate change with an “all-lands” approach is frequently mentioned, but a process for doing so is rarely defined. In addition to representatives from the USFS and NPS, several other agencies and organizations participated in the resource sector workshops. This type of partnership enables a coordinated and complementary approach to adaptation that crosses jurisdictional boundaries. The IAP also provides a venue for agencies to learn from the practices of others so that the most effective adaptation strategies can be identified.

Risks and vulnerabilities resulting from climate change and gaps in scientific knowledge and policy need to be assessed on a continual basis. Adaptation is a prominent focus of the IAP, with emphasis on creating resilience in human and natural systems. Communicating climate change information and engaging employees, partners, and the public in productive discussions is also an integral part of successfully responding to climate change. The need for partnerships and collaborations on climate change issues was clearly identified in the IAP. Sharing climate change information, vulnerability assessments, and adaptation strategies across administrative boundaries will contribute to the success of climate change responses throughout the Intermountain West.

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Chapter 2: Biogeographic, Cultural, and Historical Setting

Hanna K. Olson and Don W. Fallon

Introduction

The Intermountain Adaptation Partnership (IAP) encompasses unique landscapes within the Intermountain Region of the U.S. Forest Service (USFS), from rugged mountains to deep canyons, from alpine snowfields to wild and scenic rivers (fig. 1.1). The area defined by the boundaries of the Intermountain Region contains both private and Federally owned lands, including 12 national forests and 22 national parks. Before Euro-Americans settled this area, Native American tribes occupied the land for thousands of years. With Euro-American settlement came timber extraction, mining, grazing, water extraction, and increased recreation to the region. Urban growth has increased significantly during recent decades, bringing new businesses and development that affect socioeconomic and natural environments.

Climate, biogeography, natural resource conditions, and management issues differ considerably from Idaho to Nevada, and from western Wyoming to the southern border of Utah. To capture how these differences influence potential climate change effects and adaptation strategies, the IAP region was divided into six subregions that are detailed in this assessment: the Middle Rockies, Southern Greater Yellowstone, Uintas and Wasatch Front, Plateaus Great Basin and Semi Desert, and Intermountain Semi Desert subregions (fig. 1.1, table 2.1). The Intermountain Semi Desert contains no national forests, but is identified as a discrete area that may be of interest to those outside the USFS. Each subregion is briefly characterized in the next section.

Table 2.1—Subregions within national forests and national forests within subregions of the Intermountain Adaptation Partnership region.

National forest	Subregions	Number of subregions in a national forest
Ashley	Uintas and Wasatch Front, Plateaus	2
Boise	Middle Rockies	1
Bridger-Teton	Southern Greater Yellowstone	1
Caribou-Targhee	Middle Rockies, Southern Greater Yellowstone, Uintas and Wasatch Front	3
Dixie	Plateaus, Great Basin and Semi Desert	2
Fishlake	Plateaus, Great Basin and Semi Desert	2
Humboldt-Toiyabe	Great Basin and Semi Desert	1
Manti-La Sal	Uintas and Wasatch Front, Plateaus	2
Payette	Middle Rockies	1
Salmon-Challis	Middle Rockies	1
Sawtooth	Middle Rockies, Uintas and Wasatch Front	2
Uinta-Wasatch-Cache	Uintas and Wasatch Front, Plateaus, Great Basin and Semi Desert	3
Subregion	**National forest**	**Number of national forests in a subregion**
Middle Rockies	Boise, Caribou-Targhee, Payette, Salmon-Challis, Sawtooth	5
Southern Greater Yellowstone	Bridger-Teton, Caribou-Targhee	2
Uintas and Wasatch Front	Ashley, Caribou-Targhee, Manti-La Sal, Uinta-Wasatch-Cache, Sawtooth	5
Plateaus	Ashley, Dixie, Fishlake, Manti-La Sal, Uinta-Wasatch-Cache	5
Great Basin and Semi Desert	Dixie, Fishlake, Humboldt-Toiyabe, Uinta-Wasatch-Cache	4
Intermountain Semi Desert	None	0

Descriptions of Subregions

Middle Rockies Subregion

The Middle Rockies subregion is part of the Rocky Mountains and extends over 16 million acres of central Idaho (fig. 2.1). The subregion is characterized by rugged mountain ranges and intermontane valleys vegetated with coniferous forests, as well as sagebrush-steppe ecosystems in the lower elevations, particularly in the southern and eastern portions (fig. 2.2). The subregion includes the Payette, Salmon-Challis, Boise, and Sawtooth National Forests, and a small portion of the Caribou-Targhee National Forest. This area is bordered by the Centennial Mountains near the Montana-Idaho border, the Lemhi Mountains along the Continental Divide of the western Montana-Idaho border, the northeastern Beaverhead Mountains, and the Salmon River Mountains in the northern section of the subregion. The area extends southward to the Intermountain Semi Desert subregion, which is dominated by geographic features associated with the Snake River Plains volcanic fields. Designated wilderness areas encompass almost 1.5 million acres of this subregion.

Geologically, the area is relatively young with emplacement of Cretaceous igneous intrusions (batholiths) roughly 120 million years BP, and younger Columbia basalts on the western boundary. During the Pleistocene (roughly 10,000 to 130,000 years BP), mountain glaciers carved and gouged the bedrock while depositing glacial till and associated river deposits in the intermontane valleys. The modern mountain ranges are characterized by high elevation ridges and deeply incised river valleys, such as those associated with the Salmon River in the Frank Church River of No Return Wilderness (Demarchi 1994).

Numerous rivers run through the Middle Rockies subregion. The Salmon River, flowing westward and spanning

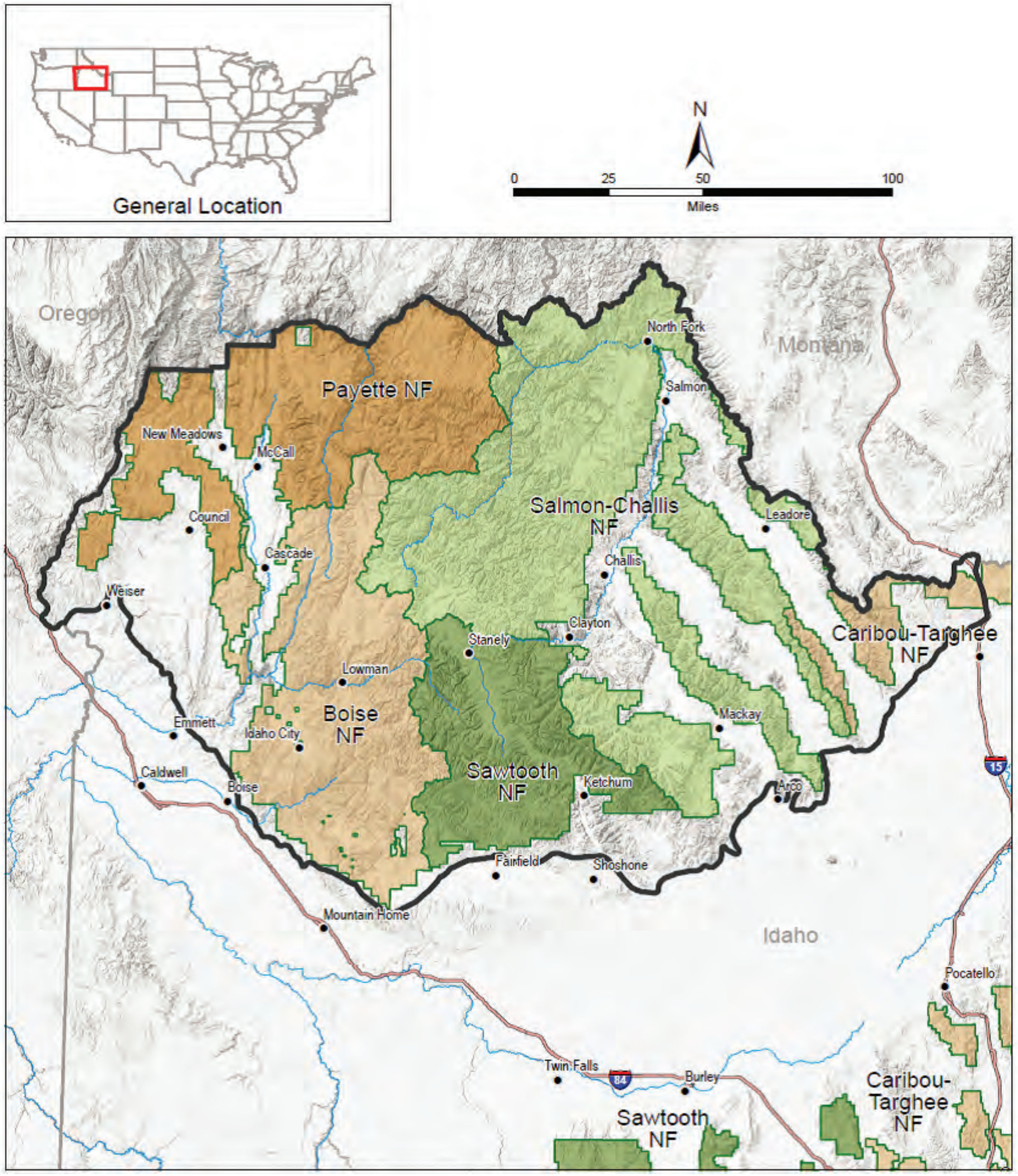

Figure 2.1—National forests within the Middle Rockies subregion of the Intermountain Adaptation Partnership region.

Figure 2.2—Rugged mountain topography in the Salmon-Challis National Forest. Subalpine forest and montane shrubs characterize the higher elevations (photo: U.S. Forest Service).

425 mi, divides northern Idaho from the remainder of the State. Major subbasins include the Little Salmon River, the Lemhi River, and the Big and Little Lost Rivers in east-central Idaho. Dry land farming occurs in valleys within the southeastern portion of central Idaho. The 1,000-mile-long Snake River enters the eastern edge of the subregion and is joined by the Salmon River near Riggins, Idaho, where river incision has created Hells Canyon, the deepest river gorge in North America. High flows of the merged rivers exceed those of the Colorado River (Idaho Department of Health and Welfare 1999). In the northwestern portion of the Middle Rockies subregion, the Boise River and Payette River are major tributaries of the Snake River. The Payette River leads to the popular recreation areas of Lake Cascade and Lake Payette. The Lemhi River is fed by the Bitterroot Range and the Big Lost River Range, and is a critical spawning habitat for Federally protected steelhead trout (*Oncorhynchus mykiss*) and Chinook salmon (*Oncorhynchus tshawytscha*) (Idaho Department of Health and Welfare 1999). The Big Lost River and the Little Lost River Range are named for their disappearance underground as they leave their valleys and flow into the Intermountain Semi Desert subregion.

Climate varies along a gradient between the western and eastern areas of central Idaho. Maritime atmospheric patterns are prevalent near the northwestern border of the subregion, delivering high precipitation that allows coniferous forests to thrive. Toward the southeastern border, the climate creates an arid environment that supports sagebrush and grassland ecosystems at lower elevations. Eastern Idaho experiences large temperature variation during the year, and precipitation differs considerably from the western portions of the subregion, with monsoonal summer moisture and snowier winters. The abrupt elevation gradients associated with the steep mountain ranges of central Idaho creates an orographic (rain-shadow) effect in which condensed moisture is deposited on the western or windward mountain slopes, and reduced moisture falls on leeward valley sides of the mountains.

Mixed conifer and subalpine forests are the dominant vegetation in the Middle Rockies. Heavily forested areas are most common in the northern portion of the subregion, progressing to more arid lowlands in the southeast. Dominant species include Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta* var. *latifolia*), grand fir (*Abies grandis*), subalpine fir (*A. lasiocarpa*), Engelmann spruce (*Picea engelmannii*), and quaking aspen (*Populus tremuloides*) (Brown and Chojnacky 1991). Of these species, Douglas-fir, ponderosa pine, lodgepole pine, grand fir, subalpine fir, and Engelmann spruce are commercially harvested (USDA FS 2016). Since 1952, ponderosa pine cover has decreased by 40 percent because of its high timber value (O'Laughlin et al. 1993). Conifer species with high ecological value but no commercial value include whitebark pine (*Pinus albicaulis* Engelm.), limber pine (*P. flexilis*), alpine larch (*Larix lyallii*), and western juniper (*Juniperus occidentalis*) (Brown and Chojnacky 1991).

Among the abundant shrub species are serviceberry (*Amelanchier alnifolia*), Rocky Mountain maple (*Acer glabrum*), tall Oregon-grape (*Berberis aquifolium*), snowbrush ceanothus (*Ceanothus velutinus*), and multiple species of sagebrush (*Artemisia* spp.) (Pyke et al. 2015; Robson and

Kingery 2006). Idaho fescue (*Festuca idahoensis*) and bluebunch wheatgrass (*Pseudoroegneria spicata*) are common grassland species. Conservation of rare plant species in the subregion is an important management responsibility (Tilley et al. 2013).

Over 300 animal species live in the Middle Rockies. Large mammals include Canada lynx (*Lynx canadensis*), grizzly bear (*Ursus arctos*), elk (*Cervus elaphus*), gray wolf (*Canis lupus*), bighorn sheep (*Ovis canadensis*), and moose (*Alces alces*). Smaller vertebrates include American beaver (*Castor canadensis*), American pika (*Ochotona princeps*), snowshoe hare (*Lepus americanus*), yellow-bellied marmot (*Marmota flaviventris*), and Rocky Mountain tailed frog (*Ascaphus montanus*) (Link et al. 2000). The Middle Rockies are home to over 400 bird species, including bald eagle (*Haliaeetus leucocephalus*), golden eagle (*Aquila chrysaetos*), osprey (*Pandion haliaetus*), multiple owl species, trumpeter swan (*Cygnus buccinator*), greater sage-grouse (*Centrocercus urophasianus*), and white-headed woodpecker (*Picoides albolarvatus*).

Fish rearing and spawning sites of both native and nonnative fish species are common in the rivers, lakes, and ponds of the Middle Rockies. Steelhead trout, cutthroat trout (*O. clarkii*), and bull trout (*Salvelinus confluentus*) are sensitive species found throughout the subregion. Nonnative lake trout (*S. namaycush*) and brook trout (*S. fontinalis*) were introduced into Idaho's lakes and streams during the 1900s and continue to thrive (Dillon and Grunder 2008). Since the 1880s, dams and reservoirs have altered water flows and decreased water quality in some rivers, leading to declines in the white sturgeon (*Acipenser transmontanus*) population (Dillon and Grunder 2008).

Before the 1900s, wildfires in the Middle Rockies subregion maintained grasslands and open forests in lower elevation and drier portions of the landscape. Historical fire frequencies were 10 to 20 years for ponderosa pine and dry Douglas-fir forests in Boise National Forest (Crane and Fischer 1986). In recent decades, grand fir and Douglas-fir have increased in ponderosa pine stands in response to decreased fire frequency. The resulting dense, multistoried stands are more susceptible to crown fires, insects, and fungal pathogens. Sagebrush communities generally have lower wildfire frequencies, but are increasingly affected by cheatgrass (*Bromus tectorum*) and other nonnative species. These annual species create fine fuels that facilitate more frequent fire, mostly to the detriment of native species.

Lodgepole pine, whitebark pine, and limber pine have undergone high mortality from mountain pine beetle (*Dendroctonus ponderosae*) outbreaks in much of central Idaho. A warmer climate has encouraged higher reproductive rates in the beetles and allowed them to survive at higher elevations (Gibson et al. 2008). Western spruce budworm (*Choristoneura occidentalis*) attacks Douglas-fir, grand fir, and pine, causing mortality and low vigor in host stands (Fellin and Dewey 1982). Balsam woolly adelgid (*Adelges piceae*) causes subalpine fir mortality and lower growth in grand fir (Lowrey 2015).

Forest diseases are especially prominent in conifer forests in the Middle Rockies. The nonnative fungus white pine blister rust (*Cronartium ribicola*) has caused extensive mortality in western white pine (*Pinus monticola*), whitebark pine, and limber pine (Cairns 2015). The formerly abundant western white pine has been mostly replaced by Douglas-fir and grand fir, driving forest succession toward more susceptible stand composition. Although efforts to eradicate blister rust have been unsuccessful, decades of natural selection have increased rust resistance in remnant western white pines, providing a foundation for regeneration of this species in the future (Schwandt et al. 2013). Parasitic dwarf mistletoe (*Arceuthobium* spp.) is also fairly common in coniferous forests. The spread rate of mistletoe has accelerated in dense, multistoried Douglas-fir stands because of the abundance of susceptible hosts and ease of mistletoe dispersal and regeneration. Long-term effects include growth reduction of the host and reduced forest productivity (Giunta et al. 2016).

No Native American communities or reservations reside within the Middle Rockies, although portions of national forests are traditional use areas. Historically, riverbanks in the Salmon-Challis National Forest provided fishing and foraging grounds for the Sheepeater Indians, the Nez Perce Tribe, and the Flathead Tribe. After the Lewis and Clark expedition during the early 19th century, assistance from Indian tribes opened the way for fur trappers, explorers, miners, ranchers, and settlers to populate what is now Lemhi County. Previously, the Whitebird band of the Nez Perce Tribe occupied portions of Payette National Forest, and utilized summer hunting and fishing grounds along the Little Salmon River. Other bands camped along the Little Salmon and Salmon Rivers as a primary source for salmon throughout the harvesting season. A wide variety of plant species provided materials for food and construction (Reddy 1993). In the mid-1800s, the Federal Government gained control of the land in Idaho, restricting the Nez Perce to the northwestern part of the State.

Resource-dependent economic activities in the Middle Rockies include livestock grazing, logging, recreation, and tourism. The gold rush of the mid-19th century brought settlers to the mountainous areas of the IAP region. The initial boom quickly died out, leaving only ghost towns to mark the once-promising gold and copper mines. Several mineral exploration projects are still operating and more have been recently proposed. Between the 1860s and 1870s, the livestock industry grew within the South Boise, Atlanta, and Deadwood mining districts (Jones 1990). After the gold rush, summer grazing activity extended beyond the outskirts of mining towns, and became established along the Boise and Payette river valleys (Jones 1990). The economic viability of livestock grazing has declined in recent decades, although large areas of national forest and other Federal lands still have grazing allotments. Exposure of bighorn sheep to cattle-borne diseases is a concern for wildlife managers, and programs are aimed at renewing the viability of bighorn sheep populations on Federal lands (USDA FS 2011).

Timber operations came to the IAP region during the "great buying rush" between 1899 and 1908. These operations supported the expanding railroad system with railroad ties, as well as traditional building products. By 1902, the Payette Lumber and Manufacturing Company had been established, with ponderosa pine as the main commodity. The company continued to expand throughout the early 20th century, resulting in more sawmills, higher lumber production, and a growing economy. However, timber production has declined significantly in the past 30 years. Counties south of the Salmon River currently contribute up to 11 percent of Idaho's overall timber harvest and 45 percent of the State's timber exports. Valley County provides the largest annual timber harvest in the State: 65 million board feet (Brandt et al. 2012).

Travel and tourism support a significant portion of the subregional economy. A study conducted in the Sawtooth National Recreation Area found that 77 percent of visitors traveled to the forest for recreational purposes such as viewing natural features, hiking, and driving for pleasure (Headwaters Economics 2014). In 2012, 6.5 million visitors to Idaho national forests (including outside the subregion) spent over $300 million on recreation activities.

Southern Greater Yellowstone Subregion

The Southern Greater Yellowstone subregion covers 6.5 million acres of eastern Idaho, and western Wyoming (fig. 2.3). Bridger-Teton National Forest and Caribou-Targhee National Forests are the only national forests in this subregion. The Bridger-Teton spans the eastern portion of the Idaho-Wyoming border from Jackson Hole, Wyoming, eastward toward west-central Wyoming and contains 3.4 million acres of watersheds and wildlands. Approximately 2 million acres of wilderness land, as well as Grand Teton National Park, are contained within the subregion. There are several designated wilderness areas located on USFS lands in the subregion, including the Teton Wilderness and Wind

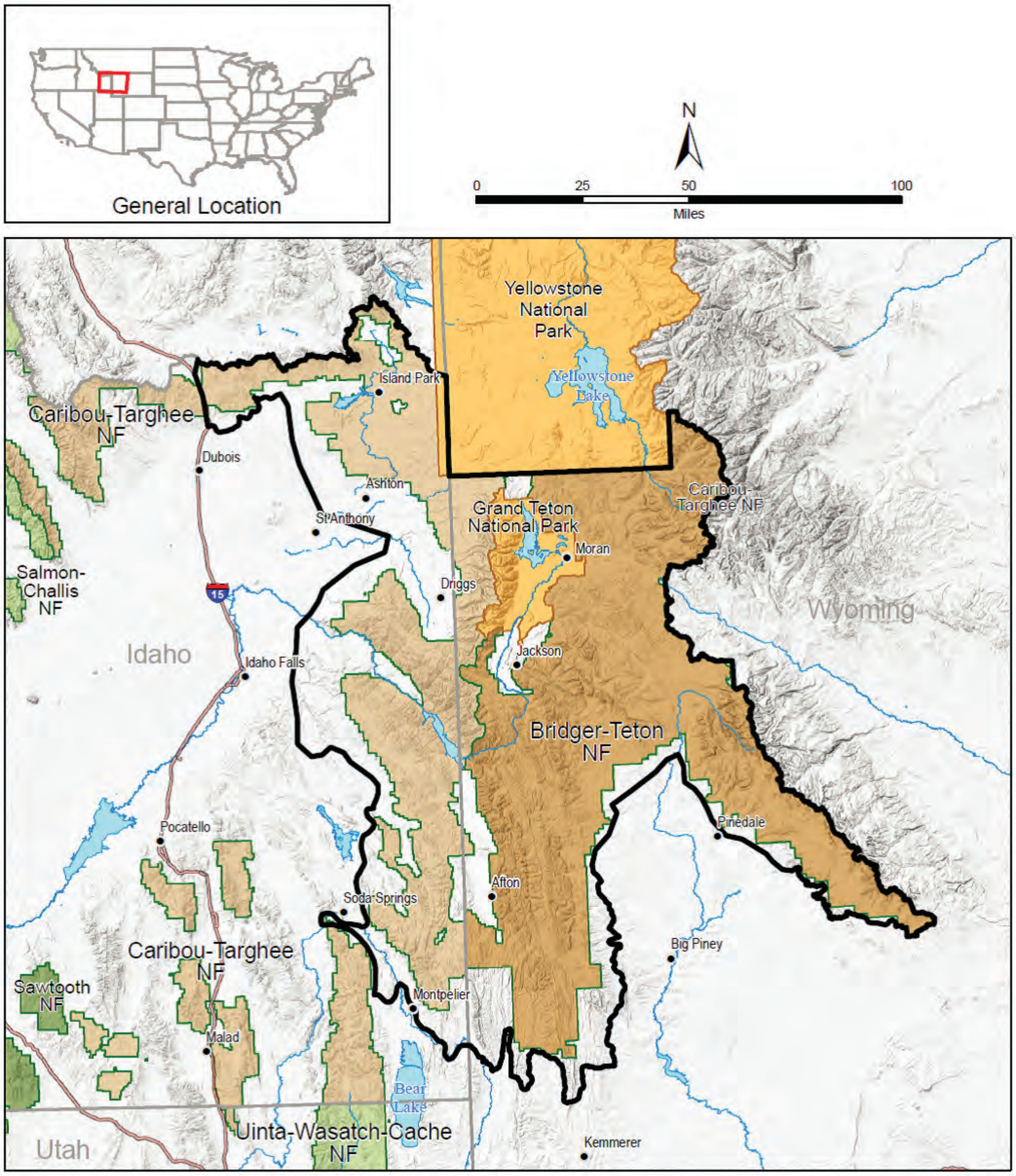

Figure 2.3—National forests and national parks within the Southern Greater Yellowstone subregion of the Intermountain Adaptation Partnership region.

River Range Wilderness in Wyoming, and two smaller wildernesses in Idaho: the Jedediah Smith Wilderness, known for karst limestone formations and caves, and the Wineger Hole Wilderness, which was set aside to protect grizzly bear habitat.

Physiography of this area reflects a wide variety of geologic mountain-building events. The subregion is part of the Greater Yellowstone Area, which extends south from the Centennial Mountains and Yellowstone National Park, through Grand Teton National Park, and southward to include the Wind River Range and Wyoming Range in Wyoming. The Centennial Mountains are a result of uplift and faulting that form steep, high-relief mountain ranges with sharp alpine ridges and cirques at high elevation. Faulting in the Centennial Mountains is fairly recent, and young faults are also present along the western border of Wyoming in the Teton Range, where active block faulting continues today. In the southeastern portions of the subregion, deformation and faulting produced the Wind River Range, with over 2,500 lakes in alpine and piedmont settings. Intermontane valleys include alluvial terraces and floodplains on the valley floor, and glacial till and moraines along the mountain flanks. The Wyoming Range, Caribou Range, and other smaller mountains of southeastern Idaho and western Wyoming were formed from low-angle thrust faulting associated with overthrust belt mountain building. Some smaller areas of volcanic activity produced lava flows and basalt in southeastern Idaho. The volcanic hotspot that underlies present-day Yellowstone National Park created volcanic tuff and tephra deposits in the Absaroka Range, and giant volcanic craters in the Island Park area. Glaciers covered most mountain ranges at times during the Pleistocene, carrying till and debris from the mouths of drainages to produce moraines that were dissected and buried by subsequent erosion and sedimentation from rivers and streams.

As elevation increases in the Southern Greater Yellowstone subregion, average temperatures decrease, and annual precipitation increases (Knight et al. 2014). Mountain ecosystems tend to be cool and moist, although mountain slopes facing south may experience dry environments similar to lower elevations. Direct solar radiation and increased rates of evaporation allow higher elevations to support more arid vegetation, such as mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) and grassland species (Knight et al. 2014). Alpine ecosystems are found on the uppermost ridges and peaks, dominated by alpine vegetation and stunted conifers. Subalpine ecosystems are typically coniferous forests with wildflower meadows, lush wetlands, and arid shrublands along mountain flanks (fig. 2.4). Overall, the steep and rugged topography of the mountain ranges provides conditions with 60 to 80 inches of annual precipitation in higher elevations and as little as 15 inches of precipitation at lower elevations. This translates to heavy snowfall at high elevations throughout the subregion, with prevailing winds dispersing snow accumulations on exposed ridges and slopes.

The largest river system in the subregion is the Snake River, including the North, South, and Henry's forks. This system drains to the Columbia River through the Intermountain Semi Desert subregion. To the southeast, the Green River, Sandy River, and Newfork River drain southward to the Colorado River system and the Pacific Ocean, while a small area in the northeastern portion of the subregion drains to the Gulf of Mexico. Smaller rivers, such as the Greys River, Blackfoot River, Portneuf River, and Hoback River, emanate from surrounding mountains and join the larger rivers in the valleys. Numerous reservoirs and piedmont lakes are located along the river network, including Island Park Reservoir in eastern Idaho, Palisades Reservoir near the Idaho-Wyoming border, and several lakes at the base of the Wind River Range.

Vegetation in the Southern Greater Yellowstone subregion varies from high-elevation alpine grasslands and shrublands, through vast coniferous subalpine forests, to sagebrush shrublands and agricultural lands at the lowest

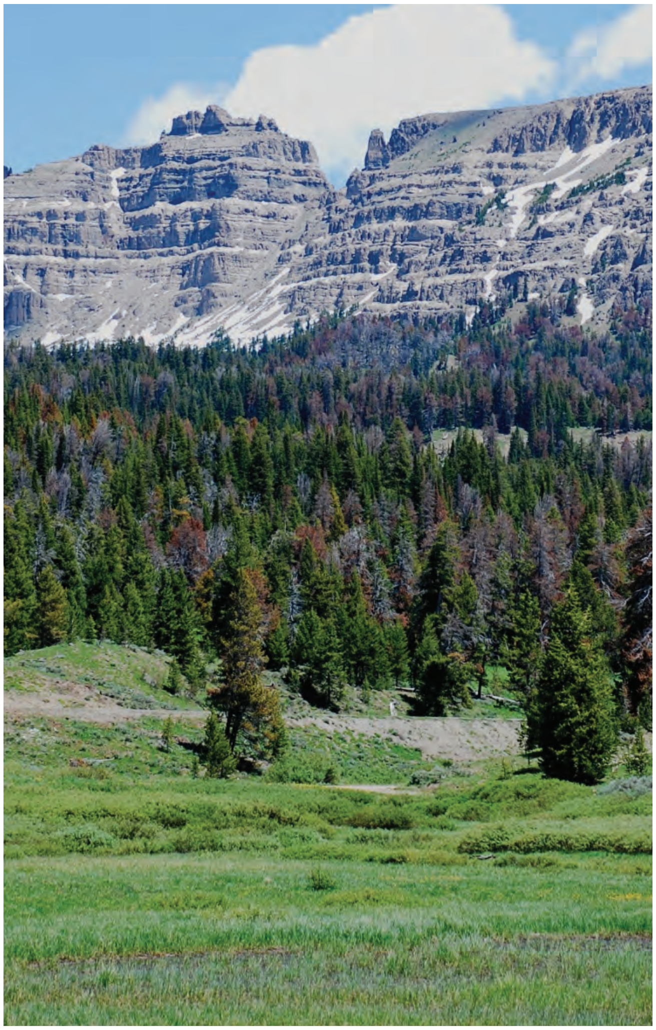

Figure 2.4—Complex mountain topography, alpine meadows, and dense coniferous forests, typical of the Southern Greater Yellowstone subregion of the Intermountain Adaptation Partnership region (photo: U.S. Forest Service).

elevations. At the uppermost elevations, high precipitation (mostly as snow), short growing seasons, and cold temperatures create a harsh environment where only stunted trees and hardy plants survive. Middle elevations are dominated by coniferous forests, typically Douglas-fir, lodgepole pine, Engelmann spruce, and subalpine fir. These forests were historically logged to provide railroad ties for the expanding railroad system to the south. Low elevations are dominated by several species of sagebrush. These areas are used as rangelands for small communities in the winter, as cold weather moves livestock to their lower elevation winter ranges (Blackwell and Reese 2001). In some cases, hay from surrounding agricultural areas is delivered to feed grounds in winter to reduce wildlife mortality. Stands of quaking aspen are found throughout middle elevations, providing important habitat for wildlife and subalpine herbaceous species.

Wildfire plays an important role in maintaining the biodiversity of terrestrial ecosystems. Since the big northern Idaho wildfires in 1910, fire suppression has been implemented to protect urban communities and other resources (Caribou-Targhee National Forest 2005). As a result, many conifer forests are relatively mature, in some locations blending with aspen woodlands, riparian zones, mountain meadows, and sagebrush-grassland habitats. Biodiversity in these ecosystems has decreased, promoting high-severity fires, loss of habitat for bighorn sheep and greater sage-grouse, and western balsam bark beetle (*Dryocoetes confusus*) outbreaks in subalpine fir. Prescribed fire has been implemented in some locations to reduce fuels, improve wildlife habitat, and increase habitat heterogeneity (Caribou-Targhee National Forest 2005).

White pine blister rust and mountain pine beetle have reduced whitebark pine populations near the northern border of the subregion. Whitebark pine provides forage for grizzly bear and black bear (*Ursus americanus*) during the winter. Mountain pine beetle has affected lodgepole pine populations, causing increased mortality throughout the Intermountain West. Douglas-fir and Engelmann spruce stands have suffered stunted growth and mortality from the spread of western spruce budworm.

About 100 species of mammals live within the subregion. Common rangeland and forest species include black bear, Rocky Mountain elk (*Cervus canadensis*), moose, mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), and bighorn sheep. Areas near Yellowstone National Park provide protection for grizzly bear and gray wolf. Small vertebrates include American pika, American beaver, wolverine (*Gulo gulo*), and numerous amphibians. Grassland ecosystems support large areas for livestock grazing. The National Elk Refuge was established in 1912 to provide feed, sanctuary, and habitat for one of the largest elk herds on Earth. In early fall, elk migrate from the surrounding uplands down to Jackson Hole, where hay from the surrounding communities is used as forage for the surviving elk.

Over 350 avian species reside within the subregion. Riparian and forest habitats provide nesting sites for bald eagle, golden eagle, peregrine falcon (*Falco peregrinus*), and other raptors. Greater sage-grouse occupies sagebrush-grassland ecosystems, and is a high-priority species for conservation. Trumpeter swan, sandhill crane (*Grus canadensis*), Canada geese (*Branta canadensis*), and many species of ducks are common in the wetlands of Bridger-Teton National Forest.

World-class fishing is supported along all rivers in the Southern Greater Yellowstone subregion. Cutthroat trout and mountain whitefish (*Prosopium williamsoni*) are indigenous species, whereas brook trout, brown trout (*Salmo trutta*), lake trout, and golden trout (*Oncorhynchus mykiss aguabonita*) have been introduced in many lakes throughout the river system.

Beginning around 11,000 years BP, bands of Shoshone, Blackfoot, and Bannock Indians occupied western portions of the subregion (State of Wyoming 2013). Farther east, nomadic hunters and gatherers migrated throughout the valleys and mountains of the Wind River and Absaroka Ranges. At the beginning of the 19th century, trappers and explorers began to frequent western Wyoming and started trading with the Indian tribes of the area. Over time, Native American tribes were confined to smaller portions of the subregion.

After the Lewis and Clark expedition, John Colter traversed the Continental Divide and descended into Jackson Hole during the winter of 1807–1808 (State of Wyoming 2013). Other settlers soon followed, establishing trading posts along the Wind River, Gros Ventre, Teton, and Wyoming Ranges. Wyoming became the focus for Governmental expeditions, fur trapping, and hunting for the next 30 years. Independent trappers began to appear in the Jackson Hole Valley, changing the socioeconomic trajectory of the area. With increasing settlement of western Wyoming, forest reserves were established to protect water, wood, wildlife, recreation, and forage. These reserves would eventually become the Caribou-Targhee and Bridger-Teton National Forests. The Civilian Conservation Corps contributed to an increase in national forest infrastructure and expansion of the timber industry. Timber has remained an important component of local economies, although the volume of harvests has decreased greatly in the past 30 years. Thinning is now used to reduce stand densities and improve wildlife habitat.

The gold rush of 1870, when gold was found near Caribou Mountain, sparked a 20-year run of gold mining in eastern Idaho and western Wyoming, after which mining of phosphate deposits for fertilizers was conducted in the Caribou-Targhee National Forest for 50 years. Recently, exploration for oil and gas reserves has been conducted along the southern portion of the subregion, mostly in the surrounding basins.

Tourism is a vital industry in the area, with Jackson Hole serving as a major entrance for millions of visitors each year to Grand Teton and Yellowstone National Parks. The Grand Targhee and Jackson Hole resorts attract skiers from around the world. Other activities, such as camping, hunting, and fishing, are popular summer activities for visitors to the subregion.

Uintas and Wasatch Front Subregion

The northern portion of the Uintas and Wasatch Front subregion includes the Albion, Black Pine, Raft River, and Sublett Mountains along the Idaho-Utah border. Sagebrush and grasslands dominate the low to middle elevations that surround islands of higher elevation coniferous forests. Farther south, the rugged Wasatch Front is the western border of the subregion, with high ridges and an abrupt transition from high desert to alpine ecosystems (fig. 2.5). National forests in the subregion are the Uinta-Wasatch-Cache National Forest, Ashley National Forest, and southern portions of the Sawtooth and Caribou-Targhee National Forests (fig. 2.6). Over 600,000 acres are dedicated to wilderness, including the Wellsville Mountain Wilderness. The Curlew National Grassland encompasses over 47,000 acres.

The complex topography of the subregion has resulted from millions of years of mountain building, sedimentation, and erosion. Warm, shallow water once covered the area of the Wasatch and Uinta Mountains, depositing thick layers of fossil-bearing gray sediment. Once compression of the North American Plate began, thrust faulting and buckling on the eastern half of the Wasatch Front created highly deformed mountain ranges that shed sediment into the lower valleys to create the sandstone and limestone valleys of the present day (Atwood 2012). Local and regional uplift brought the landscape to its current position, allowing rivers and glaciers to carve steep slopes and deposit high volumes of sediment within the surrounding basins and ranges. The Wasatch fault displays faulting along the base of the steep Wasatch Front where fault scarps have displaced beach deposits of ancient Lake Bonneville. This lake was the larger precursor to the present-day Great Salt Lake, forming from meltwaters during warming periods of the Pleistocene.

Near the southeastern corner of the subregion, the Green River flows into Flaming Gorge Reservoir, continuing southeastward and emerging near Vernal, Utah. Numerous tributaries that run through the Ashley and Uinta-Wasatch-Cache National Forests provide water for critical watersheds, including Strawberry Reservoir, where diversions and tunnels carry the water from the Uinta Basin and the Colorado River drainage to the Wasatch Front for agricultural and municipal use.

The northern portion of the subregion has hot summers with little precipitation and winters that receive high amounts of precipitation at higher elevations, but less at lower elevations. The southern portion experiences both dry summer and wet winter patterns, as well as wet summer and dry winter patterns (Shaw and Long 2007). The western portion of the subregion has average summer temperatures above 90 °F and average winter temperatures below 20 °F. The eastern portion typically experiences wet summers and dry winters, with annual precipitation as low as 7 to 10 inches at lower elevations.

Coniferous forests are prominent in the southern portions of the subregion, especially in the Wasatch and Uinta Mountains. Scattered patches of coniferous forests occur along the middle to high slopes of the northern mountain ranges, which are surrounded by sage-steppe ecosystems in valleys. Dominant conifer species, including subalpine fir, Engelmann spruce, lodgepole pine, and Douglas-fir, account for a large proportion of the forest types (Heyerdahl et

Figure 2.5—U-shaped valleys, rugged mountain ranges, scattered alpine lakes, and dense coniferous forests, which are common in the Uintas and Wasatch Front subregion of the Intermountain Adaptation Partnership region (photo: U.S. Forest Service).

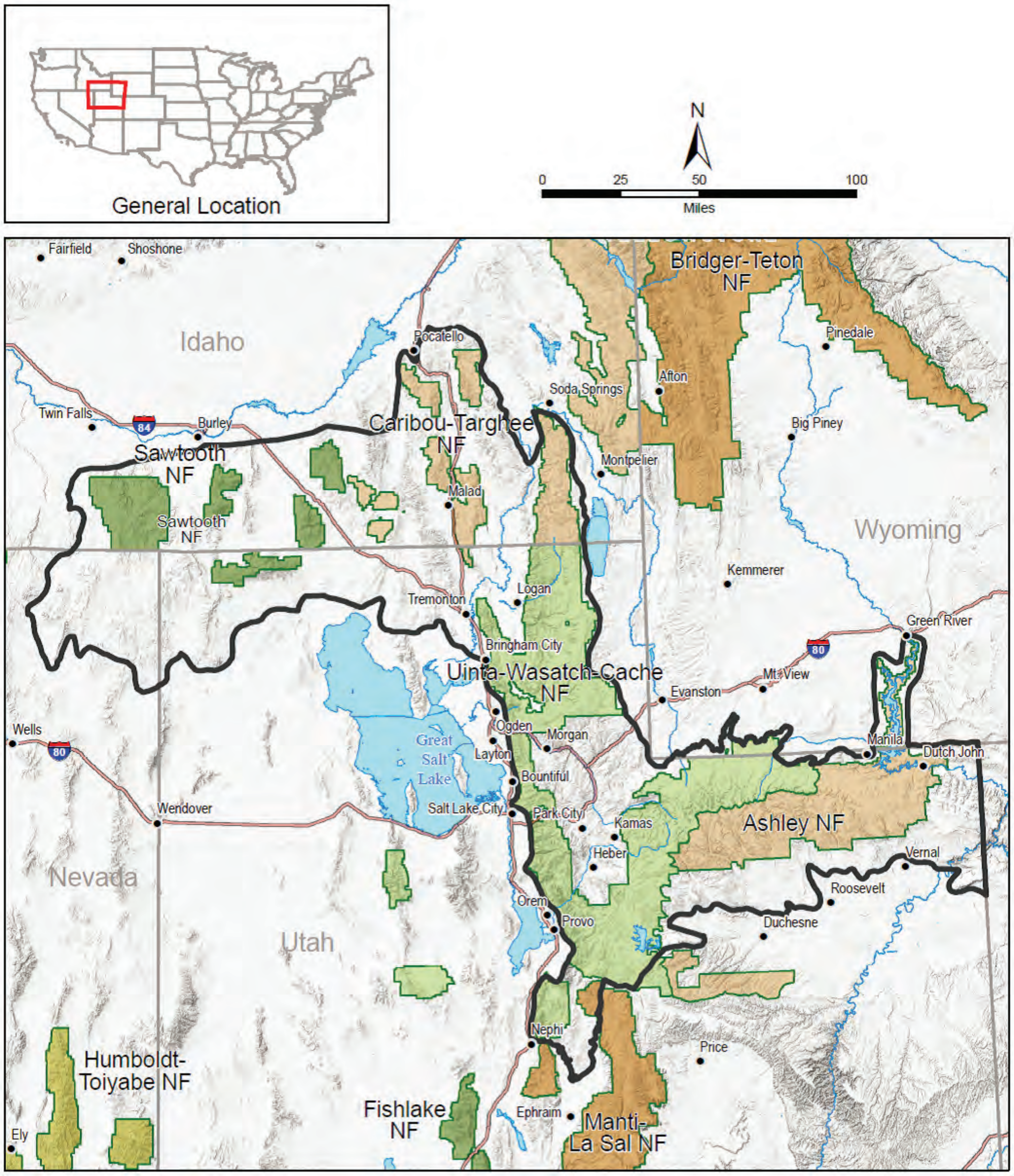

Figure 2.6—National forests within the Uintas and Wasatch Front subregion of the Intermountain Adaptation Partnership region.

al. 2011). Utah juniper (*Juniperus osteosperma*) and pinyon pine (*Pinus edulis*) occupy arid, shallow, and rocky soils at lower elevation. Lower elevations also provide habitat for Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) and mountain big sagebrush, as well as bluebunch wheatgrass, bottlebrush squirreltail (*Elymus elymoides*), Sandberg bluegrass (*Poa sandbergii*), and Thurber's needlegrass (*Achnatherum thurberuanum*). These shrub-steppe systems provide habitat for small fauna, ungulates, and local populations of greater sage-grouse.

Wildfire regimes influence the overall health and biodiversity of all ecosystems, with most fires occurring during July through October (Morris 2006). Fire exclusion in the Wasatch Range and Uinta Mountains has mixed conifer forests that are relatively mature and dense with high fuel loadings, making them susceptible to crown fire. Low-vigor stands in Uinta-Wasatch-Cache National Forest provide suitable conditions for bark beetle outbreaks, such as the outbreak in 1980 when beetle populations were extremely high and conditions for beetle survival were optimum (Shaw and Long 2007). These forests have been subject to outbreaks by mountain pine beetle and other beetle species during the past 15 years.

Moose are common in wetlands of most intermontane valleys. Mountainous topography provides habitat for elk, black bear, bighorn sheep, mule deer, and small populations of mountain goats (*Oreamnos americanus*). Sensitive species within the Albion Range include mountain lion (*Felis concolor*) and Canada lynx. Small vertebrates include lizards, rattlesnakes, sagebrush vole (*Lemmiscus curtatus*), and muskrat (*Ondatra zibethicus*).

Rivers, streams, creeks, and reservoirs throughout the Uintas and Wasatch Front subregion support both native and nonnative fish. Colorado River cutthroat trout (*O. clarkii pleuriticus*) is native to the Green River watershed, and the Bonneville cutthroat trout (*O. c. utah*) is native to other drainages. These species attract anglers from around the world for recreational fishing. Nonnative fish include numerous trout and bass species, kokanee salmon (*O. nerka*), walleye (*Sander vitreus*), and yellow perch (*Perca flavescens*).

Numerous avian species inhabit various ecosystems of the subregion. Olive-sided flycatcher (*Contopus cooperi*), chipping sparrow (*Spizella passerina*), and chickadees (*Poecile* spp.) are common in subalpine forests. Raptors, including red-tailed hawk (*Buteo jamaicensis*), golden eagle, and bald eagle, populate low rangelands that border the mountains. Along the Wasatch Front, hermit thrush (*Catharus guttatus*), fox sparrow (*Passerella iliaca*), mountain bluebird (*Sialia currucoides*), and sandhill crane are common near small reservoirs and streams. In the Uinta Mountains, alpine habitat is occupied by pine grosbeak (*Pinicola enucleator*), three-toed woodpecker (*Picoides dorsalis*), and gray jay (*Perisoreus canadensis*). Many species of shorebirds and waterfowl populate reservoirs across the subregion.

Native American tribes once lived throughout the area. In 1500, the Northern Utes occupied central Utah, western Colorado, southern Wyoming, and northern New Mexico. Utah Valley with its abundant supply of fish and other natural resources supported most of the population (Simmons 2000). With the acquisition of horses in 1600, the Utes were able to extend their range and travel to the Great Plains to hunt American bison (*Bison bison*). The Uintah and Ouray Indian Reservation is now home to the Ute Tribe and is situated south of the Ashley National Forest.

Agriculture accounts for a large portion of the economy. The animal industry is the single largest sector of farm income in Utah. River valleys and cultivated fields provide fertile soils for the production of hay, corn, barley, and a variety of fruit. Orchards of apples, apricots, and peaches are scattered throughout the subregion and concentrated along the Wasatch Front. In the southeastern portion of the subregion, melons and other fruits provide economic benefits to smaller communities. Specialty products such as soap and honey also contribute agricultural income in some communities.

Watersheds throughout the subregion are an important source of water for municipal, industrial, and recreational use, and for hydroelectric power. Flaming Gorge National Recreation Area, Strawberry Reservoir, and other smaller reservoirs provide these water resources, as well as popular destinations for recreation. Watershed and groundwater management are a component of resource management for urban populations along the Wasatch Front; water supplies are decreasing with increasing urban populations, making water conservation a significant concern. The Bear River, Jordan River, Weber River, and Ogden River are sources for this water, relying on dams and diversions to create power and allocate water resources. Regulations restricting construction, wastewater, and livestock operations help ensure adequate water supplies and water quality, although overdraft has occurred in aquifers in northern Utah since 1985 (Burden 2015).

Mining projects have been proposed throughout the subregion, including sites that are focused on hard rock such as gold or copper mining, and soft rock such as phosphate mining. Drilling for oil and gas has expanded, including proposed drilling of up to 400 new wells over a 20-year period in the Vernal Basin area. About 50 active oil and gas wells are currently in national forest lands within the subregion. Coal mining is a major industry, with coal fields scattered throughout the subregion. Tourism continues to provide economic stimulus to many mountainous areas along the Wasatch Front. Several world-class ski resorts such as Snowbird, Alta, and Park City serve local and international enthusiasts. Snowbasin and Park City hosted the 2002 Olympic Games.

Plateaus Subregion

The Plateaus subregion covers the southern half of Utah and a small portion of western Colorado, including Ashley, Manti-La Sal, Fishlake, and Uinta-Wasatch-Cache, Dixie National Forests, as well as Zion, Bryce Canyon, Capitol Reef, Arches, and Canyonlands National Parks (fig. 2.7). Rugged mountain landscapes contrast with the red-rock desert of Utah badlands, where millions of years of erosion have carved steep canyons and intricate rock formations through the sandstone and carbonate composition of the Colorado Plateau. About 150,000 acres are devoted to wilderness. Mountain ranges, plateaus, cliffs, and canyons characterize the rugged landscape (fig. 2.8), providing recreational and economic benefits for surrounding communities.

In the northwestern portion of the Plateaus subregion, Manti-La Sal National Forest contains the La Sal, Manti, North Horn, and Abajo Mountains. Rugged topography, alpine meadows, and forests cover these north-south trending ranges. The Tushar Mountain Range in Fishlake National Forest provides the basin for Fish Lake, which is a popular location for summer activities. Dixie National Forest contains white cliffs, red canyons, and several mountain peaks covered by dense forests and desert shrublands. Sedimentary rocks are pronounced at Cedar Breaks National Monument and at adjacent national parks, Glenwood Canyon National Recreation Area, and Grand Staircase-Escalante National Monument.

The major river network in the Plateaus subregion belongs to the Green and Colorado River system. Major tributaries flow through the surrounding lowlands and empty into Lake Powell. The Dirty Devil, Virgin, and San Juan Rivers are smaller tributaries that are locally important. The north-to-south running Green River joins the Colorado River in Canyonlands National Park. The Colorado River then flows to the southwest, carving steep cliffs through sandstone bedrock and continuing into Arizona. Glen Canyon National Recreation Area contains the second largest reservoir in the United States, providing hydroelectric power, water resources, and recreation. The westerly

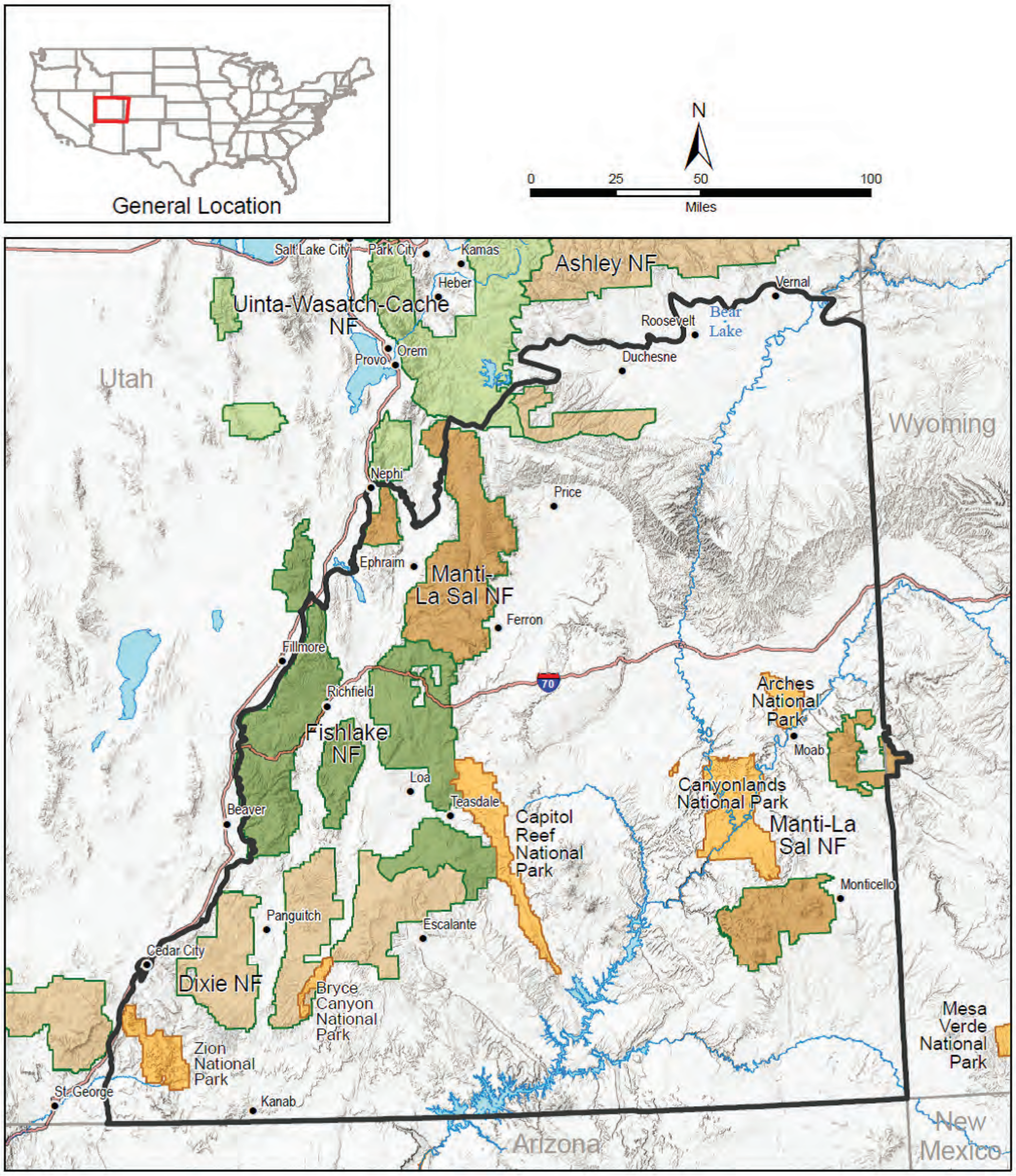

Figure 2.7—National forests and national parks within the Plateaus subregion of the Intermountain Adaptation Partnership region.

Figure 2.8—A red-rock landscape in the Plateaus subregion of the Intermountain Adaptation Partnership region. Steep cliffs line canyons that have been powerfully eroded throughout geologic history (photo: U.S. Forest Service).

flowing San Juan River begins in southwestern Colorado, flowing southeast until it meets the Colorado River near the mouth of Glen Canyon.

The Colorado Plateau is the dominant physiographic feature of this area, characterized by isolated buttes, mesas, plateaus, steep escarpments and cliffs, and gently folded sedimentary rocks. Several small mountain ranges such as the La Sal Mountains and Henry Mountains provide higher elevations from the surrounding lowlands, supplying water to the tributaries. Millions of years of evaporate deposition, folding, wind and water erosion, and salt deformation formed the diverse landscape. Between 70 and 265 million years BP, a shallow marine depositional environment covered the Colorado Plateau, forming limestone, sandstone, shales, marine fossils, and salt deposits (Harris et al. 1997).

Erosion processes, such as by wind and rivers, shaped the bedrock and topography of this area. Stream incisions dissect this relatively flat area through down-cutting and headward erosion processes. Melting of Pleistocene glaciers provided large volumes of water to be carried throughout the Colorado River network, and incised drainages. As uplift continued, river incision further carved deep canyons throughout the flat landscape, creating landmarks that can be observed today (Harris et al. 1997). Strong winds have eroded the smooth arches and other geologic formations in Arches National Park and Natural Bridges National Monument (Harris et al. 1997).

Dominant ecosystems of the Plateaus subregion include coniferous and deciduous forests at higher elevations, and woodlands, mountain shrub communities, sagebrush shrublands, grasslands, and desert ecosystems at lower elevations. Other more isolated ecosystems are also important including riparian wetlands, and unique niches within the associated canyons, cliffs, and talus slopes. High mountain ranges support subalpine ecosystems of coniferous and deciduous forests throughout the western portion of the subregion and in the La Sal and Henry Mountains. Coniferous forests of ponderosa pine, Douglas-fir, white fir (*Abies concolor*), Engelmann spruce, and limber pine occupy mid- to upper slopes. Mountain shrub communities intermix with forests, and are dominated by understory layers of mountain big sagebrush, Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*), common snowberry (*Symphoricarpos albus*), and serviceberry (*Amelanchier alnifolia*). Deciduous woodlands of pinyon pine, Utah juniper, quaking aspen, and Gambel oak (*Quercus gambelii*) exist throughout the subregion and mix with the sagebrush shrublands and agricultural grassland ecosystems at lower elevations. These stands contain understory layers of black sagebrush (*Artemisia nova*), mountain big sagebrush, and curl-leaf mountain mahogany (*Cercocarpus ledifolius*) (Mohlenbrock 2006). Utah juniper has encroached into sagebrush areas, depleting habitat of greater sage-grouse. Riparian areas create hotspots of biodiversity for flora and fauna, and help moderate flooding, sediment deposition, and water temperature (Knight et al. 2014). Riparian ecosystems are vulnerable to damage from livestock grazing and construction activities for roads and other infrastructure (Utah Division of Wildlife Resources 1991).

Some 480 plant species are found in the subregion. Common shrubs include mountain big sagebrush, black sagebrush, greenleaf manzanita (*Arctostaphylos patula*), fourwing saltbush (*Atriplex canescens*), rubber rabbitbrush (*Ericameria nauseosa*), antelope bitterbrush (*Purshia tridentata*), Mormon tea (*Ephedra viridis*), and greasewood (*Sarcobatus vermiculatus*) (Mohlenbrock 2006). Grasses include Salina wildrye (*Leymus salinus*), galleta (*Hilaria jamesii*), and purple three-awn (*Aristida purpurea*) (West 1983). Many of these species are tolerant of high salt concentration in low-elevation soils, especially ancient lake beds.

A particularly fragile feature of desert ecosystems is known as a “cryptobiotic crust.” Cyanobacteria and other organisms create these crusts on the soil surface where they live and retain carbon, fix nitrogen, and stabilize soil. These crusts thicken through time, providing nutrients to the dry soil below. The crust is vulnerable to disturbances (e.g., human footprints, vehicles) that disrupt its structure and reduce plant growth.

Large mammal species include mule deer, bighorn sheep, elk, mountain lion, black bear, and coyote (*Canis latrans*). Smaller vertebrates include red squirrel (*Tamiasciurus hudsonicus*), hoary bat (*Lasiurus cinereus*), pinyon mouse (*Peromyscus truei*), and desert cottontail (*Sylvilagus audubonii*). Bird species include red-tailed hawk, northern goshawk (*Accipiter gentilis*), Cooper’s hawk (*A. cooperi*), wild turkey (*Meleagris gallopavo*), boreal owl (*Aegolius funereus*), and numerous warblers. Amphibians and reptiles include tiger salamander (*Ambystoma tigrinum*) and milk snake (*Lempropeltis triangulum*) (West 1983).

The Plateaus subregion contains diverse fisheries in streams, lakes, and reservoirs. Common species of fish include rainbow trout (*Oncorhynchus mykiss*), cutthroat trout, lake trout, brook trout, speckled dace (*Rhinichthys osculus*), desert sucker (*Catostomus clarki*), and yellow perch. The Virgin River system provides habitat for the rare Virgin River chub (*Gila seminude*), Virgin River spinedace (*Lepidomeda mollispinis*), and woundfin (*Plagopterus argentissimus*). Nonnative fish, stream diversions, and poor water quality have reduced the abundance of these species.

Native Americans arrived in the Plateaus subregion around 12,500 years BP. Hunting of mammoths, giant sloths, and American bison sustained these peoples until the megafauna became extinct around 8,000 years BP, when the Puebloan people emerged and populated the entire region (Hatt 2014). Native Americans had diverse lifeways focused on hunting, fishing, food gathering, and eventually agriculture. Near the end of the 19th century, pioneers began to settle southeastern Utah for mineral extraction, farming, and ranching (Hatt 2014). Native American populations were greatly reduced following Euro-American contact. Currently, the Ute Indians and Navajo Nation have large reservations within the subregion.

Geologic evolution of the subregion created extensive deposits of coal, oil, gas, tar sands, oil shale, uranium, and potash (Hatt 2014). Coal beds have allowed the subregion to become a major contributor to U.S. energy production. On a local scale, coal, oil, and gas industries support economic development. Renewable energy sources include wind, hydroelectric, geothermal, and solar (Hatt 2014). In 2010, Ashley National Forest sold more than 1.3 million cubic feet of timber (Ashley National Forest 2010), representing a significant source of income for local communities.

National parks, national forests, and other lands contribute significantly to the tourism economy of the Plateaus subregion, attracting millions of visitors, of which two-thirds are from out of state. Diverse landscapes from alpine forests to the red-rock deserts provide a wide range of attractions for recreation and tourism. Summer offers hunting, fishing, hiking, mountain biking, and off-road travel, and winter attracts skiers, snowmobilers, and other winter sport enthusiasts.

Great Basin and Semi Desert Subregion

The Great Basin and Semi Desert subregion is the largest subregion, occupying over 100 million acres, and covering most of Nevada, the western half of Utah, small sections of southern Idaho, and portions of east-central California (fig. 2.9). Sections of Humboldt-Toiyabe National Forest are distributed throughout Nevada and parts of east-central California. The western half of the Dixie National Forest and the northern tip of the Fishlake National Forest are included near the eastern border of the subregion.

Between 300 and 800 million years BP, deep oceans covered western Utah, depositing limestone and dolomite sediments. These deposits were buried by thick layers of shale, forming large coal beds that underlie much of the subregion. Between 18 and 40 million years BP, volcanism formed large calderas, cinder cones, and lava flows throughout Nevada and western Utah. Large areas of mineral deposits (silver, gold, molybdenum, zinc, beryllium, iron, and copper) were formed in hydrothermal veins and host rock. Around 65 million years BP, Utah began to

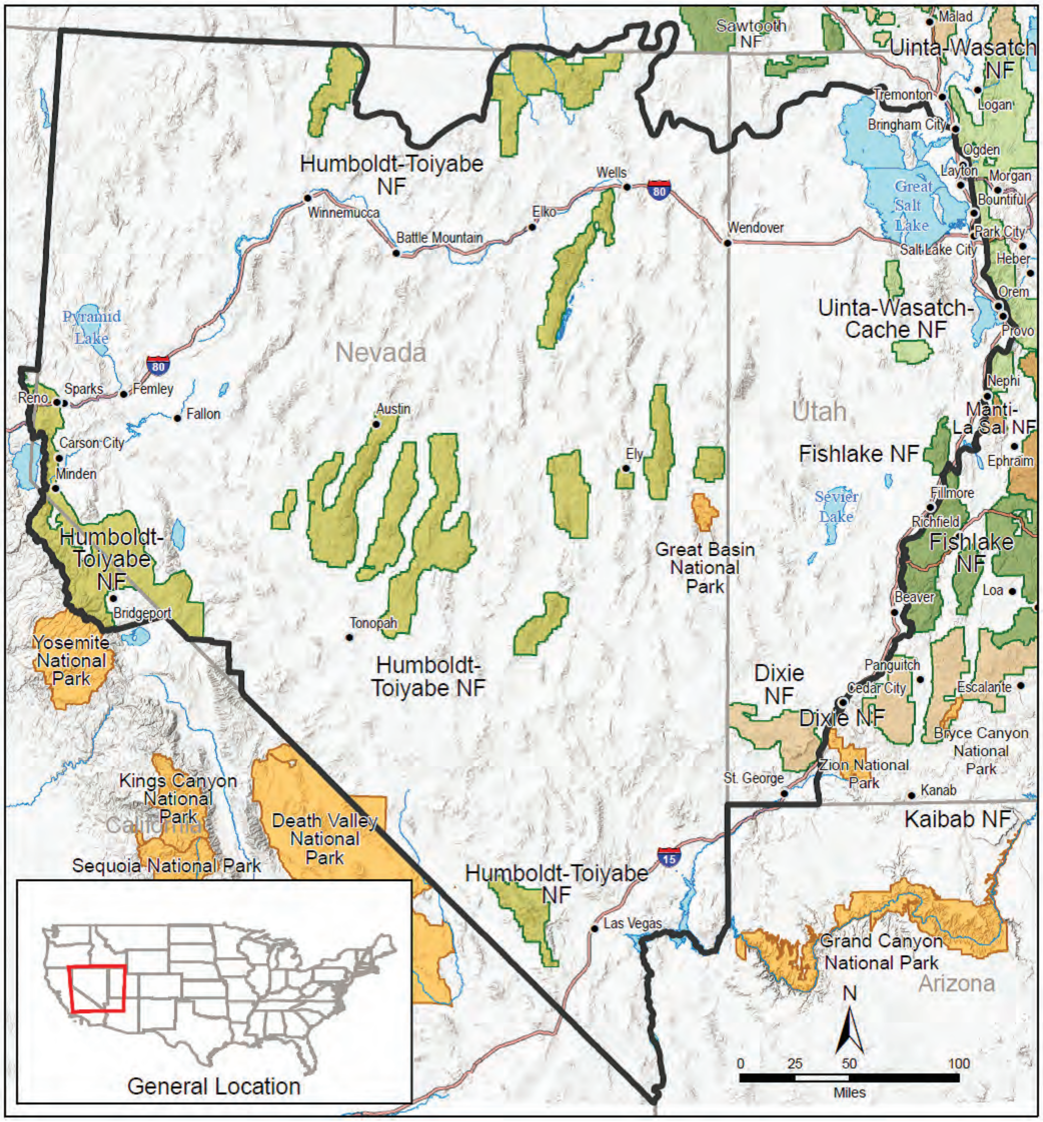

Figure 2.9—National forests and national parks within the Great Basin and Semi Desert subregion of the Intermountain Adaptation Partnership region.

sink and extensional faulting produced the basin-and-range topography of the Great Basin (Black 2011). More than 150 different mountain ranges are scattered throughout Nevada and Utah, including the Schell Creek Range, Toiyabe Range, Ruby Mountains, Shoshone Mountains, and Snake Range. These mountains are typically isolated and surrounded by intervening lowlands.

Around 10,000 years BP, melting glaciers of the Rocky Mountains and Sierra Nevada filled valleys of the Great Basin (Black 2011). Lake Bonneville and Lake Lahontan formed, covering most of western Utah. As climate warmed, both lakes evaporated and left remnant lakes (e.g., Sevier Lake and the Great Salt Lake from Lake Bonneville), as well as numerous dry playas.

Climate in the Great Basin and Semi Desert subregion is mostly desert and semiarid. The high Sierra Nevada traps moisture coming from the Pacific Ocean, creating a significant rain-shadow effect that makes Nevada the driest State in the United States. Average temperatures in northwestern Nevada are about 50 °F, with hot, dry summers and moderately cool winters (WRCC 2016). Farther south, average temperatures are about 65 °F; summers are long and hot, and winters are short and mild. Little precipitation falls in the southern part of the subregion, whereas the northwestern portion receives more precipitation because of proximity to the Sierra Nevada.

The Humboldt, Colorado, Sevier, and Truckee Rivers are the major river networks in the subregion. Smaller river networks include the Carson and Walker Rivers. Supplied with water from the Rocky Mountains to the north and east, the Colorado River flows in the southeastern portion of the subregion. The Humboldt River runs 290 miles through northern Nevada (the longest U.S. river that exists entirely within one State), and drains into the Humboldt Sink, a playa in western Nevada. The headwaters of the Humboldt River drain the East Humboldt and Jarbidge Ranges, and the river continues westward, gathering water from scattered tributaries along the way during the spring and losing surface water to groundwater during much of the rest of the year. The Sevier River is Utah's longest river, flowing 279 miles through western Utah and emptying into the nearly dry Sevier Lake (Seligman et al. 2008).

With elevations ranging from 4,100 to 13,065 feet, the Great Basin and Semi Desert subregion exhibits a broad spectrum of ecosystems. High elevations contain a mixture of alpine, subalpine, woodland, riparian, and shrub habitats. Subalpine ecosystems include quaking aspen woodlands, coniferous forests, pinyon-juniper woodlands, and mountain shrublands. Aspen woodlands dominate more than 250,000 acres and are commonly found between 5,200 and 10,500 feet, providing wildlife habitat, areas for livestock grazing, and recreation opportunities. Lower elevations are dominated by sagebrush-steppe ecosystems (fig. 2.10), which encompass most of the subregion, and include numerous small spring-fed riparian and wetland areas.

Mountain shrub communities of mountain big sagebrush, serviceberry, Gambel oak, and many other species occupy mountain slopes at 5,000 to 9,000 feet elevation. These are the most widespread communities in the subregion, providing nesting, food resources, and shelter for many vertebrate and invertebrate species. Riparian zones are common along the lower portions of the mountain ranges in Humboldt-Toiyabe National Forest. Springs, rivers, creeks, and lakes offer moist conditions for grasses and forbs and habitat for mammals, migratory songbirds, and wildflowers.

Coniferous forests, including bristlecone pine (*Pinus longaeva*), limber pine, whitebark pine, and ponderosa pine, occur at mid- to high elevations. In the eastern Sierra Nevada, coniferous forests also include Jeffrey pine (*Pinus jeffreyi*), lodgepole pine, western white pine, Douglas-fir, white fir, and Shasta red fir (*Abies magnifica*). Pinyon-juniper woodlands exist at middle elevations, dominated

Figure 2.10—Sagebrush and desert shrub habitats characteristic of the Great Basin and Semi Desert subregion of the Intermountain Adaptation Partnership region (photo: U.S. Geological Survey).

by pinyon pine and Utah juniper. These woodlands provide habitat for mule deer, desert cottontail, pinyon jay (*Gymnorhinus cyanocephalus*), and Clark's nutcracker (*Nucifraga columbiana*). Expansion of pinyon-juniper woodlands has displaced some shrub-steppe habitat, and cutting and mechanical treatments are used to control the extent of woodlands in some locations.

Sagebrush is common throughout the Great Basin and Semi Desert subregion, providing habitat for sage sparrow (*Artemisiospiza belli*), sage thrasher (*Oreoscoptes montanus*), loggerhead shrike (*Lanius ludovicianus*), burrowing owl (*Athene cunicularia*), and greater sage-grouse. Both large and small vertebrates, including pronghorn and mule deer, inhabit sagebrush ecosystems.

Other large mammals in this subregion include desert (*Ovis canadensis nelsoni*), California (*O.c. californiana*), Rocky Mountain (*O.c. canadensis*), and Sierra Nevada (*O.c. sierra*) bighorn sheep; elk; mountain goat; black bear; and mountain lion. Small mammals include several species of rabbits, Sierra Nevada red fox (*Vulpes vulpes necator*), coyote, bobcat (*Lynx rufus*), Palmer's chipmunk (*Tamias palmeri*), American marten (*Martes americana*), and numerous bat species. Wild horses and burros are common across the entire State, competing with wildlife and livestock for scarce forage. Birds in the subregion include greater sage-grouse, goshawk, California spotted owl (*Strix occidentalis occidentalis*), great gray owl (*Strix nebulosi*), flammulated owl (*Psiloscops flammeolus*), burrowing owl (*Athene cunicularia*), red-tailed hawk, golden eagle, prairie falcon (*Falco mexicanus*), and Cooper's hawk.

Many fish species occupy streams and major rivers in the subregion. Rivers and streams of eastern Nevada contain Bonneville cutthroat trout, interior redband trout (*Oncohynchus mykiss gairdneri*), and bull trout. The Sevier River contains primarily brown trout, rainbow trout, and cutthroat trout. Lahontan cutthroat trout (*O. clarkii henshawi*), a Federally listed threatened species, occurs in isolated mountain streams throughout much of Nevada. Silver King Creek in California contains the only population of Paiute cutthroat trout (*O. clarkii seleniris*).

Desert ecosystems support Pacific tree frog (*Hyla regilla*), Columbia spotted frog (*Rana luteiventris*), and red-spotted toad (*Bufo punctatus*). The mountain yellow-legged frog (*R. muscosa*) and Yosemite toad (*B. canorus*) occupy the higher elevations in the far western part of the subregion. Reptiles include side-blotched lizard (*Uta stansburiana*), zebra-tailed lizard (*Callisaurus draconoides*), Great Basin collared lizard (*Crotaphytus bicinctores*), coachwhip (*Masticophis flagellum*), speckled rattlesnake (*Crotalus mitchellii*), and Gilbert's skink (*Plestiodon gilberti*) (Knight et al. 2014). Many species of hummingbirds and small songbirds populate both desert and mountain ecosystems (Knight et al. 2014).

Wildfire regimes in the subregion have been altered where nonnative species have proliferated following fire. At the end of the 19th century, cheatgrass was introduced to the shrublands. This species is highly flammable, increases the spread rate of wildfires, and regenerates quickly after fire, outcompeting sagebrush and other perennial species (Blank et al. 2008). Public policy has encouraged fire suppression throughout the subregion, which has resulted in single-age sagebrush habitats that lack herbaceous and perennial grass species (Blank et al. 2008). Some shrub cover is so dense that biodiversity is low within these habitats.

Before Euro-American settlement, Native American tribes claimed lands that are now in Humboldt-Toiyabe and Dixie National Forests. In the Nevada portion of the area, the ancestral land of the Southern Paiute, Northern Paiute, Western Shoshone, and Washoe Indians has been inhabited for over 4,500 years. The Fremont, Anasazi, and Paiute Indians inhabited what is now Dixie National Forest. Several Indian reservations occupy the area, including those for the Summit Lake Paiute Tribe, Pyramid Lake Paiute Tribe, Walker River Paiute Tribe, Moapa Band of Paiute Indians, Goshute Confederated Tribes, Te-Moak Tribe of Western Shoshone Indians-South Fork band, Skull Valley band of Goshute Indians, Paiute Indian Tribes-Shivwits band, and a portion of the Shoshone-Paiute Tribe.

The 19th-century California gold rush brought Euro-American settlers to the area. Emigrant roads and trails connected mining towns, logging sites, and stagecoach stops throughout the region. Industries and economic pressure grew with continued settlement of the American West throughout the 19th century. Nevada leads the country in production of gold, barite, diatomite, and mercury, and is the only State that produces magnesite, lithium, and specialty clays (Price 2004).

Oil and gas reserves lie below the eastern part of the subregion. The National Forest System evaluates lands for drilling potential in accordance with the Federal Onshore Oil and Gas Leasing Reform Act of 1987 (Dixie National Forest 2011). Drilling is allowed within some areas of Dixie National Forest and Humboldt-Toiyabe National Forest, excluding designated wilderness, although no drilling has been conducted on Dixie National Forest since 1987. Most expressions of interest in drilling have been processed by the Bureau of Land Management for its lands adjacent to national forests.

Several prominent conservation issues influence resource management in this subregion. Humboldt-Toiyabe National Forest is home to over 800 wild horses and burros. The Wild Free-Roaming Horses and Burros Act of 1971 (Public Law 92-195) protects wild horses and burros of the American West, but competition for forage and water resources with domestic livestock is controversial. Fragmentation and loss of sagebrush habitat have made the Columbia spotted frog a candidate endangered species, susceptible to extirpation in some areas. Protection of the species has been implemented in the greater Humboldt River watershed of central and northeastern Nevada. Conservation of greater sage-grouse, one of the highest profile natural resource issues in the West, is influenced by the loss of sagebrush ecosystems, with declining populations of sage-grouse in Nevada and Utah. Methods to sustain both the habitat and population of sage-grouse include restoration of shrub-steppe ecosystems and control of nonnative species (Nevada Department of Wildlife 2013).

Intermountain Semi Desert Subregion

The Intermountain Semi Desert subregion covers 5.5 million acres. No national forests are located here, although 500,000 acres of wilderness area have been reserved, along with Craters of the Moon National Monument and Idaho National Laboratory in the north-central part of the subregion (fig. 2.11).

The western half of the subregion contains the Snake River Plain and Camas Plain. Uplands consist of the Owyhee Plateau located along the Idaho-Nevada border, and the Blackfoot Mountains. Flat plateaus and volcanic plains dotted with cinder cones and other volcanic remnants characterize the landscape. Deep river canyons, granite domes, and rugged peaks distinguish the Owyhee Mountains from the low-lying areas along the Snake River to the north, where basalt sheets underlie the irrigated plains. The eastern half of the subregion begins just north of the junction with Idaho, Utah, and Wyoming, extending west into the Great Basin. Desert habitats are uniformly distributed throughout the plains and plateaus.

The northwestern corner of the subregion typically has the same maritime climate trends as northern and central Idaho. Within the Snake River Plain, the climate is influenced by warm, dry Pacific air masses and cold, moist Arctic air masses that converge from western and northern directions, respectively. This interaction allows for freezing winter temperatures, summer thunderstorms, and hot, humid summers. The Snake River Plain and the area south to the Nevada/Idaho border receive an average of 10 to 15 inches of precipitation annually (Chandler 2003). However, the higher elevation Owyhee Mountains receive more precipitation and prolonged freezing temperatures during the winter. The Blackfoot Mountains have cool, dry winters and hot, dry summers.

The South Fork of the Boise River runs westward across the northwestern corner of the Intermountain Semi Desert subregion, joining the North and Central Forks of the Boise River at Arrow Rock Reservoir. Originating from the northeastern corner of the subregion, the Snake River cuts across the middle of the Snake River Plain from the Southern Greater Yellowstone subregion to the Oregon-Idaho border.

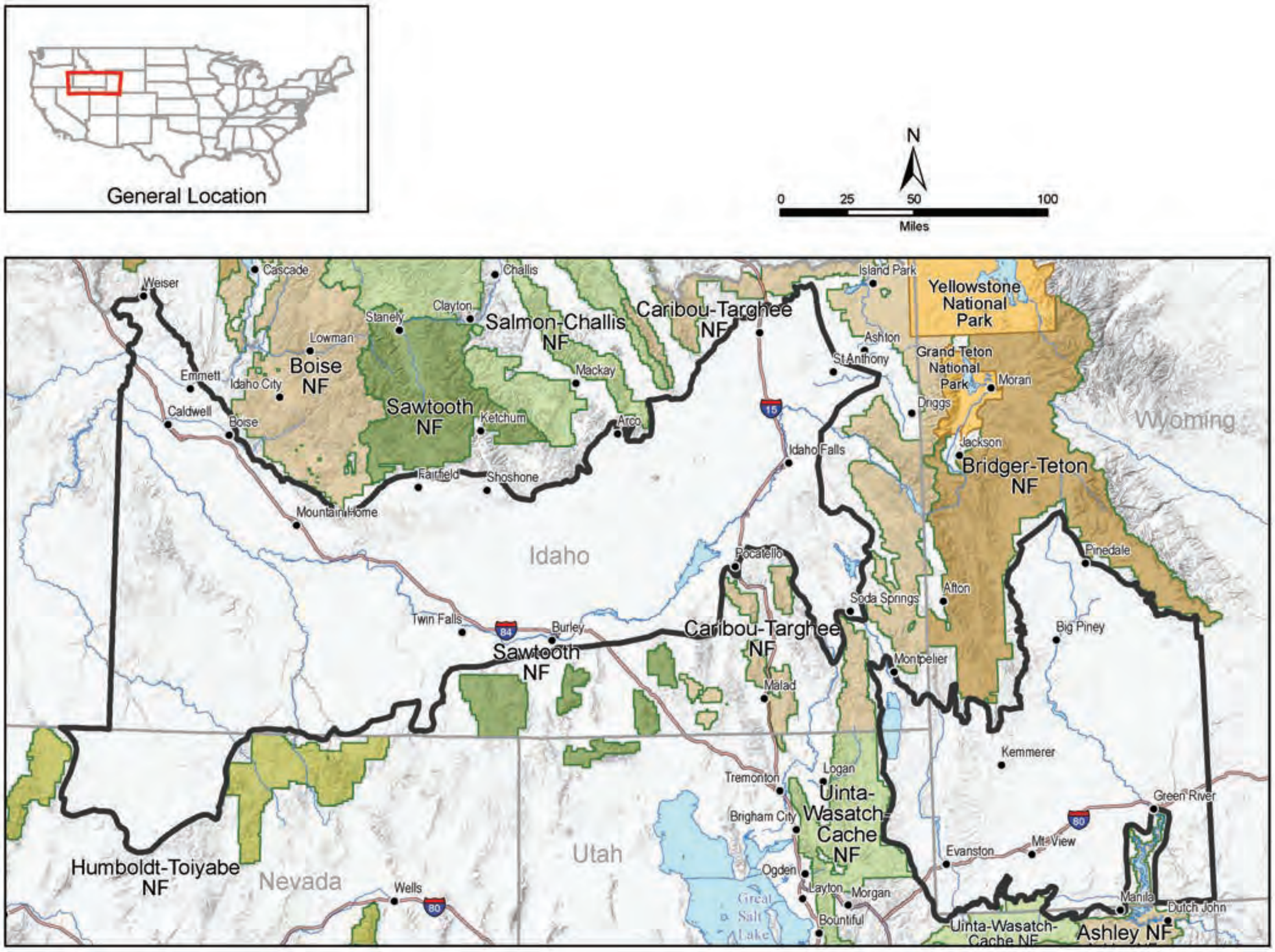

Figure 2.11—Location of the Intermountain Semi Desert subregion of the Intermountain Adaptation Partnership region.

Impoundments to the Snake River, such as those at Lake Walcott and American Falls Reservoir, provide hydroelectricity and irrigation water for nearby agriculture. In the northeastern areas, the Big Lost River disappears from its central Idaho source, drains to the Snake River aquifer below the surface of the volcanic rocks, and re-emerges near Thousand Springs Creek. Incising through canyons of the Owyhee Mountains, the Owyhee River flows generally northward to the Snake River near the Oregon-Idaho border, forming one of the largest subbasins of the Columbia River system.

The Snake River Plain is believed to have originated 16 to 17 million years BP as a hotspot of the Earth's crust moved from west to east, producing lava flows and basalt throughout the subregion. Large basalt flows erupted onto the surface in volcanic rift zones. Between 12,000 and 15,000 years BP, powerful floods cut through the Snake River basin from Lake Bonneville to the south, depositing alluvial sediments derived from adjacent mountain ranges. The Owyhee Plateau marks the highland portions of the subregion, characterized by warped volcanic deposits that eventually converge with the lower plains (Chandler 2003).

Sagebrush-steppe ecosystems are distributed throughout lower elevations in the subregion, giving way to mountain big sagebrush and other subalpine systems at higher elevations (fig. 2.12). The northern border of the western section of the subregion is dominated by subalpine ecosystems similar to those of the Middle Rockies subregion. Farther to the south, the high desert habitats of the Great Basin become more prevalent with more arid vegetation.

High desert habitats are dominated by open desert with low-lying sagebrush and grasslands. As the Snake River flows along the natural arc-shape of the plain, riparian zones are plentiful and contain habitat for willows (*Salix* spp.), quaking aspen, narrowleaf cottonwood (*Populus angustifolia*), and chokecherry (*Prunus virginiana*). Sagebrush shrublands, including mountain big sagebrush, greasewood, and shadscale (*Atriplex confertifolia*), cover most of the central and southern portions of lower elevations (Chandler 2003). Nonnative Russian thistle (*Salsola kali*), cheatgrass, and other species have degraded the once productive grazing land that lies between Twin Falls and the Boise River.

Wildfire frequency in the subregion has increased since the early 1900s. Before European settlement, fire intervals were 60 to 110 years, allowing for productive native grasslands to thrive (Manier et al. 2011). Introduction of cheatgrass has reduced intervals to less than 5 years in some places. After fires occur, cheatgrass regenerates quickly, limiting the growth of native vegetation and providing fuel for subsequent fires. Addressing this change in ecology and disturbance regimes is a major challenge for resource management in the Snake River Plain. In addition, juniper woodlands have expanded into sagebrush and grasslands of the lower plains, reducing wildlife habitat, water quality, and forage for grazing.

The subregion is home to a wide range of mammals, including mule deer, whitetail deer (*Odocoileus virginianus*), black bear, Rocky Mountain elk, bighorn sheep, pronghorn, and American bison. Smaller mammals include badger (*Taxidea taxus*), coyote, yellow pine chipmunk (*Tamias amoenus*), Great Basin pocket mouse (*Perognathus parvus*), and bobcat (Chandler 2003).

Greater sage-grouse can be found throughout the sagebrush-steppe ecosystem, especially in the Owyhee Canyonlands. Steeper cliffs of the Canyonlands provide important nesting and foraging habitat for raptor species, such as red-tailed hawk, golden eagle, and peregrine falcon. These species also populate the eastern and western plains, which are home to osprey, American kestrel (*Falco*

Figure 2.12—Highly incised river canyons, flat plateaus, and sagebrush-grasslands characteristic of the Intermountain Semi Desert subregion of the Intermountain Adaptation Partnership region, shown here in Birds of Prey National Conservation Area (photo: Natural Resources Conservation Service).

sparverius), bald eagle, and prairie falcon as well. In the juniper highlands and Blackfoot Mountains, iconic birds include common poorwill (*Phalaenoptilus nuttallii*), broad-tailed hummingbird (*Selasphorus platycercus),* bushtit (*Psaltriparus minimus*), and green-tailed towhee (*Pipilo chlorurus*).

Within the Snake River system, anadromous fish, including steelhead trout and Chinook salmon, arrive in the spring. Interior redband trout, bull trout, mountain whitefish, and other fish species inhabit the Owyhee River and Bruneau River. The Owyhee River contains large populations of non-native brown trout and rainbow trout.

The Fort Hall Reservation, located in southeastern Idaho, is home to the Shoshone-Bannock Indian Tribes. The Fort Bridger Treaty of 1868 and the Indian Reorganization Act of 1934 granted self-governing rights to the tribes (Shoshone-Bannock Tribes 2015). Historically, the tribes consisted of hunters and gatherers who traveled in spring and summer collecting winter supplies. Riparian zones along the Snake River provided a diversity of plant food sources. Abundant salmon in the river were harvested year round, along with mammals that inhabited the river banks. American bison was valued as a primary food and raw material for tribal communities. By 1864, bison had vanished from the area, and land ownership changed from ancestral tribal lands to the reservation system. Resource management and land ownership policies in the surrounding area of the current-day reservation are administered by U.S. and Tribal Governments.

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Chapter 3: Historical and Projected Climate

Linda A. Joyce and Marian Talbert

Introduction

The Intermountain Adaptation Partnership (IAP) region is characterized by extreme temperatures and precipitation; it is home to some of the driest, hottest, and coldest locations in the conterminous United States. The region has numerous mountain ranges, high-elevation basins and valleys, and low-elevation mesas and canyons. Climate is influenced by this diverse and complex terrain. The IAP region is bounded on the eastern side by the Rocky Mountains and on the western side by the Sierra Nevada. For this region, moisture comes predominantly from the Pacific Ocean, and consequently much of the moisture occurs as orographic precipitation in the mountains.

This chapter provides a brief discussion of the current climate in each of the six subregions to set the context for projected changes in climate under two future scenarios. The Great Basin and Semi Desert, and the Intermountain Semi Desert subregions are warmer and drier than the Southern Greater Yellowstone and Middle Rockies subregions. The Plateaus, and Uintas and Wasatch Front subregions have intermediate amounts of precipitation. Within each subregion, climate influences the ecosystem services that forests and rangelands provide. Thus, an understanding of how climate may change in the future is vital for long-term planning and management.

This chapter focuses on the historical record of climate, primarily temperature and precipitation, and the projected changes in temperature and precipitation. Chapter 4 describes the effects of climate on hydrological processes, snowpack and glaciers, streamflow, sediment yield, and drought. The impacts of climate change on wildfire and geologic processes, such as mass wasting, are discussed in Chapter 8. Other chapters review literature on the effects of climate change on particular resources, such as individual species in Chapter 9.

Assessing Climate Futures for Natural Resource Management

Information on weather and climate are used to inform the decisionmaking process in natural resource management. Day-to-day resource management practices are implemented with information on real-time conditions of temperature, precipitation, wind, humidity, and other meteorological factors. These specific conditions over a relatively short time period and in a particular place are what we call weather. This information is used to make on-the-ground real-time decisions, such as the start of prescribed fire activities.

Long-term resource management strategies and plans are informed by the observed dynamics of precipitation, temperature, wind, snowfall, and other measures of weather over a long time period in a particular place. Climate is defined by this long-term meteorological information. Understanding the climate of an area assists managers in identifying both the general characteristics of the area and the risks associated with potential extremes of weather conditions, such as flooding, drought, wildfire, and extreme heat or cold events. Typically, the most recent three full decades (e.g., 1981–2010) are used to determine the normal climate, or the average conditions on an annual, monthly, or daily basis. Long-term records (>30 years) are also used to assess the risk of specific weather events and thresholds that have relevance to management, such as in the sizing of culverts and bridges.

Although long-term records of climate can help to establish the characteristics of the average climate or the probability of certain extreme events, future climate may be different than the past 30 to 60 years (Walsh et al. 2014). To understand how climate might change, scientists use global climate models (GCMs), which are supercomputer-based simulations that represent the key components, interactions, and feedback processes of the climate system, based on fundamental physical laws and decades of observations of the atmosphere, oceans, ice sheets, and biosphere. These models have been used to study the physical dynamics of the atmosphere and the interaction between the atmosphere and the surface of the Earth, as well as interactions with ocean currents moving heat around the globe. Information on future changes in climate provided by GCMs can be helpful in understanding how the environmental settings of plants, animals, and habitats may change in the future; how runoff and seasonal flows may vary with precipitation and timing of snowmelt; and how wildfire, insects and disease patterns may change.

Scenarios

Climate models have been an important part of the Intergovernmental Panel on Climate Change (IPCC) assessments since 1990. In 1995, atmospheric scientists came together to coordinate a standardized set of model runs (also called experiments) for evaluating changes to past and future global climate: the Coupled Model Intercomparison Project (CMIP) (Meehl et al. 2007). This project also developed a web portal where these GCM results could be archived and made available for use by other scientists. This approach allows for a rigorous comparison of results across the models because the models have similar initial conditions and similar changes in atmospheric chemistry and land use cover over time. This approach improves our understanding of the range of possible future climate change.

Many of the model experiments focus on improving the ability of the model to describe climate; however, these models can also be used to look at the evolution of climate over time when a description of how the future may develop is constructed. A climate scenario is a simplified representation of future climate, based on climatological relationships constructed for investigating the potential consequences of human-caused climate change (Stocker et al. 2013). Climate dynamics are influenced by land surface changes, such as building cities or changing land use from forest to agriculture, by the chemical composition of the atmosphere, and by human contributions to the atmosphere through land management, energy sources, and industrial processes. Constructing a scenario requires describing how these forces may develop over time. The goal of working with scenarios is to understand uncertainties and alternative conditions associated with climate change, thus informing decisions or options for a range of possible futures (IPCC Data Distribution Center 2016).

Climate scenarios in the last three IPCC assessments have been constructed in two ways (table 3.1). In the third and fourth IPCC assessments, scenario development started with specific assumptions about population growth, economic growth, and policies related to alternative energy and conventional fossil fuel sources; then the resultant greenhouse gas emissions to the atmosphere were projected (Solomon et al. 2007). These scenarios were called SRES scenarios, named for the report that developed them, the Special Report on Emission Scenarios (Nakićenović et al. 2000). These different combinations of population, economic growth, and energy policy resulted in scenarios that ranged from low emissions (B1) to high emissions (A1FI), with a range of scenarios in between.

For the IPCC Fifth Assessment Report (Stocker et al. 2013), scenario development focused on radiative forcing in the atmosphere. Here the emphasis was on adding different amounts of energy to the climate system over time. Scientists reviewed current estimates on radiative forcing, the total amount of extra energy entering the climate system throughout the 21st century and beyond. They used this information to construct a set of scenarios that would bound these estimates, from lesser amounts of energy entering the climate system to greater amounts of energy. These

Table 3.1—Scenarios used by climate models in the Special Report on Emission Scenarios (SRES) and representative concentration pathway (RCP) scenarios in the Intergovernmental Panel on Climate Change (IPCC) assessment reports.

	SRES scenarios	RCP scenarios
Definition	A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases, aerosols) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships. Concentration scenarios, derived from emissions scenarios, are used as input to a climate model to compute climate projections.	Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases and aerosols and chemically active gases, as well as land use/land cover (Moss et al. 2008). The word “representative” signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. The term “pathway” emphasizes that not only the long-term concentration levels, but also the trajectory taken over time to reach that outcome, are of interest (Moss et al. 2010).
Different scenarios	Scenario family is a set of scenarios that have a similar demographic, societal, economic, and technical change storyline. Four scenario families compose the SRES scenario set: A1, A2, B1, and B2.	RCP 2.6: One pathway where radiative forcing peaks at approximately 3 W m^{-2} before 2100 and then declines. RCP 4.5 and RCP 6.0: Two intermediate stabilization pathways in which radiative forcing is stabilized at approximately 4.5 W m^{-2} and 6.0 W m^{-2} after 2100. RCP 8.5: One high pathway for which radiative forcing reaches greater than 8.5 W m^{-2} by 2100 and continues to rise for some amount of time.
Use in models	Used to drive climate models in CMIP3[a]	Used to drive climate models in CMIP5.
Use in IPCC assessments	Houghton et al. (2001), Solomon et al. (2007).	Stocker et al. (2013).

[a] CMIP = Coupled Model Intercomparison Project; versions 3 and 5 are cited here.

scenarios are called representative concentration pathways (RCPs) (van Vuuren et al. 2011) because these scenarios represent one of many possible ways in which population, economic growth, and energy policy would lead to the specific radiative forcing characteristics. Consequently, the scenarios are defined by the amount of energy that is added to the atmosphere. For example, RCP 2.6 assumes a total radiative forcing increase of 2.6 Watts per square meter (0.82 British thermal units per square foot) by 2100, whereas RCP 8.5 assumes a much larger increase in the radiative forcing (8.5 Watts per square meter [2.7 British thermal units per square foot]). Intermediate scenarios include RCP 4.5 and RCP 6.0.

The RCPs focused on the implications of energy added to the atmosphere and consequently were not designed to mimic particular SRES scenarios. But because the SRES scenarios have been used for many analyses of climate change effects on natural resources (Walsh et al. 2014), an understanding of how the RCP and the SRES scenarios compare is helpful in interpreting past analyses. The comparison by Rogelj et al. (2012) considers climate sensitivity uncertainty, synthesizes the understanding of climate system and carbon cycle behavior, and is constrained by observed historical warming. Rogelj et al. (2012) identify analogs between RCP 4.5 and SRES B1, RCP 6.0 and SRES B2, and RCP 8.5 and SRES A1FI (table 3.2). The SRES A1B has a greater range in temperature changes than RCP 6.0, and a warmer upper range. Rogelj et al. (2012) note that temporal patterns differ between the SRES and RCP scenarios.

Climate Projections for the Region

This report uses scenarios RCP 4.5 and RCP 8.5 to explore future climate in the IAP region. These scenarios capture a moderate and a high future warming. In addition, more GCMs have used these scenarios than RCP 2.6 or RCP 6.0. The breadth of these scenarios and the availability of a larger set of projections enhance our understanding of the possible ranges in future climate. The term “climate projection” is used to describe the results of a climate model when forced by a particular scenario.

For an overview of projected future climate in the IAP region, we use the most recent climate change projections based on RCP 4.5 and RCP 8.5 scenarios (Stocker et al. 2013). Output from GCMs is at a scale too coarse to represent climate patterns in subregions and management areas relevant for the IAP. Therefore, we drew on climate projections that had been downscaled using the bias-correction and spatial disaggregation (BCSD) method (Maurer et al. 2007). We used projections from 36 climate models for RCP 4.5 and 34 climate models for RCP 8.5 (see Appendix 2). The variables available for each BCSD climate projection include monthly precipitation and monthly surface air temperature for the 1950–2099 period. Spatial resolution of the data is 1/8 degree latitude-longitude (about 7 square miles), and data cover the entire IAP region. Climate projections were archived by CMIP; hereafter climate projections that used SRES scenarios are referred to as “CMIP3” and climate projections that used the RCP scenarios as “CMIP5.”

Historical mean annual temperature and precipitation vary across the IAP region (figs. 3.1, 3.2). We use a base period of 1979–2009 for the mean historical climate, and show mean temperatures and precipitation projected for two periods: 2030–2059 and 2070–2099. These time periods were selected to summarize climate that has influenced the current environmental conditions (base period) and two future periods that will be relevant to long-term management action (e.g., road construction, management of hydrological infrastructure, or vegetation planting). Historical mean

Table 3.2—Probabilistic estimates of temperature increase above preindustrial levels based on representative equilibrium climate sensitivity distribution for six Special Report on Emission Scenarios (SRES) market scenarios and four representative concentration pathway (RCP) scenarios (Rogelj et al. 2012).

	2090–2099		2100	
Scenario	Median	66% range	Median	66% range
	------------ °F	------------	------------	------------
SRES B1	4.3	3.6–5.6	4.5	3.6–5.8
SRES A1T	5.2	4.5–6.7	5.4	4.5–6.8
SRES B2	5.2	4.3–6.3	5.4	4.7–6.7
SRES A1B	6.1	5.0–7.6	6.3	5.2–7.9
SRES A2	7.0	5.8–8.6	7.6	6.3–9.4
SRES A1F1	8.5	7.0–10.4	9.0	7.4–11.2
RCP 3-PD (2.6)	2.7	2.3–3.4	2.7	2.3–3.4
RCP 4.5	4.3	3.6–5.2	4.3	3.6–5.4
RCP 6.0	5.2	4.5–6.5	5.4	4.7–6.7
RCP 8.5	8.3	6.8–10.3	8.8	7.2–11.0

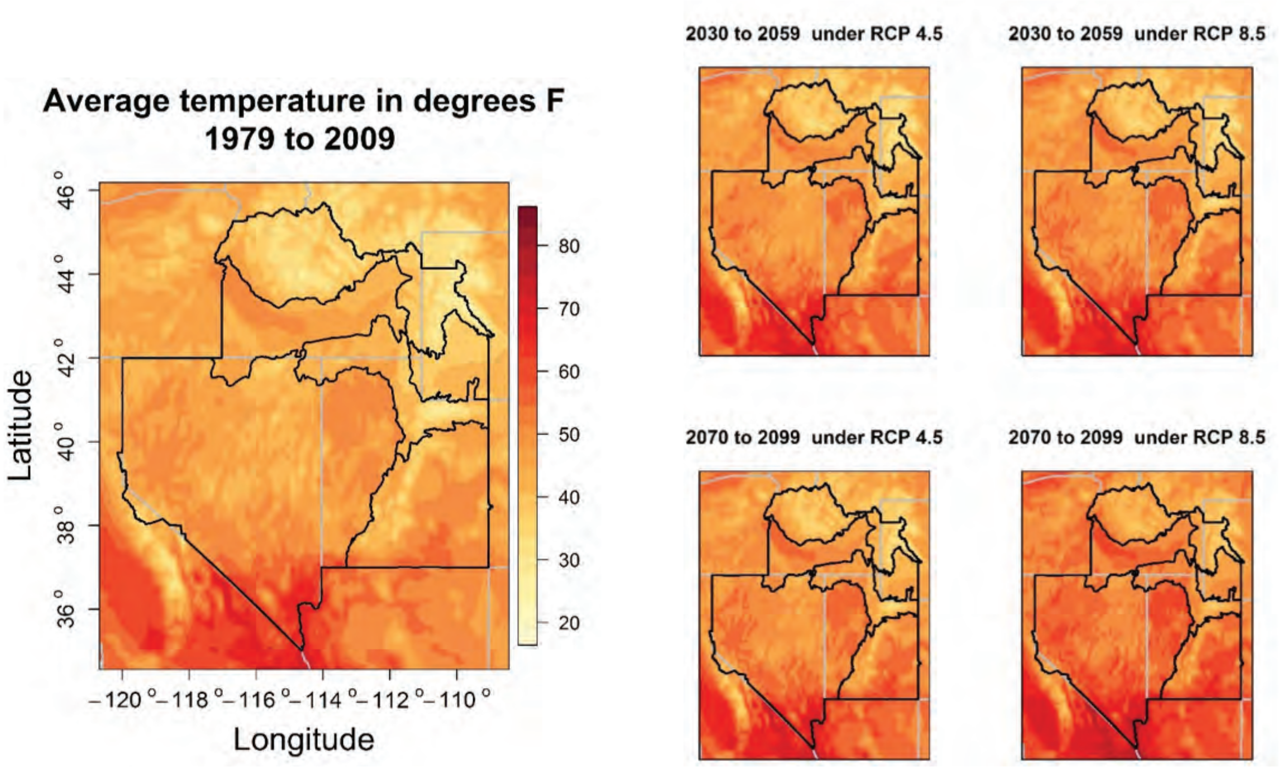

Figure 3.1—(a) Historical (1979–2009) and (b–e) projected (2030–2059 and 2070–2099) mean annual monthly temperature (°F) under RCP 4.5 and RCP 8.5 scenarios for the entire Intermountain Adaptation Partnership region. Projected climate is the 36-model mean for RCP 4.5 and the 34-model mean for RCP 8.5. Spatial resolution of the data is 1/8th degree latitude-longitude.

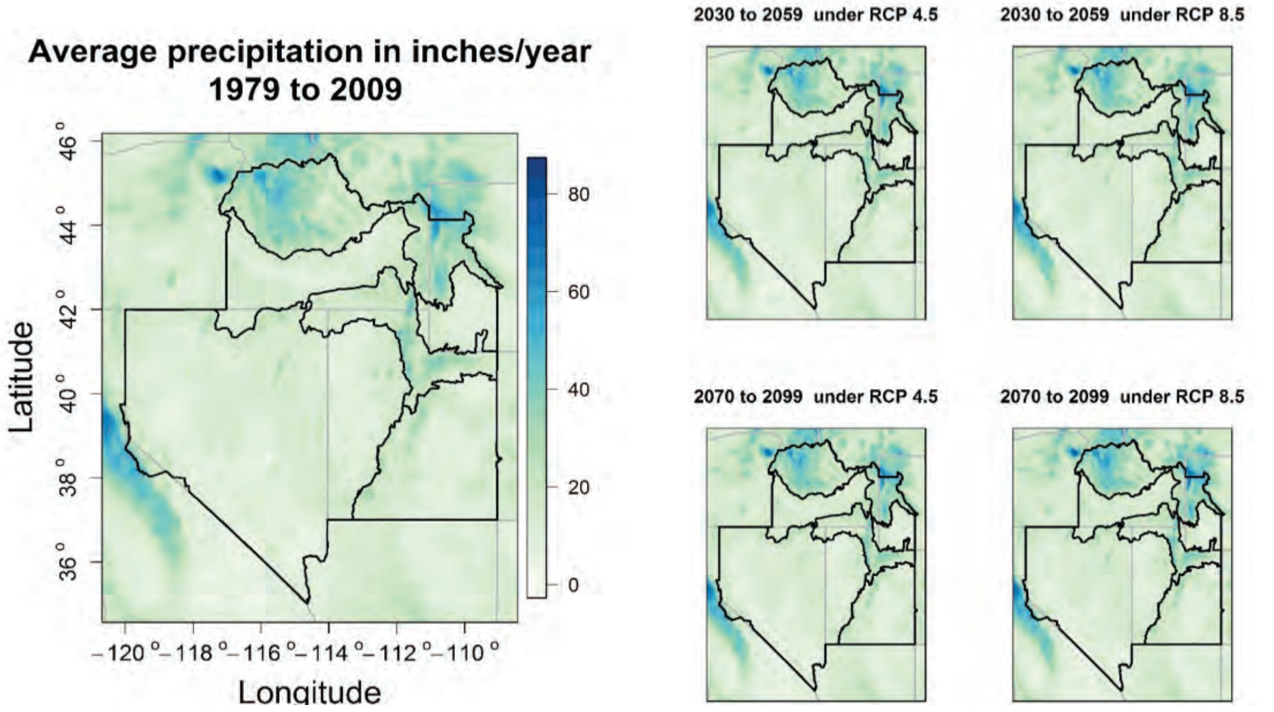

Figure 3.2—(a) Historical (1979–2009) and (b–e) projected (2030–2059 and 2070–2099) total annual precipitation (inches) under RCP 4.5 and RCP 8.5 scenarios for the entire Intermountain Adaptation Partnership region. Projected climate is the 36-model mean for RCP 4.5 and the 34-model mean for RCP 8.5. Spatial resolution of the data is 1/8th degree latitude-longitude.

annual temperatures can vary from nearly 20 °F to 75 °F within the IAP region. Historical total annual precipitation ranges from less than 3 inches to above 70 inches. All subregions of the IAP are expected to see increases in mean annual temperature. Temperatures are projected to increase more by the end-of-century period (2070–2099) and under the warmer scenario, RCP 8.5. Precipitation changes are less consistent; the northern parts of the IAP region may have precipitation increases.

Several resource chapters in this report have drawn on published literature about the effects of climate change on natural resources which used SRES scenarios and CMIP3 models. The question arises as to the regional differences between the CMIP3 projections under SRES scenarios and the CMIP5 projections under RCP scenarios. Understanding these differences may be helpful in interpreting the different projections used across these studies. Here, we compare CMIP5 climate projections under RCP 4.5 and RCP 8.5 scenarios from this study with CMIP3 models under the SRES scenario A1B, which has been used in several natural resource assessments, including the cold-water fisheries analysis in chapter 5.

To identify differences between these two sets of scenarios, we compare the projected changes in mean temperature with change in total annual precipitation over a common period for the IAP region. We obtained 10 CMIP3 global climate projections for the A1B scenario (moderate emissions) from Littell's group. We estimate the change in temperature and percentage change in precipitation between the future period (2040–2060) and the historical period (1979–2009) for the CMIP3 models that Littell et al. (2011) used and the CMIP5 models used in this study. In figure 3.3, the projected change in mean annual temperature is shown on the horizontal axis, and the percentage change in precipitation is shown on the vertical axis. Change is described as the difference in temperature and percentage change in precipitation between historical and projected future values. We show all CMIP5 models used in this study. We show only the mean (ensemble) of all 10 CMIP3 models and two individual models (pcm1 and miroc_3.2), as these projections from Littell et al. (2011) are used most often.

Across all CMIP5 models, projected change in temperature by the 2040–2060 period ranges from just under 2 °F to nearly 8 °F (fig. 3.3). Generally, the projected change for CMIP5 models under the RCP 8.5 scenario (shown in red) is greater than the change projected under the RCP 4.5 scenario (shown in yellow), but not always. For example, the RCP 8.5 projections for models FIO-ESM (number 15 in fig. 3.3) and MRI-CGCM3 (number 34 in fig. 3.3) show temperature changes that are less than the median changes for all RCP 4.5 models. The projected change in precipitation ranges from a decrease of about 12 percent to an increase of nearly 30 percent. However, 28 of the 36 projections under RCP 4.5 and 29 of the 34 projections under RCP 8.5 indicate an increase in precipitation. Across the IAP region, mean temperatures are projected to warm by 3.5 °F to almost 5 °F over the next 50 years, with precipitation projected to increase slightly, by 5 to 8 percent.

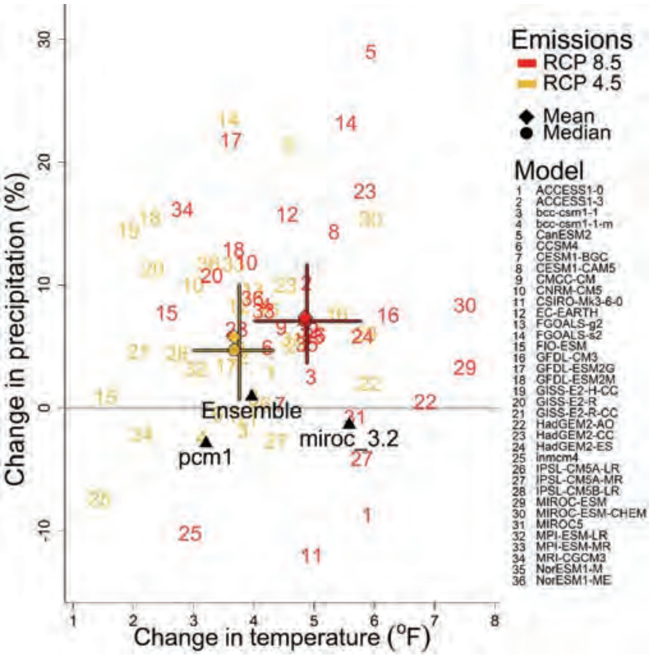

Figure 3.3—For the entire Intermountain Adaptation Partnership region, change in mean annual temperature (°F) and total annual precipitation (%) from the simulated historical climate (1979–2009) and the projected climate (2040–2060) using the CMIP5 RCP 4.5 and RCP 8.5 scenarios and the CMIP3 A1B scenario. Each CMIP5 model result is labeled by a number with a key in the legend (e.g., 29 is MIROC-ESM) in colors to indicate RCP 4.5 (yellow) and RCP 8.5 (red) (see table 3.2). The crosses in the middle represent the median and 25 to 75 percent of the RCP 4.5 and the RCP 8.5 projections used in this study. The mean values for the CMIP5 changes are shown on the figure as colored diamonds. The CMIP3 results are labeled in black triangles (see table 3.2 and Littell et al. [2011]).

The CMIP3 projections for the A1B scenario are within the mean temperature range of the CMIP5 projections (fig. 3.3). The A1B ensemble projection of a nearly 4 °F increase in temperature is similar to the mean increase for the RCP 4.5 scenario; both of these scenarios are considered moderate in terms of future warming. The two individual model projections under the A1B scenario span the temperature range of the individual model projections under RCP 4.5. For precipitation, the CMIP3 models under the A1B scenario project a slight increase (ensemble) and decreases in precipitation (pcm1 and miroc_3.2). We conclude that when this set of CMIP3 results are compared with CMIP5 results for the IAP region, future temperatures are projected to be similar. However, CMIP5 precipitation projections collectively show a greater likelihood of increases in precipitation than the CMIP3 projections (fig. 3.3). This slight increase in projected precipitation with the CMIP5 models might be considered when evaluating the impact of analyses using CMIP3 climate projections.

Climatic Variability and Change in the Subregions

Historical Climate

To understand historical climatic variability and trends at the subregional scale in the IAP region, we compared three gridded datasets: Parameter-elevation Regressions on Independent Slopes Model (PRISM) (PRISM Climate Group 2014), Maurer (Maurer et al. 2002), and TopoWx (Oyler et al. 2015a). These three datasets used observed point measurements of precipitation, temperature, and other climatic factors to produce continuous, digital grid estimates of monthly, yearly, and event-based climatic parameters. Because of differences in the station data used by these gridded products as well as the models and assumptions used to interpolate to a grid, these models do not always agree on the historical climate or trend for a region. For example, in the western mountains, PRISM has been shown to have an artificial amplification in warming trend (Oyler et al. 2015b).

The Middle Rockies subregion encompasses central Idaho, an area known as the "Idaho Batholith," and the Salmon River Mountains. Climate is strongly influenced by interactions with topography, elevation, and aspect. Westerly winds bring in moisture from the Pacific Ocean, but moisture is precipitated over the western blocking mountains. Elevations range from 3,000 to 10,000 feet, with the highest peaks in the Salmon River Mountains. The deep dissections of this subregion can be seen in the ridge patterns in temperature (fig. 3.1a) and large gradients in precipitation (fig. 3.2a).

Climate in the Middle Rockies is characterized by cold winters with moderate to heavy snow accumulations at higher elevations. Throughout the 1940–2009 period, mean minimum temperatures showed a distinct increasing trend (fig. 3.4). Mean maximum temperature ranged from 48 to 54 °F over this period (fig. 3.5). As with other subregions, no warming trend is evident across the entire time period. In the last 25 years, however, the Middle Rockies maximum temperatures showed a slight increasing trend (fig. 3.5); similar increasing trends in summer temperatures were noted by Isaak et al. (2010) for the Upper Boise River watershed. Annual precipitation over the historical period ranged from 20 inches to greater than 35 inches per year. Precipitation patterns were highly variable, with a slight downward trend in the last 25 years (fig. 3.6).

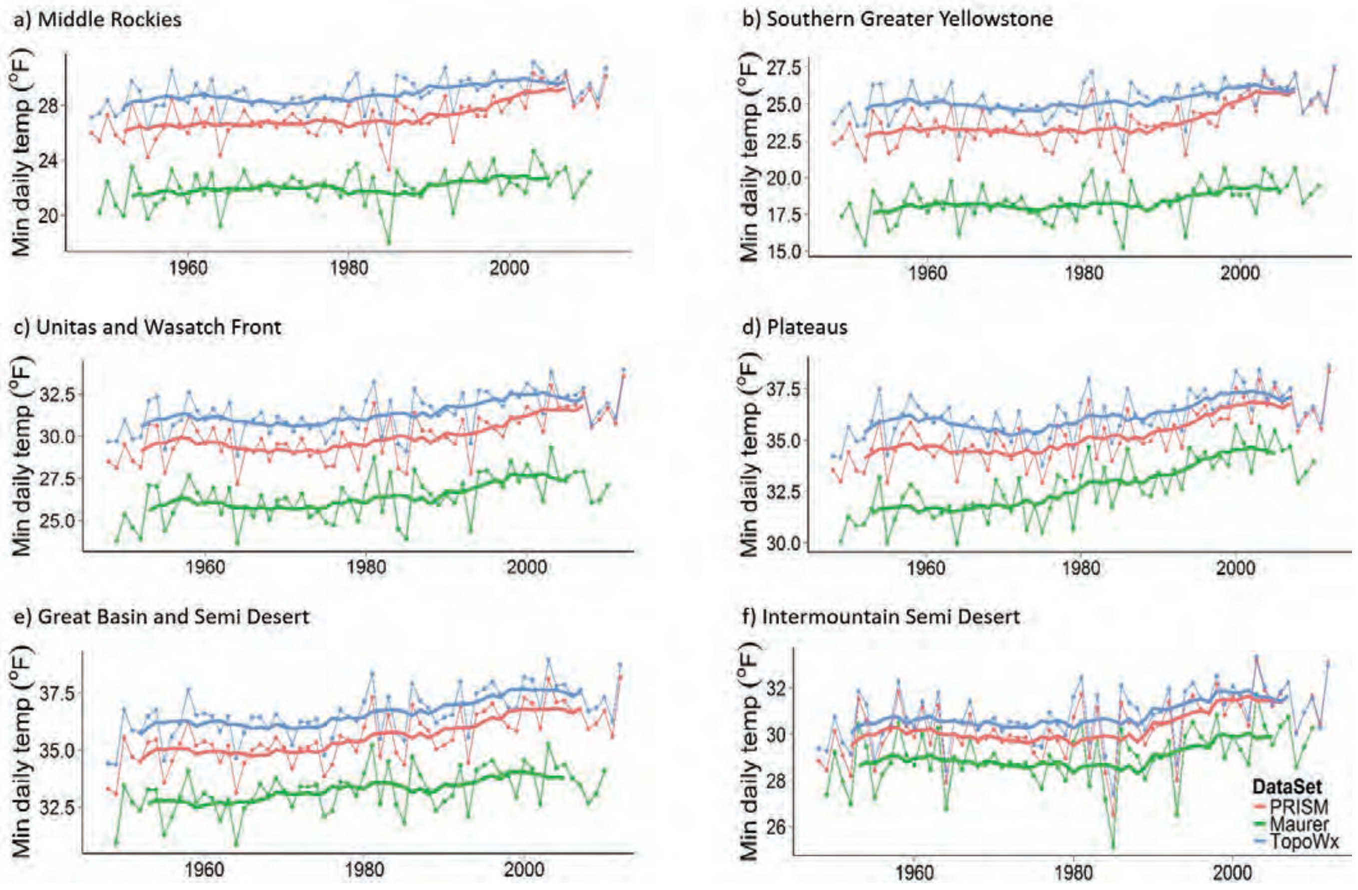

Figure 3.4—Annual historical mean monthly minimum temperature from the monthly gridded PRISM, Maurer, and TopoWx datasets for 1949–2010 for all six subregions of the Intermountain Adaptation Partnership region. The heavy lines are the 10-year rolling average from each dataset to show short-term trends.

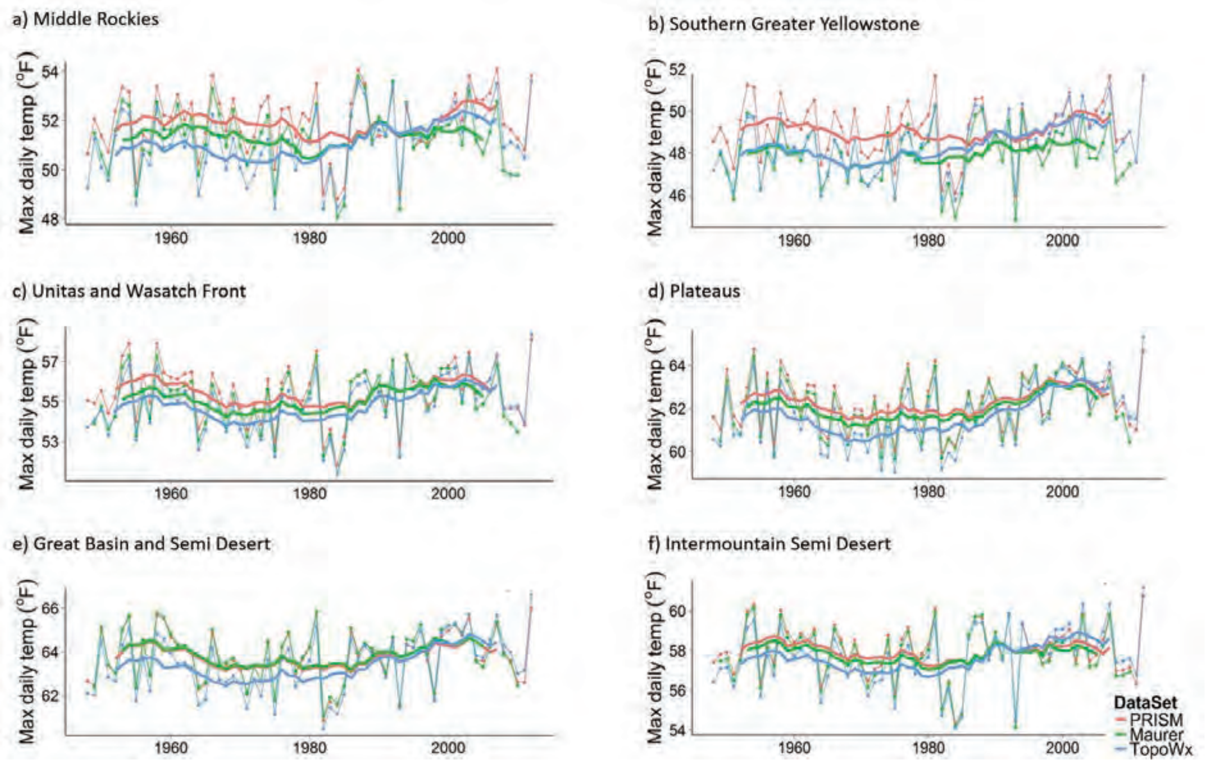

Figure 3.5—Annual historical mean monthly maximum temperature from the monthly gridded PRISM, Maurer, and TopoWx datasets for 1949–2010 for all six subregions of the Intermountain Adaptation Partnership region. The heavy lines are the 10-year rolling average from each dataset to show short-term trends.

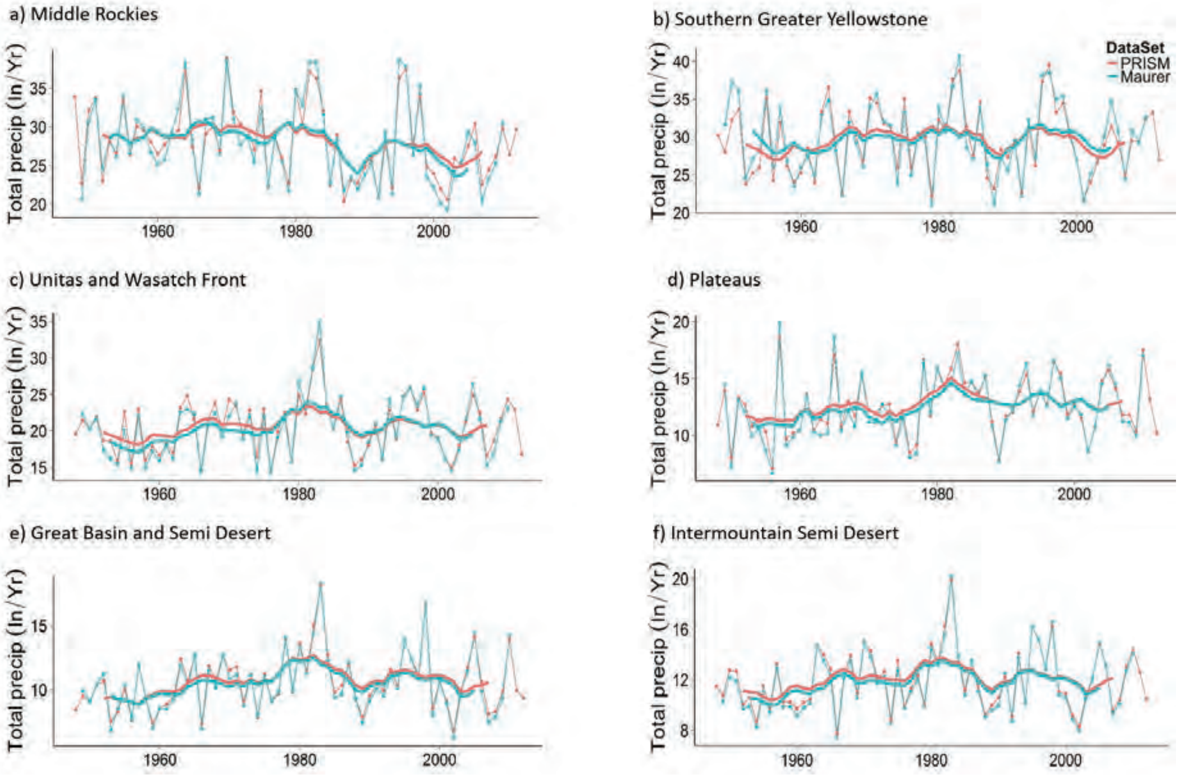

Figure 3.6—Historical total annual precipitation from the monthly gridded PRISM and Maurer et al. (2007) datasets for 1949–2010 for all six subregions of the Intermountain Adaptation Partnership region. The heavy lines are the 10-year rolling average from each dataset to show short-term trends.

The Southern Greater Yellowstone subregion includes Grand Teton National Park, and the Targhee and Bridger-Teton National Forests. This subregion and the Middle Rockies are the coldest subregions (figs. 3.4, 3.5). Mean minimum temperatures in the Southern Greater Yellowstone subregion showed an increasing trend over the last 50 years of the historical period (fig. 3.4). Monahan and Fisichelli (2014) reported that recent annual mean temperatures (last 10-, 20-, or 30-year periods) for Grand Teton National Park were higher than 90 percent of the historical temperatures over the 1901–2012 period. They also found that recent minimum temperatures in the coldest month (last 10-, 20-, or 30-year periods) were greater than 95 percent of the historical record. In contrast, maximum temperatures showed an increasing trend only during the last 25 years (fig. 3.5).

Climate in the Southern Greater Yellowstone subregion, as in the Middle Rockies, is strongly influenced by the mountains and interactions among topography, elevation, and aspect. Few mountains block the western passage of moist air from the Pacific Ocean to the Teton Range; consequently, the Teton Range, along with portions of southwestern Yellowstone National Park, are among the wettest areas in the larger Greater Yellowstone Area. Annual precipitation on the west side of the Teton Range can exceed 70 inches, with most of this precipitation falling as snow. In contrast, precipitation on the east side of the Teton Range can be as little as 19 inches (Davey et al. 2006). The Southern Greater Yellowstone subregion is the wettest in the IAP region (fig. 3.6). No trend is found in annual precipitation over the last 50 years although distinct wet and dry periods occurred. Davey et al. (2006) describe a 6-year drought (1999–2005) as the longest drought in the Grand Teton National Park since the Dust Bowl drought of the 1930s.

Climate in the Uintas and Wasatch Front can be characterized as humid continental, with warm to hot summers, cold winters with abundant snowfall, and no distinct dry period (Gillies and Ramsey 2009). As with the Middle Rockies and the Southern Greater Yellowstone subregions, climate in this subregion is strongly influenced by the terrain and interactions among topography, elevation, and aspect. The Wasatch Range generally runs north to south, and the Uinta Mountains extend east and west. These ranges crest above 10,000 feet, with the highest point of 13,498 feet at Kings Peak in the Uinta Mountains. As in most of the subregions, minimum temperatures trended upward over the last 50 years (fig. 3.4). Mean maximum temperatures were between about 53 and 57 ^{o}F, with no clear trends over the historical period (fig. 3.5). Gillies et al. (2012) concluded that during the last half-century, the proportion of winter (January–March) precipitation falling as snow across Utah has decreased by 9 percent, the result of a significant increase in rainfall combined with a minor decrease in snowfall. Although warming temperatures play a role, climate features such as circulation patterns also contribute to these changes.

Mean annual precipitation within the Uintas and Wasatch Front subregion ranged from 10 inches to more than 40 inches (fig. 3.6). Over the last 50 years, precipitation exhibited no annual trend, although dry or wet periods are evident. Morrisette (1988) reported that the 1982–1986 precipitation reached 134 percent of normal in the Salt Lake drainage area, resulting in historically high levels in the Great Salt Lake. Using tree-ring analyses, DeRose et al. (2015) concluded that 1986 was the fourth wettest year over the last 1,200 years in the Bear River watershed. They also reported that although the later part of the 20th century was the second wettest period (40 years), the first half was the fourth driest period in the past 1,200 years. Using tree rings to reconstruct streamflow for the Weber River, Bekker et al. (2014) reported that the 20th-century instrumental record includes the fewest extreme dry years in the 576-year, tree-ring-based reconstruction. In the Uinta Mountains, severe droughts have occurred, on average, two to five times per century (MacDonald and Tingstad 2007). Strong decreases in winter precipitation characterized the major droughts in the Uinta Mountains: the 1930s Dust Bowl event, the 1976–1977 event, and the 1987–1989 event. These later two droughts were related to decreases in eastern Pacific Ocean sea surface temperatures (MacDonald and Tingstad 2007). Droughts in the Wasatch Range occurred during the 1400s and 1500s; even though droughts were fewer in the 1700s and 1800s, they had longer duration (Bekker et al. 2014). The tree-ring studies consistently emphasize the importance of local conditions in understanding climate-vegetation relationships (Louderback et al. 2015).

The Plateaus subregion encompasses three ecological provinces of the Colorado Plateau. The Uinta Basin is a gently rolling plateau that the Green River and its tributaries have eroded into many spectacular canyons (Leydsman McGinty and McGinty 2009). In the High Plateaus province, north-south trending faults and valleys separate individual plateaus, such as the Awapa, Aquarius, and Paunsaugunt Plateaus (Leydsman McGinty and McGinty 2009). The Uinta Basin and the High Plateaus are cooler than the Canyonlands province. The Colorado River has eroded the Canyonlands into many deep, sheer-walled canyons, plateaus, mesas, buttes, and badlands. In addition, the La Sal and Abajo Mountains rise above the Colorado Plateau in southeastern Utah. Precipitation in this subregion ranges from 14 to 35 inches, with the highest precipitation in the High Plateaus province.

Minimum temperatures in the Plateaus subregion showed an upward trend over the entire historical period (fig. 3.4). Mean maximum temperature in the subregion ranged between 59 and 65 ^{o}F over the last 50 years, showing a slight upward trend after 1980 (fig. 3.5). No trend is seen in precipitation over the last 50 years, although higher precipitation occurred in the 1980s (fig. 3.6). Tree-ring reconstruction of precipitation from 1200–2001 in the Uinta Basin indicates significant precipitation variability at interannual to decadal scales, with more severe dry events prior to 1900 than after (Gray et al. 2004).

The Great Basin and Semi Desert subregion has great climatic diversity (Svejcar et al. 2016). The surrounding mountains, as well as the mountains within, strongly influence the climate of this subregion. A series of north-south mountain ranges within the subregion are interspersed among low-elevation basins, resulting in wide local variations in temperature and precipitation (fig. 3.1). Elevation ranges from less than 1,500 feet to more than 10,000 feet. Extreme temperatures can range from -15 to 120 ^{o}F (WRCC 2016b,c).

The Great Basin and Semi Desert subregion is the warmest of the subregions. For the larger Southwest region in the United States, Kunkel et al. (2013) reported an increase in mean annual temperature, with greater warming for minimum temperature than maximum temperature, over the last 115 years. That pattern for minimum and maximum monthly temperature was also seen in this subregion; mean minimum temperatures ranged from 30 to 38 ^{o}F (fig. 3.4) and mean maximum temperatures from 60 to 66 ^{o}F (fig. 3.5).

The primary source of moisture for the Great Basin and Semi Desert subregion is the Pacific Ocean, with seasonal monsoonal influences from the Gulf of Mexico. Much of the moisture from the Pacific Ocean is lost through orographic precipitation as the moisture flows upward and then over the bordering Sierra Nevada and Cascade Range. Mean annual precipitation varied from less than 8 inches to more than 15 inches over the last 50 years (fig. 3.6), with wet and dry years evident. Annual snowfall ranges from less than 1 inch to 124 inches (WRCC 2016b,c).

The Intermountain Semi Desert subregion includes two distinct areas: the large valley encompassing the Snake River plains in Idaho, and the southwestern area in Wyoming (Chapter 2). The long, large valley in Idaho gradually rises in elevation from 3,300 feet in the Magic Valley, through the Lower Snake River Plain, to the eastern end of the Upper Snake River Plain at 5,600 feet (Andretta and Geerts 2010). Swan Falls, on the Snake River in Idaho, has a mean annual temperature of 55 ^{o}F (WRCC 2016a). The Central Mountains, where the Boise, Payette, Salmon-Challis, and Sawtooth National Forests are located, bound this valley to the north. To the south and east of this subregion lies the Southern Highlands at elevations from 6,500 to 8,200 feet, Eastern Highlands, and Upper Snake Highlands of Idaho. As with the Great Basin and Semi Desert subregion, topography plays a role in the climate; however, with fewer barriers to the west, this area of the subregion receives greater moisture (fig. 3.2).

The Wyoming portion of this subregion encompasses the Green River Basin, a valley bounded on the northern edges by the Gros Ventre Mountains to the west and the Wind River Mountains to the east. The nearly 4,000-square-mile area is high, dry sagebrush-steppe, basically a desert where winter brings wind and cold, and little snow (Ostlind 2011). Temperatures are cooler in the Wyoming section than in the Idaho valley (fig. 3.1); mean annual temperature for Big Piney in the northern part of Green River Basin is 36 ^{o}F, making for a short growing season. Winter extremes can reach -50 ^{o}F as cold air settles in the Green River Basin.

Mean minimum temperatures for this subregion showed a slight warming trend over the 1949–2010 period (fig. 3.4). Mean maximum temperatures during this time ranged from about 55 to 60 ^{o}F, with little trend (fig. 3.5). Hoekema and Sridhar (2011) reported regional warming in the Snake River Basin, particularly in spring, over the last 35 years. This subregion and the Great Basin and Semi Desert are the driest subregions. Annual precipitation in the Intermountain Semi Desert subregion is generally between 8 and 12 inches (fig. 3.6). Precipitation showed no trend over the historical period.

Projected Climate

Changes in annual and seasonal temperature and precipitation are summarized by subregion in table 3.3. Trends in annual and seasonal temperature and precipitation projections are shown as figures for each subregion (see box 3.1 for more information on the format of these subregional figures): Middle Rockies (figs. 3.7–3.9), Southern Greater Yellowstone (figs. 3.10–3.12), Uintas and Wasatch Front (figs. 3.13–3.15), Plateaus (figs. 3.16–3.18), Great Basin and Semi Desert (figs. 3.19–3.21), and Intermountain Semi Desert (figs. 3.22–3.24).

In the future, all subregions in the IAP are projected to see increases in annual and seasonal minimum and maximum temperatures, with greater changes under the RCP 8.5 scenario by 2100 than under the RCP 4.5 scenario (table 3.3). Within each subregion, temperatures vary greatly across landscapes, the result of topography and aspect. In the Middle Rockies, the projected increase in minimum temperature under the RCP 8.5 scenario will bring the subregional median temperature above freezing (fig. 3.7a); this projected increase suggests that for some areas in the IAP region, a biologically meaningful threshold could be crossed. Similar patterns for an increase in median minimum temperature above freezing occur in the Southern Greater Yellowstone subregion under the RCP 8.5 scenario only (fig. 3.10), and Uintas and Wasatch Front (fig. 3.13), the Plateaus (fig. 3.16), and the Intermountain Semi Desert subregions (fig. 3.22) under both scenarios. For most subregions, annual precipitation projections are highly variable with no discernible trend over time or between the two scenarios. However, slight increases in annual precipitation are projected under the RCP 8.5 scenario for the Middle Rockies, the Southern Greater Yellowstone, and the Intermountain Semi Desert subregions (figs. 3.7, 3.10, 3.22), which lie in the northern part of the IAP region.

Seasonal temperatures across the subregions are projected to increase and may cross biologically meaningful thresholds in particular seasons (table 3.3). Minimum seasonal temperatures are projected to rise in all seasons across all subregions under both the RCP 4.5 and RCP 8.5 scenarios (figs. 3.8, 3.11, 3.14, 3.17, 3.20, 3.23). Maximum seasonal temperatures are also projected to rise in all seasons under both RCP 4.5 and RCP 8.5 across all

Table 3.3—Summary of projected changes in annual and seasonal temperature, and precipitation for each Intermountain Adaptation Partnership subregion.

Subregion	Temperature	Precipitation	Seasonality
Middle Rockies	By 2100, median maximum temperature is projected to rise about 6 °F under RCP 4.5 and about 10 °F under RCP 8.5; the two ensemble projections begin to diverge after 2045. Median minimum temperature is projected to rise about 5 °F under RCP 4.5 and about 10 °F under RCP 8.5.	Annual precipitation projections are highly variable with no discernible trend under RCP 4.5 and a slight increasing trend under RCP 8.5.	Maximum temperatures are projected to increase by 5 to 10 °F across the seasons. The greatest departure from historical seasonal minimum temperatures occurs in summer. Over the historical period, summer minimum temperatures ranged around the mid- to upper 30s. By 2040, the projected median is 40 °F and rises to nearly 50 °F under the RCP 8.5 scenario by 2100 (fig. 3.9). By 2100, the median projections for spring, summer, and fall under the RCP 8.5 scenario are outside of historical ranges.
Southern Greater Yellowstone	By 2100, median maximum temperature is projected to rise about 5 °F under RCP 4.5 and about 11 °F under RCP 8.5; projections for the two RCPs begin to diverge around 2040. By 2100, median minimum temperature is projected to increase about 6 °F under RCP 4.5 and about 12 °F under RCP 8.5. Median minimum temperatures are projected to remain below freezing under RCP 4.5. However, minimum temperatures are likely to rise to just under freezing by 2100 under RCP 8.5.	Annual precipitation projections are highly variable with no discernible trend under RCP 4.5 and a slight increasing trend under RCP 8.5.	Maximum temperature is projected to increase in all seasons, with winter temperatures rising about 3 °F and all other seasons rising about 5 °F under RCP 4.5 by the end of the 21st century. Under the warmest scenario, seasonal temperatures increase about 10 °F in winter, spring, and fall, but by more than 12 °F in summer by the end of the 21st century. Median minimum temperatures for all seasons by the 2080s are projected to be outside of historical ranges in the warmest scenario. Median minimum spring and fall temperatures are projected to increase, such that some projections rise above freezing by the end of the 21st century under the RCP 8.5 scenario.
Uintas and Wasatch Front	By 2100, median maximum temperature is projected to rise about 5 °F under RCP 4.5 and about 11 °F under RCP 8.5. Projections for the two scenarios begin to diverge around 2040. By 2100, median minimum temperature is projected to rise about 5 °F under RCP 4.5 and about 12 °F under RCP 8.5. Median minimum temperatures are projected to rise above freezing in both scenarios (by 2050 under RCP 8.5 and by 2075 under RCP 4.5).	Annual precipitation projections are highly variable with no discernible trends.	Maximum temperatures are projected to increase in all seasons, with winter temperatures rising about 4 °F and all other seasons rising about 6 °F under RCP 4.5 by the end of the 21st century. Maximum median temperatures by the 2080s are outside of the historical range of values for all seasons in the warmest scenario. Median minimum spring and fall temperatures are projected to rise above freezing by the 2080s in both scenarios. The greatest departure from historical seasonal minimum temperatures occurs in summer.

Table 3.3—*Continued.*

Subregion	Temperature	Precipitation	Seasonality
Plateaus	By 2100, median maximum temperature is projected to rise about 5 °F under RCP 4.5 and about 10 °F under RCP 8.5. By 2100, median minimum temperature is projected to rise about 5 °F under RCP 4.5 and about 12 °F under RCP 8.5; the two ensemble projections begin to diverge after 2050. By 2050, median minimum temperature is projected to rise above freezing in both scenarios.	Precipitation projections are highly variable with no discernible trend over time or between the two scenarios.	Maximum temperature is projected to increase in all seasons by about 5 °F under RCP 4.5 and by about 10 °F under RCP 8.5 by the end of the 21st century. The greatest departure from historical temperatures by 2100 is projected to occur in summer, where median temperatures rise above 95 °F under the RCP 8.5 scenario. Projected median maximum temperatures for winter, spring and autumn are also outside of historical ranges by end of the 21st century. The greatest departure from historical seasonal minimum temperatures is projected to occur in summer. Minimum temperatures in summer are projected to rise about 6 °F by 2100 under RCP 4.5 and over 10 °F under RCP 8.5, with the variation well outside of the historical ranges.
Great Basin and Semi Desert	By 2100, median maximum temperature is projected to rise about 5 °F under the RCP 4.5 scenario and about 10 °F under the RCP 8.5 scenario. Historically median minimum temperature has ranged around freezing; in the near future, it is projected to rise above freezing, and by end of century, is projected to increase by 6 to 10 °F. The two ensemble projections begin to diverge after 2050.	Precipitation projections are highly variable with no discernible trend over time or between the two scenarios.	Maximum temperature is projected to increase by 5 °F in winter and spring under the RCP 4.5 scenario and by 10 °F under the RCP 8.5 scenario by the end of the 21st century. Summer and fall temperatures are projected to increase by 12 °F by the end of the 21st century under the RCP 8.5 scenario. Median minimum spring temperatures rise above freezing for both scenarios by 2100 and for the RCP 8.5 scenario, temperatures approach 40 °F. Median minimum and maximum projections for the both scenarios in all seasons by 2100 are outside of the historical range.
Intermountain Semi Desert	By the mid-21st century, median maximum temperature is projected to rise about 5 °F under RCP 4.5 and about 10 °F under the RCP 8.5. Median minimum temperature is projected to rise about 5 °F under RCP 4.5 and about 11 °F under RCP 8.5. By 2100, the projected changes for minimum temperature rise above freezing.	The highly variable precipitation projections show no discernible trend over time under the RCP 4.5 and suggest a slight increase under the RCP 8.5 scenario.	Maximum temperature increases in all seasons to the end of the 21st century in both climate scenarios. The greatest departure from historical temperatures by 2100 occurs in summer under RCP 8.5, when projected mean temperatures approach 95 °F, nearly 15 °F above historical temperature. Median minimum seasonal temperatures are projected to rise in all seasons. Median minimum and maximum values for all seasons under the RCP 8.5 scenario are outside of the historical ranges by 2100.

subregions (figs. 3.9, 3.12, 3.15, 3.18, 3.21, 3.24). Thus, the frequency of days with extreme heat in summer is likely to increase. Winter precipitation is an important reservoir for mountain and surrounding lower elevation communities. Few subregional or site-specific projections for snowpack have been made for the IAP region. For the Wasatch Range and Uinta Mountains, Klos et al. (2014) used only RCP 8.5 and 20 climate models (similar to the projections used in this chapter), and they report that these ranges will have fall-through-spring temperatures such that wintertime precipitation will begin to shift from strongly snow dominated to a mixed rain-snow regime by the mid-21st century. The shoulder months of November and March will shift to rain, with December through February retaining a snow-dominated system longer. For additional discussion of snowpack and climate change, see Chapter 4. Also see Rice et al. (2017) for a review of climate change literature for the Uintas and Wasatch Front area.

Box 3.1—Template for Projected Climate Change Figures

For each of the six subregions, a common template for figures has been used to describe the projected climate. The first figure for each subregion (figs. 3.7, 3.10, 3.13, 3.16, 3.19, 3.22) shows the historical simulations and projections for annual daily minimum and maximum mean temperatures (°F), and total annual precipitation (inches) under the RCP 4.5 and RCP 8.5 scenarios based on the CMIP5 BCSD data. These figures show the historical climate simulations by the CMIP5 models, which reflect the pre-2010 climate forcings. These historical simulations are bias corrected and downscaled in the same manner as model future projections. In these figures, we overlaid the gridded historical observation data (blue line) from Maurer et al. (2002). In most regions, the historical simulated minimum and maximum temperatures and annual precipitation are less variable than the historical observed gridded climate. The future projections are shown in colors: red for RCP 8.5 and yellow for RCP 4.5. The ensemble median from all 20 models for each scenario is shown in the heavy line; the 5th- and 95th-percent quantiles for all models are shown by the shaded area. Typically, climate projections under the higher emissions scenario (RCP 8.5) will indicate a higher temperature by 2100 than climate projections under the RCP 4.5 scenario.

The second figure for each subregion (figs. 3.8, 3.11, 3.14, 3.17, 3.20, 3.23) shows the seasonal daily minimum temperature (°F) for the historical and projected period 1950–2100. Winter is defined as the months of December, January, and February. Spring is defined as March, April, and May; summer as June, July, and August; and fall as September, October, and November. We use box plots here, where each box is an aggregation of 20 years of modeled historical or projected seasonal data. For example, the box labeled "1960" represents the seasonal average of 1950 to 1969. We used the 20-year period here to explore the temporal changes over this century. The modeled historical boxes are gray, and boxes for projections use the same colors as in other figures: yellow for RCP 4.5 and red for RCP 8.5. The central line in each box is the median, indicating the same number of modeled historical or projections above and below this line. The hinges or edges of the boxes are the first and third quartiles. Whiskers extend past the first and third quartile by 1.5 times the interquartile range.

The third figure for each subregion (figs. 3.9, 3.12 3.15, 3.18, 3.21, 3.24) shows the seasonal daily maximum temperature (°F) for the historical and projected period. These figures are set up in the same way as the second figures. There is large variability and no discernible trend in the seasonal precipitation projections, and hence, less confidence overall in the finer scale precipitation projections; these figures are not shown here.

Summary and Conclusions

For this overview, the projected climate was derived from climate models in the CMIP5 database, which was used in the most recent IPCC reports. We quantified changes in temperature and precipitation by the 2040 period (2030–2059) and 2080 period (2070–2099). Over the next 100 years, annual minimum and maximum temperatures are projected to rise by as much as 10 °F in the IAP region. Projections for annual precipitation are highly variable. For most subregions in the IAP area, precipitation remains variable; slight increases in total annual precipitation are projected for the Middle Rockies, Southern Greater Yellowstone, and Intermountain Semi Desert subregions under the RCP 8.5 scenario. As with annual temperature, winter, spring, summer, and fall temperatures are projected to increase, with summer temperatures showing the greatest increases in several subregions. For many subregions, the seasonal temperatures by end of century are outside of the historical observed ranges. Many of the resource chapters draw from existing scientific literature that used climate projections from the 2007 IPCC reports (the CMIP3 database). In mid-century (2040–2060), CMIP3 and CMIP5 temperature projections are similar. However, CMIP5 precipitation projections appear to be slightly wetter than those in CMIP3.

Acknowledgments

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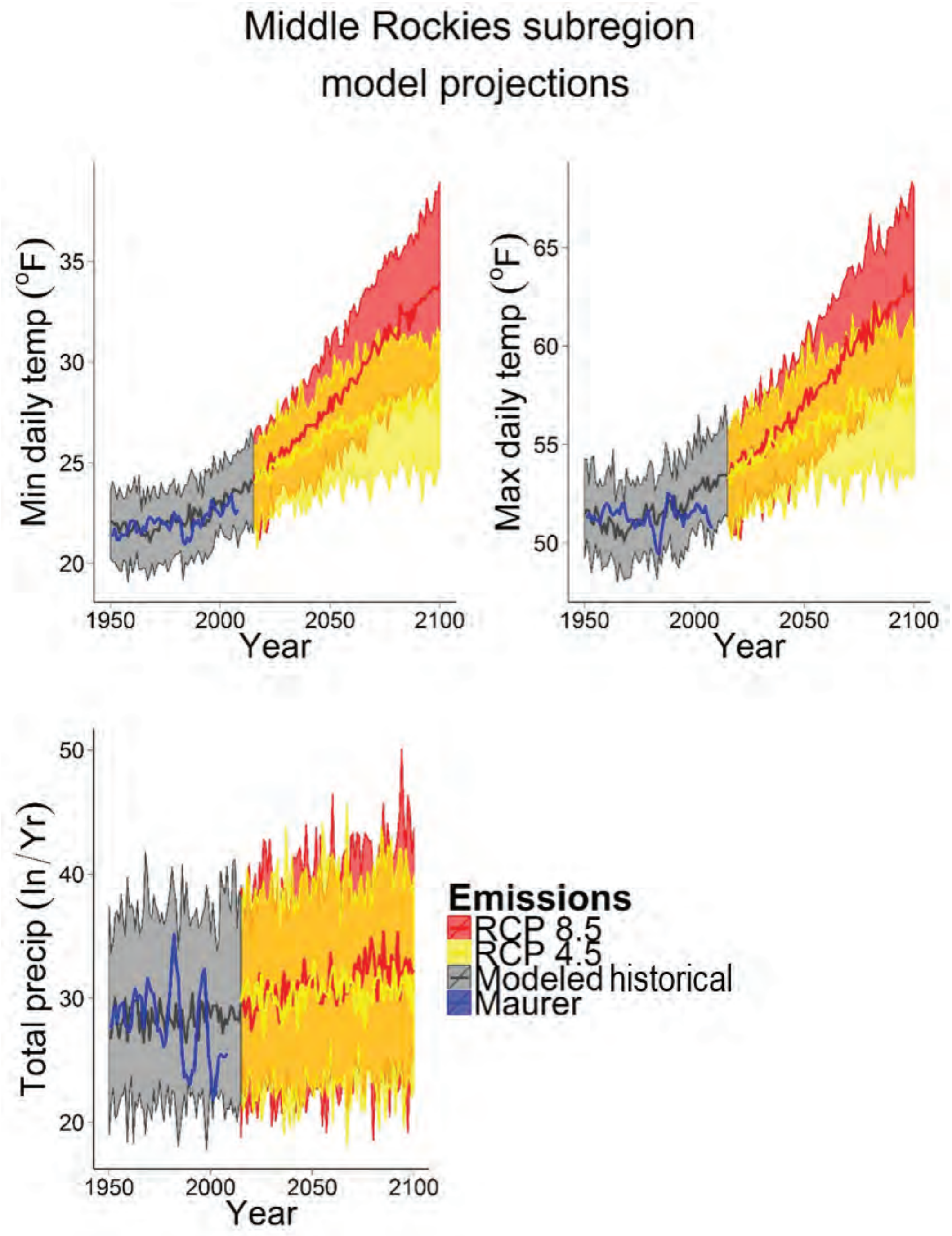

Figure 3.7—Historical modeled and projected annual mean monthly minimum temperature, annual mean monthly maximum temperature, and total annual precipitation for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios based on CMIP5 data for the Middle Rockies subregion of the Intermountain Adaptation Partnership region. Historical annual data from the gridded Maurer et al. (2007) dataset are also shown. See box 3.1 for further explanation.

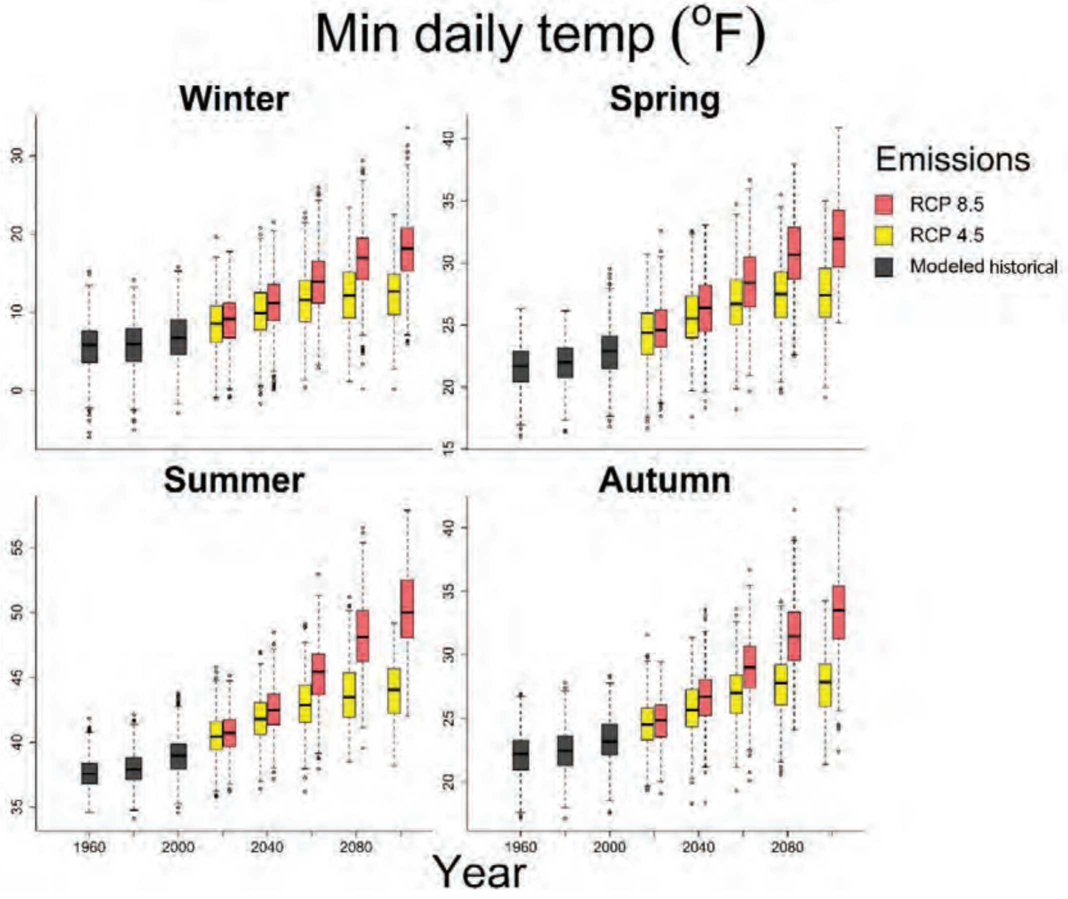

Figure 3.8—Historical modeled and projected seasonal mean monthly minimum temperature for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios for the Middle Rockies subregion of the Intermountain Adaptation Partnership region. See box 3.1 for further explanation.

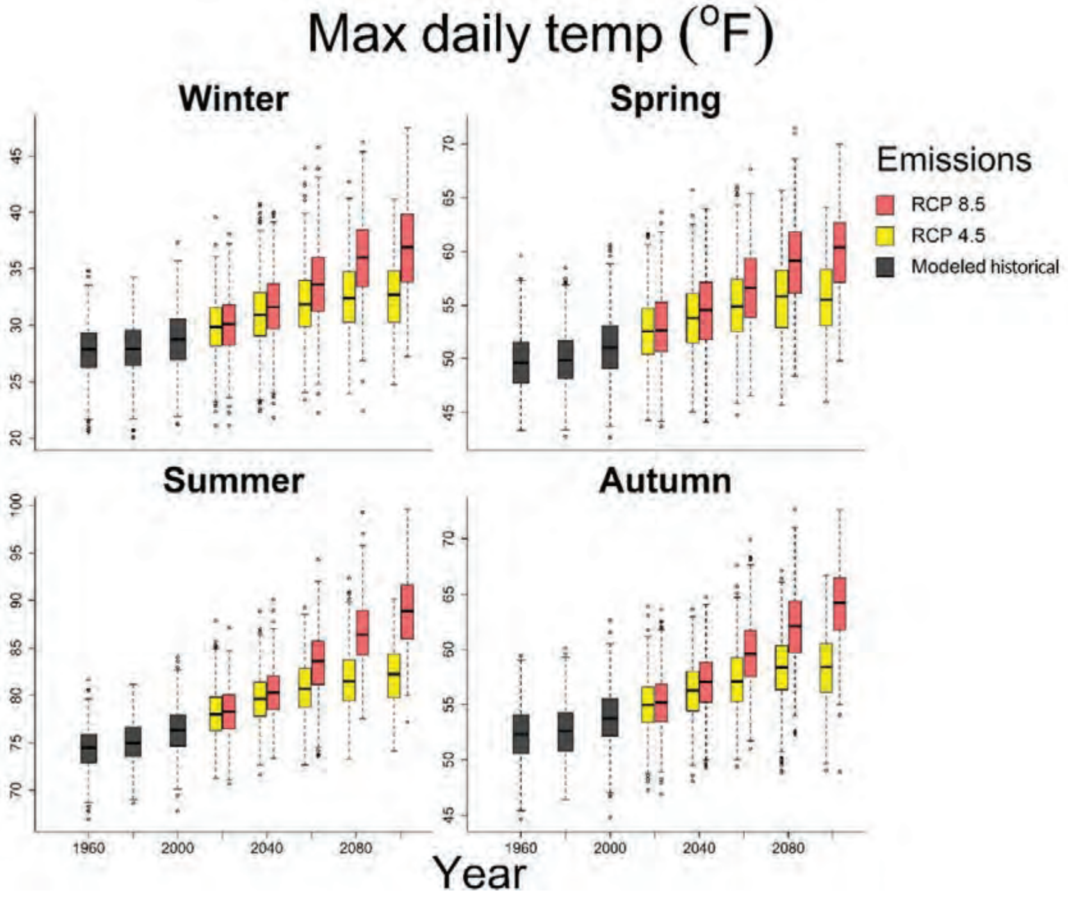

Figure 3.9—Historical modeled and projected seasonal mean monthly maximum temperature for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios for the Middle Rockies subregion of the Intermountain Adaptation Partnership region. See box 3.1 for further explanation.

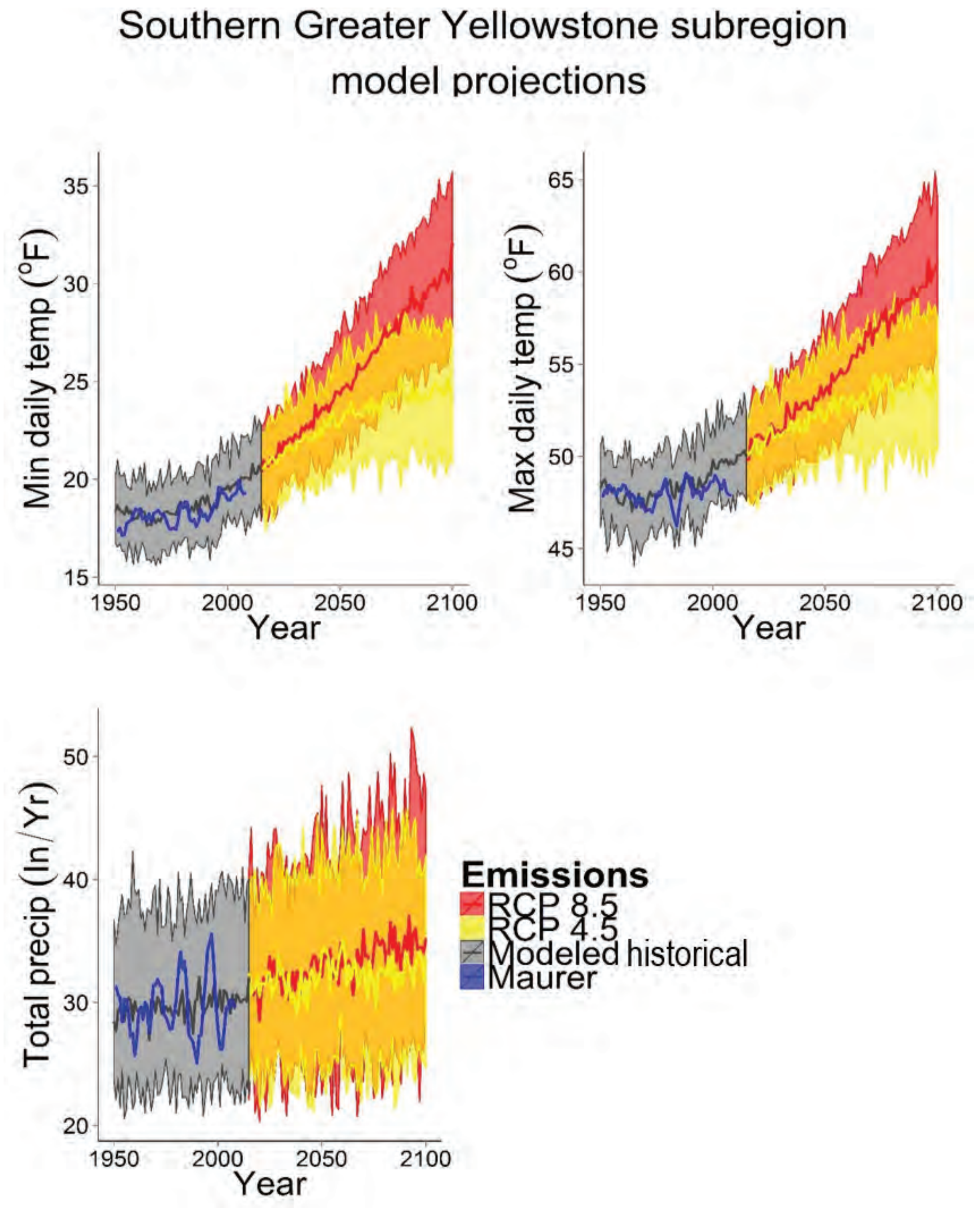

Figure 3.10—Historical modeled and projected annual mean monthly minimum temperature, annual mean monthly maximum temperature, and total annual precipitation for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios based on CMIP5 data for the Southern Greater Yellowstone subregion of the Intermountain Adaptation Partnership region. Historical annual data from the gridded Maurer et al. (2007) dataset are also shown. See box 3.1 for further explanation.

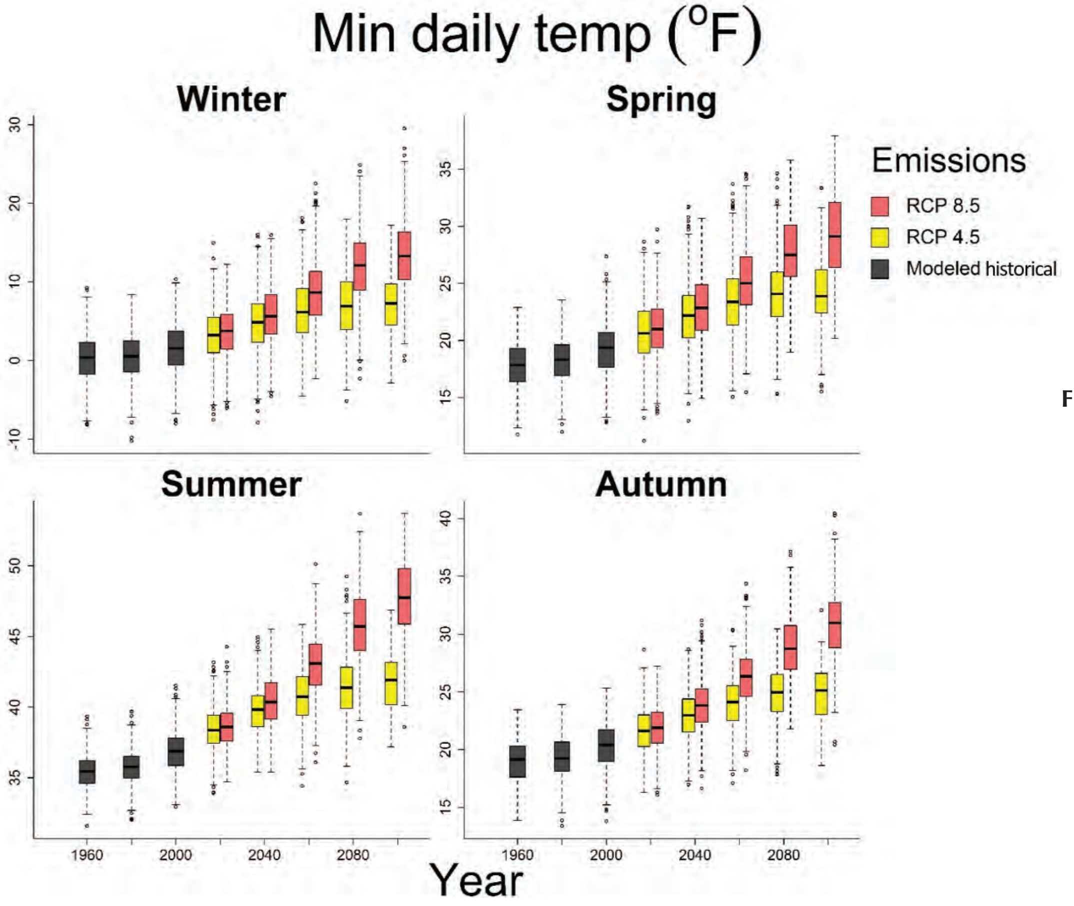

Figure 3.11— Historical modeled and projected seasonal mean monthly minimum temperature for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios for the Southern Greater Yellowstone subregion of the Intermountain Adaptation Partnership region. See box 3.1 for further explanation.

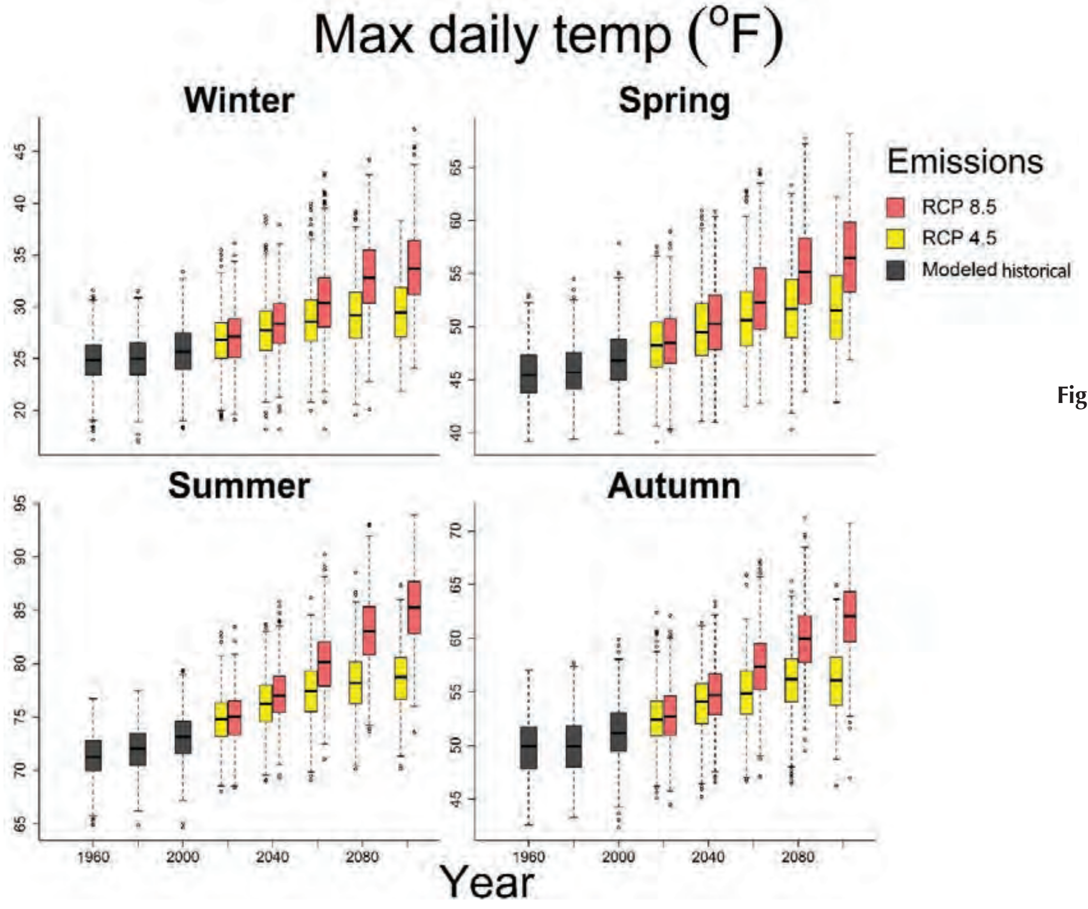

Figure 3.12—Historical modeled and projected seasonal mean monthly maximum temperature for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios for the Southern Greater Yellowstone subregion of the Intermountain Adaptation Partnership region. See box 3.1 for further explanation.

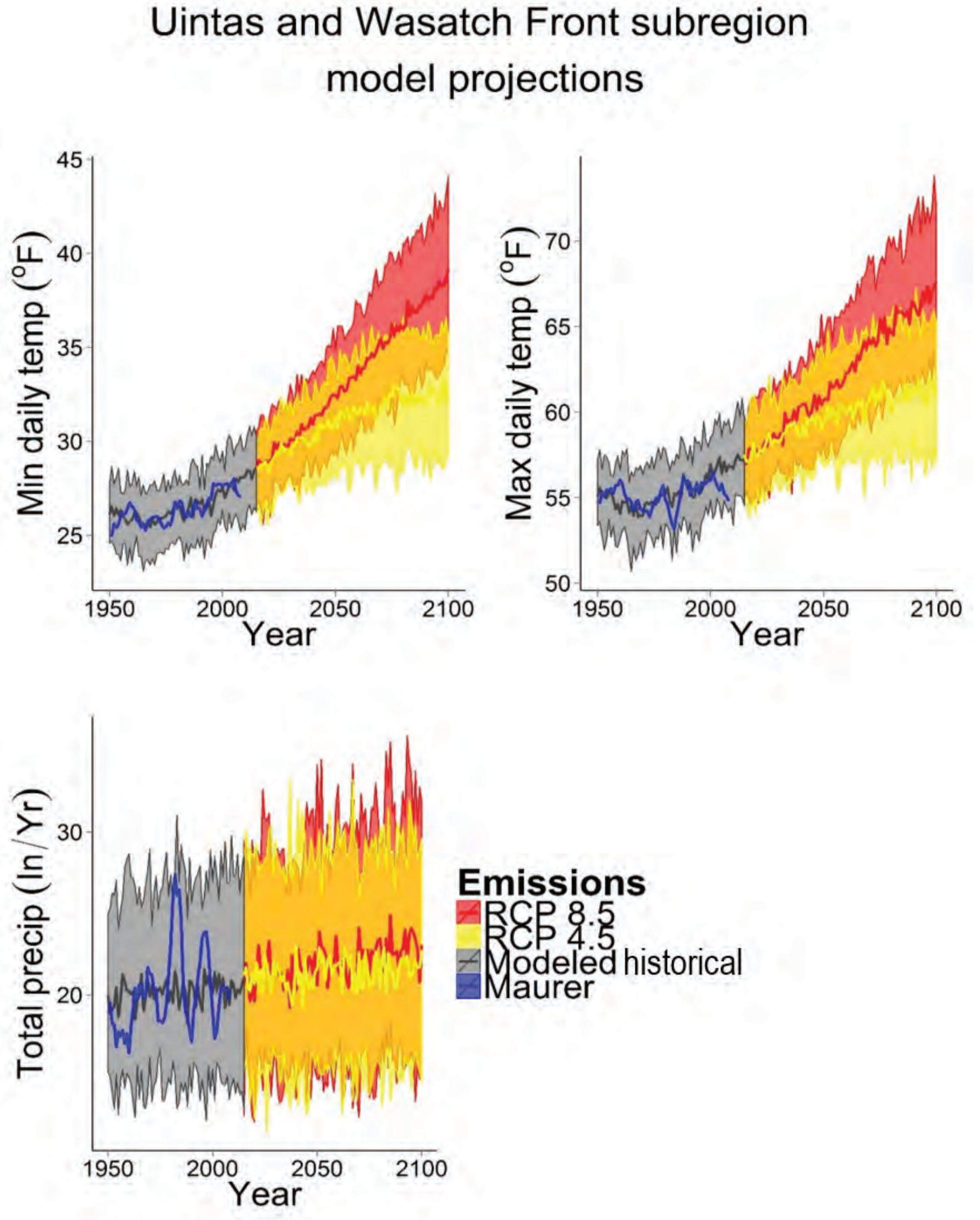

Figure 3.13—Historical modeled and projected annual mean monthly minimum temperature, annual mean monthly maximum temperature, and total annual precipitation for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios based on CMIP5 data for the Uintas and Wasatch Front subregion of the Intermountain Adaptation Partnership region. Historical annual data from the gridded Maurer et al. (2007) dataset are also shown. See box 3.1 for further explanation.

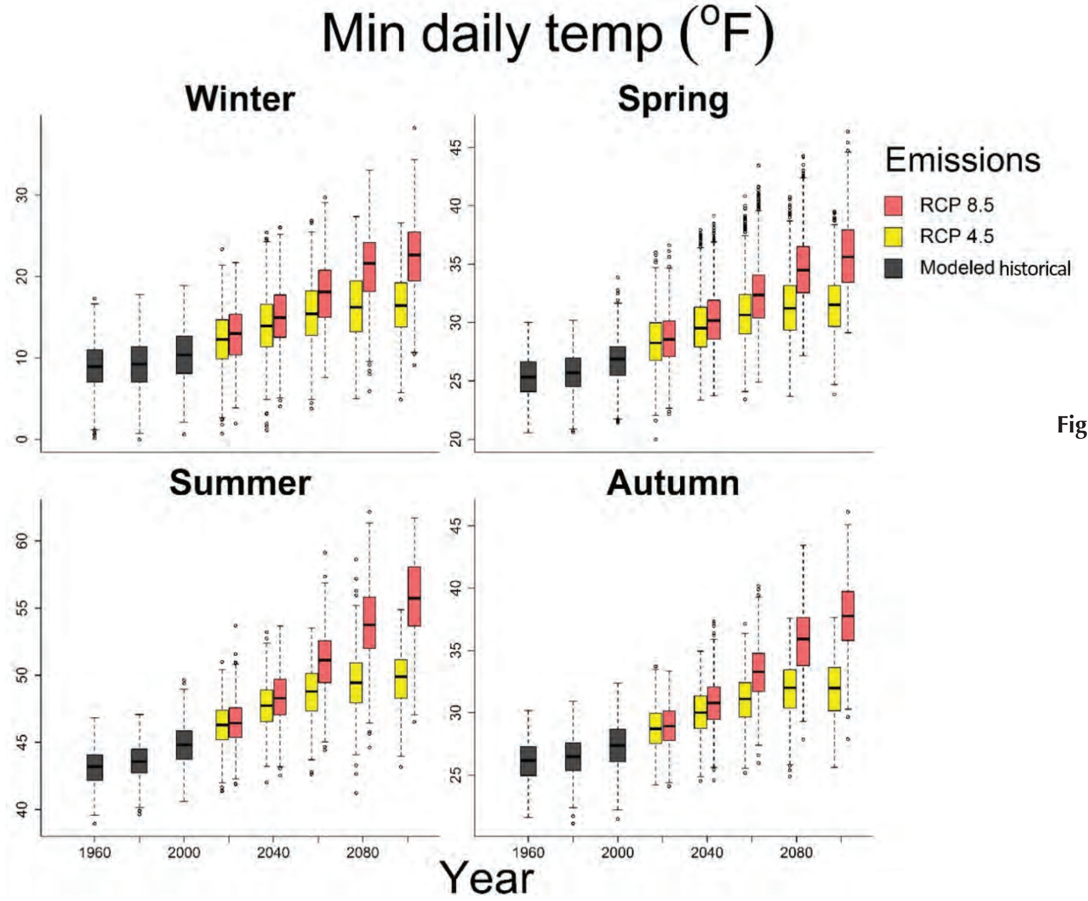

Figure 3.14— Historical modeled and projected seasonal mean monthly minimum temperature for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios for the Uintas and Wasatch Front subregion of the Intermountain Adaptation Partnership region. See box 3.1 for further explanation.

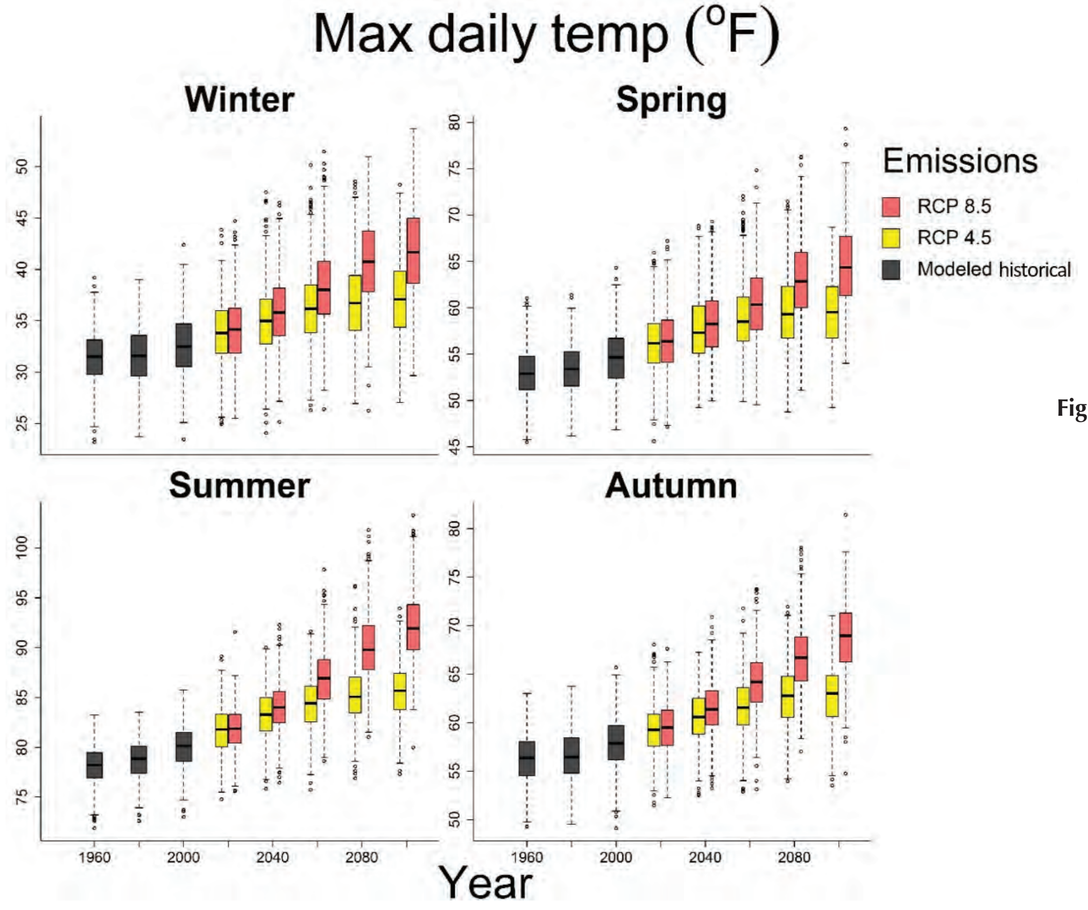

Figure 3.15— Historical modeled and projected seasonal mean monthly maximum temperature for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios for the Uintas and Wasatch Front subregion of the Intermountain Adaptation Partnership region. See box 3.1 for further explanation.

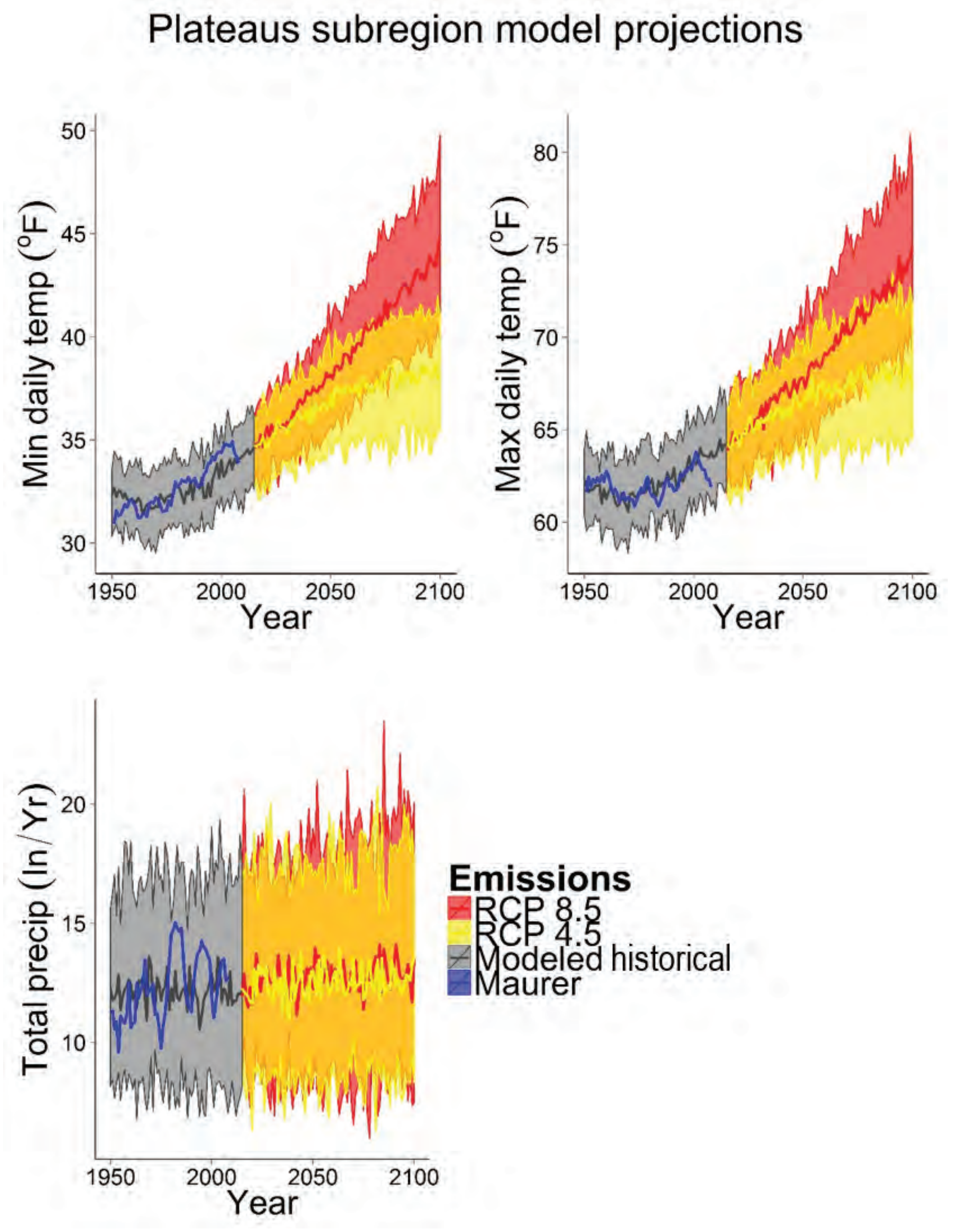

Figure 3.16—Historical modeled and projected annual mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios based on CMIP5 data for the Plateaus subregion of the Intermountain Adaptation Partnership region. Historical annual data from the gridded Maurer et al. (2007) dataset are also shown. See box 3.1 for further explanation.

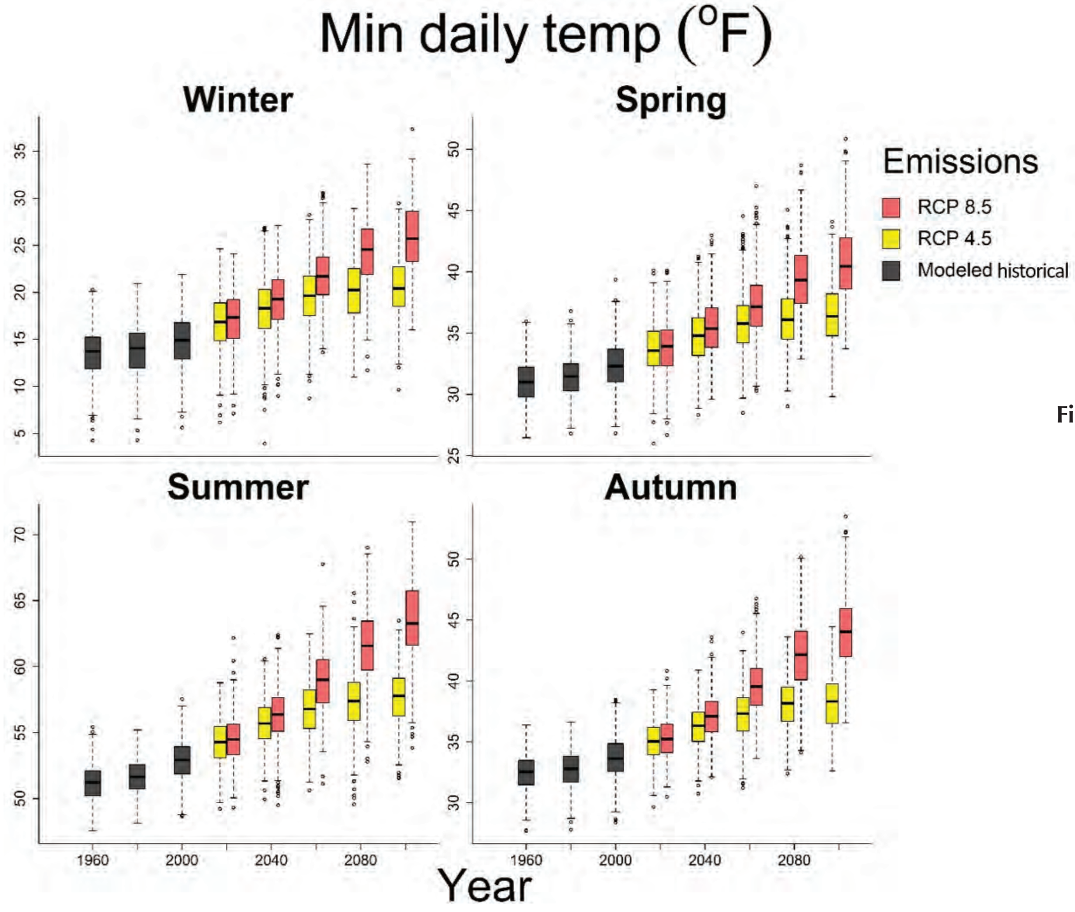

Figure 3.17— Historical modeled and projected seasonal mean monthly minimum temperature for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios for the Plateaus subregion of the Intermountain Adaptation Partnership region. See box 3.1 for further explanation.

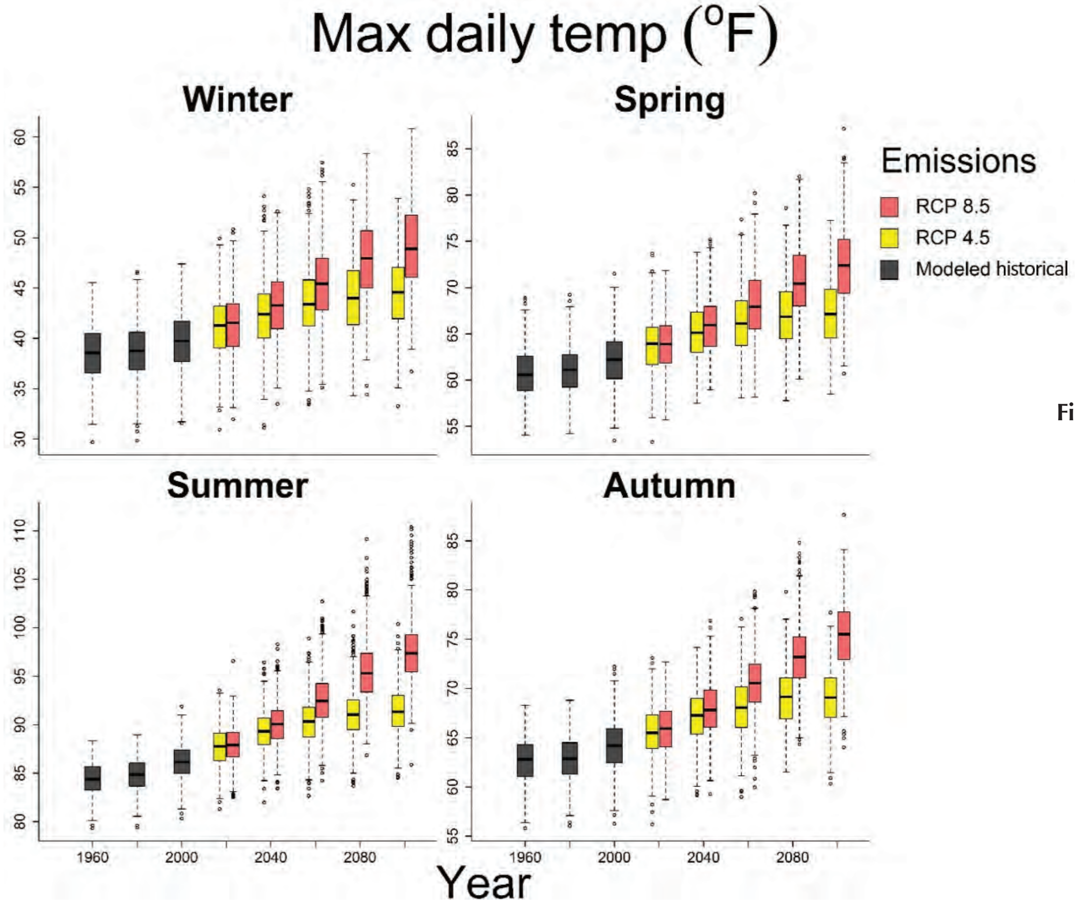

Figure 3.18— Historical modeled and projected seasonal mean monthly maximum temperature for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios for the Plateaus subregion of the Intermountain Adaptation Partnership region. See box 3.1 for further explanation.

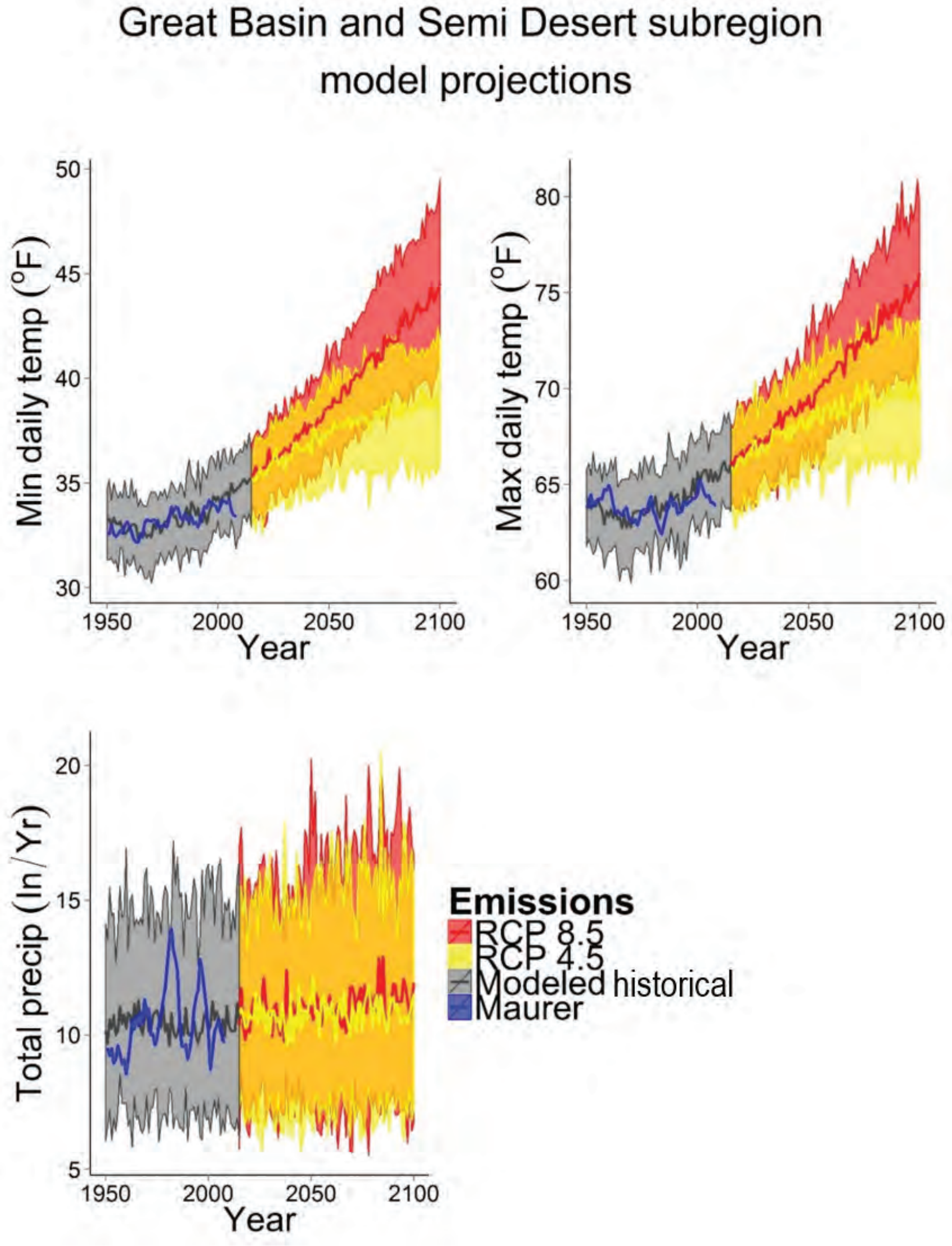

Figure 3.19—Historical modeled and projected annual mean monthly minimum temperature, annual mean monthly maximum temperature, and total annual precipitation for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios based on CMIP5 data for the Great Basin and Semi Desert subregion of the Intermountain Adaptation Partnership region. Historical annual data from the gridded Maurer et al. (2007) dataset are also shown. See box 3.1 for further explanation.

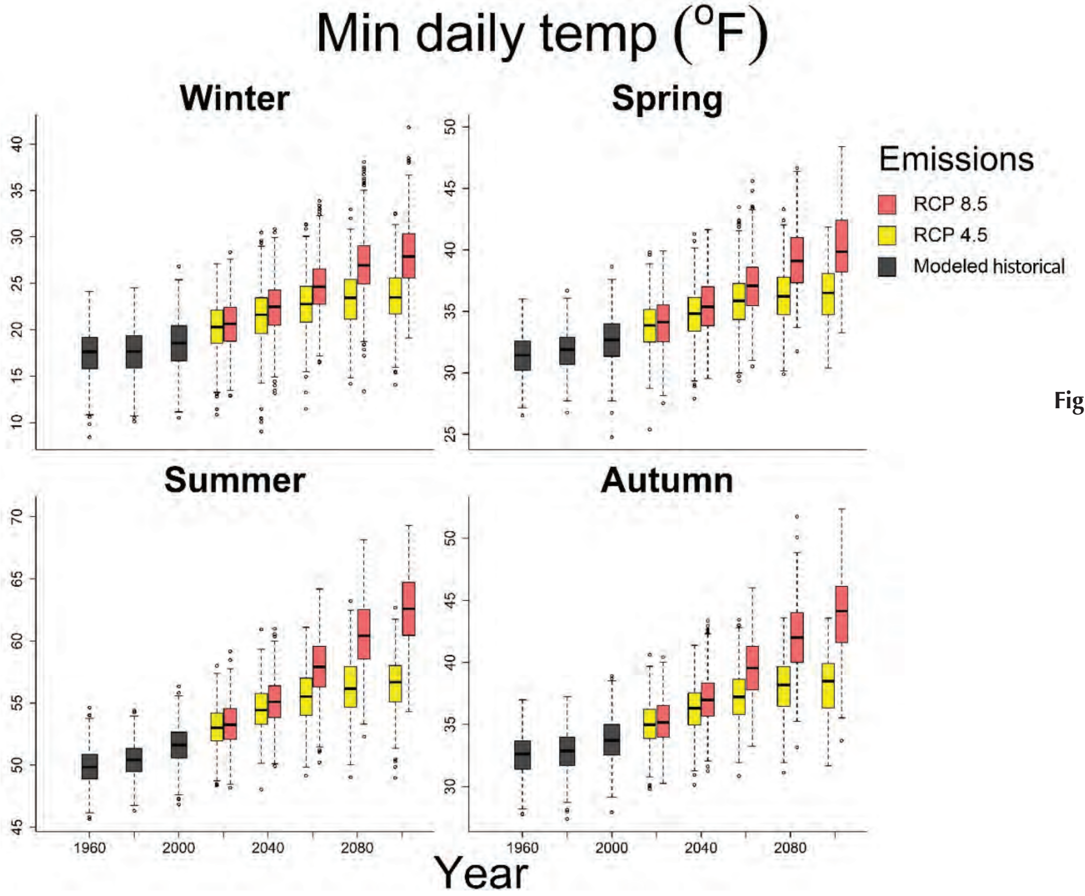

Figure 3.20—Historical modeled and projected seasonal mean monthly minimum temperature for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios for the Great Basin and Semi Desert region of the Intermountain Adaptation Partnership region. See box 3.1 for further explanation.

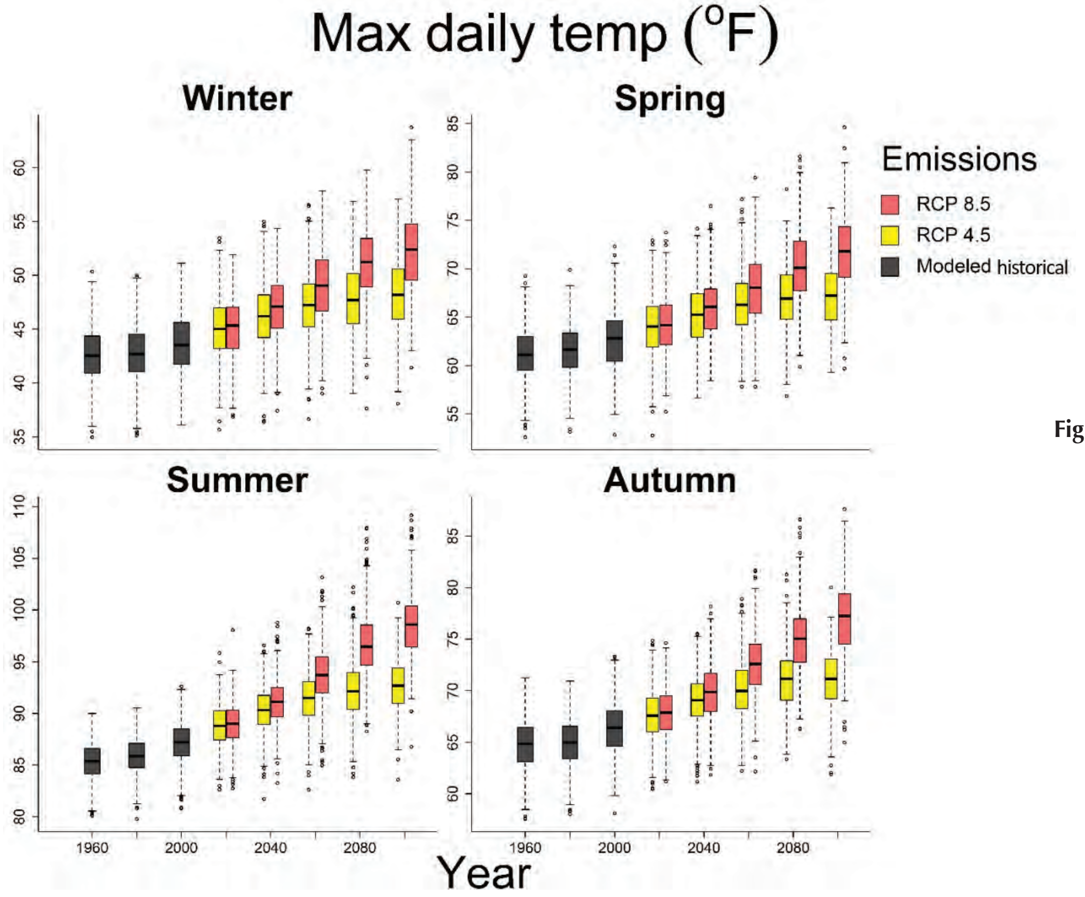

Figure 3.21—Historical modeled and projected seasonal mean monthly maximum temperature for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios for the Great Basin and Semi Desert subregion of the Intermountain Adaptation Partnership region. See box 3.1 for further explanation.

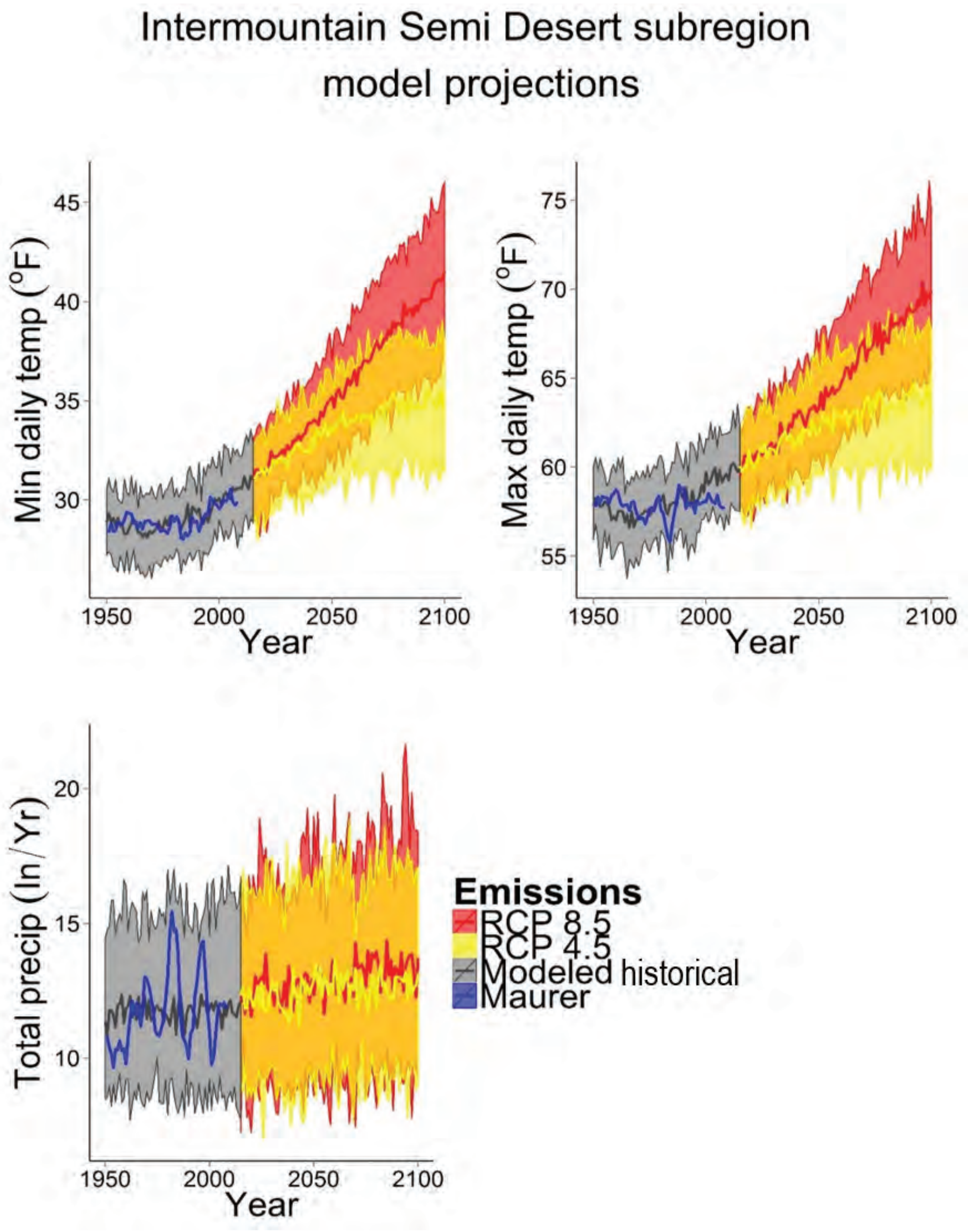

Figure 3.22—Historical modeled and projected annual mean monthly minimum temperature, annual mean monthly maximum temperature, and total annual precipitation for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios based on CMIP5 data for the Intermountain Semi Desert subregion of the Intermountain Adaptation Partnership region. Historical annual data from the gridded Maurer et al. (2007) dataset are also shown. See box 3.1 for further explanation.

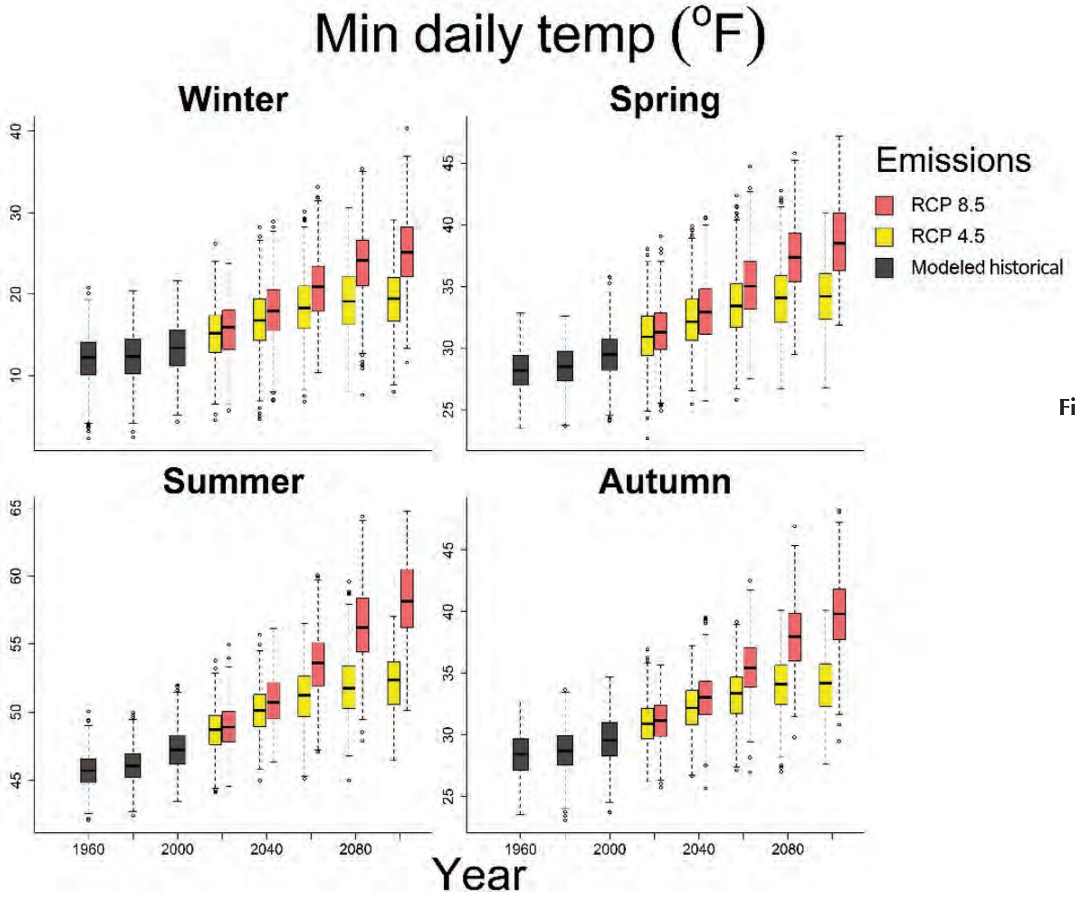

Figure 3.23—Historical modeled and projected seasonal mean monthly minimum temperature for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios for the Intermountain Semi Desert subregion of the Intermountain Adaptation Partnership region. See box 3.1 for further explanation.

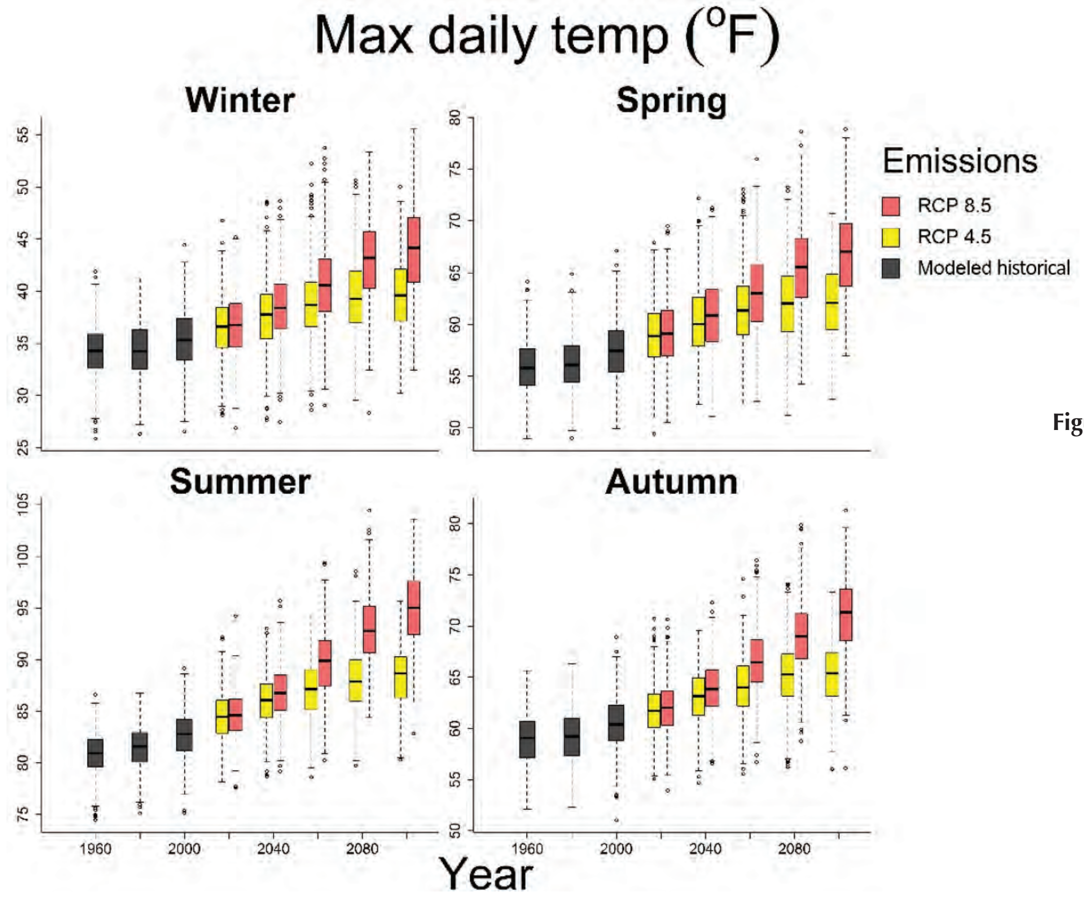

Figure 3.24— Historical modeled and projected seasonal mean monthly maximum temperature for 1950–2100 under RCP 4.5 and RCP 8.5 emissions scenarios for the Intermountain Semi Desert subregion of the Intermountain Adaptation Partnership region. See box 3.1 for further explanation.

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Appendix 2—Models Included in the Climate Analysis for the Intermountain Adaptation Partnership Region

Following are the climate models we used in the Intermountain Adaptation Partnership Region climate analysis, and the institutions that developed them. CMIP5 climate projections for RCP 4.5 and RCP 8.5 scenarios were obtained for these models using the downscaled CMIP3 and CMIP5 climate and hydrology projections archive at: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections. The first model run was selected for this analysis. Model runs were available for both RCP 4.5 and RCP 8.5 scenarios, except for the NASA Goddard Institute for Space Studies models GISS-E2-H-CC and GISS-E2-R-CC.

Institution	Climate model
Commonwealth Scientific and Industrial Research Organization and Bureau of Meteorology, Australia	ACCESS1-0
	ACCESS1-3
Beijing Climate Center, China Meteorological Administration	bcc-csm1-1
Beijing Climate Center, China Meteorological Administration	bcc-csm1-1-m
Canadian Centre for Climate Modelling and Analysis	CanESM2
National Center for Atmospheric Research	CCSM4
Community Earth System Model Contributors	CESM1-BGC
	CESM1-CAM5
Centro Euro-Mediterraneo per i Cambiamenti Climatici	CMCC-CM
Centre National de Recherches Météorologiques/Centre Européen de Recherche et Formation Avancée en Calcul Scientifique	CNRM-CM5
Commonwealth Scientific and Industrial Research Organization, Queensland Climate Change Centre of Excellence	CSIRO-Mk3-6-0
EC-EARTH consortium	EC-EARTH
Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences, and Center for Earth System Science, Tsinghua University	FGOALS-g2
Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences, and Center for Earth System Science, Tsinghua University	FGOALS-s2
The First Institute of Oceanography, State Oceanic Administration, China	FIO-ESM
NOAA Geophysical Fluid Dynamics Laboratory	GFDL-CM3
	GFDL-ESM2G
	GFDL-ESM2M
NASA Goddard Institute for Space Studies	GISS-E2-H-CC
	GISS-E2-R
	GISS-E2-R-CC
Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)	HADGEM2-AO
Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)	HADGEM2-CC
Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)	HADGEM2-ES

Institute for Numerical Mathematics	INM-CM4
Institut Pierre-Simon Laplace	IPSL-CM5A-LR
	IPSL-CM5A-MR
	IPSL-CM5B-LR
Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	MIROC-ESM
	MIROC-ESM-CHEM
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC5
Max Planck Institute for Meteorology (MPI-M)	MPI-ESM-LR
Max Planck Institute for Meteorology (MPI-M)	MPI-ESM-MR
Meteorological Research Institute	MRI-CGCM3
Norwegian Climate Centre	NorESM1-M
Norwegian Climate Centre	MorESM1-ME

Chapter 4: Effects of Climate Change on Hydrology, Water Resources, and Soil

Mark J. Muir, Charles H. Luce, Joseph T. Gurrieri, Marek Matyjasik, Jeffrey L. Bruggink, Stacey L. Weems, James C. Hurja, David B. Marr, and Sarah D. Leahy

Introduction

Water is critical to life, and many of the effects of climate change on ecosystems are mediated through altered hydrology. Snow accumulation and melt are consistently cited as the most important changes to water in the western United States (Barnett et al. 2005; Service 2004), affecting when water will be available for forests, fish, and people. Changes in summer atmospheric circulation patterns may alter the ability of summer precipitation to provide a midsummer respite from seasonal drought and dampening of wildfire spread (IPCC 2013) (Chapter 8). Declining summer water contributions will challenge municipal and agricultural water supplies (Barnett and Pierce 2009; Dawadi and Ahmad 2012). Aquatic and terrestrial ecosystems—including riparian areas, wetlands, and groundwater-dependent ecosystems—will be affected by lower base flows (Kormos et al. 2016; Rood et al. 2008), earlier snowmelt (Luce et al. 2014), increased periods of drought (Cayan et al. 2009), increased sediment delivery (Goode et al. 2012), and higher midwinter floods (Goode et al. 2013). Soils will likewise be affected by increased temperatures and shifts in precipitation and hydrological processes, with effects on physical and biological processes and attributes of soils.

This chapter describes potential changes to hydrological processes, groundwater resources, and soil attributes and processes in the Intermountain Adaptation Partnership (IAP) region with a changing climate. We specifically discuss potential changes in snowpack and glaciers, streamflow, drought, sediment yield, and groundwater recharge, and in soil temperature, moisture, carbon, nitrogen, biological activity, and chemical properties. The *Soil Resources* section concludes with an example vulnerability assessment method and application.

Hydrological Processes

Climate and Hydrological Processes

Warming temperatures are the most certain consequence of increased carbon dioxide in the atmosphere. The hydrological consequences of warmer temperatures include less snowpack and greater evaporative demand from the atmosphere. In general, snowpack depth, extent, and duration are expected to decrease, particularly at lower and middle elevations, because of a combination of less precipitation falling as snow (Pierce et al. 2008) and slightly earlier melt (Luce et al. 2014). The degree of change expected as a result of warming varies considerably over the landscape as a function of temperature (Luce et al. 2014). Places that are warm (near the melting point of snow) are expected to be more sensitive than places where temperatures remain subfreezing throughout much of the winter despite warming (Woods 2009).

The relationship of evapotranspiration (ET) to a warming climate is more complicated (Roderick et al. 2014). Warmer air can hold more water, which means that even if relative humidity stays constant, vapor pressure deficit—the difference between actual water content of the air and water content at saturation—increases. That difference between actual and saturation drives a water vapor gradient between leaves and the atmosphere that can draw more moisture out of the leaves. This is likely to cause more evaporation in a warmer climate (Cook et al. 2014; Dai 2013).

However, evaporation is an energy-intensive process, and there is only so much additional energy that will be available for evaporation. In addition, one needs to consider both the water balance and the energy balance when considering future warming (Roderick et al. 2015). The observation that temperatures are warmer during drought is related more generally to the lack of water to evaporate, leading to warmer temperatures, than to warmer temperatures causing faster evaporation (Yin et al. 2014). Unfortunately, when potential ET models based on air temperature (including Penman-Monteith) are applied as postprocessing to global climate model (GCM) calculations, an overestimate of increased ET is likely, because the energy balance is no longer tracked (Milly 1992; Milly and Dunne 2011). The reality is that most of the increased energy from increased longwave radiation will result in warming rather than increased evaporation (Roderick et al. 2015).

Precipitation has a direct effect on hydrological processes, although precipitation is less commonly discussed because climate change projections are uncertain (Blöschl and Montanari 2010; IPCC 2013). Figure 4.1 helps to illustrate how the IAP region is located in an area of high uncertainty in regard to precipitation projections, slightly overlapping with projected increases to the north and drying to the south (Walsh et al. 2014). The bounds of uncertainty (-20 to +30 percent) are large, making it difficult to accurately project the effects of precipitation on many hydrological processes (e.g., floods, hydrological drought, snow accumulation, groundwater recharge). As a consequence, we use an ensemble average precipitation for streamflow projections here. In this assessment, we also discuss uncertainty surrounding the mean estimate to illustrate which processes or hydrological outcomes are most uncertain and where. Not all processes are sensitive to precipitation, and uncertainty in outcomes caused by uncertainty in precipitation is not the same everywhere for a given process.

Background information can help to clarify where and when some precipitation estimates may be more reliable than others. Two primary concepts are applied for precipitation change: dynamic (referring to changes in wind and atmospheric circulation) and thermodynamic (referring to how much water the air can hold) (Seager et al. 2010). Dynamic drivers of precipitation change include changes in global circulation patterns (e.g., the Hadley cell extent) and changes in mid-latitude storm tracks. Changes in teleconnection patterns (e.g., the North American Monsoon System [NAMS]) fall into this category and are very important for this region. Thermodynamic changes reflect the fact that the atmosphere can hold more water (Held and Soden 2006), leading to an expectation on the order of a 3.9 percent increase in precipitation per 1 °F of temperature change. There are, however, other physical limits on the disposition of energy driving the cycling of water in the atmosphere. These lead to estimates on the order of less than 1 percent per 1 °F of temperature change at the global scale, with individual grid cells being less or potentially negative, particularly over land (Roderick et al. 2014). Different approaches to scaling the thermodynamic contribution are a reason for differences among models, although the dynamic process modeling differences can be great as well.

One outcome of thermodynamically driven changes is that when precipitation occurs, the same total volume is expected to fall with greater intensity, leading to shorter events and longer dry periods between events. The number of consecutive dry days is projected to increase across the western United States, which will affect portions of the IAP region (fig. 4.1). In the Pacific Northwest, this projection is connected to an expected decrease in summer precipitation, but for the Southwest, it is more likely connected to a decrease in monsoonal moisture during the late spring (fig. 4.2). In general, the NAMS is expected to weaken (IPCC 2013), particularly in the early portion of the monsoon season (Cook and Seager 2013), which could have substantial effects across the southern portion of the IAP region. Late spring and early summer precipitation contributions can be an important determinant of the severity of summer drought and length of fire seasons (Abatzoglou and Kolden 2013). Pairing longer periods of precipitation deficit in summer with decreasing snowpack may be particularly challenging for vegetation and aquatic ecosystems.

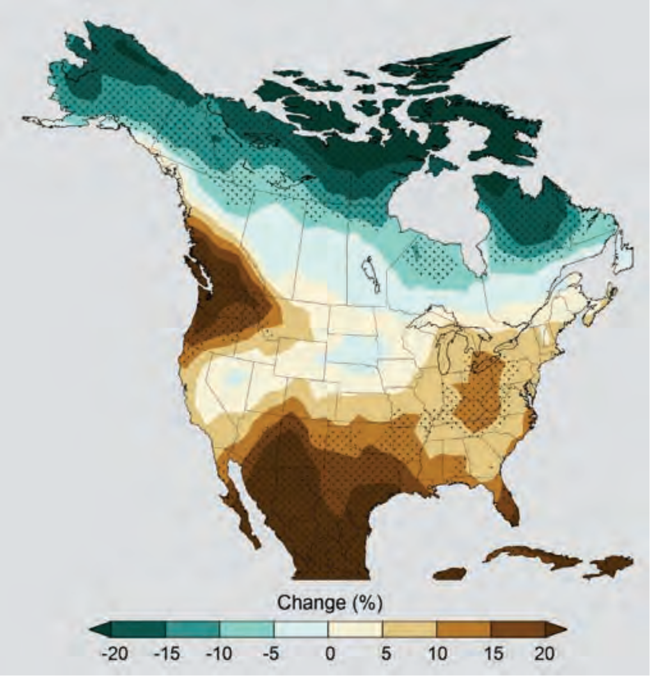

Figure 4.1—Projected change in the number of consecutive dry days for 2071–2099 (compared to 1970–1999) for the RCP8.5 emissions scenario (from Walsh et al. [2014]).

Changes in orographic enhancement of precipitation over mountainous areas also have dynamic effects. Historical changes in westerly windflows have led to a decrease in the enhancement of winter precipitation by orographic lifting over mountain ranges (Luce et al. 2013), raising the question of whether such a pattern may continue into the future. There is general agreement among GCMs projecting further decreases in windspeed into the 21st century, but the correlation is applicable only to the northern portion of the IAP region. Westerly winds are strongly correlated with precipitation in mountainous areas (fig. 4.3), but valley precipitation is not, nor is precipitation in much of southern Idaho. The historical trend in westerlies was driven by pressure and temperature changes spatially consistent with those expected under a changing climate; however, the rapidity of the changes in the last 60 years may have been partly enhanced by normal climatic variability.

Dynamic downscaling using a regional climate model (RCM) with small (~8 mile) cells provides a means to estimate orographically induced precipitation, which cannot be simulated with the large cell size of GCMs. Although the GCM shows general moistening over most of the area, the RCM shows a pattern of drying or no change on the upwind side of major mountain ranges, with moistening limited to valleys in the lee. Because mountainous areas are where most of the precipitation falls (and streamflow originates), this is a potentially important aspect of future changes. The Variable Infiltration Capacity (VIC) model simulations

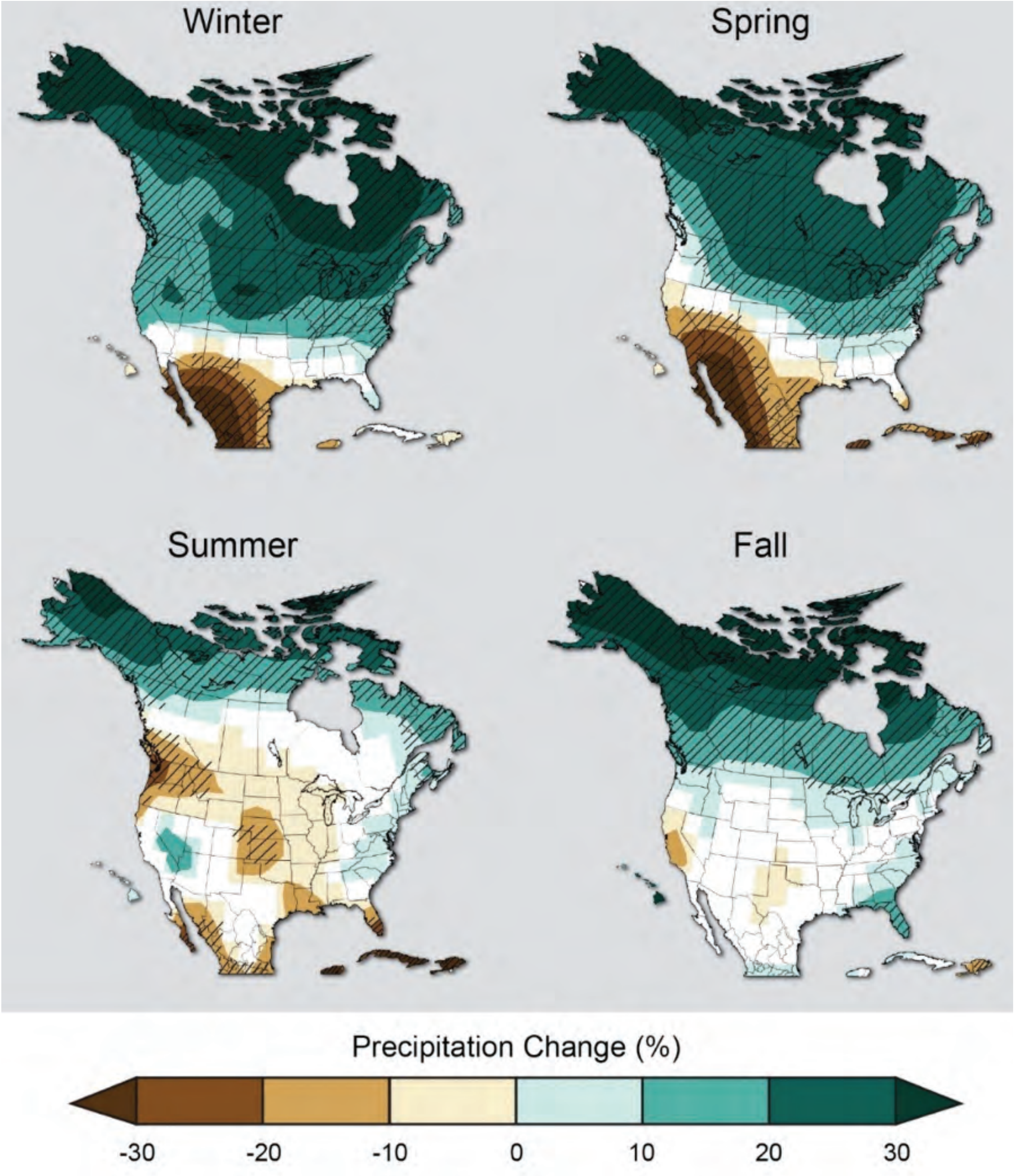

Figure 4.2—Projected change in seasonal precipitation for 2071–2099 (compared to 1970–1999) under the RCP 8.5 emissions scenario (Walsh et al. 2014). Hatched lines indicate model agreement and nonhatched areas have the highest uncertainty. The Intermountain Adaptation Partnership region sits in an area of high uncertainty, between projected moistening to the north and drying to the south.

discussed later in this chapter do not include this effect, so for purposes of general discussion, it can be considered an additional source of uncertainty for precipitation.

The range of potential changes to climate is complex, particularly for such a varied landscape as the IAP region (fig. 4.2), and current climatological settings vary over the landscape at both large and small spatial scales. Precipitation seasonality and amount differ between mountain and valley locations. Trends and drivers for climatic variation will also differ from the northern to southern portions of the region. Fundamentally, topography is an important factor affecting seasonality, precipitation amount, and potential trends. Because most forests and generation of water supply are generally in mountainous areas, it is important to recognize how topography affects climate. Specific hydrological outcomes of interest are discussed in the following sections.

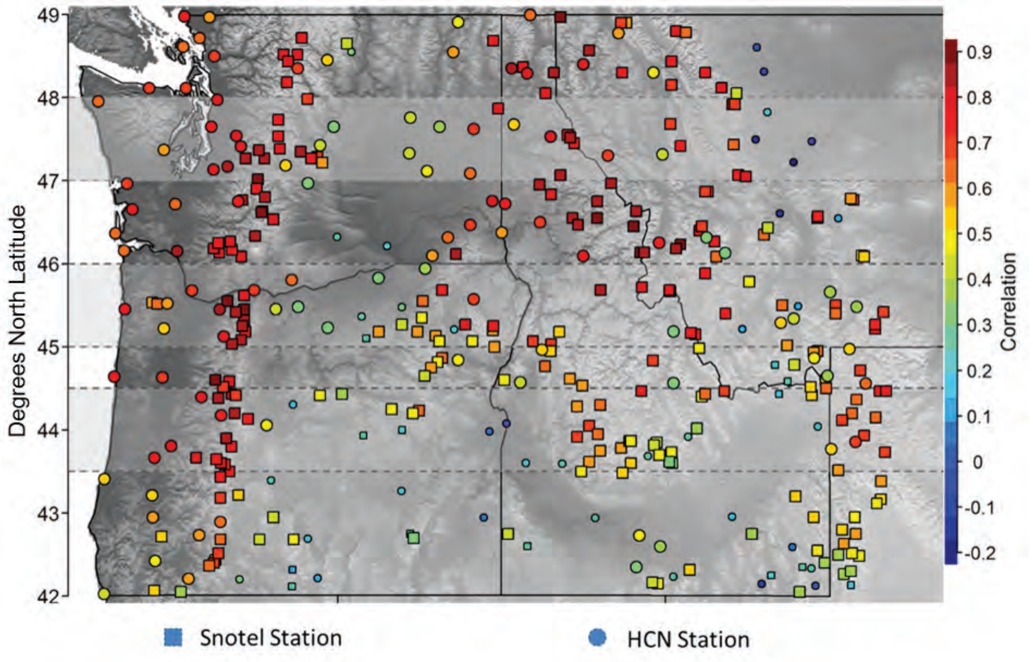

Figure 4.3—Correlation of winter precipitation to winter westerly windspeed across the Pacific Northwest, showing snowpack telemetry (SNOTEL) and Historical Climate Network (HCN) stations (from Luce et al. [2013]).

Snowpack and Glaciers

Snowpack

Snowpack declines are among the most widely cited changes occurring with climate change, through the effect of warmer temperatures on the fraction of precipitation falling as snow (Barnett et al. 2008). About 70 percent of the water supply in the western United States is tied to mountain snowpacks (Service 2004), so changes in snowpack are highly relevant to municipal and agricultural water supplies and timing (Stewart et al. 2005).

Historical trends in snowpack accumulation have been negative across most of the western United States (Mote et al. 2005; Regonda et al. 2005). However, care must be taken when looking at individual sites, which can be influenced by site-specific effects such as vegetation changes, physical site changes, sensor changes, and measurement technique (Clayton and Julander 2015). Temperature sensitivity of the snowpack is highest in places that are already relatively warm (warm snowpacks), and warm snowpacks with high precipitation are likely to undergo some of the largest changes in snow storage as the climate warms (Luce et al. 2014; Nolin and Daly 2006).

The most sensitive locations within the IAP region include the eastern Sierra Nevada and mid- to lower-elevation sites across Idaho, Utah, and Nevada (figs. 4.4–4.7). In contrast, many interior portions of the IAP region are cold enough to be relatively insensitive to warming and strongly sensitive to precipitation variation (Luce et al. 2014; Mote 2006). At the coldest and highest elevations, in the Uinta, Teton, Wind River, and some central Idaho ranges, for instance, there could be increases in snow water equivalent (SWE) if precipitation increases (Rice et al. 2017). Despite warming temperatures, a large proportion of precipitation would still fall as snow in these areas. This means that the future of snow, and consequently hydrology in these regions, depends on one of the more uncertain parts of GCM projections: the precipitation.

Precipitation uncertainty can be substantial, but it does not translate into equal uncertainty in snowpack changes everywhere (fig. 4.8). We estimated sensitivity of April 1 SWE using data from 524 snowpack telemetry (SNOTEL) stations across the western United States in a space-for-time model (Luce et al. 2014). This allowed us to determine where in the western United States snowpack was more sensitive to variability in precipitation or variability in temperature. We computed an index of uncertainty as the ratio (R_u) of the effects on snow (ΔS) from the likely range of precipitation values (about ±7.5 percent for 1 standard deviation across models) in the numerator, to ΔS from the relatively certain temperature change in the denominator:

$$R_u = \frac{\Delta S\ \mathit{across\ precipitation\ uncertainty}\ (+7.5\%)}{\Delta S\ \mathit{expected\ from\ warming}}$$

We found strong certainty of large changes in April 1 SWE for the Cascade Range, Sierra Nevada, and the Southwest ($R_u < 0.2$). But we found substantial uncertainty ($R_u > 0.6$) in outcomes for interior locations such as the Greater Yellowstone Area and higher elevations in Idaho and Utah, where cold temperatures leave the snowpack more sensitive to precipitation than to temperature changes (fig. 4.8). The uncertainty ratio in these colder areas suggests that relatively large increases in precipitation could help counter the effects of warming on snowpack loss. These results are similar to those seen using a physically based model across the western United States (Gergel et al. 2017).

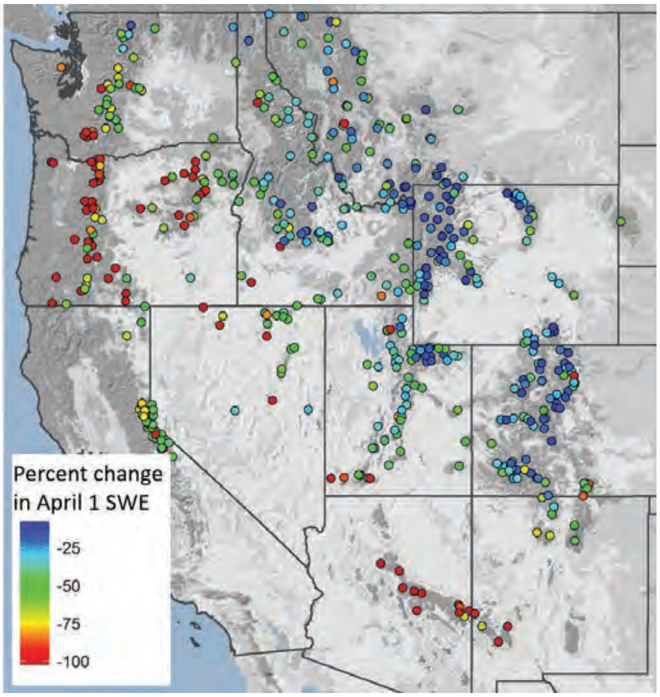

Figure 4.4—Estimated April 1 snow water equivalent (SWE) sensitivity (percentage change) for a 5.5-°F increase in winter average temperature at each snowpack telemetry station (modified from Luce et al. [2014]).

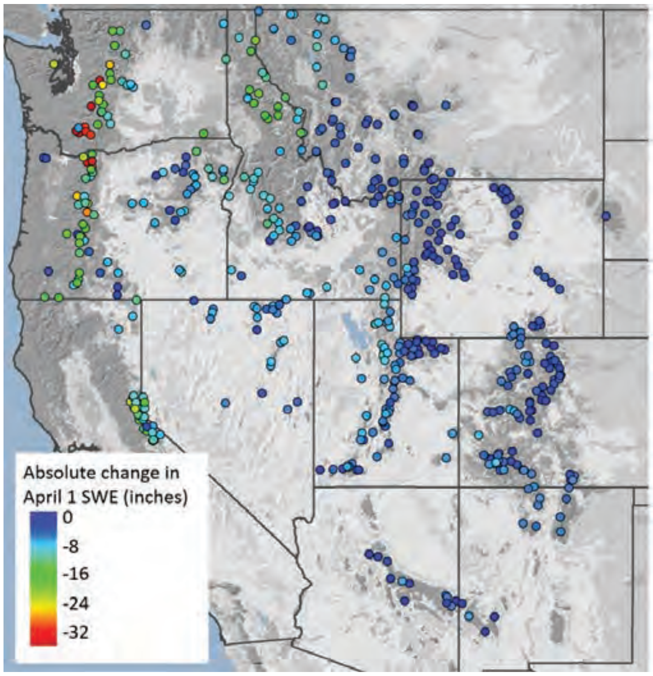

Figure 4.5—Estimated April 1 snow water equivalent (SWE) sensitivity (absolute change in inches) for a 5.5-°F increase in winter average temperature at each snowpack telemetry station (modified from Luce et al. [2014]).

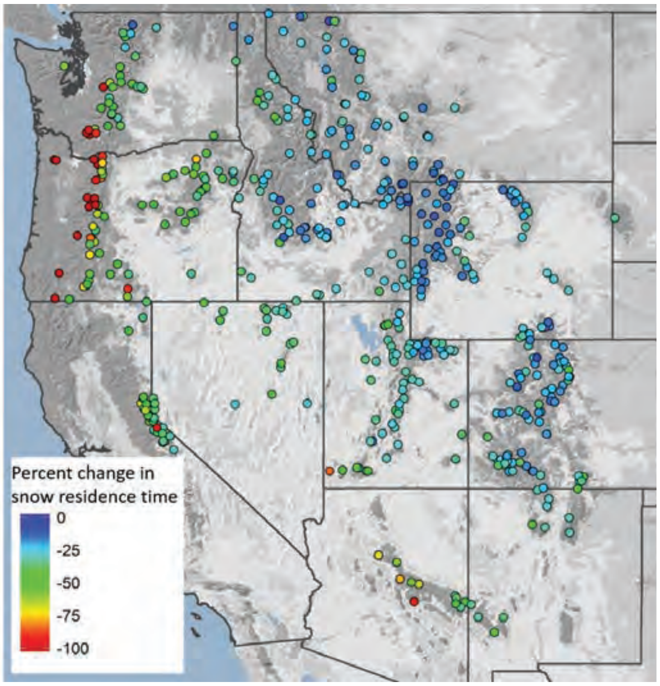

Figure 4.6—Estimated mean snow residence time sensitivity (percentage change) for a 5.5-°F increase in winter average temperature at each snowpack telemetry station (modified from Luce et al. [2014]).

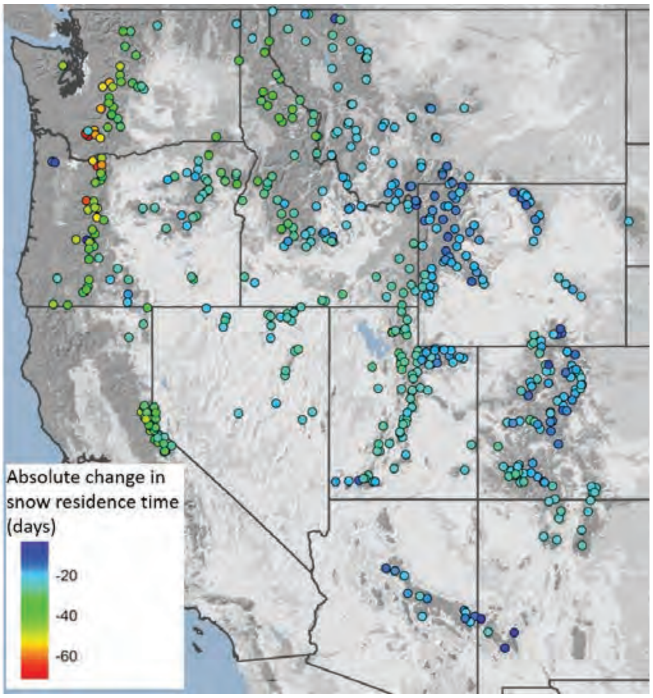

Figure 4.7—Estimated mean snow residence time sensitivity (absolute change in days), for a 5.5-°F increase in winter average temperature at each snowpack telemetry station (modified from Luce et al. [2014]).

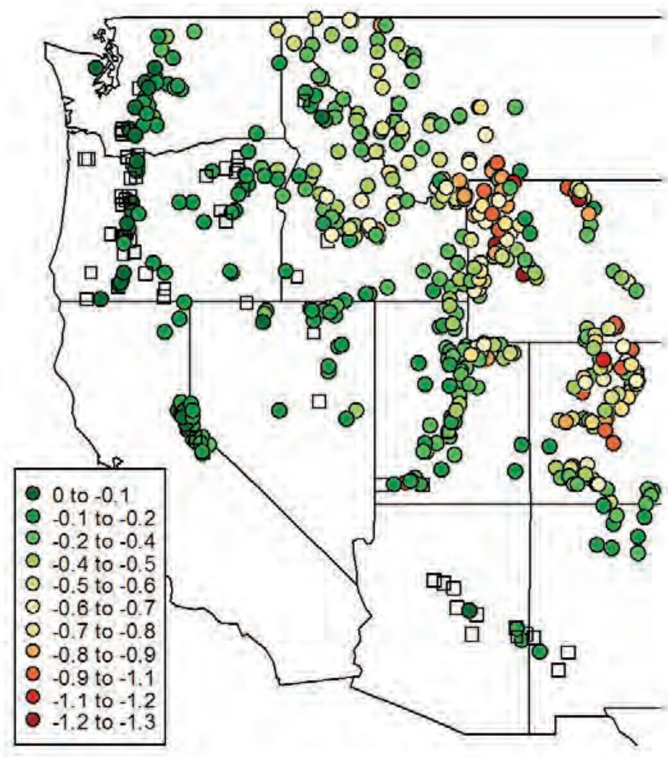

Figure 4.8—Uncertainty ratio for April 1 snow water equivalent. Orange to dark red sites are strongly influenced by precipitation in contrast to temperature. Thus, temperature-based projections for snow water equivalent in those sites may be inaccurate if precipitation changes are large. At dark green (and white) sites, temperature effects will predominate, and precipitation changes in either direction are inconsequential.

Glaciers

Glaciers are limited throughout the IAP region but do occur in central Idaho, in western Wyoming, and in an isolated location at Wheeler Peak in Great Basin National Park (see maps at Portland State University 2009). Declines in the extent of glaciers in the Wind River Range have been observed over the 20th century (Marston et al. 1991).

Estimating future changes in glaciers is complex (Hall and Fagre 2003), but empirical relationships derived for glaciers indicate a brief future for them, with many glaciers becoming fragmented or disappearing by the 2030s. Increasing temperatures yield a rising equilibrium line altitude (ELA), decreasing the effective contributing area for each glacier as warming progresses. Warming of 5.5 °F can translate to an elevation rise of 1,000 to 1,600 feet in snow-rain partitioning and summer temperatures. Those changes do not directly equate to a shift in ELA, which depends on the geometry and topography of the contributing cirque.

Temperate alpine glaciers are well known for being as, or more, sensitive to precipitation variations as they are to temperature variations (McCabe and Fountain 1995), which has very likely contributed to changes in glacial dynamics across the Pacific Northwest. Westerlies and their contribution to winter precipitation have changed over the northern part of the region since the 1940s (Luce et al. 2013), and April 1 SWE at these elevations and latitudes is relatively insensitive to temperature. However, summer temperature is a strong predictor of glacial behavior, and changes in summer temperatures could affect the melt rate and additional snow contributions in glaciers because this area receives significant spring and summer precipitation (Hall and Fagre 2003).

Streamflow

Streamflow changes of significance for aquatic species, water supply, and infrastructure include annual yield, summer low flows (average, extreme), peakflows (scouring floods), peakflow seasonality, and center of runoff timing. Irrigation water for crops and urban landscapes is typically needed in summer months. Annual yield, summer low flows, and center of runoff timing are important metrics with respect to water supply, but they are most relevant to surface water supplies rather than groundwater supplies, although changes in long-term annual means could be informative for the latter. The mean summer yield (June through September) is used for summer low flows. Center of runoff timing is the date on which 50 percent of the annual runoff has flowed out of a basin and is an effective index for the timing of water availability in snowmelt-driven basins. Shifts to earlier runoff in the winter or spring disconnect streamflow timing from water supply needs such as agricultural irrigation. Center of timing can be redundant with other metrics that measure impact more directly, but with care in interpretation, it can help clarify different potential causal mechanisms, such as changing precipitation versus changing temperature.

Peakflows are important to fish and infrastructure. Scouring flows can damage eggs in fish redds if they occur while the eggs are in the gravel or alevins are emerging (Goode et al. 2013; Tonina et al. 2008). Winter peakflows can affect fall-spawning fish (chinook [*Oncorhynchus tshawytscha*], bull trout [*Salvelinus confluentus*], and brook trout [*S. fontinalis*]), whereas spring peakflows affect spring-spawning cutthroat trout (*O. clarkii*), resident rainbow trout (*O. mykiss*), and steelhead (*O. m. gairdneri*) (Wenger et al. 2011a,b). Spring peakflows associated with the annual snowmelt pulse are typically muted in magnitude compared to winter rain-on-snow events for two reasons. The rain-on-snow events can generate larger water input rates (rainfall precipitation plus high melt rate), and they tend to affect much larger fractions of a basin at a time, so scouring is less of a risk to spring-spawning fishes. Consequently, a shift to more midwinter events can yield higher peakflow magnitudes, which can also threaten infrastructure such as roads, recreation sites, and water management facilities (e.g., diversions, dams).

Historical changes in some of these streamflow metrics have been examined in northern portions of the IAP region, specifically earlier runoff timing (Cayan et al. 2001; Stewart et al. 2005) and declining annual streamflows (Clark 2010; Luce and Holden 2009). Declining low flows (7Q10) have also been observed in the western half of the Northern Rockies (Kormos et al. 2016), associated more with declining precipitation than warming temperature effects for the historical period. Low-flow changes and timing changes in projections are generally associated with expected changes in snowpack related to temperature (e.g., more melt or precipitation as rain in winter, yielding a longer summer dry period). Low-flow changes driven by these timing changes are strongly dependent on groundwater conditions in the basin (Tague and Grant 2009), which vary considerably across the IAP region as discussed later in the Groundwater Resources section.

Streamflow Projections

Streamflow projections for an ensemble of Coupled Model Intercomparison Project Phase 3 (CMIP3) models under the A1B scenario (Littell et al. 2011) were produced from the VIC model (Liang et al. 1994) for the western United States (University of Washington, Climate Impacts Group 2017)) (figs. 4.9–4.13). Differences between the climate described by CMIP3 projections and the more recently developed CMIP5 projections are minimal with respect to temperature (Chapter 3). The gridded VIC data were used to estimate streamflow by using area-weighted averages of runoff from each VIC grid cell within a given basin, following the methods of Wenger et al. (2010), to accumulate flow and validate. Streamflow metrics were calculated for stream segments in the National Hydrography Dataset Plus (version 2) stream segments (USDA FS n.d.).

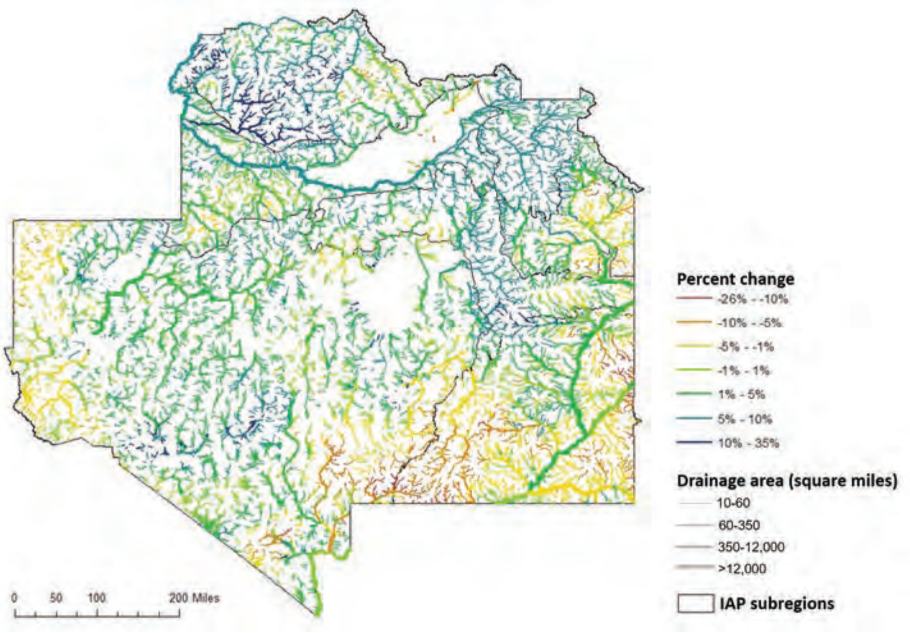

Figure 4.9—Percentage change in mean annual flow projections in the Intermountain Adaptation Partnership (IAP) region between a historical period (1970–1999) and the 2040s. Projections are from the Variable Infiltration Capacity model, following the methods of Wenger et al. (2010).

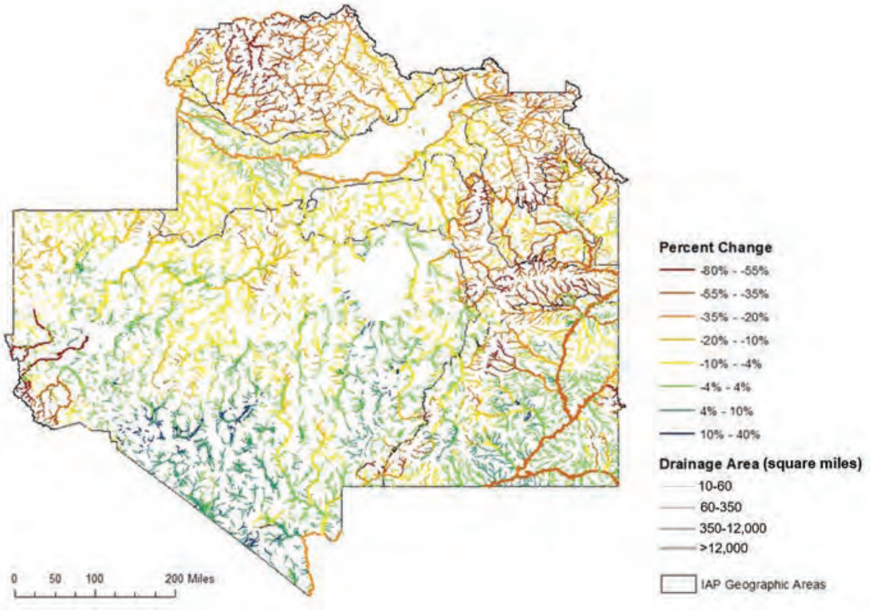

Figure 4.10—Percentage change in mean summer flow projections in the Intermountain Adaptation Partnership region between a historical period (1970–1999) and the 2040s. Projections are from the Variable Infiltration Capacity model, following the methods of Wenger et al. (2010).

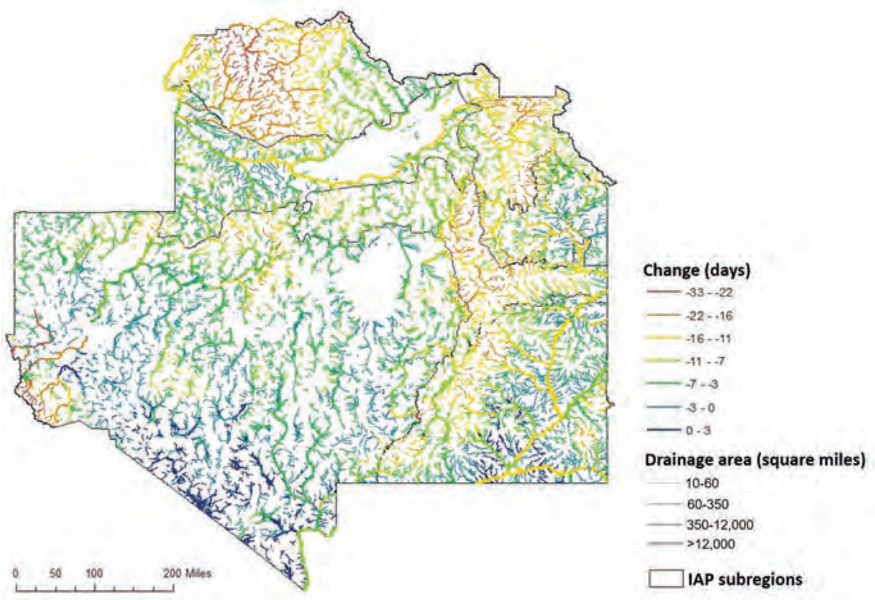

Figure 4.11—Change (days) in the center of flow mass projections in the Intermountain Adaptation Partnership region between a historical period (1970–1999) and the 2040s. Projections are from the Variable Infiltration Capacity model, following the methods of Wenger et al. (2010).

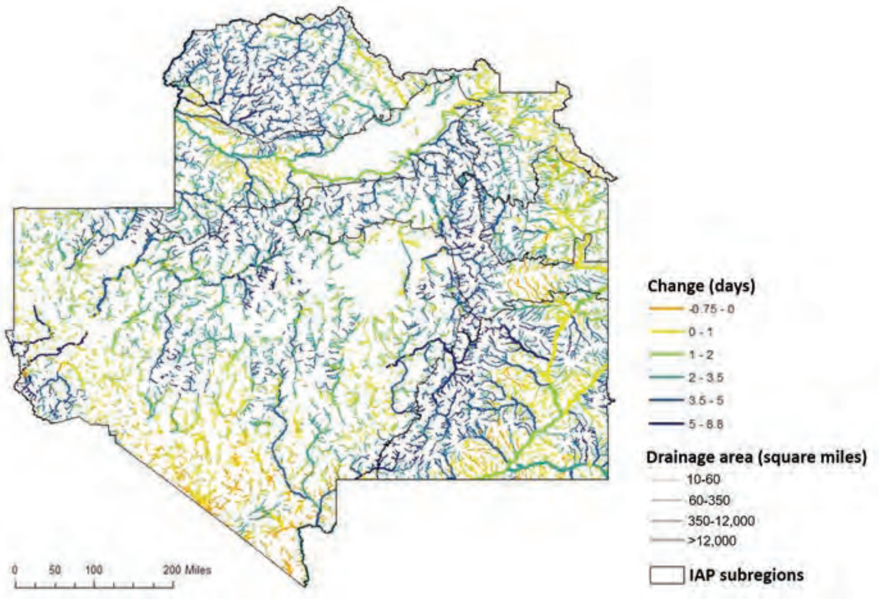

Figure 4.12—Projections of change (days) in the number of mid-winter floods (95th-percentile flow) in the Intermountain Adaptation Partnership region between a historical period (1970–1999) and the 2040s. Projections are from the Variable Infiltration Capacity model, following the methods of Wenger et al. (2010).

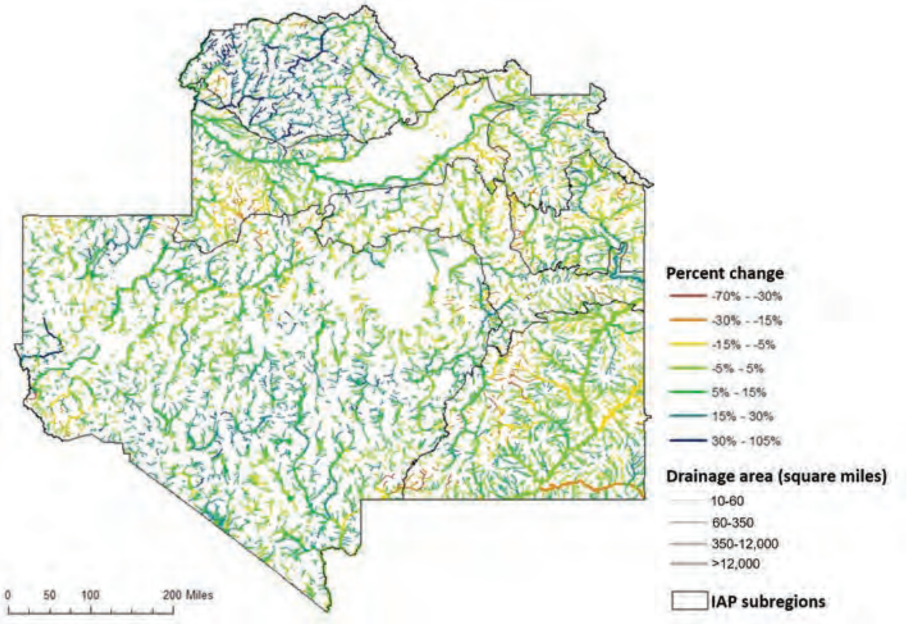

Figure 4.13—Percentage change in 1.5-year flood magnitude (approximate "bankfull" flow) in the Intermountain Adaptation Partnership region between a historical period (1970–1999) and the 2040s. Projections are from the Variable Infiltration Capacity model, following the methods of Wenger et al. (2010).

Uncertainty in climate model inputs can be a significant factor in uncertainty for outcomes related to natural resources (Wenger et al. 2013). Downscaling for these runs was done statistically, not dynamically, using an RCM to account for orographic enhancement changes, so GCM expectations for precipitation are implicit in the streamflow estimates. No effects of change in orographic enhancement are inherent in these images; thus, uncertainty may be higher (in a drier direction) on the windward side of mountain ranges.

Mean annual flow projections (fig. 4.9) suggest a slight increase across the northern portion of the IAP region, which ties back to the general moistening predicted by CMIP3 GCM runs (also illustrated in fig. 4.2). Minor changes are displayed through the central part of the region. The decreases shown in the southern part of the region are associated with changes in the Hadley cell circulation, which has also been described as an expansion of the mid-latitude deserts.

Despite projections of slightly increased annual flow across much of the region, summer low flows are expected to decline (fig. 4.10), with relatively uniform changes in mountainous areas, particularly in wetter ranges. The primary mechanism expected to drive lower summer base flows is reduced snowpack in winter, leading to less stored water. The VIC model simulations do not include the effects of large groundwater reserves; thus, this effect could be moderated in systems where groundwater flow contributes a substantial volume of water to late summer flows (see more discussion in the *Groundwater Resources* section on where this may be important). Although such groundwater support could moderate the percentage declines as shown in figure 4.10, actual low-flow runoff rates could have greater declines in such places because the fractional decline is applied to a larger pre-change low-flow rate (e.g., Tague and Grant 2009). This is an important consideration when dealing with water rights, in which actual volumes or flows, rather than percentages, are allocated to individual rights.

Places where summer precipitation plays an important role, particularly the southern portion of the region, are more likely to see low flows affected by summer precipitation patterns. Shifts in circulation that affect how moisture flows from the Gulf of Mexico in summer are expected to negatively affect precipitation. Increased spacing between precipitation events (IPCC 2013; Luce et al. 2016) and decreased moisture in the early portion of the monsoon season (Cook and Seager 2013) are other likely occurrences. These summer wet areas are also more likely to have greater losses of precipitation with increased evaporation, but it is important to recognize energy balance constraints when estimating the degree of loss (Roderick et al. 2014). This is not done in the VIC modeling, which uses only the temperature outputs from GCMs without reevaluating the change in energy balance from a different hydrological formulation; loss by evapotranspiration may thus be overestimated (Milly and Dunne 2011).

Generally, areas showing a change in summer low flows also show a shift to earlier center of flow mass timing (2–4 weeks) (fig. 4.11) and a shift to stronger changes in mountains dominated by snowmelt runoff. Changes in timing are related to snow residence time and earlier snowmelt runoff (figs. 4.6, 4.7).

Projected changes in the number of winter floods (95th percentile flow) show more of an effect in mid- and lower-elevation mountain ranges. Higher elevation and colder ranges, which will preserve more snowpack, show less change (fig. 4.12). The shift to more midwinter rain and more rain-on-snow flooding depends strongly on the elevational range of each basin. At middle elevations, temperatures are projected to increase enough that rain is likely on snowpacks, even in midwinter. Consequently, projected peakflow increases are generally stronger in these mid-elevation mountainous areas (fig. 4.13). Greater midwinter flooding could increase both the occurrence and magnitude of peakflows (fig. 4.14), as well as the potential for scour in gravel riverbeds (Goode et al. 2013).

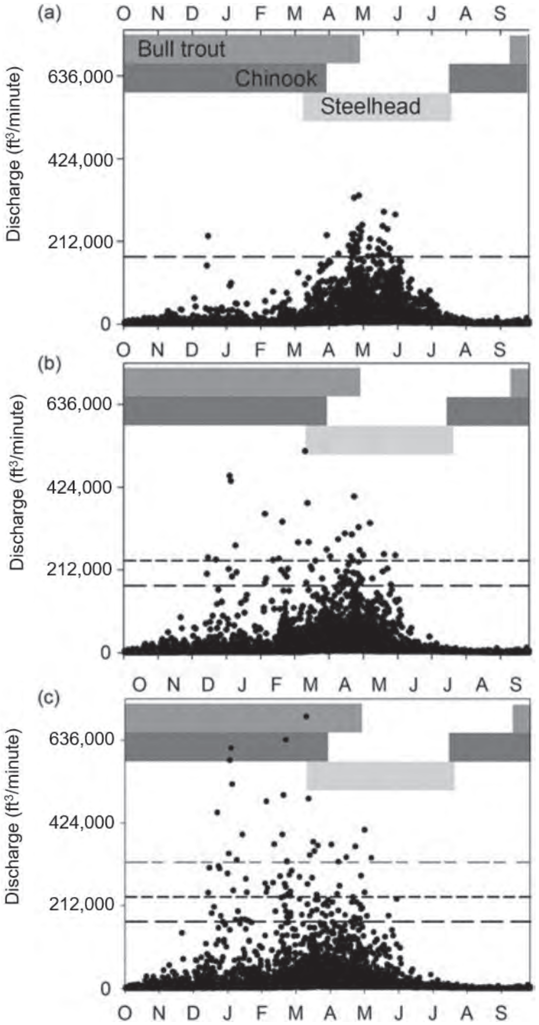

Figure 4.14—Illustration of increased mid-winter flooding potential. Projected streamflows are from Variable Infiltration Capacity modeling for (a) current conditions, (b) 2040s, and (c) 2080s. The long, short, and gray dashed lines indicate the 2-year flood for each period (current, 2040s, and 2080s, respectively) (from Goode et al. [2013]).

Drought

Several studies help to provide a paleoclimatic context for evaluating drought in the IAP region. For example, both an early and an updated reconstruction of streamflow in the Colorado River Basin indicate that water allocation agreements were developed during one of the wettest periods in the last 500 years (Stockton and Jacoby 1976; Woodhouse et al. 2006), and that droughts were more severe before the 20th century (Woodhouse et al. 2006). Similarly, DeRose et al. (2015) found that in the Bear River of the Great Basin, the latter half of the 20th century was the second wettest period in the last 1,200 years. Other studies have also demonstrated high variability and severe droughts in the Uinta Mountains (MacDonald and Tingstad 2007), Weber River (Bekker et al. 2014), Logan River (Allen et al. 2013), and Great Salt Lake (Wang et al. 2012). Figure 4.15 illustrates a general correlation in wet and dry cycles between these basins over time, but also some unique differences based on onsite-specific factors (DeRose et al. 2015).

Understanding long-term climate dynamics is critical for sustainable management of environmental resources. In combination with projections for climate change, knowledge of past climatic conditions can help inform water and land management decisions. For a more extensive discussion of drought, paleoclimatic history, and effects on forests and streams, see Luce et al. 2016.

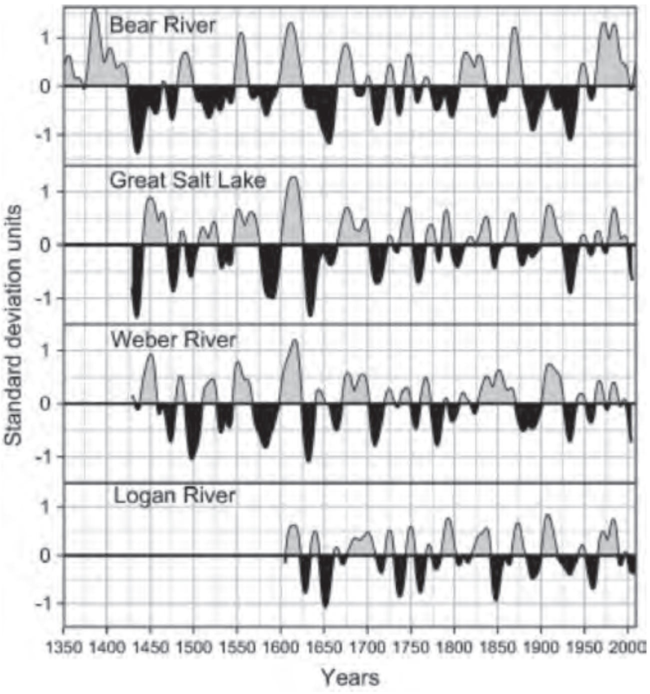

Figure 4.15—Comparison between the Bear River and other Wasatch Front hydroclimate reconstructions, illustrating the cyclical nature of wet and dry periods in the Intermountain Adaptation Partnership region (from DeRose et al. [2015]).

Sediment Yield

The delivery and transport of sediment through mountain rivers affect aquatic habitat and water resource infrastructure. Although climate change is expected to produce significant changes in hydrology and stream temperature, the effects of climate change on sediment yield have received less attention. Climate change is expected to increase sediment yield primarily through the effects of temperature and hydrology on vegetation disturbances (wildfire, insects, drought-related mortality) (Goode et al. 2012).

A conceptual model (fig. 4.16) of sediment yield (solid black line) relative to climate can help to illustrate the regulating role of vegetation. The dashed lines indicate the relative increase in resistance to erosion that vegetation provides as the driving force of precipitation increases. The biggest divergence in the lines occurs in semiarid climates where sufficient precipitation is available to drive erosion, but there is a limited amount of vegetation to stabilize hillslopes from erosion. The result is higher sediment yield in semiarid climates. The red arrow and circle on the plot depict the potential shift of current temperate forest climates to more semiarid climates, increasing overall erosion potential and sediment yield (Goode et al. 2012) (fig. 4.16).

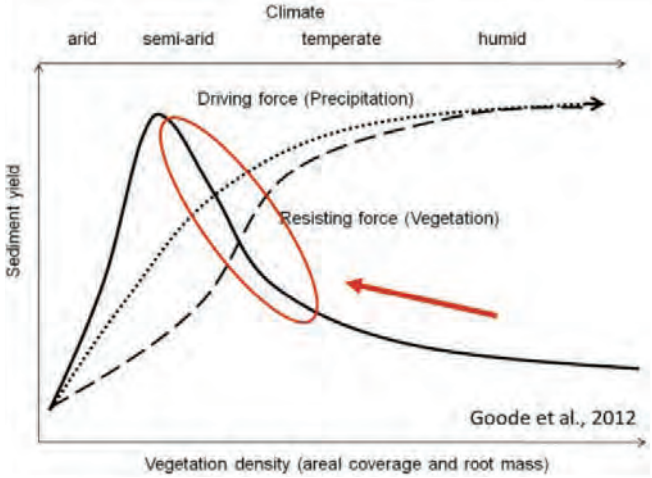

Figure 4.16—Conceptual plot of sediment yield (solid black line) relative to hydroclimate and the regulating role of vegetation. The red arrow and circle illustrate the potential shift of current temperate forest climates, which under a warming climate could become more like semiarid climates, increasing erosion potential and sediment yield (from Goode et al. [2012]).

Groundwater Resources

Climate change is likely to have significant, long-term implications for groundwater resources in the IAP region. Climate change is expected to cause a transition from snow to rain, resulting in diminished snowpack, shifts in streamflow to earlier in the season (Leibowitz et al. 2014; Luce et al. 2012), and changes in groundwater recharge to aquifers and groundwater discharge to groundwater-dependent ecosystems (GDEs). In this section, we synthesize existing information about occurrence of groundwater resources in five of the six subregions, describe potential effects of climate change, and describe how climate change can affect GDEs, including aquifers, streams, wetlands, and springs.

Groundwater is broadly defined as "all water below the ground surface, including water in the saturated and unsaturated zones" (USDA FS 2012). Groundwater resources include water residing in the subsurface, as well as ecosystems that depend on the presence or discharge of groundwater.

Groundwater-dependent ecosystems are "communities of plants, animals and other organisms whose extent and life processes are dependent on access to or discharge of groundwater" (USDA FS 2012). In the IAP region, GDEs include springs, springbrooks, groundwater-supported lakes, fens, streams, and rivers with base flow and riparian wetlands or phreatophytic vegetation along segments known as "gaining river reaches." **Fens** are wetlands supported primarily by groundwater with a minimum depth (usually 12–16 inches) of accumulated peat (Chadde et al. 1998; USDA FS 2012a). **Springs** are entirely supported by groundwater. These GDEs contribute significantly to local and regional biodiversity (Murray et al. 2006).

The fundamental hydrological processes that influence GDEs are: (1) amount, timing, and type of precipitation (rain or snow); (2) groundwater recharge; (3) groundwater quality; (4) groundwater discharge; and (5) evapotranspiration (Lins 1997). Along stream segments referred to as "gaining reaches," groundwater enters the stream from the banks or the channel bed, and the volume of downstream streamflow is subsequently increased (Winter 2007; Winter et al. 1996). Groundwater can contribute substantially to late summer streamflow (Gannett 1984) and is the source for cool-water upwellings that serve as refugia for cold-water aquatic species (Lawrence et al. 2014; Torgersen et al. 1999, 2012).

Hydrogeologic Setting

Hydrogeologic setting provides a context for assessing potential climate-induced changes to groundwater resources. Geologic units respond differently to changes in precipitation because of differences in hydraulic conductivity, transmissivity, primary versus secondary porosity, and fracture patterns. In a study that combined aerial photography (over 50–80 years) and climate analysis, Drexler et al. (2013) showed that five fens in the Sierra Nevada (California) decreased 10 to 16 percent in area. This decrease in area occurred over decades with high mean minimum air temperature and low SWE and snowpack longevity. However, two fens in the southern Cascade Range, underlain by different geology than the Sierra Nevada, did not change in area, suggesting that the hydrogeologic setting plays an important role in mediating GDE functionality.

Several different hydrogeologic settings have been delineated in the IAP region, including igneous/metamorphic, sedimentary, karst, and unconsolidated sediments. Igneous and metamorphic rocks with low permeability and porosity, with low-volume groundwater discharges, and that are recharged only during large infrequent precipitation or snowmelt events may not be vulnerable to changes in temperature and precipitation. However, aquifers in sedimentary formations, karst formations (fig. 4.17), and unconsolidated sediments may be more sensitive to climate change because they have high permeability, high porosity, and larger volume discharges to GDEs.

Groundwater Systems in the Intermountain Adaptation Partnership Region

Middle Rockies Subregion

Located in central Idaho, the Middle Rockies subregion is underlain with predominantly igneous and volcanic rocks with carbonate (fig. 4.17) and other sedimentary rocks in the southeast. Groundwater occurs in fractured and weathered crystalline rocks and sedimentary rocks (USGS 2000). Sand and gravel aquifers are found in floodplains and terraces in the valleys. Bedrock aquifers are the only source of groundwater across much of the subregion. Igneous, metamorphic, and sedimentary rocks that underlie the mountains generally yield little water to wells. Recharge to the basin aquifer system is by precipitation that falls directly on basin floors and by snowmelt that runs off the surrounding mountains and is transported into the basins by tributary streams.

Southern Greater Yellowstone Subregion

The Southern Greater Yellowstone subregion in western Wyoming and eastern Idaho consists primarily of sedimentary rocks but also contains igneous and metamorphic rocks (USGS 2000). Aquifers include sedimentary rocks, sand, and gravel along streams and basin-fill aquifers adjacent to the mountain blocks. Groundwater occurs in pore spaces, joints, fractures, faults, and solution openings in carbonate rocks. Many basins are bounded by mountain front faults. The most important aquifers are basin-fill aquifers, but they are recharged mainly from the mountain blocks. Deposits that fill the basins are mostly alluvium derived from the weathering and erosion of consolidated rocks that underlie the mountains bordering the basins. Primary recharge areas are generally located along the mountain fronts and extend into some mountain valleys. Groundwater is obtained principally from the basin-fill deposits. Basin margin faults are likely to influence flow from the bedrock aquifers to the basin-fill aquifers by forming barriers and highly permeable pathways, depending on the fault-zone geometry.

Uintas and Wasatch Front Subregion

Consolidated rocks of Precambrian to Tertiary age, which form the Wasatch Range and other mountain ranges in the Uintas and Wasatch Front subregion, yield water chiefly through complex systems of fractures, joints, solution

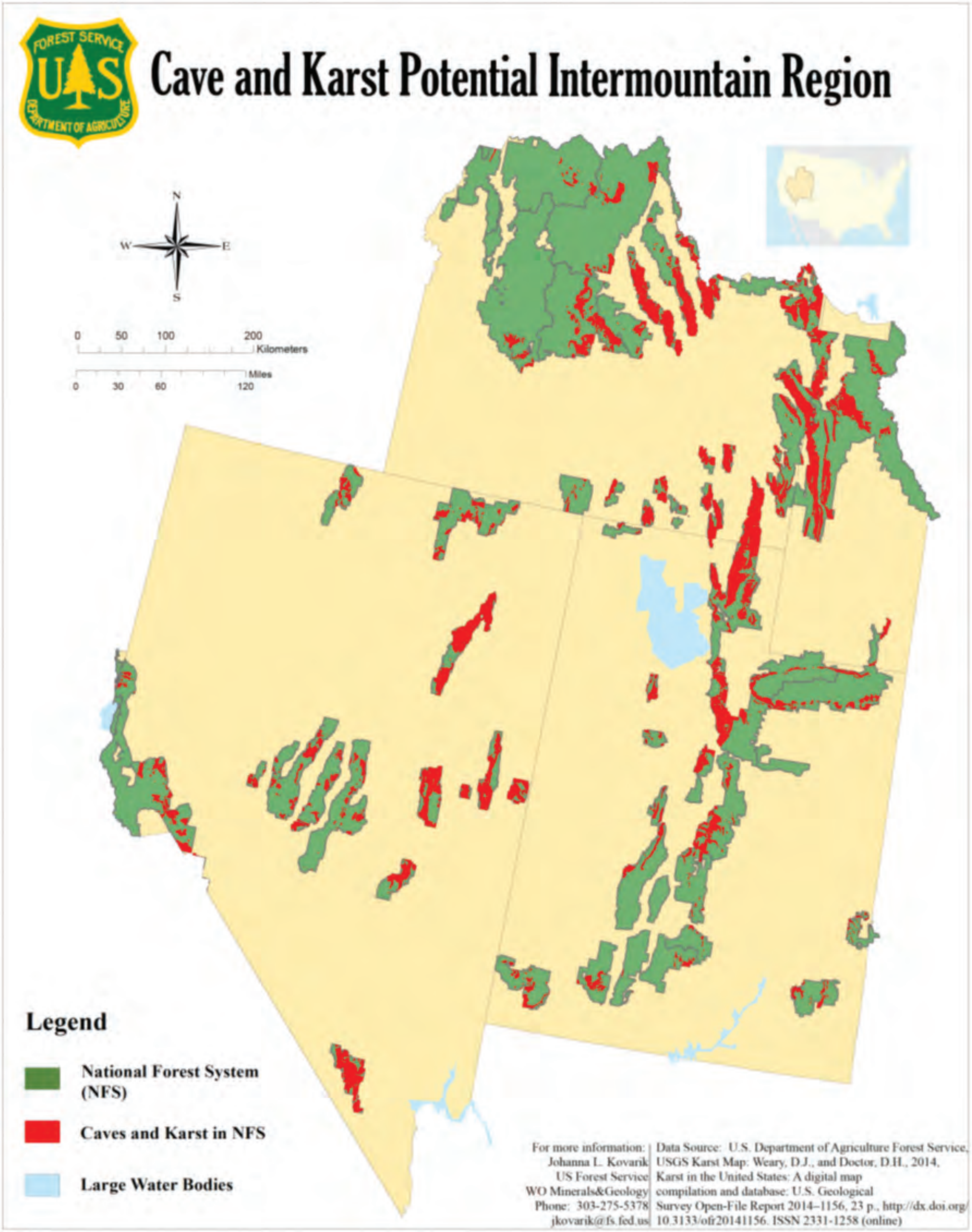

Figure 4.17—Areas with cave and karst potential composed of carbonate and minor volcanic rocks in the U.S. Forest Service Intermountain Region (from Weary and Doctor [2014]).

cavities, fault zones, and vesicles (Price 1985). These water-bearing zones, which are not present at all locations, are difficult to find and delineate. Wells in consolidated rocks also have small yields, and the depth to the saturated zone can be great. Consequently, the consolidated rocks in the Wasatch Front area are not considered to be favorable sources of water for withdrawal from wells. As a unit, however, they do absorb, store, and transmit large volumes of water to downstream aquifers. This is particularly true for carbonate units (fig. 4.17). In Utah, the aquifers in Cache Valley, the lower Bear River area, and along the Wasatch Front provide water to 84 percent of the population of Utah.

Geologic conditions vary considerably throughout the Wasatch Front area, and thus, groundwater occurrence, movement, quality, and availability also vary. Most of the wells that obtain water from the consolidated rocks are used for domestic supply and produce only a few gallons of water per minute. However, some of the springs that discharge from these rocks (especially carbonate rocks) produce several hundred to more than 1,000 gallons per minute. Alluvial fans make up much of the valley fill near mountain fronts.

Plateaus Subregion

Colorado Plateau aquifers underlie the Plateaus subregion of eastern Utah. Principal aquifers in the Colorado Plateau include the Uinta-Animas, Mesaverde, Dakota-Glen Canyon, and Coconino-De Chelly (USGS 2000). Distribution of aquifers on the Colorado Plateau is controlled in part by the structural deformation and erosion that have occurred since deposition of the sediments composing the aquifers. Much of the land is underlain by rocks that contain aquifers capable of yielding usable quantities of water of quality suitable for most agricultural or domestic use. In general, the aquifers in the Colorado Plateau area are composed of permeable, moderately to well-consolidated sedimentary rocks. These rocks range in age from Permian to Tertiary and vary greatly in thickness, lithology, and hydraulic characteristics.

Relatively impermeable confining units separate each of the four principal aquifers in the Colorado Plateau. The two thickest units are the Mancos (underlying the Mesaverde aquifer) and Chinle-Moenkopi (underlying the Dakota-Glen Canyon aquifer). Groundwater recharge to the Uinta-Animas aquifer generally occurs at higher elevations along the margins of each basin. The Mesaverde aquifer is at or near the land surface in extensive areas of the Colorado Plateau.

Great Basin and Semi Desert Subregion

The Great Basin and Semi Desert Subregion lies within the Basin and Range Physiographic Province, which contains three principal aquifer types: (1) volcanic-rock aquifers, which are primarily tuff, rhyolite, or basalt of Tertiary age; (2) carbonate-rock aquifers (fig. 4.17), which are primarily limestones and dolomites of Mesozoic and Paleozoic age; and (3) basin-fill aquifers, which are primarily unconsolidated sand and gravel of Quaternary and Tertiary age (USGS 2000). These aquifers underlie most of Nevada, western Utah, and southern Idaho. All the precipitation that falls in the area is returned to the atmosphere by ET, and streams do not carry water to the oceans.

Fracturing in carbonate rocks (limestone and dolomite) may enable groundwater to circulate through the fractures where the water can dissolve the slightly soluble rock and enlarge and increase the size and number of pathways for water movement through the rock. Such dissolution eventually can change a relatively impermeable carbonate rock into a permeable water-yielding unit. Carbonate rocks predominate in a 20,000- to 30,000-foot thick sequence of Paleozoic and Lower Mesozoic rocks in an extensive area of southern and eastern Nevada and are present on all National Forests in the region. The location of solution-altered zones of enhanced permeability within these carbonate rocks is poorly known. Although extrusive igneous rocks (primarily basalt) can be permeable in local areas, most other types of consolidated rock are not sufficiently permeable to transmit large volumes of water, and bedrock generally forms a relatively impermeable boundary to the Basin and Range aquifers.

The groundwater flow systems of the Basin and Range area are in individual isolated basins or in two or more hydraulically connected basins. The impermeable rocks are boundaries to the flow system, and most of the groundwater flows through basin-fill deposits. If carbonate rocks underlie the basins, substantial quantities of water can flow between basins through the carbonate rocks and into the basin-fill deposits. Most recharge to the basin-fill deposits originates in the mountains as snowmelt. Major faults that cut the alluvial deposits can act as partial barriers to the movement of groundwater.

Dependence of Special Habitats on Different Water Sources

Groundwater-dependent ecosystems occur in locations with abundant growing-season water. Because precipitation is the ultimate source of water and directly influences streamflow characteristics and groundwater dynamics, it is expected that climate-induced changes in precipitation will affect riparian areas, wetlands, and GDEs. Availability of water is also influenced by physical watershed characteristics that affect infiltration and surface and hillslope runoff, including lithology, soil depth, and topography (Jencso et al. 2009).

Groundwater Recharge in Mountain Aquifers in the Western United States

Most aquifers in Western mountains are small compared to the major aquifer systems in the basins. Despite being small, these aquifers are essential in storing and transmitting groundwater that becomes recharge to the adjacent major aquifer systems. Altered recharge caused by climate change will translate into altered mountain aquifer storage and discharge, which will, in turn, directly influence recharge to downgradient aquifers and stream base flows. Between 61 and 93 percent of diffuse mountain catchment recharge becomes streamflow available for downstream aquifer recharge by stream loss (Meixner et al. 2016).

Snowmelt is likely to contribute the majority of recharge in most mountainous regions of the western United States, either because most of the precipitation falls as snow, or snowmelt infiltrates below the root zone more effectively than rainwater (Earman et al. 2006). Snowmelt can compose a large fraction of recharge because much of the water released from the snowpack occurs over a prolonged period in early spring when ET is low (Ajami et al. 2012; Earman et al. 2006). Consequently, mountain recharge is sensitive to the climatic shifts that result in changes in SWE noted earlier in the chapter.

Recharge in many mountainous areas is permeability limited rather than recharge limited where thin soils overlie low-permeability crystalline bedrock (Flint et al. 2008). Lower maximum annual SWE in these areas may decrease overland flow of snowmelt to streams, but has little influence on recharge because spring snowmelt substantially exceeds the unsaturated zone storage capacity (Blankinship et al. 2014). Conversely, bedrock permeability in karst areas is so high that most snowmelt and rainfall infiltrates into the porous rock, flows in conduits, and is discharged to the surface as springs or discharges directly to fill aquifers.

Higher minimum temperatures will reduce the longevity of snowpack, and decrease the length of time aquifer recharge can occur, potentially leading to less groundwater recharge. Some watersheds will be shifting from snow-dominated to rain-dominated, which may result in declines in groundwater recharge (Earman and Dettinger 2011; Safeeq et al. 2013, 2014). Recharge could also increase in these areas as a result of a more gradual release of water from snowpack from enhanced winter melting (Byrne et al. 2014; Musselman et al. 2017). Projecting future mountain recharge requires knowledge of groundwater flow systems that is generally unavailable.

In summary, recharge is likely to decrease in the southern IAP region, but changes in other parts of the region are uncertain because of limited understanding of mountain recharge processes and groundwater flow in mountains (Meixner et al. 2016). However, there are existing approaches (e.g., Safeeq et al. 2014) that can be used to develop sensitivity maps from available information about geology, stream recession behavior, and other factors. These approaches could be used to evaluate sensitivities for future mountain recharge in the IAP.

Current Resource Conditions

Steep elevation gradients, varied bedrock, and glacial landforms influence the distribution, characteristics, and water chemistry of groundwater-dependent features. Existing information on the condition and distribution of GDEs in National Forests of the IAP region is limited. Here, we rely on data compiled by the Spring Stewardship Institute, the National Hydrography Dataset (USGS 2017), and the National Wetlands Inventory (NWI) (USFWS n.d.) to assess the current condition of springs, wetlands, and GDEs in the region.

Springs are usually small, averaging less than 0.5 acre, with few spring habitat patches larger than 2 acres (Kreamer et al. 2015). Thus, springs fall below the scale of most landscape mapping efforts and are therefore neglected in remote sensing, soil, and floristic mapping. Recently, National Forests in the U.S. Forest Service Intermountain Region and the Spring Stewardship Institute have begun to map springs and other GDEs, but the known occurrence of these are limited, and many more springs certainly exist (table 4.1).

Table 4.1—Area of palustrine emergent wetlands with saturated water regime and number of mapped springs in the U.S. Forest Service Intermountain Region. Differences in wetland area reflect different mapping accuracy and limitation among national forests; wetlands less than 1 to 3 acres are generally not included (USFWS n.d.).

National Forest	Wetland area	Springs
	Acres	*Number*
Ashley	18,388	426
Boise	92	442
Bridger-Teton	3,397	140
Caribou-Targhee	262	1,467
Dixie	1,048	652
Fishlake	1,259	622
Humboldt-Toiyabe	1,275	4,286
Manti-La Sal	1,894	481
Payette	218	155
Salmon-Challis	205	692
Sawtooth	224	1,211
Uinta-Wasatch-Cache	19,269	917
Total	47,530	11,491

Springs play a key role as groundwater discharge zones that deliver cool water to warming streams, support late-season streamflows in summer, and deliver relatively warm water during winter months (Lawrence et al. 2014; Winter 2007). Most streams and rivers in the region are at least partially groundwater dependent (Santhi et al. 2008). Locations of groundwater discharge to streams have been identified by using remote sensing (Torgersen et al. 1999) and field techniques (Torgersen et al. 2012), but have not been systematically mapped.

Wetlands can be identified by targeting palustrine/emergent wetlands with a saturated water regime (Cowardin et al. 1979) in the NWI database (table 4.1). To ascertain whether these wetlands are indeed fens, each wetland would require a field visit to determine if it is supported (at least in part) by groundwater and is peat-forming (Chadde et al. 1998; USDA FS 2012a, b). Fens occupy a small portion of the landscape, but contribute substantially to biodiversity of plants and animals (Blevins and Aldous 2011). In an otherwise arid region, perennially saturated fens are critical habitat for invertebrate and amphibian species. Although not explicitly differentiated as fen vegetation, several herbaceous-dominated plant associations frequently occur in fens.

Since 2008, GDEs, mostly springs and fens, have been inventoried and documented in National Forests by using draft and final versions of the Groundwater-Dependent Ecosystems Level I and Level II inventory methods

(USDA FS 2012a, b). The Level I guide (USDA FS 2012a) describes basic methods for assessment of GDEs within a given area (e.g., National Forest, ranger district, specific project area) and is intended to qualitatively document the location, size, and basic characteristics of each GDE site. The Level II guide presents more detailed inventory (USDA FS 2012b) in addition to protocols for more comprehensive characterization of the vegetation, hydrology, geology, and soils at a given site.

Inventories have been conducted in Ashley, Caribou-Targhee, Dixie, Humboldt-Toiyabe, Manti-La Sal, and Sawtooth National Forests. Inventories in Humboldt-Toiyabe National Forest targeted springs with terrestrial and aquatic flora and fauna values. In the GDE Level I protocol (USDA FS 2012a), a series of 25 management indicator statements assist in identifying potential concerns and needs for management action based on observations recorded during field inventories. Three of the most important indicators are aquifer functionality, soil integrity, and vegetation composition. Most inventories targeted sites where proposals for water development could be damaging, or portions of grazing allotments and watersheds with specific management concerns. Findings of inventories commonly show notable resource impacts through water diversion, soil disturbance, and effects of livestock on vegetation.

Potential Climate Change Effects on Groundwater and Groundwater-Dependent Ecosystems

Groundwater recharge has been examined in only a few locations (Tague and Grant 2009), and little is known about groundwater recharge processes in many watersheds, including those that may be shifting from snow-dominated to more rain-dominated hydrological regimes (Safeeq et al. 2013, 2014). Depending on elevation and hydrogeologic setting, slowly infiltrating precipitation that includes both rain and snow may recharge some groundwater aquifers as effectively as rapid, seasonal snowmelt runoff. Although rain-on-snow zones are expected to shift upwards in elevation, the influence of these shifts on groundwater recharge is unknown.

Small, unconfined aquifers (especially surficial and shallow aquifers) are more likely to have renewable groundwater on shorter time scales and may respond rapidly to changes in climate (Healy and Cook 2002; Lee et al. 2006; Sophocleous 2002; Winter 1999). Larger, deeper, and confined aquifers are more likely to have nonrenewable groundwater, may be less sensitive to the direct effects of climate change, and are projected to have a slower response (Wada et al. 2012).

Groundwater storage can moderate surface water response to precipitation changes (Maxwell and Kollet 2008), and changes to groundwater levels can alter the interaction between groundwater and surface water systems (Hanson et al. 2012). Climate-induced changes in connectivity between groundwater and surface water could directly affect stream base flows and associated wetlands and other GDEs (Earman and Dettinger 2011; Kløve et al. 2012; Tujchneider et al. 2012). Short flow-path groundwater systems, including many that provide base flow to headwater streams, could change substantially in timing of discharge in response to changes in seasonality of recharge (Waibel et al. 2013). In contrast, regional-scale aquifer systems, with flow paths on the order of tens of miles, are much less affected by shifts in seasonality of recharge. These effects may be highly variable, depending on local hydrogeology.

Altered groundwater levels in wetlands can reduce groundwater inflow, leading to lower water table levels and altered wetland water balances. For local and intermediate-scale systems, the spatial extent of some GDEs is likely to contract in response to decreasing surface water and groundwater and increasing temperatures. Changes in groundwater and surface water will also vary depending on location within the watershed, as well as future land use.

Effects of changing climate on the ecology of GDEs will depend on changes in groundwater levels and recharge rates, as influenced by the size and position of groundwater aquifers (Aldous et al. 2015). GDEs supported by small, local groundwater systems tend to exhibit more variation in temperature and nutrient concentrations than regional systems (Bertrand et al. 2012). It is likely that larger systems will be more resilient to climate change.

Freshwater springs depend on continuous discharge of groundwater, forming ecotones between subsurface-surface water and aquatic-terrestrial environments (Ward and Tockner 2001). Springs and springbrooks support locally unique biological communities (Barquin and Death 2006). However, climate-induced changes in recharge may cause decreased summer flows with possible drying, as well as increased winter flow and inundation of biological communities (Green et al. 2011).

Many biogeochemical processes are temperature dependent, so climate-induced changes in groundwater temperature may negatively affect the quality of groundwater, and, in turn, influence aquatic communities (Figura et al. 2011). However, because the thermal regime of groundwater systems is less dependent on air temperature patterns than surface waters, the effects of rising air temperatures are likely to be less pronounced in springs and other GDEs.

Peat-accumulating processes in fens will be influenced by increasing temperatures and local and regional changes in hydrological regime. Reduced groundwater levels tend to promote soil aeration and organic matter oxidation. Generation and maintenance of peat soils over time depend on stable hydrological conditions. In recent studies of peatlands exposed to groundwater lowering, responses such as soil cracking, peat subsidence, and secondary changes in water flow and storage patterns have been observed (Kværner and Snilsberg 2011). Wetland plant species can respond to even slight changes in water table elevation (Magee and Kentula 2005; Shipley et al. 1991; Vitt and Slack 1984), and shifts in composition of vascular and bryophyte species could occur with lowered water tables.

Some riparian ecosystems depend on the presence of flowing water, although streamflow may not be perennial along all stream segments and can vary considerably with season, physical features of the watershed, and water source. Depending on physical characteristics of a given stream segment, the volume of streamflow can also drive seasonal changes in water table elevation of the adjacent riparian area (Jencso et al. 2011). These hydrological and fluvial processes and resulting geomorphic surfaces are essential for the persistence of riparian vegetation (Naiman et al. 2005). According to long-term daily flow data, different streams in the region are supported by perennial runoff, snow plus rain, and stable groundwater levels (Poff 1996).

Changes in water table elevations and streamflow volumes may affect riparian areas and their plant communities (Jencso et al. 2009; Naiman et al. 2005). Examples of changes in flow systems are decreased summer base flows (see earlier *Hydrological Processes* section), lower riparian water table elevations, and reduced hydrological connectivity between uplands and riparian areas (Jencso et al. 2009, 2011). Streamflow volume along gaining reaches increases with the inflow of groundwater to the channel. Stream water can also drain from the channel bed and banks to the groundwater system (losing reaches), resulting in a loss of downstream surface flow volume (Winter et al. 1996). Gaining and losing stream reaches result in different aquatic communities in the channels and different riparian plant communities on the floodplains. The extent to which gaining or losing characteristics of specific reaches may change in response to climate-induced changes in precipitation, streamflow characteristics, and groundwater discharge is unknown.

In wetlands and riparian ecosystems, hydrological variables are consistently the strongest predictors of plant species distributions (e.g., Cooper and Merritt 2012). Current understanding of the water sources used by riparian and wetland plants is limited to a few highly valued or highly invasive species (mostly woody). However, riparian and wetland plant species use water from multiple sources (surface water, soil water, groundwater), depending on life stage and season (Busch and Smith 1995; Cooper et al. 1999; Goslee et al. 1997). In assessing the vulnerability of riparian and wetland species to climate-induced changes in streamflow or groundwater, the availability of water at all life stages must be considered, from plant recruitment and establishment, to reproducing adults, to persistence at later life stages (Cooper and Merritt 2012).

Climate-induced changes in precipitation, drought, and streamflow will influence the distribution of riparian vegetation via changes in local hydrological regimes, especially if summer base flows decrease. If water table elevation can be assumed to be in equilibrium with water levels in the stream, reduced base flows could result in lower riparian water table elevations and subsequent drying of streamside areas, particularly in wide valley bottoms. Wetland and riparian plant communities will respond to climate-induced changes in hydrological variables differently as a function of species composition (Merritt et al. 2010; Weltzin et al. 2000).

Although ET is not expected to increase substantially from the landscape generally as outlined earlier in the chapter, water supplies around riparian areas and GDEs are consistently high. Riparian areas and GDEs compose a very small fraction of the landscape, so they affect the land-surface energy balance only very slightly. Consequently, the increased net radiation and atmospheric demand will induce higher ET rates in riparian areas and GDEs, and this higher ET rate will not substantially feed back into the regional energy balance. Higher ET will result in drying in these ecosystems, potentially stressing characteristic plant species and resulting in compositional shifts in vegetation. If plant cover is reduced in riparian areas, erosion may increase.

Soil Resources

The potential effects of climate change on soils are multifaceted; changes in soil physical, biological, and chemical processes can occur with changing climate, which may in turn affect other processes such as carbon cycling and vegetation growth. Soil responses to climate change will vary by geographic location and are determined by the interactions of soil, vegetation, and the degree of management intervention. The following sections provide a summary of potential effects of climate change on soils in the IAP region.

Soil Temperature and Moisture

Soil temperature and moisture are the primary drivers of change for all soil processes. Potential changes to these soil properties with climate change have been well studied, but where and when the changes may occur is difficult to predict. The magnitude of projected change is variable depending on existing soil resources and existing climate. The properties and processes of soils are not independent, and a change to one soil property will affect other soil properties and processes. For example, changes to soil temperature and moisture will affect carbon and nitrogen cycles, which can in turn affect soil properties such as water holding capacity, cation exchange capacity, soil nutrient content, and aggregate stability (Brevik 2013).

An increase in soil temperature will generally produce an increase in soil biological activity and soil respiration. However, the rate and magnitude of change are dependent on soil moisture (Kardol et al. 2010). In the current semiarid soils of the IAP region, an increase in soil temperature without an increase in soil moisture is likely to create soils that have reduced biological activity and less potential to store carbon. If soil moisture is limiting with increased soil temperatures, the soils may become a net source of carbon until equilibrium is reached. However, an increase in soil temperature could be offset by an increase in water available for biological activity and vegetation production, resulting in little change or a possible increase in carbon storage. In the colder and wetter areas of the IAP region, an increase in soil temperature may lead to longer growing seasons if soil moisture is not limiting (Kurylyk et al. 2014). Thus, the timing and type of moisture will determine soil biological activity, respiration, and ultimately vegetation supported by the soil.

Changes to soils with climate change will not be uniform across the IAP region. Soil responses to temperature and moisture are highly dependent on the soil parent material. Soils derived from coarse-textured granitic soils will transfer heat more efficiently downward into the soil profile than fine-textured limestone soils. The heat transfer downward can affect soil processes and even groundwater temperatures, and it could ultimately affect surface water temperatures where groundwater is the source for surface water. Fine-textured soils, which are capable of storing water longer in the soil profile, will generally have a higher buffering capability to changes in soil temperature and moisture.

The timing of soil moisture can also affect soil erosional processes. A shift away from winter precipitation as snow to greater amounts of rain and more intense rain storms can generate a higher frequency of runoff and erosional process from disturbance events such as fire (Litschert et al. 2014). Runoff from extreme rain events could increase for shallow soils with little capacity to store water.

Soil Carbon and Nitrogen

Soils are a major component of carbon and nitrogen cycles. Changes in soil temperature and moisture will affect carbon and nitrogen cycles. Management of soil organic matter can affect both of these cycles at local and global scales. The greenhouse gases carbon dioxide, methane, and nitrous oxide are regulated to some extent by the soil organic matter. Soils provide both a source and sink for carbon and nitrogen and the greenhouse gases associated with carbon and nitrogen. Changes to the carbon and nitrogen cycles may include an increase or reduction in cycling rates or storage of carbon and nitrogen. Soil temperature and moisture drive the type of change that will occur as they affect microbial activity and plant composition.

Soil Carbon Pool

Soil organic carbon (SOC) is derived from soil organic matter (SOM). The SOM is composed of plant and animal residues, cells and tissues of soil organisms, and substances produced by decomposing organisms. The SOC is the carbon component of SOM. Generally, about 58 percent of SOM is SOC by weight. Most soil orders within the IAP region have a near-surface SOC content (by mass) of 0.5 percent (for the hotter and drier areas) to 8 percent (for the cooler and wetter areas; Histosols excluded) (Brady 1999). Hereafter, we use SOC to represent both SOC and SOM, as these properties are likely to have similar response to climate change.

Soil organic carbon may be the best indicator and contributor to soil health because SOC supports many soil processes and functions. These include providing nutrients for plants, binding soil particles together and thereby maintaining structure, providing an energy source for microbes, increasing water infiltration and retention, and providing cation-anion exchange for retention of ions and nutrients. Climate change will affect SOC and ultimately the functions and processes supported by SOC.

Globally, SOC may contain more than three times as much carbon as is found in the atmosphere or terrestrial vegetation. In forest ecosystems, SOC may be as much as 80 percent of the total terrestrial carbon pool, and in nonforest ecosystems, SOC may be as much as 95 percent of the total terrestrial carbon pool (Meyer 2012). Soils can store and release carbon at the same time. If soils store more carbon than they release back to the atmosphere, the soil is a carbon sink. If soils are releasing more carbon than what is being stored, they become a carbon source. Therefore, the management of SOC is critical to the management of atmospheric carbon concentrations (Woodall et al. 2015).

Carbon is stored in soils in organic or inorganic forms. Soil organic carbon originates from carbon fixation during photosynthesis and microbial decomposition (Thomey et al. 2014). Inorganic carbon (IC) is in rocks and minerals. An example of IC is limestone, or calcium carbonate. The stable IC is released slowly through weathering or anthropogenic manipulation, such as mining and conversion to other chemical compounds. Although IC is slow to change, it represents a large portion of stored carbon in many ecosystems, such as drier shrublands and grasslands. Many of the drier rangeland soils include carbonate horizons within the soil profile. Climatic changes may affect the release of IC. Higher atmospheric carbon dioxide concentrations and a warmer and wetter climate will increase weathering of rocks and acidification in the carbonate layers in the soil, which will release greater amounts of carbon into the active carbon cycle (USDOE 2014).

Different soils have different capacity to store carbon. The differences are related to parent material, existing climate, and terrestrial ecological community types. Shrublands have a higher percentage of SOC stored lower in the soil profile (below 3 feet). Forests have most of their SOC in the first 3 feet of the soil. Changes to vegetative composition can affect long-term carbon storage. A shift from shrublands to annual grasslands will eventually move the bulk of carbon from deep in the soil profile to the upper 8 inches (USDOE 2014). This may be happening with conversions of shrublands to cheatgrass (*Bromus tectorum*) in the IAP region. This process is very slow, however, and respiration of carbon deep in the soil profile is much slower than near the soil surface. A shift from shrublands to forest will increase near-surface carbon pools as a result of litter addition and deeper reserves being tapped by roots for the production of biomass (Nave et al. 2013).

Soils have SOC storage limits set by soil physical and chemical composition as well as microbial and plant community types, all of which are determined by soil moisture and temperature. Most soils in the IAP region are at SOC saturation for the existing climate (Woodall et al. 2015). Soils that are degraded or furthest from potential SOC saturation have the greatest ability to sequester additional carbon. These are generally areas with vegetation that has been altered for long periods of time, such as agricultural fields. Most of the soils in the IAP region could sequester additional carbon if soil temperatures decrease and soil moisture increases. This is particularly true with the lower-elevation soils. However, soil moisture may not increase in a warming climate.

Soil Physical Properties Related to Carbon and Climate Change

Changes to SOC can alter several soil properties, including soil structure, bulk density, and soil porosity (Pal Singh et al. 2011). These soil properties affect water infiltration, rooting depth, soil erosional losses, and water holding capacity. A reduction in SOC will change soil structure through reducing the bonds between soil particles and the microbial "glue" that helps hold soil particles together. This can lead to less resistance of the soil to erosive forces of wind and water. A change in soil structure can also lead to changes in soil porosity and bulk density. Soil porosity and pore size distribution are important for soil water management and maintaining release rates of greenhouse gases (carbon dioxide, methane, and nitrous oxide) within the soil. A loss of macropores with reduction in SOC could lead to slower water infiltration rates, increased runoff, decreased nutrient cycling, reduced plant growth (above and below ground), and poor aeration of the soil, resulting in a decreased capacity to oxidize greenhouse gases, specifically methane. A reduction in SOC also leads to increased risk of surface compaction with management activities through an increase in surface bulk density of soils. Surface compaction restricts water infiltration and increases surface runoff.

Although the changes to soil physical properties with loss of SOC are highly variable across the landscape, they do provide potential indicators that can be used to prioritize management in a changing climate; the soil types where current management is already having negative effects on soil physical properties could be the soil types that are prioritized for climate change adaptation actions. For example, areas where excessive runoff and soil loss have occurred because of grazing management may be a priority. These areas would be expected to have a higher risk of soil quality loss under a warmer and drier climate with reduction in plant growth and SOC development.

Soil Nitrogen

SOM typically contains about 5 percent nitrogen; therefore, the distribution of soil nitrogen closely parallels that of SOM (Brady 1999). Nitrogen cycles are closely tied to carbon cycles, although they may respond differently to changes in climate. On average, nitrogen fixation occurs at a rate of about 9 pounds per acre for forested sites and 13 pounds per acre for grasslands (Brady 1999). Forest soils may contain 15 times as much nitrogen as the standing vegetation, including roots (Brady 1999). About 29 to 56 percent of the soil nitrogen pool is found in the upper 4 inches (Page-Dumroese and Jurgensen 2006), making the soil nitrogen pool highly susceptible to loss from erosion.

Although most of the nitrogen in terrestrial systems is found within the soil, the mineralization of nitrogen is required to provide a form of nitrogen that plants can utilize. Nitrogen mineralization occurs through decomposition of organic material by soil micro-organisms. Warmer soil temperatures increase decomposition by microbial activity, thus increasing nitrogen mineralization. However, soil moisture may have a greater effect on net nitrogen mineralization through changes in the form of nitrogen (Emmett et al. 2004).

Nitrogen could be limiting to plants in some soils of the IAP region even if conditions for plant growth improve with changes in climate. If plant growth increases with increased atmospheric carbon dioxide, then organisms that decompose residual plant material will need more nitrogen to survive. If nitrogen is tied up by soil microflora and microfauna, the nitrogen would be unavailable to plants. Thus, any positive effects of increased atmospheric carbon dioxide may be offset by the reduction in available soil nitrogen (Brevik 2013), particularly on nitrogen-limited soils. In the IAP region, those areas most susceptible to reduction in nitrogen are forested areas on soils with coarse-textured parent material.

Soil Biological Activity

Soil organisms perform many functions in the soil, including decomposition and nutrient cycling. As with other soil processes, the soil biology is affected by other soil processes and the inherent soil composition and climate. Thus, the effects of climate change on soil biology will be variable. Some models project that a warming of the soil will create greater microbial activity, resulting in more carbon being released to the atmosphere because of increased decomposition (Kardol et al. 2010). Other models suggest that a warming of the soil will result in lower microbial growth and less carbon released through respiration (Wieder et al. 2013). In the warm and dry desert ecosystems, such as those in the Great Basin and Semi Desert and Intermountain Semi Desert subregions, the effects of soil warming are expected to increase microbial activity and carbon dioxide released to the atmosphere (Thomey et al. 2014). In cooler and wetter ecosystems, projections are mixed (Steinweg et al. 2013).

Vegetation composition can affect soil biology, soil processes, and soil response to climate change. Some soil organisms prefer specific plant types, and plant diversity increases soil biological diversity. Greater biodiversity in soils is likely to increase soil resilience to climate change (Kardol et al. 2010).

Soil Chemical Properties

Potential effects of climate change on soil chemical properties are linked to other biological and physical changes in the soil, all of which are driven by soil temperature and moisture. Soil pH is closely tied to organic matter, parent material, and soil moisture. A warming climate with additional or similar precipitation will lower soil pH (Pal Singh et al. 2011). A warming climate with less precipitation may increase pH on some higher-elevation soils and have little effect on existing lower-elevation high-pH soils (Pal Singh et al. 2011).

In areas that are expected to experience increased drought, such as drier shrubland and grassland systems, an increase in the accumulation of carbonates and salts in the soil profile is expected. This would result in a salinization of the soil and have significant effects on vegetation composition. In wetter areas of the IAP region, an increase in soil temperatures may cause an increase in acidification from the decomposition of organic matter. This could change species composition and diversity to favor species more adapted to acidic soils.

Cation exchange capacity (CEC) is the ability of the soil to retain nutrients such as calcium, potassium, and magnesium and make them available to the soil solution and plants. It also provides the capacity to retain and immobilize some cations that may be toxic to soil microbes and plants in high amounts, such as aluminum and manganese. The CEC is generally low in coarse-textured soils or soils with low amounts of SOC. Soils with a subsurface argillic horizon (higher CEC) are likely to be able to moderate a shift in nutrient exchange, specifically a loss of SOC and other major soil nutrients requiring cation exchange sites. An increase in soil temperatures could lead to a reduction of SOC and the CEC of soils. A reduction in CEC would result in loss of base cations in the soil that are released to groundwater and surface water (Pal Singh et al. 2011).

Managing soil resources for optimum SOC will limit the effects of climate change to the CEC. Areas with low SOC are the most susceptible to CEC changes in soils due to climate change, as they have poor buffering capabilities. In the IAP region, these are primarily drier rangeland soils, particularly those that have been vegetated for many decades with annual shallow-rooted grasses.

Weathering of rock and erosion of soil is a continuous process. Changes to rainfall and wind as well as changes to chemical, physical, and biological properties of soils can affect the type, amount, and rates of runoff and erosion of soil. More precipitation may not have any long-term effects on erosion and runoff, because vegetation will respond positively to increases in available soil moisture. However, an increase in the number of intense rain events may result in an increasing rate of erosion. A reduction in the amount of precipitation generally reduces the rate of erosion. However, lower vegetation cover in response to low soil moisture may result in increased rates of erosion from wind and water. Areas of the IAP region that are most susceptible to increased erosion are the lower-elevation shrublands and grasslands, where a warmer and drier climate will reduce the potential for vegetative cover.

Regional-Scale Soil Vulnerability Ratings

The potential magnitude of change to soil resources in a changing climate is extremely variable because of the heterogeneity of soil types and their potential response across the landscape. Identifying the degree of potential change and risk to soils spatially across a landscape is difficult, even with detailed soils data. However, general projections can be made across large landscapes by using different soil and landscape attributes, particularly vegetation composition and productivity. The following section provides a general rating of soil vulnerability to climate change across the IAP region. The rating is based on general soil characteristics and data from Natural Resources Conservation Service STATSGO datasets (NRCS 2017).

Several assumptions were used to develop a regionwide rating of soil vulnerability to climate change. These include:

- The existing climate will generally be warmer and drier in the future across all subregions in the IAP.
- Soils that are currently capable of holding water longer and deeper within the soil profile have a greater buffering capacity to change.
- Soils that are currently cooler and wetter, or have higher SOC, are less susceptible to climate change.
- Many soil properties will change in a changing climate.
- The ratings of soil vulnerability to climate change are based on general surrogates of landscape and soil conditions. Data on detailed soil properties, such as available water holding capacity, were not available across the region to make predictions.
- Soil properties used to derive a vulnerability map were soil temperature and moisture regimes (combined into subclasses), and SOC from depths of 0 to 12 inches.
- Soil polygons contain many soil components. The components were combined by dominant condition for soil temperature and moisture subclasses and by weighted averages for SOC.

A combined STATSGO soil map was made for all lands within the IAP region. Soil temperature and moisture classes were determined for each polygon based on the dominant condition within the polygon. The soil temperature and moisture classes were further combined according to soil taxonomy to create 44 different subclasses. These subclasses were combined qualitatively based on common soil temperature and moisture breaks to create four class ratings of low, moderate, high, and very high susceptibility to a warming and drying climate. The same STATSGO soil map was used to create a SOC map for the 0 to 4 inches soil depth (the database was poorly populated for depths deeper than 4 inches). Each polygon received a value for SOC. The

Table 4.2—Final rating classes for soil vulnerability to climate change, based on a combination of soil temperature/moisture rating and soil organic carbon rating.

	Organic carbon rating = Low	Organic carbon rating = Moderate	Organic carbon rating = High	Organic carbon rating = Very high
Temperature/moisture rating = Low	Low	Low	Moderate	High
Temperature/moisture rating = Moderate	Low	Moderate	Moderate	High
Temperature/moisture rating = High	Moderate	Moderate	High	Very High
Temperature/moisture rating = Very high	High	High	Very High	Very High

polygon values were assigned to one of four classes (low, moderate, high, very high) of SOC such that all classes contained the same number of polygons in each class. This method of creating general SOC classes was chosen because threshold class values for SOC are not available.

The ratings for soil temperature and moisture were then combined with the ratings for SOC into a four-class rating of soil vulnerability to climate change. A simple matrix was used to determine the final rating (table 4.2). The final soil vulnerability rating was applied to each polygon, and a general soil vulnerability map to climate change was developed (fig. 4.18). The map represents soils that may or may not be capable of sustaining existing ecosystems in a changing climate. The map suggests that soils at higher elevations and deeper soils are not as susceptible to climate change as the soils in warmer and drier areas. But this does not mean soils will not change in wetter or cooler climates or in locations high in SOC.

The regional-scale soil vulnerability map is a coarse estimation of potential change to soils with climate change. Local data and information are needed to estimate vulnerability at a local scale. Other soil properties that should be considered in creating a local map include: available water holding capacity, soil depth, hydrological soil group, erodibility (K) factor, soil texture, parent material, SOC, and calcium carbonate content (inorganic carbon), as well as vegetation type, geology, slope, aspect, and elevation. An example of how to create a soil vulnerability rating at a forest-project scale is given next.

Example Project-Scale Assessment of Soil Vulnerability to Climate Change

At the individual forest level, local soils information could be utilized to create maps of soil vulnerability to climate change at the project, watershed, or landscape scale. The Uinta-Wasatch-Cache National Forest used available soil data and applied a soil vulnerability assessment to a watershed-scale project during the project planning stage. The assessment was used initially to identify potential projects that would help create more resilient ecosystems and then to stratify fieldwork. Vegetation manipulation is one example of a specific adaptive management strategy to maintain or enhance soil health. Quaking aspen (*Populus tremuloides*) and pinyon-juniper vegetative communities were examined for this example.

A soil map was created for two watersheds within a project boundary. Vegetation and geology layers were added, as well as a digital elevation model to create slope and aspect. Soil available water holding capacity, soil depth to a restrictive layer, hydrological group, parent material, and soil temperature and moisture regimes were included in a matrix and rated for each soil type to derive vulnerability to climate change. Using soil indicators, along with vegetation and geology layers, we can estimate nutrient content, SOM, and how well a soil retains moisture. These estimates were used to assign a rating for soil vulnerability to climate change (table 4.3). The higher the point value rating, the more resilient and resistant the soil resources are to the effects of a warmer and drier climate. This information was added to the soil attribute table in a geographic information system (GIS). Potential focus areas for fieldwork verification and for recommended vegetation projects to meet desired conditions were identified by creating intersects for vegetation attributes of interest. An example of an interpretive map is shown in figure 4.19.

The value ranges or ratings will be used to focus attention on soil resources that best meet vegetation management objectives. Soils that are more suitable or resistant to change (less vulnerable to climate change) are those expected to better maintain soil moisture and nutrient conditions favorable for the vegetative communities present. These soils will be areas of opportunity for vegetation management designed to sustain existing vegetation community types.

Conclusions from the soil vulnerability analysis include:

1. Sustaining aspen vegetative communities within the project area will be one of the objectives of the project. Vegetative treatments will be implemented to promote aspen retention and increase diversity of aspen age classes. The climate change soil vulnerability rating was determined for each of the aspen polygons in the treatment area. An examination of the rating criteria showed some aspen stands with

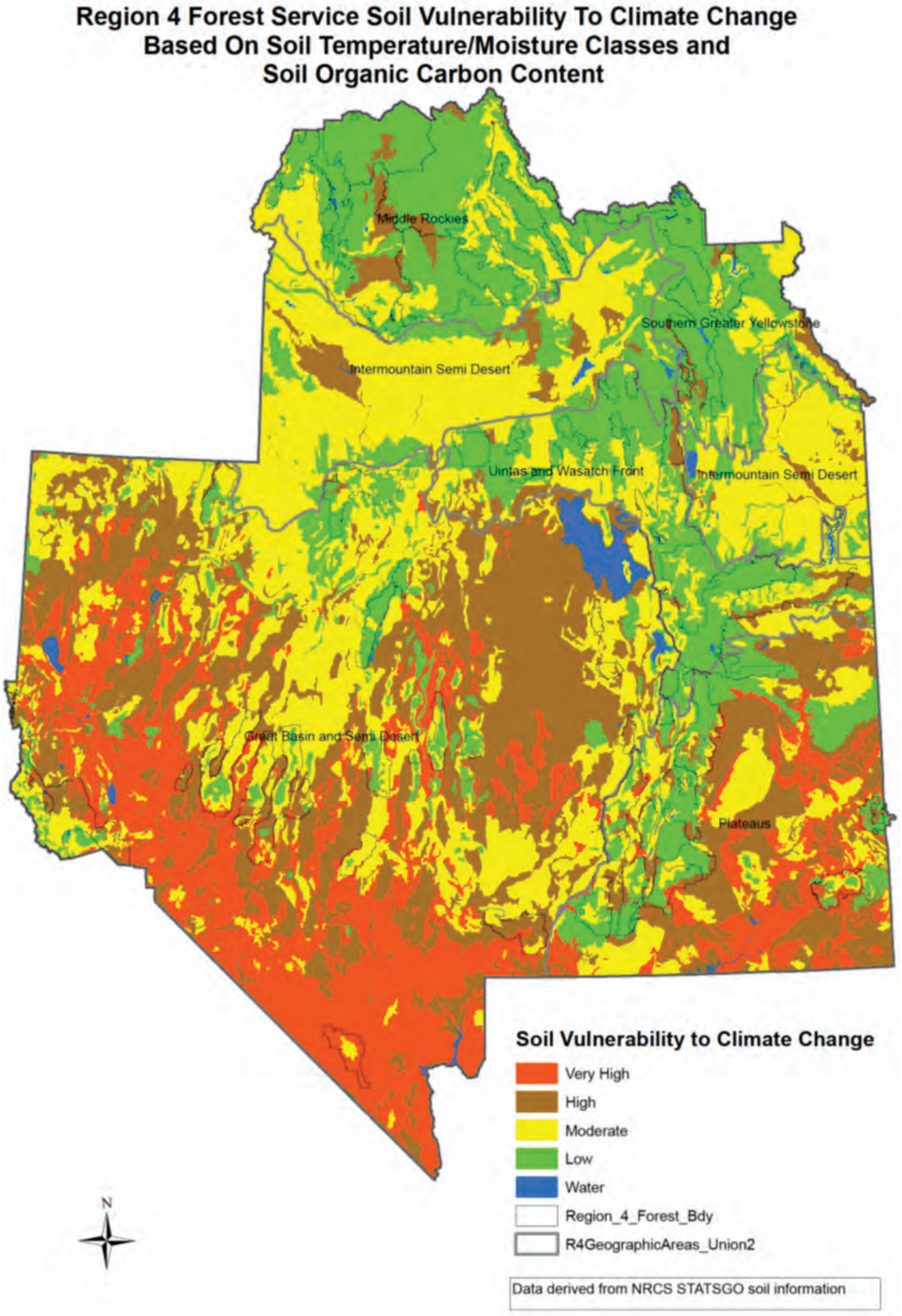

Figure 4.18—Soil vulnerability to climate change in the Intermountain Adaptation Partnership region, based on ratings in table 4.2 (combination of soil temperature/moisture and soil organic carbon).

Table 4.3—Forest-level soil vulnerability indicators and ratings.

Water holding capacity		**Soil depth**		**Hydrological group**		**Aspect**		**Parent material**		**Soil temperature/ moisture regime**		**Point value range**	**Suitability rating**	**Vulnerability rating**
Value[a]	*Pts*[b]	*Inches*	*Pts*	*Group*	*Pts*	*Group*	*Pts*	*Texture*	*Pts*	*Value*[a]	*Pts*			
VH	12	60+	12	A	9	N	9	Fine	9	L	9	46–60	VH	VL
H	9	40–60	9	B	6	E	6	Medium	6	M	6	33–45	H	L
M	6	20–40	6	C	3	W	3	Coarse	3	H	3	20–32	M	M
L	3	11–20	3	D	0	S	0			VH	0	7–19	L	H
VL	0	0–10	0									0–6	VL	VH

[a] VH = very high, H = high, M = moderate, L = low, VL = very low.

[b] Pts = points.

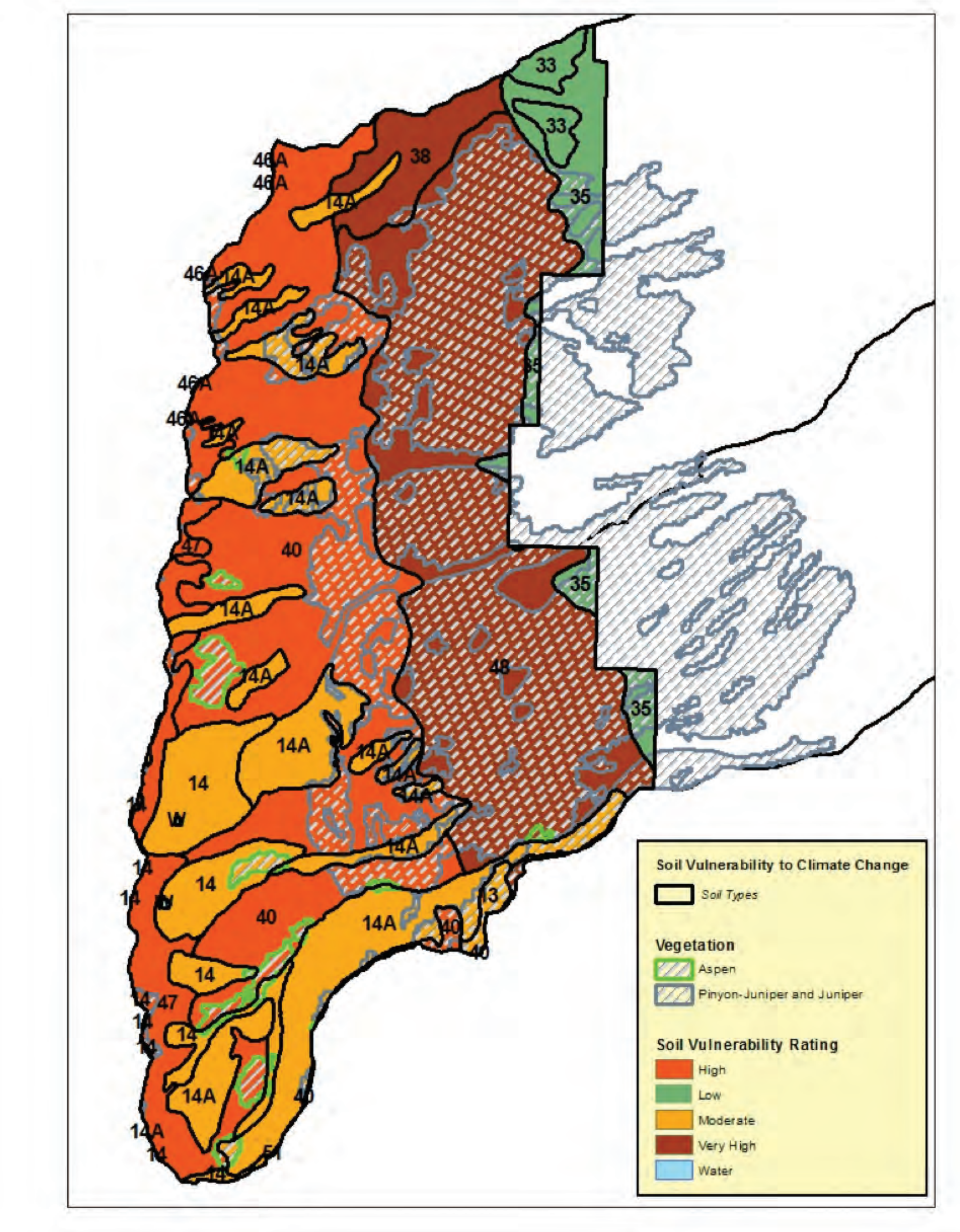

Figure 4.19—Example of soil vulnerability to climate change at a small spatial scale, based on ratings in table 4.2 (combination of soil temperature/moisture and soil organic carbon). Numbers indicate soil series mapping units (not discussed here).

a very high to high vulnerability rating and some with a moderate vulnerability rating. Aspen stands with a moderate vulnerability rating will be areas for recommended project work to maintain aspen community types. The aspen stands located within the high and very high vulnerability areas will not be recommended for aspen regeneration treatments unless a site visit indicates available water could be sustained in a warmer, drier climate.

2. Pinyon-juniper encroachment into shrublands and grasslands is occurring because of a lack of fire. Removal of the pinyon and juniper is recommended in areas that currently have mountain big sagebrush in the understory, with the objective of increasing sagebrush cover. Removal would be accomplished through mechanical treatments (mastication) and lop-and-scatter. Very high to low soil vulnerability ratings were found across the project area where pinyon-juniper exists. Soils that were rated as very high to high in vulnerability are areas with shallow soils and low available water holding capacity. Pinyon-juniper may decrease in dominance in these areas with a reduction in available soil water due to climate change. Removal of pinyon and juniper may make these areas more susceptible to invasion by nonnative species such as cheatgrass. In areas rated as having low to moderate vulnerability to climate change, the ability to manage for restoration of shrublands may be higher as soils are expected to retain soil moisture longer. Site visits will be used to verify potential for management.

Summary and Conclusions

Climate change will alter fundamental physical processes in the IAP region, including hydrological processes and soil processes. Changes in physical processes will in turn affect biological processes, including soil microbial processes and vegetation growth and development. These physical and biological effects of climate change are complex and will be highly variable across the IAP region.

Warming temperatures will reduce snowpack accumulation and advance snowmelt timing in the region. Despite mixed signals from precipitation and temperature changes in the historical record, future temperature changes are expected to be higher than historical temperature trends, and future precipitation declines are expected to be less pronounced—and increased precipitation is possible. Earlier streamflow center of timing is expected over much of the region, and summer low flows are expected to be lower. Total water yields may decrease due to increased ET, but precipitation amounts are uncertain. Increasing precipitation could outweigh ET effects on total water yields, but decreasing precipitation could substantially exacerbate declines in annual water yield and low flows. The frequency and extent of midwinter flooding are expected to increase. Flood magnitudes are also expected to increase because rain-on-snow-driven peakflows will become more common.

Places with seasonally intermittent snowpacks are likely to see snow more rarely. Some mid- to low-elevation seasonal snowpacks are likely to become intermittent. Higher-elevation snowpacks may or may not undergo substantial changes in April 1 SWE, snow residence time, or center of melt timing, depending on precipitation outcomes. In warmer locations, temperature-dependent changes are relatively robust even if precipitation increases. In colder locations, a precipitation increase within the range of projected possibilities could cancel or overwhelm the effects of even a relatively large temperature change. Alternatively, a precipitation decrease could exacerbate projected temperature-related declines.

Glacier accumulation zones are at some of the highest elevations of the region, so they may respond positively if precipitation increases. Annual dynamics of mass balance with respect to input and output suggest that the equilibrium line (demarcating places where annual snow does not completely melt each summer) will increase in elevation, regardless of precipitation; where that elevation falls on each glacier will influence glacier response. Most glaciers will be reduced in volume and area and may become small enough to prevent movement. If climate at higher elevations becomes both warmer and drier, glaciers are unlikely to persist.

Groundwater recharge is likely to decrease in the southern portion of the IAP region, but changes in recharge remain uncertain throughout the region given limited understanding of mountain recharge processes and groundwater flow in mountain blocks. Groundwater recharge has been examined in only a few locations, and little is known about groundwater recharge processes in many watersheds. Higher minimum temperatures will reduce the longevity of snowpack, and decrease the length of time aquifer recharge can occur, potentially leading to faster runoff and less groundwater recharge. Some watersheds will be shifting from snow-dominated to rain-dominated, which may result in declines in groundwater recharge. Because many biological processes are temperature dependent, climate-induced changes in groundwater temperature may negatively affect aquatic communities. But because the thermal regime of groundwater systems is less dependent on air temperature patterns than on surface waters, the effects of rising air temperatures are likely to be less pronounced in groundwater discharges. Plant species in GDEs can respond to even slight changes in water table elevation, and shifts in composition of both vascular and bryophyte species could occur with lowered water tables.

Soil temperature and moisture are the primary drivers of change for all soil processes. The magnitude of projected change in soils with climate change is variable and depends on existing soil resources and existing climate. An increase in soil temperature will generally produce an increase in soil biological activity and soil respiration. In the current semi-arid soils of the IAP region, an increase in soil temperature without an increase in soil moisture is likely to result in reduced biological activity, increased respiration, and decreased potential to store carbon. In the colder and wetter areas of the IAP region, an increase in soil temperature may lead to greater biological activity and to longer growing seasons if soil moisture is not limiting. Soils derived from coarse-textured parent material will transfer heat more efficiently down into the soil profile than will fine-textured soils. The heat transfer downward can affect soil processes and even groundwater temperatures. Fine-textured soils are capable of storing water longer in the soil profile, providing a buffer to warming and higher water demands by plants.

Changes in soil temperature and moisture will affect carbon and nitrogen cycles. Changes to carbon and nitrogen cycles may include an increase or reduction in cycling rates or storage of carbon and nitrogen. Soil organic carbon may contain more than three times as much carbon as is found in the atmosphere or terrestrial vegetation, and it supports many soil processes and functions. These include providing nutrients for plants, binding soil particles together and thereby maintaining structure, providing an energy source for microbes, increasing water infiltration and retention, and providing cation/anion exchange for retention of ions and nutrients. Climate change will affect SOC and ultimately the functions and processes supported by SOC. Most of the soils in the IAP region can sequester additional carbon if soil temperatures decrease and soil moisture increases. However, most climate models suggest warmer soil temperatures and various soil moisture changes. The warming temperatures without additional moisture may reduce SOC and capability of soils to store carbon.

Changes to SOC with climate change can cause changes to several soil properties that are directly tied to the amount of SOC. These include soil structure, bulk density, and soil porosity. These soil properties affect water infiltration, rooting depth, soil erosional losses, and water holding capacity. These properties are potential indicators that can be used to determine the effects of climate change and where management changes may be needed to adapt to a changing soil environment.

Soil organisms perform many functions including decomposition and nutrient cycling. The effects of climate change on soil biology are mixed. Warming of the soil may result in greater microbial activity, releasing more carbon to the atmosphere through increased decomposition. Warming of the soil may also result in slowed microbial growth and less carbon being released through respiration. Greater soil biodiversity is expected to increase soil resilience to changing climate.

Potential effects to soil chemical properties with climate change are linked to other biological and physical changes in the soil, all of which are driven by the soil temperature and moisture inputs. Salinization, acidification, pH, and cation exchange capacity are soil processes and properties that will change with changes to climate. In general, the lower-elevation, drier shrubland and grassland soils are more vulnerable to changes in soil chemical processes and properties.

There are many potential management actions to decrease vulnerabilities to climate change. The information in this chapter was used as the basis for development of climate change adaptation strategies and tactics for water use, GDEs, and soils (Appendix 4, Chapter 14).

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Chapter 5: Effects of Climate Change on Native Fish and Other Aquatic Species

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Introduction

The diverse landscapes of the Intermountain Adaptation Partnership (IAP) region contain a broad range of aquatic habitats and biological communities. A number of aquatic species are regional endemics, several are threatened or endangered under the U.S. Endangered Species Act (ESA), and many have declined because of the introduction of nonnative aquatic species, habitat fragmentation, and human development. Environmental trends associated with human-caused climate change have been altering the habitats of these species for several decades (Barnett et al. 2008; Hamlet and Lettenmaier 2007; Luce and Holden 2009; Mote et al. 2005), and more significant changes are expected during the 21st century (chapters 3, 4). For animals that live in or near aquatic environments such as fishes, amphibians, crayfish, mussels, and aquatic macroinvertebrates, changes in habitat and hydrological regimes are expected to shift their abundance and distribution (Ficke et al. 2007; Hauer et al. 1997; Poff et al. 2002; Rieman and Isaak 2010; Schindler et al. 2008). This is primarily because many of these species are ectothermic; thus, thermal conditions dictate their metabolic rates and most aspects of their life stages—how fast they grow and mature, whether and when they migrate, when and how often they reproduce, and when they die (Magnuson et al. 1979). Buffering these changes are the topographic diversity and steep environmental gradients of many landscapes throughout the IAP region, which contribute to slow climate velocities (sensu Loarie et al. 2009) and often create climate refugia where populations of many species can persist under all but the most extreme climatic changes (Isaak et al. 2016a; Morelli et al. 2016).

A large literature exists that describes the many interactions among climate change, aquatic environments, and cold-water fishes such as trout, salmon, and char (Hauer et al. 1997; Isaak et al. 2012a,b; ISAB 2007; Mantua and Raymond 2014; Mantua et al. 2010; Mote et al. 2003; Rieman and Isaak 2010; Young et al. 2018). Rather than revisiting those sources, we focus on providing information specific to the IAP region. First, we describe the ecology, status, and climate vulnerabilities of species of concern. Through discussions with scientists and U.S. Department of Agriculture Forest Service (USFS) Intermountain Region staff and national forest resource managers, species were chosen for their perceived vulnerability to climate change and their societal prominence as ESA-listed threatened and endangered species. The species are Rocky Mountain tailed frog (*Ascaphus montanus*), Idaho giant salamander (*Dicamptodon aterrimus*), western pearlshell mussel (*Margaritifera falcata*), springsnails (*Pyrgulopsis* spp.), Yosemite toad (*Anaxyrus canorus*), Sierra Nevada yellow-legged frog (*Rana sierrae*), bull trout (*Salvelinus confluentus*), and cutthroat trout (*Oncorhynchus clarkii*). Second, we develop spatially explicit model projections and geospatial datasets showing where bull trout and cutthroat trout are most likely to occur in current and future climates. These projections are used to assess the potential and future distribution of suitable habitats for these species, but could also be used to design and implement long-term conservation strategies or monitoring programs. Although the availability of biological datasets and models for stream networks restricted our projections to trout in streams, the approach used here is easily extended to other aquatic species as more geographic data on these taxa are gathered and models are extended to standing waters. The preceding information was used to develop climate adaptation options for species of concern, including how new technologies and ongoing development of better information could enable strategic implementation of those options to maximize their effectiveness.

Analysis Area Network and Stream Climate Scenarios

This assessment encompasses all streams in the USFS Intermountain Region that flow through its 12 national forests and lands downstream of those forests. To delineate a network that represented streams within this area, geospatial data for the 1:100,000-scale National Hydrography Dataset (NHD)-Plus Version 2 were downloaded from the Horizons Systems website (Horizon Systems Corp. http://ww.horizon-systems.com/nhdplus/; McKay et al. 2012) and filtered by minimum flow and maximum stream slope criteria. Summer flow values predicted by the Variable Infiltration Capacity (VIC) hydrological model (Wenger et al. 2010) were obtained from the Western U.S. Flow Metrics website (USDA FS https://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml) and

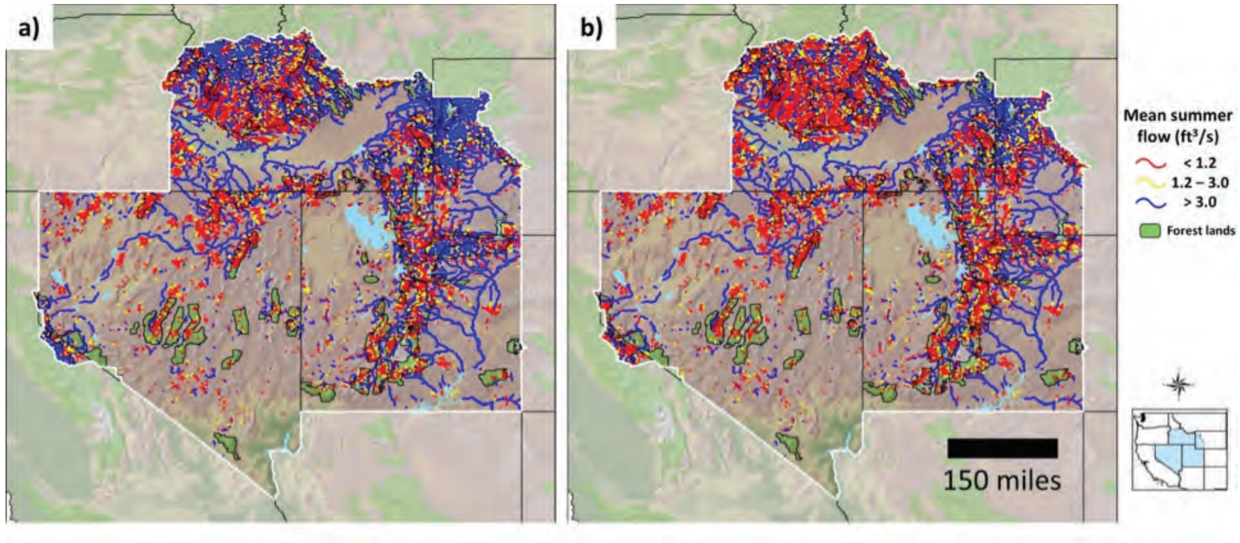

Figure 5.1—Stream network showing channels with perennial flows for (a) the baseline period and (b) 2080s based on the A1B emissions trajectory. Increasing prevalence of red stream reaches late in the century indicates a trend towards lower summer flows as winter snow accumulations decrease and melt earlier in the spring.

linked to NHDPlus stream reaches. Reaches with summer flows less than 0.2 cubic feet per second, approximating a wetted width of 3 feet (based on an empirical relationship developed in Peterson et al. 2013b), or with slopes greater than 15 percent were trimmed from the network because they are rarely occupied by fish or other aquatic vertebrates (Isaak et al. 2017b). The steepest headwater reaches are also prone to frequent large disturbances (e.g., postfire debris torrents) that may cause local extirpations of fish populations (Bozek and Young 1994; Miller et al. 2003). To exclude dry channels throughout much of the Great Basin, reaches that were coded as intermittent in the NHDPlus network were also trimmed. Application of these criteria resulted in a final network extent of 55,700 miles (fig. 5.1), which was almost evenly split between USFS (48 percent) and non-USFS (52 percent) lands.

Scenarios representing mean August stream temperature were downloaded from the NorWeST website (USDA FS https://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html) and linked to reaches in the analysis network. NorWeST scenarios have a 0.6-mile resolution and were developed by applying spatial-stream network models (Isaak et al. 2016b, 2017b; Ver Hoef et al. 2006) to temperature records for 8,726 summers of measurement at 4,277 unique stream sites within the IAP region. The predictive accuracy of the NorWeST model (cross-validated $r^2 = 0.91$; cross-validated root mean square prediction error = 2.0 °F), combined with substantial empirical support, provided a consistent and spatially balanced rendering of temperature patterns and thermal habitat for all streams. To depict temperatures during a baseline period, we used the S1 scenario, which represented average conditions for 1993–2011 (hereafter 2000s). The mean August stream temperature during this period was 57 °F for all streams, although temperatures were significantly colder in streams flowing through national forests, where the average was 52 °F (table 5.1, fig. 5.2).

Future stream temperature scenarios were also downloaded from the NorWeST website (USDA FS n.d.b) and chosen for the same climate periods (2030–2059, hereafter 2040s; 2070–2099, hereafter 2080s) and emissions scenario (A1B) as those used for the streamflow analysis in the IAP hydrological assessment (Chapter 4). With respect to scenarios used in other chapters of the IAP assessment, the A1B scenario is similar to the RCP 6.0 scenario associated with CMIP5 simulations (Chapter 3). The future NorWeST scenarios used were S30 (2040s) and S32 (2080s), which accounted for differential sensitivity and slower warming rates of the coldest streams (Luce et al. 2014). Future stream temperature increases were projected to range from 1.4 to 2.3 °F by mid-21st century and from 2.3 to 4.0 °F by late century, with variation occurring within and among river basins (table 5.2, fig. 5.2). Future temperature increases imply warming rates similar to those observed in recent decades (Isaak et al. 2012b, 2017a) and shifts of stream temperature isotherms upstream at 1,000 to 1,600 feet per decade (Isaak and Rieman 2013; Isaak et al. 2016a).

Changes in several ecologically relevant streamflow characteristics were discussed in the hydrological assessment (Chapter 3), indicating that future snowmelt and spring runoff will occur earlier, summer flows will decrease, stream intermittency may increase in marginal areas, and more high-flow events will occur during the winter in transitional watersheds where air temperatures are near freezing (Hamlet and Lettenmaier 2007). Those projections concur with historical trends that show streams now run off 1 to 3 weeks earlier in the spring (Stewart et al. 2005), and that summer flows have decreased 10 to 30 percent in the last 50 years (Leppi et al. 2012; Luce and Holden 2009). Hydrological changes make it likely that mountain wetlands

Table 5.1—Projected changes in mean August air temperatures, streamflow, and stream temperatures for major river basins in the Intermountain Adaptation Partnership region. Projections are based on the A1B emissions scenario represented by an ensemble of 10 global climate models that best predicted historical climate conditions during the 20th century in the northwestern United States (Hamlet et al. 2013; Mote and Salathé 2010). Additional details about scenarios are provided elsewhere (Hamlet et al. 2013; Wenger et al. 2010). For more information on flow, see the western United States flow metrics website (USDA FS n.d.c) and the Pacific Northwest Hydroclimate Scenarios Project website (University of Washington, Climate Impacts Group 2010). For more information on stream temperatures, see Isaak et al. (2017b), Luce et al. (2014), and the NorWeST website (USDA FS n.d.b).

	2040s (2030–2059)			2080s (2070–2099)		
NorWeST unit[a]	**Air temperature change**[b]	**Streamflow change**	**Stream temperature change**[c]	**Air temperature change**	**Streamflow change**	**Stream temperature change**
	°F	*Percent*	*°F*	*°F*	*Percent*	*°F*
Salmon River basin	5.9	-22.3	2.3	9.9	-31.4	3.7
Upper Snake River, Bear River basins	5.8	-7.6	1.5	9.5	-9.5	2.4
Middle Snake River	5.8	-19.5	2.2	9.8	-26.7	3.7
Utah basins	4.7	+2.3	2.2	10.4	12.6	4.0
Lahontan basin	4.8	+2.6	1.4	10.7	+6.5	2.4

[a] Boundaries of NorWeST production units as described in USDA FS (n.d.c).

[b] Changes in air temperature and stream flow are expressed relative to the 1980s (1970–1999) baseline climate period.

[c] Changes in stream temperatures account for differential sensitivity to climate forcing within and among river basins as described in Luce et al. (2014) and USDA FS (n.d.c).

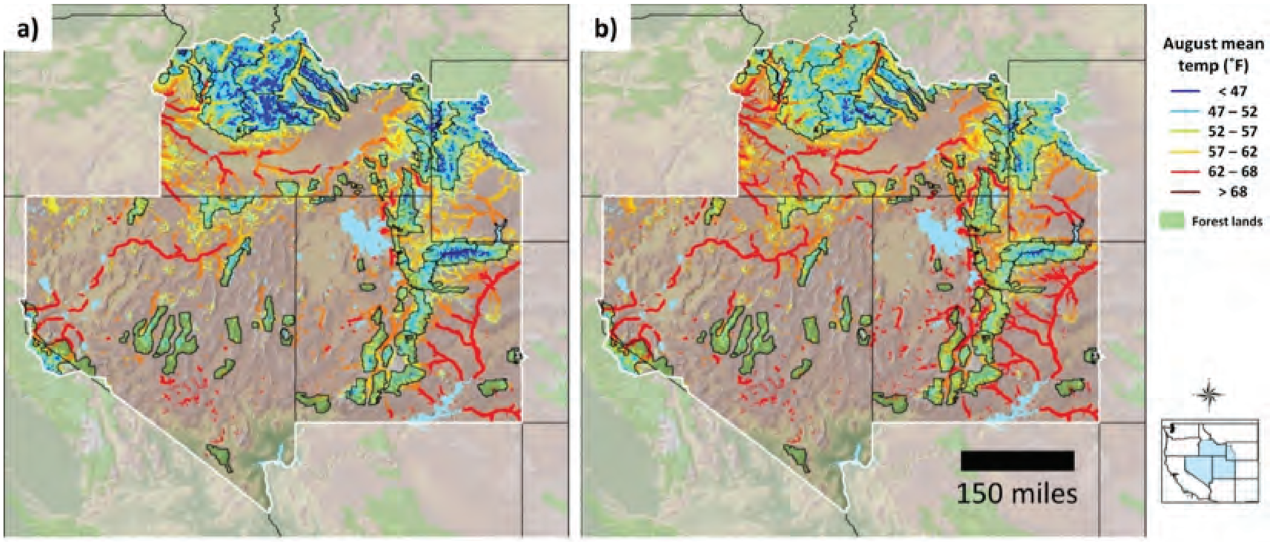

Figure 5.2—NorWeST August mean stream temperature maps interpolated from 8,726 summers of monitoring data at 4,277 unique stream sites across the 55,700 miles of streams in the analysis area. Map panels show conditions for (a) the baseline period (2000s) and (b) late-century scenario (2080s). Networks were trimmed to represent potential fish-bearing streams by excluding intermittent reaches and those with slopes greater than 15 percent and summer flows less than 0.2 cubic feet per second. High-resolution digital images of these maps and ArcGIS databases with reach-scale predictions are available at the NorWeST website (USDA FS n.d.b).

Table 5.2—Lengths of streams in the Intermountain Adaptation Partnership region (slope less than 15 percent and Variable Infiltration Capacity model-predicted summer flows greater than 0.2 cubic feet per second) categorized by mean August stream temperatures during the baseline and two future climate periods and by land administrative status. Values in parentheses are percentages of the total in the last column.

	<46 °F	46–52 °F	52–57 °F	57–63 °F	63–68 °F	>68 °F	Total[a]
Forest Service lands	*Miles (%)*	*Miles (%)*	*Miles (%)*	*Miles (%)*	*Miles (%)*	*Miles (%)*	*Miles (%)*
2000s	3,872 (14.4)	11,061 (39.5)	8,799 (32.7)	3,014 (11.2)	559 (2.1)	37 (0.1)	27,305
2040s	1,644 (6.3)	8,692 (33.1)	9,994 (38.0)	4,790 (18.2)	1,016 (3.9)	141 (0.5)	26,277
2080s	835 (3.2)	6,752 (26.2)	10,371 (40.2)	6,058 (23.5)	1,424 (5.5)	343 (1.3)	25,783
Non-Forest Service lands							
2000s	48 (0.2)	924 (3.2)	4,655 (16.2)	11,490 (39.9)	8,027 (27.9)	3,639 (12.6)	28,783
2040s	6 (0.0)	348 (1.2)	2,896 (10.2)	9,242 (32.5)	9,767 (34.3)	6,185 (21.7)	28,444
2080s	3 (0.0)	173 (0.6)	1,990 (7.0)	7,853 (26.8)	10,552 (37.3)	7,966 (28.2)	28,537

[a] Reductions in network extent in future scenarios result from projected decreases in summer flows as described in Chapter 4.

and moist areas near streams will become drier during future summer periods (Lee et al. 2015). Increased frequency or severity of wildfires in portions of the IAP region could also cause more extensive debris flows and channel disturbances in headwater streams with steep channels (Luce et al. 2012) (Chapter 3). Those combined changes suggest that stream environments and habitats for aquatic species will become more variable, subject to more disturbances, and gradually warmer throughout the rest of the 21st century.

Focal Species Ecology and Climate Vulnerability

Rocky Mountain Tailed Frog

The Rocky Mountain tailed frog occurs throughout central and northern Idaho, western Montana, and northeastern Oregon, but occurs within the IAP region only in Boise, Payette, Salmon-Challis, and Sawtooth National Forests. Populations inhabit steep, cold headwater streams, their distributions often extending upstream past waterfalls and cascades that limit fish distributions (Dunham et al. 2007; Isaak et al. 2017b). After eggs hatch in late summer, tadpoles grow for 1 to 4 years before metamorphosing into adults, which reach sexual maturity after another 4 to 5 years; local densities may be high (Hayes and Quinn 2015; Pilliod et al. 2013). Larval frogs are strictly aquatic, but adults often exploit cool, moist riparian zones to forage. Adult body size is 1 to 2 inches, and dispersal is limited, so floods and fire-related channel disturbances may suppress populations for some time after an event (Hossack and Pilliod 2011; Hossack et al. 2006). Populations are patchily distributed among headwater streams and show evidence of genetic divergence (Metzger et al. 2015).

The Rocky Mountain tailed frog is of conservation concern but does not appear on the sensitive species list of the Intermountain Region. Land use practices that warm streams, increase sedimentation, and reduce interstitial spaces in substrates or reduce habitat moisture (through loss of stream and terrestrial canopy cover) are thought to reduce habitat quality (Hayes and Quinn 2015). Nonnative fish predators may increase mortality where distributions overlap, as has been documented for other amphibians (Pilliod and Peterson 2001; Pilliod et al. 2010). Although existing data for tailed frogs suggest that the species occurs in many streams throughout its range (Isaak et al. 2017b), monitoring data are not available to describe temporal trends in abundance.

Rocky Mountain tailed frogs require cold water, so increasing temperatures may decrease the suitability of warmer downstream habitats (Isaak et al. 2017b). Their long generation times and relatively low fecundity cause populations to rebound slowly from disturbances; thus, extreme floods or postfire debris flows in steep channels may threaten persistence of some populations as climate change causes these events to become more common (Hossack and Pilliod 2011; Hossack et al. 2006). Tailed frog populations may also be negatively affected by more extreme summer droughts or wildfires that open riparian canopies, making areas adjacent to streams warmer and drier (Hossack and Pilliod 2011; Hossack et al. 2006).

Idaho Giant Salamander

The Idaho giant salamander occurs in northern and west-central Idaho and a small portion of west-central Montana, but is found within the IAP region only in Boise and Payette National Forests. Populations are patchily distributed and often co-occur with native salmonids in headwater streams, although salamanders also occupy reaches farther upstream from which fish are excluded (Sepulveda and Lowe 2009).

Giant salamander may also use lakes and ponds. Neotony (maturation as a strictly aquatic form with larval characteristics) is common (Blaustein et al. 1995). Uncertainty exists about timing of reproduction, although some literature suggests both spring and fall spawning (Nussbaum 1969). Females guard egg masses until hatching occurs and larval stages last several years before metamorphosing into adults. Adults reach body sizes of 7 to 12 inches and prey on a variety of aquatic and terrestrial species, including tailed frog tadpoles, in and near streams (Blaustein et al. 1995). Dispersal is limited, and population genetic structure varies among basins (Mullen et al. 2010).

Idaho giant salamanders are of conservation concern but do not appear on the Intermoutain Region sensitive species list. There is some indication that land use practices may affect their occurrence, but their patchy distribution and sparse datasets limit inferences about habitat requirements. They are prey for both native and nonnative fish species, but fish species presence is not known to affect their population status (Sepulveda and Lowe 2011). Overall, their distribution is poorly described, and monitoring data are not available to evaluate temporal trends. Idaho giant salamander sensitivities are presumed to be similar to Rocky Mountain tailed frogs, although the salamander may be even more susceptible to disturbance of headwater natal areas, given nest guarding behavior by females and multiyear development of larval stages before maturity (Blaustein et al. 1995; Nussbaum 1969).

Western Pearlshell Mussel

The western pearlshell mussel is found throughout the Columbia River Basin, in a portion of the Missouri River headwaters in Montana, and in internally draining basins such as the Humboldt, Truckee, and Provo Rivers. It has been recorded in all national forests in the IAP region except the three southern Utah forests. This sedentary filter-feeder inhabits cool streams and rivers at depths of 1.5 to 3.0 feet, and tends to congregate in stable substrates amid boulders, gravel, and some sand, silt, and clay (Roscoe and Redelings 1964). The species has limited mobility and will not tolerate accumulation of fine sediment. Western pearlshell larvae are obligate parasites of an array of salmonid species (Chinook salmon [*O. tshawytscha*], cutthroat trout, and rainbow trout [*O. mykiss*]; utilization of bull trout is unknown) and rely on these hosts for recruitment and dispersal (Karna and Milleman 1978; Meyers and Milleman 1977; Murphy 1942). Female mussels generally release larvae (or glochidia) in spring or early summer, depending on water temperature. Glochidia attach to fish gills and develop for a period of weeks to months. Once metamorphosed, juvenile mussels drop from their host fishes and burrow into the substrate (Murphy 1942).

The western pearlshell mussel ranges from Alaska and British Columbia south to California and east to Nevada, Wyoming, Utah, and Montana. Many examples exist of pearlshell decline or extirpation from streams and rivers across its range, especially in arid areas (Hovingh 2004; Stone et al. 2004). Threats include impoundments, loss of host fishes, channel modification, dredging and mining, pollution, sedimentation, nutrient enrichment, water diversion, degradation of native riparian vegetation, and introduction of nonnative fishes that outcompete host species. Many of these impacts, especially reduction in streamflow and increased stream temperatures, can be exacerbated by climate change.

The western pearlshell mussel occupies streams with broad ranges of thermal regimes, but nevertheless prefers cold water and perennial flows. Its habitat must also be suitable for its trout and salmon hosts, and mussel sensitivity to climatic variability will closely parallel that of salmonids. Although potentially vulnerable to climate change, the western pearlshell mussel does not face an immediate risk of extinction because it occupies such a broad geographic range.

Springsnails

Springsnails are hydrobiid snails that occur in freshwater habitats throughout much of western North America. About 100 species inhabit the IAP region (Hershler et al. 2014). These tiny mollusks (shell length 0.04–0.31 inches) are widespread and locally abundant (often greater than 100 per square foot) in perennial, groundwater-dependent springs and brooks. Spring habitats may be either ambient temperature or thermal, and springsnails are often concentrated near sources of groundwater discharge with stable water chemistry (Mladenka and Minshall 2001). They typically live on emergent plants and hard substrates, grazing on attached algae and fungi (Hershler 1998; Mladenka and Minshall 2001). They are gill breathers and do not tolerate desiccation.

Distributed from southern Canada to northern Mexico, the springsnail exhibits habitat specificity and low dispersal ability, which contribute to a high degree of endemism; many species occurr only within a single spring or seep (Hershler et al. 2014). Springsnails have life history traits that make them vulnerable to extinction. First, they have specialized habitat requirements, typically occurring in pristine, cold-water or thermal springs close to the spring source, where dissolved carbon dioxide and calcium concentrations are high (Mladenka and Minshall 2001; O’Brien and Blinn 1999). Slight changes in water chemistry or warming temperatures could negatively affect local populations (Jyväsjärvi et al. 2015). Second, springsnails are poor dispersers, and suitable habitats are generally isolated from each other by arid uplands. Once a springsnail population has been extirpated, it is unlikely to be naturally refounded. Threats to springsnails include groundwater pumping and aquifer drawdown, surface flow diversion for agriculture, impoundments, channelization of outflows, springhead development, physical alteration of thermal springs for bathing, overgrazing, and nonnative species (e.g., New Zealand mudsnail [*Potamopyrgus antipodarum*]).

The limited ability of springsnails to disperse and their narrow environmental tolerances make them vulnerable to emerging threats associated with climate change. Because they require particular hydrological conditions, specific and stable temperature regimes, and perennial flows, some taxa (e.g., eight Nevada springsnail species) have been rated as "extremely vulnerable" using the Climate Change Vulnerability Index (Young et al. 2012).

Yosemite Toad

The Yosemite toad occurs in the Sierra Nevada, restricted primarily to publicly managed lands at high elevations (3,000–12,000 feet) (Brown et al. 2015). It inhabits ponds and wet meadows as well as drier upland sites. Adult toads emerge from their overwintering refuges in rodent burrows or underground cover from late April to late June, depending on elevation and year (Brown et al. 2012). Females lay approximately 1,000 eggs per clutch in shallow standing water amid emergent vegetation. After hatching, tadpoles require 4 to 6 weeks to reach metamorphosis and are not known to overwinter (Jennings and Hayes 1994; Kagarise Sherman 1980; Karlstrom 1962). Adults spend most of their lives in upland habitats adjacent to breeding sites, and are capable of moving and dispersing several hundred feet through dry forests.

Yosemite toad populations are in decline. The Yosemite toad, once common in high-elevation aquatic ecosystems of the Sierra Nevada, had disappeared from half its historical range by the 1990s (Jennings 1996). More recent surveys indicate an 87-percent decline from watersheds occupied before 1990, with scattered remaining populations and fewer individuals per site (Brown et al. 2015). Toads were most recently recorded at 470 sites in 5 national forests (17 sites in Humboldt-Toiyabe National Forest) and about 100 more sites in national parks (Brown et al. 2015). Several factors, such as disease, drought, airborne contaminants, habitat alteration, water diversions, nonnative fishes, and wildfire, may have contributed to the declines, but there is no clear evidence targeting any particular threat (Brown et al. 2015).

The dependence of Yosemite toad on shallow, ephemeral breeding ponds filled by melting snow makes the species susceptible to risks of climate change (Kagarise Sherman and Morton 1993). Models project that climate change will lead to higher average temperatures in all seasons, higher precipitation, and decreased spring and summer runoff due to decreased snowpack (Smith and Tirpak 1989) (Chapter 4). Less runoff could affect egg and tadpole survival by premature drying of breeding sites. Earlier snowmelt could lead to earlier breeding with possible positive effects on developmental time, but negative effects and mortality from uncertain weather patterns. For example, toads that emerge early risk starvation or death in late-spring snowstorms (Kagarise Sherman and Morton 1993).

Sierra Nevada Yellow-Legged Frog

The Sierra Nevada yellow-legged frog currently inhabits the Sierra Nevada, restricted primarily to publicly managed lands at high elevations (4,500–12,000 feet), including streams, lakes, ponds, and meadow wetlands in Humboldt-Toiyabe National Forest (CDFG 2011). The species is highly aquatic during all times of the year (Mullally and Cunningham 1956). At high elevation, both frogs and tadpoles overwinter under ice in lakes and streams, and because tadpoles require 1 to 4 years to metamorphose, successful breeding sites cannot dry out in summer and need to be deep enough to preclude complete freezing or deoxygenation (Bradford 1983). Although almost always found in or near water, the frog moves seasonally between breeding ponds, foraging, and overwintering habitats, usually along watercourses. However, individuals are capable of moving several hundred feet over dry land, which facilitates recolonization of sites that have lost populations (Pope and Matthews 2001).

The Sierra Nevada yellow-legged frog was listed as endangered under the ESA after populations declined severely during the 20th century due to chytridiomycosis disease (caused by the chytrid fungus [*Batrachochytrium dendrobatidis*]), predation from nonnative fishes, livestock grazing, habitat loss and fragmentation, and perhaps airborne contaminants from the Central Valley (CDFG 2011). The species was estimated to be extirpated from 220 of 318 historical occurrence localities and most remaining populations were thought to have fewer than 100 post-metamorphic individuals (CDFG 2011). During the last 20 years, however, yellow-legged frog populations have increased significantly in Yosemite (Knapp et al. 2016). The disappearance of nonnative fish from numerous water bodies after cessation of stocking, combined with reduced susceptibility to chytridiomycosis, are thought to have stimulated the recovery (Knapp et al. 2016).

Sierra Nevada yellow-legged frogs may be vulnerable to climate change because the species relies on perennial waterbodies and needs several years to metamorphose and mature (Mullally and Cunningham 1956). Climate change could result in greater interannual climatic variability or drier summers and cause lakes, ponds, and other standing waters fed by snowmelt or streams to dry more frequently, which would reduce available breeding habitat and lead to more frequent stranding and death of tadpoles (Lacan et al. 2008). On the other hand, projected earlier snowmelt is expected to cue breeding earlier in the year, which could allow additional time for tadpole growth and development. However, earlier breeding may also expose young tadpoles and eggs to mortality from early spring frosts (Corn 2005).

Bull Trout

Bull trout are broadly distributed across the northwestern United States but are restricted to the northwestern portion of the IAP region in Boise, Humboldt-Toiyabe, Payette, Salmon-Challis, and Sawtooth National Forests (Rieman et

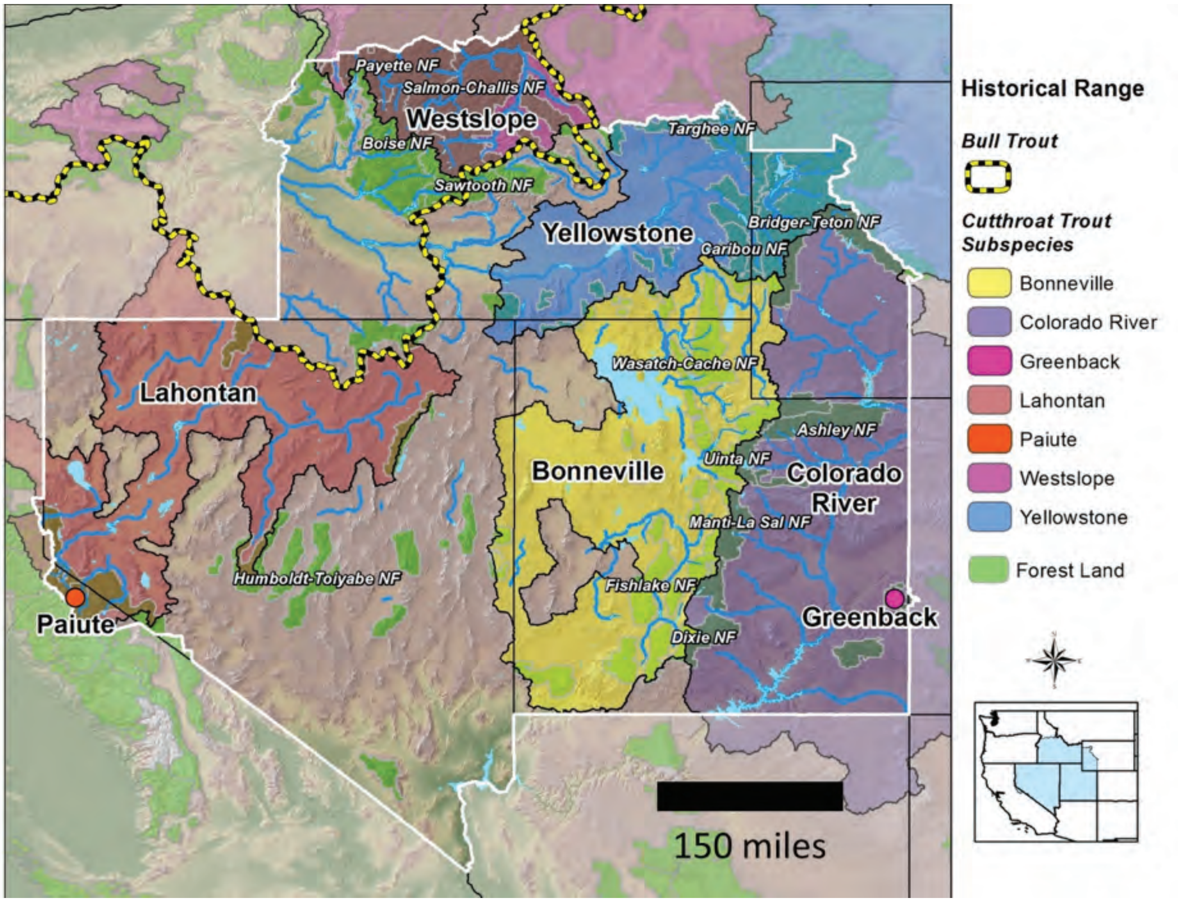

Figure 5.3—Native range distributions of (a) cutthroat trout and (b) bull trout in the Intermountain Adaptation Partnership region. The ranges of six cutthroat trout subspecies occur partly or wholly in this area.

al. 1997) (fig. 5.3). Populations may exhibit migratory or resident life histories. Migratory fish travel long distances as subadults to more productive habitats and achieve larger sizes and greater fecundity as adults before returning to cold natal headwater habitats to spawn (Howell et al. 2010; Rieman and McIntyre 1993). Fish exhibiting resident life histories remain in natal habitats and mature at smaller sizes, though often at the same age as migratory adults. Adults spawn primarily in September, and eggs incubate throughout the winter before juveniles hatch and emerge from stream substrates in late winter or early spring (Dunham et al. 2008). Reproduction and juvenile growth for the first 2 to 3 years is almost exclusively in streams with average August water temperatures less than 54 °F and flows greater than 1.2 cubic feet per second (Isaak et al. 2015). Bull trout populations are typically low density, even among strong populations in the best habitats (Isaak et al. 2017b; Rieman et al. 2006).

The bull trout is a sensitive species in the Intermountain Region and is ESA-listed as threatened (USFWS 2014). Their historical distribution has declined because of water development and habitat degradation (e.g., simplification of in-channel habitat complexity and fragmentation of some habitats), temperature increases, elimination of migratory life histories by anthropogenic barriers, harvest by anglers, and interactions with introduced nonnative fishes (Al-Chokhachy et al. 2010; Rieman et al. 1997, 2007). Encounters with nonnative fishes may involve wasted reproductive opportunities (e.g., interbreeding with brook trout [*Salvelinus fontinalis*]) (Kanda et al. 2002), competition, and predation (in streams, perhaps with brown trout [*Salmo trutta*]; in lakes, with lake trout [*Salvelinus namaycush*]) (Al-Chokhachy et al. 2016b; Martinez et al. 2009).

Bull trout evolved in western North America in interior and coastal streams that exhibit a wide array of flow characteristics and natural disturbance at scales from reaches to riverscapes (Dunham et al. 2003, 2008). Nevertheless, large habitats satisfying their restrictively cold thermal requirements for spawning and early juvenile rearing are relatively rare, and little evidence exists for flexibility in habitat use (Rieman et al. 2007). The length of connected cold-water habitats needed to support a bull trout population varies with local conditions, but current estimates suggest 10 to 30 miles are needed to ensure a high probability (>0.9) of habitat occupancy, with specifics contingent on water temperature, prevalence of brook trout, and stream slope (Isaak et al. 2015). Migratory life histories probably conferred greater resistance to extirpation under historical conditions

(Dunham et al. 2008; Rieman and Dunham 2000), but may no longer do so in some areas. Bull trout may also be sensitive to larger or more frequent winter high flows because eggs incubate in stream substrates throughout the winter where they are susceptible to bed-scour (Goode et al. 2013; Wenger et al. 2011a).

Cutthroat Trout

Cutthroat trout are represented by six subspecies in the IAP region: westslope cutthroat trout (*O. clarkii lewisi*), Yellowstone cutthroat trout (*O. c. bouvieri*), Lahontan cutthroat trout (*O. c. henshawi*), Paiute cutthroat trout (*O. c. seleniris*), Bonneville cutthroat trout (*O. c. utah*), and Colorado River cutthroat trout (*O. c. pleuriticus*) (Behnke 2002) (fig. 5.3). Although there was no historical overlap in the distribution of these subspecies, one or more were distributed throughout all national forests in the IAP region except where perennial streams are lacking (e.g., southern Nevada). These subspecies have a complex evolutionary history with two major clades (Crête-Lafrenière et al. 2012; Loxterman and Keeley 2012). One consists of westslope, Lahontan (including Paiute), and coastal cutthroat trout, and the other includes the rest of the interior subspecies. Phylogeographic structure in the latter group suggests that another one to four taxa may be present (Loxterman and Keeley 2012; Metcalf et al. 2012), but we confine our discussion to the prevailing taxonomy (Behnke 2002).

Cutthroat trout exhibit resident and migratory life history strategies similar to bull trout, but are spring spawners that reproduce in stream reaches where August temperatures are slightly warmer (up to 57 °F) (Isaak et al. 2015). Cold stream reaches where average August temperatures are less than 48 °F are suboptimal for cutthroat trout because of frequent recruitment failures associated with small numbers of growing degree days (Coleman and Fausch 2007). Cutthroat trout populations are generally found at higher densities than are bull trout (Isaak et al. 2017b).

Among cutthroat trout, all subspecies are either ESA-listed as threatened (Lahontan cutthroat trout [USFWS 1995] and Paiute cutthroat trout [USFWS 1985]) or have been petitioned for listing and found not warranted. Those not listed are on the Intermountain Region sensitive species list (Bonneville, Colorado River, westslope, and Yellowstone cutthroat trout). Distributions of these subspecies have declined more than 50 percent in response to the same stressors affecting bull trout (Behnke 2002; Shepard et al. 2005). Declines in response to nonnative species can be more severe than in bull trout, probably because cutthroat trout historically used slightly warmer habitats and overlap with more nonnative species. Brook trout have replaced cutthroat trout in many waters in the IAP region (Benjamin and Baxter 2012; Dunham et al. 2002a). These invasions seem to be influenced by the distribution of low-gradient alluvial valleys that may serve as nurseries for brook trout (Benjamin et al. 2007; Wenger et al. 2011a). Introduced rainbow trout have introgressively hybridized with cutthroat trout at lower elevations and in warmer streams (>50 °F) across their historical ranges (McKelvey et al. 2016), although genetically pure populations often persist in cold headwaters where climatic conditions limit the expansion of hybrid zones from downstream areas (Young et al. 2016, 2017).

Cutthroat trout occupy a broader thermal and stream size niche than do bull trout and can persist in small habitat patches for extended periods (Peterson et al. 2013a; Whitely et al. 2010). However, they still require cold-water natal habitat patches exceeding 2 to 6 miles to have a high probability of persistence (Isaak et al. 2015), with the habitat size depending on the prevalence of brook trout, water temperatures, and stream slope. Temperatures at the upstream extent of cutthroat trout populations in extremely cold streams will become more suitable from climate warming, but that trend may be countered by decreasing flows as snowmelt and runoff occur earlier (Chapter 3).

Climate Vulnerability and Adaptive Capacity of Focal Species

Warmer temperatures and declining summer streamflows will have broadly similar effects on aquatic species in the IAP region by reducing habitat volumes in perennial streams, fragmenting large habitat patches into smaller areas of suitable habitats (Isaak et al. 2012a; Rieman and Isaak 2010; Rieman et al. 2007), and shifting thermally suitable habitats upstream (Isaak et al. 2016a). Nonnative trout species more tolerant of warmer temperatures—brook trout, rainbow trout, and brown trout—will expand their distributions upstream and further constrain, replace, or prey on native trout and amphibians in some stream reaches. The relatively warm thermal niches of most nonnative species other than brook trout will restrict them from colonizing the coldest headwater streams, so refugial habitats, mostly at higher elevations, will continue to persist in some mountainous areas for the foreseeable future.

Wildfires may cause more extensive geomorphic disturbances and debris flows into streams, especially the smallest and steepest channels at the upstream extent of the drainage network (Miller et al. 2003; Sedell et al. 2015). Less water, more variable environments, and declining fluvial connectivity (e.g., from water development or interactions with road culverts) may favor resident life histories, as would greater separation between spawning and adult growth habitats. Smaller, more isolated populations will be more susceptible to extirpation from local environmental disturbances and during years of extreme drought and high summer water temperatures.

Species-specific vulnerabilities to these changes depend on the nexus among species ecological attributes, rates at which habitats are changing, and extent of current distributions (table 5.3). Bull trout and some cutthroat trout subspecies (e.g., westslope cutthroat trout, Yellowstone cutthroat trout) are moderately vulnerable because they are widely distributed, have good dispersal abilities, and

Table 5.3—Summary of anticipated vulnerability of selected aquatic species to climate change in the Intermountain Adaptation Partnership (IAP) region.

Species or subspecies	Taxonomy and phylogeography	Range extent[a]	Population trend	Climate vulnerability	Comment
Bull trout	Resolved	Locally common in north and elsewhere	Stable	Moderate	ESA listed[b]
Cutthroat trout subspecies					
Paiute	Resolved	Narrow endemic in west	Stable	High	ESA listed
Yellowstone	Resolved	Widespread in northeast and elsewhere	Stable	Moderate	
Westslope	Resolved	Widespread in north and elsewhere	Stable	Moderate	
Colorado River	Pending	Widespread in east and elsewhere	Stable	Moderate	
Bonneville	Pending	Restricted distribution in east	Stable	Moderate	
Lahontan	Resolved	Restricted distribution in west	Stable	High	ESA listed
Western pearlshell mussel	Resolved	Widespread in north and elsewhere	Unknown	Moderate	
Springsnails	Partially resolved	Widespread	Unknown	High	
Idaho giant salamander	Resolved	Restricted distribution in north and northern Idaho	Unknown	Moderate	
Rocky Mountain tailed frog	Resolved	Restricted distribution in north but more common elsewhere	Unknown	Moderate	
Yosemite toad	Resolved	Restricted distribution in west	Declining	High	Warranted but precluded
Sierra Nevada yellow-legged frog	Resolved	Restricted distribution in west	Increasing	High	ESA listed

[a] Geographic location (north, west, etc.) refers to IAP region only.
[b] ESA refers to U.S. Endangered Species Act.

occupy headwater habitats that are relatively resistant to thermal changes. Other subspecies of cutthroat (Bonneville, Lahontan, and Paiute cutthroat trout) are more vulnerable because distributions are limited to small numbers of isolated stream habitats.

Vulnerability of western pearlshell mussel will track that of their native trout hosts, but summer flow declines may be especially problematic because adult mollusks are immobile. Debris flows triggered by increased wildfire frequency could extirpate local mussel populations, although the species usually inhabits low-gradient stream reaches, where those events are rare (Stagliano 2005). However, fine sediments from debris flows could propagate downstream and smother mussel beds. Rocky Mountain tailed frog and Idaho giant salamanders are poor dispersers occupying headwater habitats and could be vulnerable to debris flows and more frequent disturbances.

Reduced aquifer recharge caused by altered seasonal precipitation and runoff could adversely affect groundwater-dependent and lake ecosystems that support endemic taxa such as springsnails, Yosemite toad, and Sierra Nevada yellow-legged frog (Burns et al. 2017; Hershler et al. 2014; Jyväsjärvi et al. 2015). The extreme endemism of springsnails means that the drying of individual springs could result in extirpation or extinction of a species. Arid land springs, which provide habitat for most springsnail species, are usually isolated, and dispersal of snails may be impossible without assistance by humans or other animal vectors. Recent and abrupt declines in the number and extent of Yosemite toad puts this species at high risk regardless of climate-induced environmental change. Altered aquatic habitat conditions, especially the greater environmental stochasticity that is expected, are predicted to exacerbate existing stressors and further degrade the resilience of remaining populations.

Niche conservatism suggests there is little capacity for rapid evolutionary or physiological adaptations to warmer water temperatures or desiccation within the aquatic species considered here (McCullough et al. 2009; Narum et al. 2013; Wiens et al. 2010). However, species with good dispersal abilities may track shifting habitats or recolonize previously disturbed habitats or those that have been recently restored as long as artificial barriers do not impede their movement (Fausch et al. 2009). Some species exhibit both migratory and resident life history strategies, and the relative frequencies of these strategies may evolve based on how climate change affects metabolic rates, water temperature, stream productivity, and connectivity. Development of disease resistance or other adaptive responses associated with phenology may also bolster population resilience in ways that allow species to persist in dynamic environments (Knapp et al. 2016; Kovach et al. 2012).

Climate Refugia for Native Trout

Trout Distribution Model and Scenarios

Species distribution models for bull trout and cutthroat trout were developed previously in the Coldwater Climate Shield (CS) project by compiling large species occurrence datasets (more than 4,000 sites in over 500 streams) from field biologists, peer-reviewed literature, and State and Federal agency reports (Isaak et al. 2015). The CS models use the high-resolution stream temperature and flow scenarios described earlier with stream slope and the prevalence of brook trout as predictor variables in logistic regression models that predict occurrence probabilities of juvenile bull trout and cutthroat trout in cold-water habitat (CWH) patches (fig. 5.4). Juvenile occurrence is used as an indicator of important natal habitat locations and serves as evidence of locally reproducing populations for salmonid fishes (Dunham et al. 2002b; Rieman and McIntyre 1995). The CS models are also designed to identify CWHs that are too cold (<52 °F mean August temperature) for invasions by most nonnative species other than brook trout and thus should require limited management interventions to support native trout populations.

Previously, Young et al. (2018) applied the CS models to describe bull trout and cutthroat trout distributions and refugia in the Northern Rockies Adaptation Partnership region (Halofsky et al. 2018). Here, we repeat that exercise and summarize CS model predictions for native trout populations across the IAP region. Information for these summaries was downloaded from the CS website (USDA FS https://www.fs.fed.us/rm/boise/AWAE/projects/

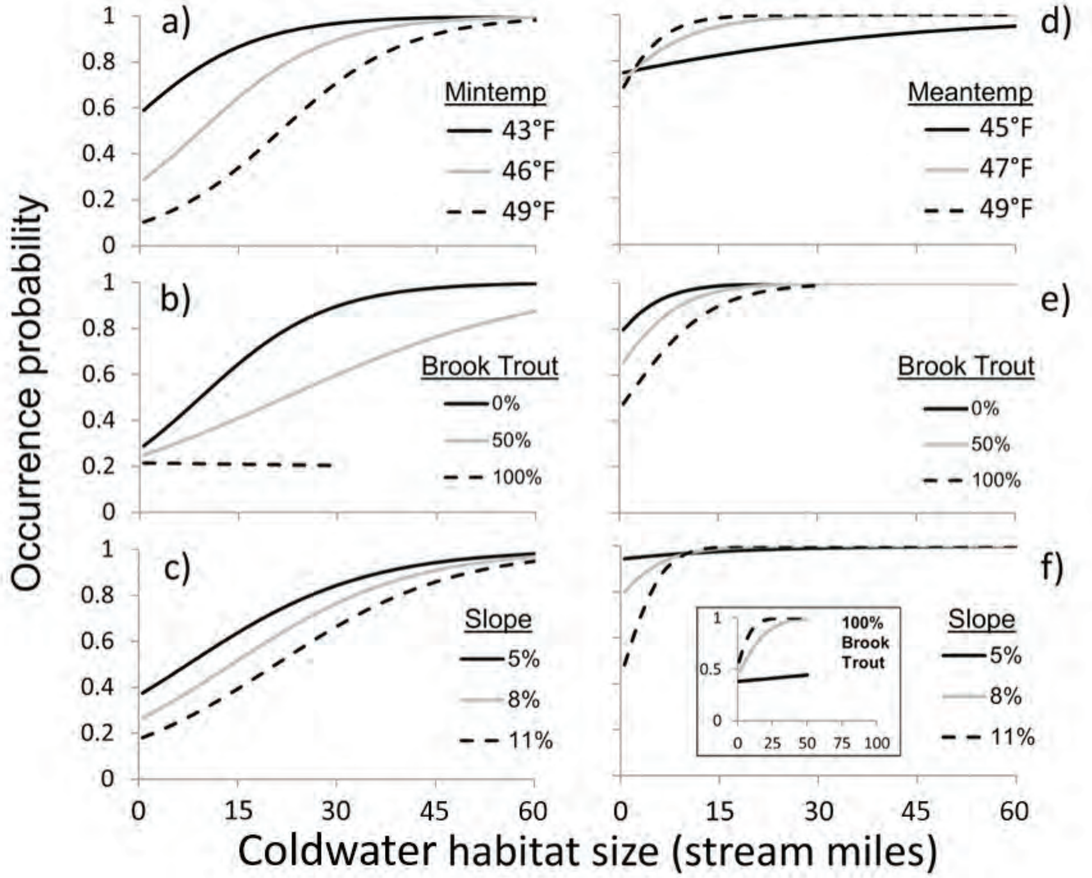

Figure 5.4—Relationships between predictor variables in the Climate Shield models and the probability of occupancy by juvenile native trout for (a–c) 512 bull trout and (d–f) 566 cutthroat trout streams characterized by cold-water habitats less than 52 °F (from Isaak et al. 2015). Relationships shown are conditioned on mean values of the two predictors not shown in a panel. An exception occurs for cutthroat trout with regard to stream slope (panel f), where brook trout values of 0 and 100 percent were used to highlight the interaction between these covariates.

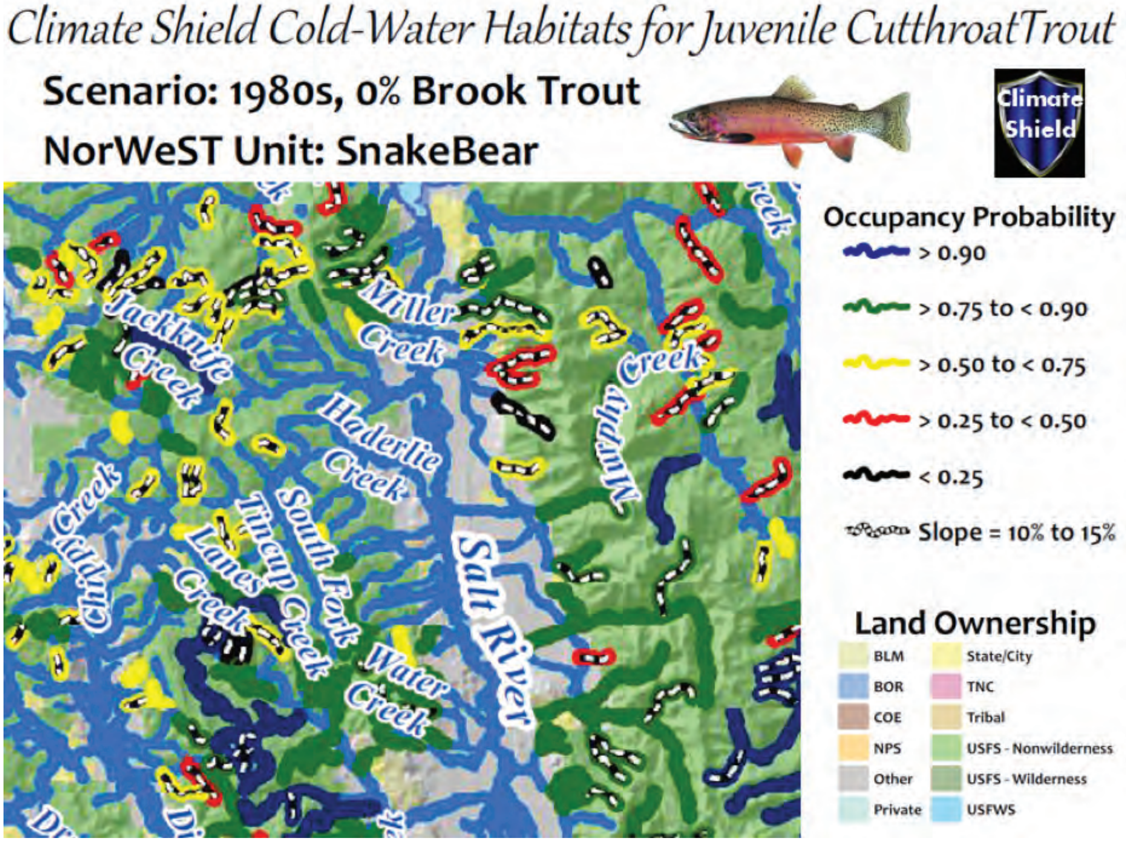

Figure 5.5—Example of a detailed Climate Shield map that shows probabilities of juvenile cutthroat trout occupancy in cold-water stream habitats. Information is available for three climate periods and five brook trout invasion scenarios for bull trout and cutthroat trout streams in the Intermountain Adaptation Partnership region at the Climate Shield website (USDA FS n.d.a).

ClimateShield.html), which also provides extensive metadata descriptions, a user-friendly digital map archive (fig. 5.5), and geospatial databases showing stream-specific model predictions for all streams in the USFS Northern, Rocky Mountain, Intermountain, and Pacific Northwest Regions in the western United States.

Scenarios used to assess native trout distributions were based on the same climate periods (2040s and 2080s) and A1B trajectory already described earlier for the NorWeST stream temperature and VIC scenarios. To account for uncertainties in brook trout distributions across the IAP region, native trout occupancy probabilities were also summarized for a pristine scenario (no brook trout) and a broad invasion scenario that assumed brook trout would be present at half the sites within each CWH (50-percent brook trout). For the IAP region, we did not summarize a scenario in which brook trout were present at all sites because their prevalence rarely exceeded 50 percent in the largest cold-water habitats (>25 miles), which are most likely to serve as strongholds for native trout (see Appendices S2 and S3 in Isaak et al. 2015), and because not all stream locations are suitable for brook trout (Isaak et al. 2017b; Wenger et al. 2011a). Brook trout prevalence may reach 100 percent in small, low-gradient streams, so native trout probabilities for a full range of invasion scenarios (0-, 25-, 50-, 75-, and 100-percent brook trout prevalence) have been calculated and integrated into the CS geospatial databases to facilitate stream-specific assessments (if local information is available on brook trout prevalence).

Cutthroat Trout Status and Projected Trends

Invasion-resistant streams with mean August temperatures less than 52 °F encompassed 15,000 miles of the 56,000-mile network draining the IAP region during the baseline period; 94 percent of those cold streams are on national forests (table 5.2). The number of discrete CWHs that were potentially occupied by juvenile cutthroat trout during the baseline period was estimated to be 2,600 and encompassed nearly 13,000 stream miles across all subspecies (table 5.4, fig. 5.6). Three subspecies—Lahontan cutthroat trout, Bonneville cutthroat trout, and Paiute cutthroat trout—had restricted ranges and are summarized separately (table 5.5). Bonneville and Lahontan cutthroat had about 620 miles of CWHs during the baseline period, whereas habitat for the Paiute cutthroat trout was less than 12 miles because it occurred in only a few streams.

Across all cutthroat trout subspecies, 89 percent of CWHs were predicted to have probabilities of occupancy exceeding 50 percent in the current period if brook trout

Table 5.4—Number and length of cold-water habitats for all subspecies of juvenile cutthroat trout by probability of occurrence for three climate periods and two brook trout invasion scenarios in the Intermountain Adaptation Partnership region.

		Probability of occurrence (percent)					Total cold-water habitats
	Period	**<25**	**25–50**	**50–75**	**75–90**	**>90**	
Cold-water habitat number				*Number*			
0% brook trout prevalence	2000s	73	206	540	872	909	2,600
	2040s	49	170	544	791	680	2,234
	2080s	66	252	479	572	476	1,845
50% brook trout prevalence	2000s	80	261	1,296	736	227	2,600
	2040s	50	193	1,152	606	233	2,234
	2080s	66	260	975	440	104	1,845
Cold-water habitat length				*Miles*			
0% brook trout prevalence	2000s	215	388	1,272	2,322	8,794	12,776
	2040s	68	288	951	1,858	5,871	9,036
	2080s	93	398	931	1,402	3,665	6,489
50% brook trout prevalence	2000s	578	864	2,894	4,447	4,208	12,991
	2040s	140	386	2,202	3,047	3,260	9,035
	2080s	93	454	2,008	2,290	1,643	6,488

were absent (table 5.4), largely because of the relatively small stream networks that a cutthroat trout population requires for persistence (e.g., 6 miles is associated with a 90-percent probability of occupancy) (fig. 5.4). Nonetheless, the largest CWHs accounted for a disproportionate amount of the habitat most likely to be occupied; 35 percent of CWHs had probabilities greater than 90 percent, but these accounted for 68 percent of the length of CWHs. As expected, the number and extent of CWHs were predicted to decrease substantially (14–50 percent) in future periods, but 1,845 potential habitats encompassing almost 6,500 miles were projected to remain in the extreme 2080 scenario.

Where headwater stream reaches are currently too cold for cutthroat trout, future warming may increase habitat suitability and the probability of occupancy in portions of the Uinta Mountains and other cold streams draining the upper Green, Salmon, and Snake Rivers. As expected, the brook trout invasion scenario did not affect the number or amount of CWHs because the habitats remained potentially suitable for cutthroat trout, but occupancy probabilities declined (table 5.4). The sensitivity of streams to brook trout invasions varies with local conditions, but impacts were most pronounced in small CWHs with low slopes (fig. 5.4).

Bull Trout Status and Projected Trends

The historical range of bull trout occupies a smaller portion of the IAP region than cutthroat trout, so the number of discrete CWHs for bull trout during the baseline climate period was estimated to be 984, encompassing 7,700 miles (table 5.6, fig. 5.7). In contrast to cutthroat trout, most CWHs for bull trout had probabilities of occupancy less than 50 percent because of the relatively large stream networks that bull trout require (30 miles is associated with a 90-percent probability of occupancy) (fig. 5.4). Although only 8 percent of CWHs had probabilities greater than 90 percent, they provided 36 percent of the total length of CWH, emphasizing the contribution of large CWHs to the amount of habitat predicted to be occupied. The requirement for larger CWHs caused projected decreases in the number (9–28 percent) and network extent (35–57 percent) of bull trout CWHs to be more substantial than those for cutthroat trout, particularly for the CWHs with the highest probabilities of occupancy. However, more than 700 CWHs representing 3,330 miles were projected to remain even in the extreme 2080 scenario.

Similar to the effect on cutthroat trout, the brook trout invasion scenario showed reduced bull trout occupancy rates (especially in CWHs with greater than 50-probability of occupancy), and as few as three to four CWHs with probabilities greater than 90 percent remained under the extreme warming scenario with a ubiquitous brook trout presence. However, many of the large bull trout habitats are less susceptible to broad-scale brook trout invasions given the preference by the latter species for small low-gradient streams (Dunham et al. 2002a; Isaak et al. 2015). Not surprisingly, CWHs with the highest bull trout occupancy probabilities in all scenarios coincided with river networks containing the largest number of cold streams (headwater portions of the Boise, Middle Fork Salmon, and Upper Salmon Rivers) (fig. 5.7).

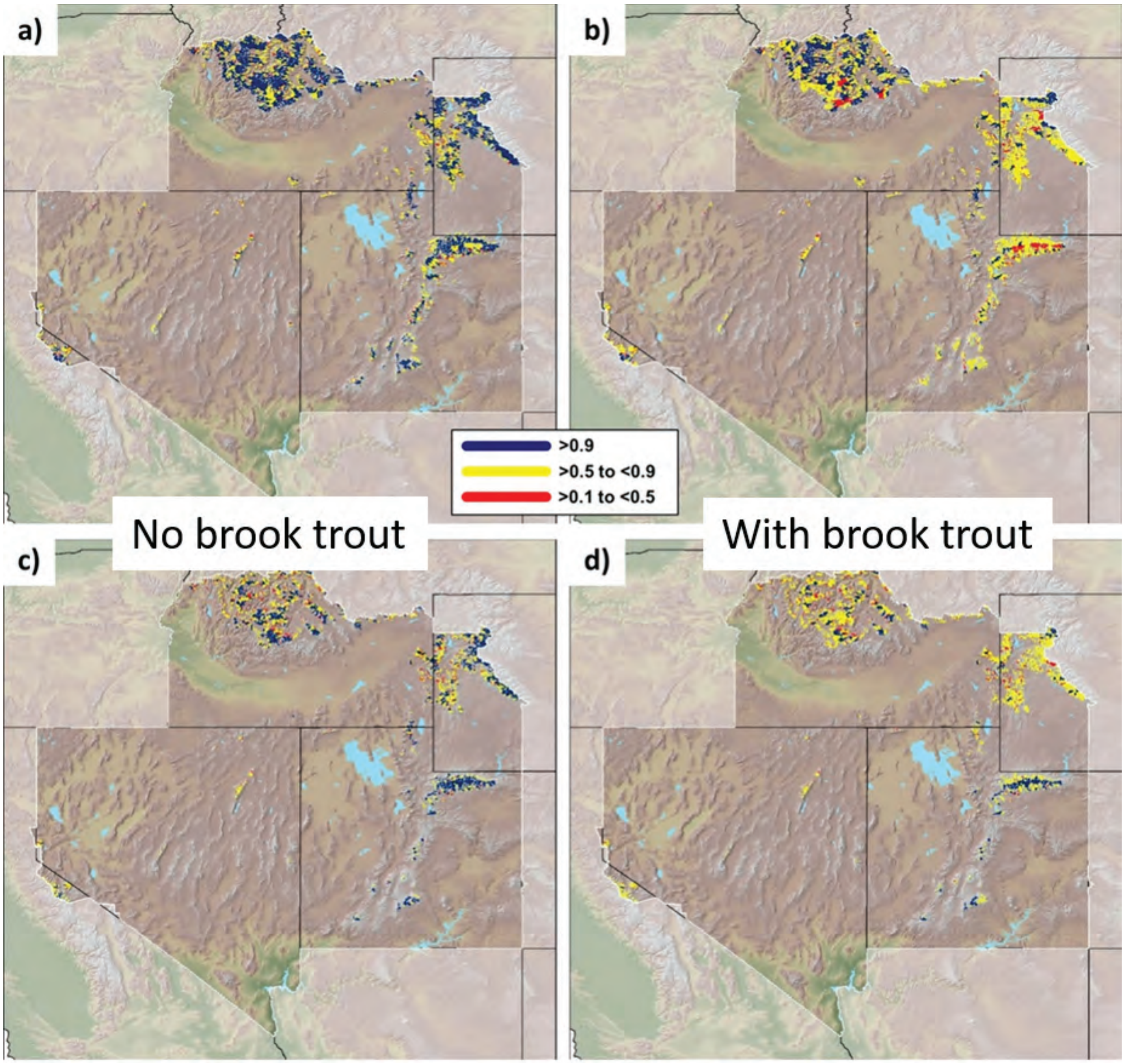

Figure 5.6—Distribution of cold-water habitats with probabilities of occupancy greater than 0.1 for juvenile cutthroat trout for (a–b) the baseline period (2000s) and (c–d) late-century scenario (2080s). Panels a and c illustrate occupancy when brook trout are absent; panels b and d illustrate occupancy when brook trout prevalence is 50 percent.

Conclusions and Implications

A changing climate has significant implications for distributions of aquatic habitats and species dependent on them in the IAP region. Vulnerability to habitat shifts or losses this century may be high, especially for taxa that have either restricted habitats or limited dispersal abilities. Yet the symptoms of rapid climate change have been manifest throughout the western United States for several decades (Barnett et al. 2008; Hamlet and Lettenmaier 2007; Luce and Holden 2009; Mote et al. 2005) without widespread losses of aquatic populations or species. Three factors help explain this apparent paradox. First, the steep topography in parts of the IAP region translates to slow climate velocities, which may enable species to track gradual shifts in their habitats (Isaak et al. 2016a). Second, the thermal and hydrological changes that have accumulated to date are relatively small compared to changes expected throughout the remainder of the 21st century (Chapter 3). Third, existing monitoring programs and analyses of available datasets may be inadequate for detecting the subtle distribution shifts or extirpation of small populations that are expected with climate change (Isaak and Rieman 2013).

In one of the few attempts to rigorously measure how distributions of stream organisms are responding to climate change, site revisits over a 20-year period revealed that juvenile bull trout distributions were contracting upstream within the Bitterroot River basin of Montana (Eby et al. 2014). In a larger study across western Montana, long-term monitoring indicated that brown trout populations were increasing in abundance and gradually expanding into streams

Table 5.5—Number and length of cold-water habitats for three cutthroat trout subspecies by probability of occurrence for three climate periods, assuming the absence of brook trout. Reduced occurrence probabilities associated with brook trout invasions would be similar to declines described in table 5.4.

		Probability of occurrence (percent)					Total cold-water habitats
Cutthroat trout subspecies	**Period**	**<25**	**25–50**	**50–75**	**75–90**	**>90**	
Bonneville		*Number*					
Cold-water habitat number	2000s	1	24	70	90	96	281
	2040s	0	12	34	62	54	162
	2080s	0	8	23	22	44	97
		Miles					
Cold-water habitat length	2000s	0	33	100	176	530	839
	2040s	0	12	39	124	310	485
	2080s	0	9	26	48	228	311
Lahontan		*Number*					
Cold-water habitat number	2000s	3	25	39	63	29	159
	2040s	2	16	40	50	25	133
	2080s	1	10	40	31	11	93
		Miles					
Cold-water habitat length	2000s	5	48	86	175	227	541
	2040s	3	31	78	137	150	399
	2080s	2	17	85	93	58	255
Paiute		*Number*					
Cold-water habitat number	2000s	0	0	0	1	2	3
	2040s	1	0	1	3	0	5
	2080s	1	0	0	2	0	3
		Miles					
Cold-water habitat length	2000s	0	0	0	4	8	12
	2040s	1	0	1	6	0	7
	2080s	1	0	0	5	0	6

that were previously too cold (Al-Chokhachy et al. 2016b). Similar monitoring efforts and site resurveys are needed at broad scales for many species to document the effects of climate change on aquatic life and to provide the basis for strategic planning and proactive conservation actions (Comte and Grenouillet 2013; Craine et al. 2007).

The first step in promulgating an informative aquatic biodiversity census is the aggregation and organization of historical datasets into functional databases, allowing species occurrence information to be linked with environmental covariates, then modeled and analyzed for trends. Development of the CS models involved organizing a small fraction of existing datasets for trout species (Isaak et al. 2015), but even this initial effort yielded significant improvements in the ability to predict where trout populations are most likely to persist, has assisted monitoring efforts, and is setting the stage for developing more precise models in the near future. For example, the spatially explicit CS model predictions are being used to guide an interagency crowd-sourcing campaign to collect environmental DNA (eDNA) samples from 7,000 locations throughout the native range of bull trout, which includes the northern portion of the IAP region (Young et al. 2017). Those samples will be paired with new spatial stream-network models (Isaak et al. 2014; Ver Hoef et al. 2006) to model bull trout occurrence at high resolution (<1 mile) across broad areas to provide accurate predictions of distribution and abundance and a better understanding of environmental constraints. This new generation of eDNA samples could be compared to historical occurrence datasets to provide broad-scale climate trend assessments. The bull trout eDNA samples also contain the DNA of many

Table 5.6—Number and length of cold-water habitats for juvenile bull trout by probability of occurrence for three climate periods and two brook trout invasion scenarios in the Intermountain Adaptation Partnership region.

		Probability of occurrence (percent)					
	Period	<25	25–50	50–75	75–90	>90	Total
Cold-water habitat number		*Number*					
0% brook trout prevalence	2000s	406	289	141	70	78	984
	2040s	538	216	90	31	23	898
	2080s	387	215	76	22	12	712
50% brook trout prevalence	2000s	474	301	132	52	25	984
	2040s	608	211	56	19	4	898
	2080s	456	197	43	13	3	712
Cold-water habitat length		*Miles*					
0% brook trout prevalence	2000s	1,158	1,480	1,245	1,003	2,806	7,692
	2040s	1,630	1,232	874	464	766	4,967
	2080s	1,059	999	645	289	344	3,336
50% brook trout prevalence	2000s	1,452	1,950	1,651	1,097	1,542	7,692
	2040s	1,994	1,531	723	529	190	4,967
	2080s	1,337	1,180	463	216	140	3,336

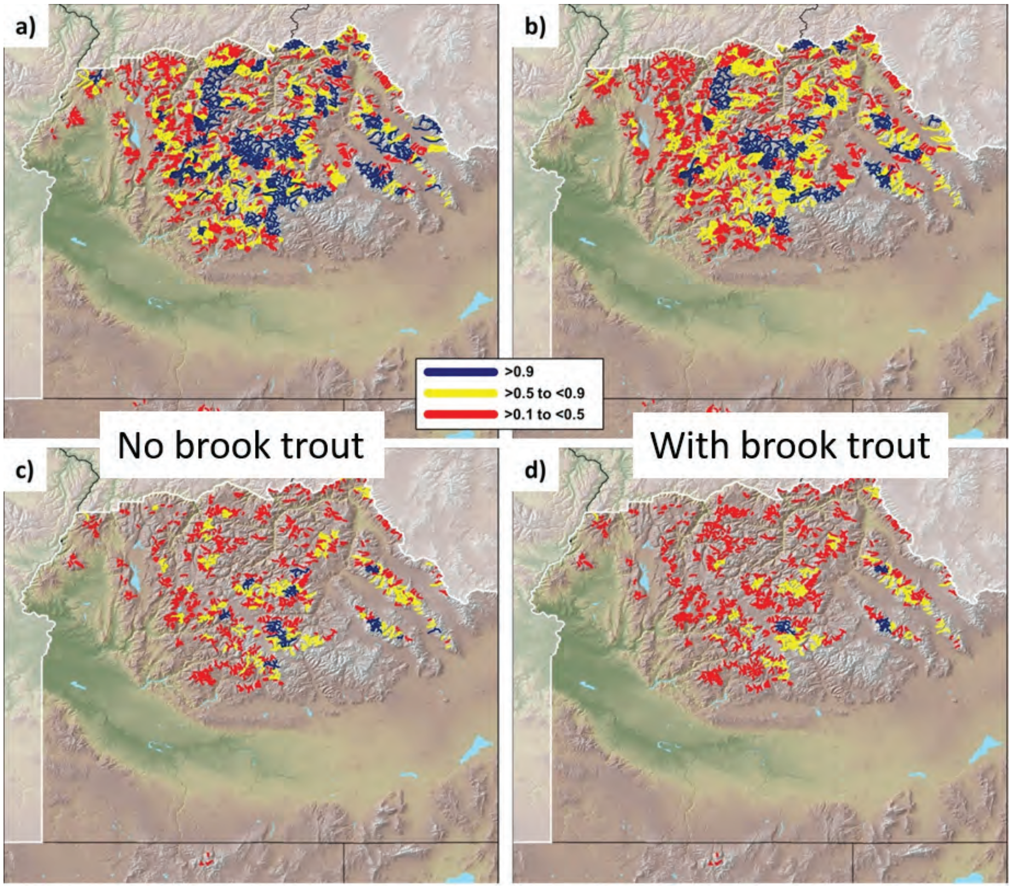

Figure 5.7—Distribution of cold-water habitats with probabilities of occupancy greater than 0.1 for juvenile bull trout for (a–b) the baseline period (2000s) and (c–d) late-century scenario (2080s). Panels a and c illustrate occupancy when brook trout are absent; panels b and d illustrate occupancy when brook trout prevalence is 50 percent.

other aquatic taxa, so will help establish baseline conditions for many species that lack data. Moreover, thousands of additional eDNA samples are now being collected annually across the western United States through partnerships with the National Genomics Center for Wildlife and Fish Conservation (http://www.fs.fed.us/research/genomics-center), so a taxonomically diverse and geographically comprehensive monitoring system for aquatic species is emerging.

For native bull trout and cutthroat trout, the CS models provided accurate, spatially explicit predictions of habitat occupancy throughout the IAP region with respect to current conditions. Assuming that species responses are related to the effects of climate on stream ecosystems—and the accuracy of the models supports this contention—the models also provide reasonably robust projections of habitat occupancy in light of anticipated climate change. Although both native trout species are regarded as coldwater taxa, their exact responses to a changing climate are expected to differ. Bull trout, and most members of the genus *Salvelinus*, are adapted to some of the coldest freshwater environments in the Northern Hemisphere (Klemetsen et al. 2003). These species also tend to inhabit highly variable environments, often with strong gradients in productivity that appear to favor migration as a life history tactic (Klemetsen 2010). It is unsurprising, therefore, that a species with those attributes near the southern end of its distribution would be susceptible to range contractions as temperatures warm. In the IAP region, we anticipate declines in bull trout distributions, but the species is unlikely to be extirpated from the region because many climate refuge habitats will persist. As climate change proceeds this century, it is possible that conditions favoring migratory or resident life histories will change, although it is unclear how these conditions would be accommodated or exploited by bull trout. As we learn more about the extent and prevalence of populations occupying CWHs with varying probabilities of occupancy, an understanding of the environmental drivers of bull trout life history may emerge.

Cutthroat trout, in contrast, can accommodate a wider range of thermal environments, consistent with their broad latitudinal distribution and an evolutionary history. Since the late Miocene or early Pliocene, this species was exposed to intervals cycling between warm/dry and cool/moist periods in western North America (McPhail and Lindsey 1986; Minckley et al. 1986). Cutthroat trout are relatively plastic with respect to life history strategies, ranging from highly migratory populations dependent on large rivers or lakes to promote growth and fecundity, to resident populations that move little and have been isolated for decades to centuries (Northcote 1992; Peterson et al. 2013b). Although we anticipate net losses in cutthroat distribution in the IAP region, they are not expected to be as severe as for bull trout, and some basins that are currently too cold to support cutthroat trout may become high-quality climate refugia in the future (Al-Chokhachy et al. 2013; Coleman and Fausch 2007; Cooney et al. 2005). Of greater importance may be how nonnative salmonids, which often displace or replace cutthroat trout, respond to warming conditions (Wenger et al. 2011a). These factors do not represent similar risks to the six cutthroat trout subspecies, primarily because of the large differences in quality and quantity of habitats currently occupied. For example, Yellowstone and westslope cutthroat trout are widely distributed, occupy many streams throughout their ranges, and exhibit a broad array of life histories. However, remaining subspecies often persist in small, isolated headwater habitats that may be especially vulnerable to brook trout invasions (Benjamin and Baxter 2012; Dunham et al. 2002a).

The presence of brook trout is problematic for both bull trout and cutthroat trout. The tolerance of brook trout to cold temperature is nearly equivalent to that of cutthroat trout, and brook trout favor the low-gradient environments preferred by cutthroat trout and bull trout (Wenger et al. 2011a). However, very large habitats appear less likely to be invaded by brook trout, possibly because this species prefers small streams but also because large systems usually contain other salmonid species, such as rainbow trout or brown trout, that compete with brook trout (Fausch et al. 2009). Rainbow trout and brown trout are expected to shift their distribution upstream as temperature isotherms optimal for these species move in that direction (Isaak and Rieman 2013; Wenger et al. 2011b), but may be constrained by unsuitable stream steepness because these species are rare where slopes exceed 4 percent (Isaak et al. 2017b). Where overlap occurs, both species appear to have negative effects on cutthroat trout, but cold, steep headwater streams that resist their invasions are expected to remain widespread.

Most current and future CWHs occur on public lands, mostly national forests, emphasizing the critical role of the USFS in conservation of native fish. Exploring an array of conservation strategies will be important because most of the CWHs are outside designated wilderness areas or national parks so are subject to various land management activities. Conservation options will vary by location because current and future CWHs are expected to be more abundant and persistent in some river basins than others across the IAP region. Where CWHs are abundant, maintaining those conditions and avoiding significant new impairments may be all that is necessary to ensure the persistence of native fish populations. In contrast, very few habitats that function as climate refugia may occur in other basins or where current habitats for some species or subspecies are very limited. Those circumstances favor strategic, active management to promote population persistence, whether by manipulating habitat or fish populations, or both. And because many CWHs are in landscapes that have multiple resource values, balancing among competing interests will remain an underlying theme of public land management (Rieman et al. 2010). Retaining native populations of aquatic organisms in many of these areas may require conservation investments that are unsustainable or could prove ineffective if climate warming accelerates appreciably this century. In these circumstances, reallocating investment resources to areas where native populations are more likely to persist may be preferable.

Climate Adaptation Options

Many things can be done to adapt to climate change and improve the resilience of aquatic species in the IAP region (Chapter 14). Climate change adaptation options for aquatic species have been the subject of a number of comprehensive reviews for the IAP region (Rieman and Isaak 2010) and the Pacific Northwest (Beechie et al. 2013; Isaak et al. 2012a; ISAB 2007; Luce et al. 2012; Williams et al. 2007, 2015; Young et al., in press b). Several key themes emerge from these reviews: (1) be strategic; (2) implement monitoring programs; (3) restore and protect natural flow, sediment, and temperature regimes; (4) manage fluvial connectivity; (5) remove or suppress nonnative species, and (6) consider assisted migration.

Be strategic—Prioritize watershed restoration such that the most important work is done in the most important places because the funds, labor, and time available for management of native fish populations are limited (Peterson et al. 2013a). Efforts are directed at only a few of the locations and problems that could be addressed. For example, climate refugia for native trout that are in wilderness areas may neither require nor be amenable to habitat modification to ensure the persistence of those populations. Similar refugia outside protected areas could be targeted to improve habitat conditions or remove or reduce nonnative species presence, particularly if doing so increases the probability of occupancy of such habitats by native species.

Implement monitoring programs—Being strategic means reducing current and future uncertainties for decisionmaking. More data are needed for streamflow (more sites), stream temperature (annual data from sensors maintained over many years), and species distributions. These data could be used for better status and trend descriptions, and to develop robust (or more accurate) models for species to understand their response to climate change, natural variation, and land management. The feasibility of monitoring at small to broad scales is increasing with the advent of rapid, reliable eDNA inventories of aquatic organisms (McKelvey et al. 2016; Thomsen et al. 2012) and the availability of inexpensive, reliable temperature and flow sensors (USEPA 2014).

Restore and maintain natural flow, sediment, and thermal regimes—Persistence of native species can be enhanced using a variety of habitat techniques to improve stream shade, narrow unnaturally widened channels, minimize flow diversions, and improve stream substrate conditions. Actions may include decommissioning or relocating roads away from streams (Al-Chokhachy et al. 2016a; Zurstadt 2015), limiting seasonal grazing in some areas, and managing streamside riparian forest buffer zones to maintain effective shade and cool, moist riparian microclimates (Nusslé et al. 2015). Tactics may also involve directly managing water, such as increasing water storage in headwater reservoirs, restoring populations of American beaver (*Castor canadensis*) (Bouwes et al. 2016; Pollock et al. 2014), or acquiring water rights to maintain or enhance summer streamflows (Elmore et al. 2015). Such actions obviously have implications and consequences far beyond enhancing the persistence of native fish populations, but being open to opportunities is part of strategic thinking.

Manage connectivity—Obstacles to fish migration may be removed in hopes of enhancing the success of migratory life history forms, or permitting native species to reoccupy former habitat or supplement existing populations. This also presents a dilemma: Accessible waters can be invaded by nonnative species that sometimes replace native species (Fausch et al. 2009). The alternative is the installation of barriers to prevent these invasions. Native populations above barriers may be secure if they can adopt resident life histories, but could be susceptible to loss from catastrophic events in small habitats and will require human intervention for refounding or supplementation. Barriers are also temporary, and eventually will require reconstruction if nonnative species still remain downstream. Barriers may also be associated with small headwater diversion structures that sometimes route fish out of streams, where they are susceptible to stranding when water ditches are seasonally dewatered (Roberts and Rahel 2008; Walters et al. 2013). Headwater diversions are numerous and may be difficult to locate, so tools for locating them may be useful. For example, the Trout Unlimited Water Transaction Tool (McFall 2017) shows the locations of all diversion points in the Idaho Department of Water Resources database relative to the CS native trout refuge streams within Idaho. The tool enables users to identify and visit points of diversions in critical trout habitats to determine their potential impact to fish populations and design mitigation strategies.

Remove nonnative species—Removal of nonnative fish species will be essential to maintain or restore some populations. These efforts typically consist of chemical treatments or electrofishing, and both tend to be feasible only in smaller, simpler habitats (Shepard et al. 2002). Both are also costly, in part because they need to be conducted on multiple occasions to be effective (Peterson et al. 2008). Chemical treatments are controversial because of their perceived effects on water quality. Furthermore, success with either method is obtained only if the source of nonnative species is removed, often by the installation of a migration barrier. Unauthorized introductions are also common, and can undermine conservation efforts. Finally, using control measures to manage the abundance of nonnative species rather than removing them has been applied in some areas (e.g., the removal of lake trout to promote bull trout persistence or regular electrofishing to depress brook trout and favor cutthroat trout). Such activities are likely to be successful only if conducted at regular intervals for the foreseeable future, which assumes funding and enthusiasm for such ventures will be available indefinitely.

Consider assisted migration—Moving native fish species from one location to another, a historically common activity in fish management, has typically been used to found populations in previously fishless waters. This tactic may be further pursued in the IAP region where a few basins are currently fishless (or have only limited populations of nonnative species) because of natural barriers such as waterfalls, and may create high-quality climate refugia in the near future. Moving native fish to such areas is feasible but controversial because other at-risk native taxa may be vulnerable to predation or competition with native fish species. Reintroductions of native species (Dunham et al. 2011, 2016) may also be performed when natural refounding is not an option, such as where populations are isolated and periodically fail, or suffer population bottlenecks. Management intervention at this level will require an understanding of genetic principles and broodstock establishment.

In conclusion, responding to the environmental trends associated with climate change will require a diverse portfolio that includes many of the actions described earlier. We need to adapt our mindsets and administrative processes to a new paradigm of dynamic disequilibrium. Under this paradigm, stream habitats will become more variable, undergo gradual shifts through time, and sometimes decline. Many populations are resilient enough to persist in, or track, suitable habitats, but others could be overwhelmed by future changes. It is unlikely that we will be able to preserve all populations of aquatic species as they currently exist this century. But as better information continues to be developed in the future, managers will have ever more precise tools at their disposal to know when and where resource commitments are best made to enhance the resilience of existing populations or to benefit other species for which management was previously not a priority. There is much to do as climate change adaptation continues in future years (Chapter 14), and USFS lands will play an increasingly important role in providing refuge habitats for aquatic biodiversity.

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Chapter 6: Effects of Climate Change on Forest Vegetation

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Introduction

Projected rapid changes in climate will affect vegetation assemblages in the Intermountain Adaptation Partnership (IAP) region directly and indirectly. Direct effects include altered vegetation growth, mortality, and regeneration, and indirect effects include changes in disturbance regimes (Chapter 8) and interactions with altered ecosystem processes (e.g., hydrology, snow dynamics, nonnative species) (Bonan 2008; Hansen and Phillips 2015; Hansen et al. 2001, 2016; Notaro et al. 2007). Some species may have decreased abundance, whereas others may expand their range (Landhäusser et al. 2010). New vegetation communities may form, and historical vegetation complexes may shift to other areas of the landscape or become rare. The consequences of land management policies and activities, including fire exclusion, fuels treatments, and grazing, interact with potential climate change effects.

Here we assess the effects of climate change on vegetation in the IAP region, based on species autecology, disturbance regimes, current conditions, and modeling results (table 6.1). We summarize how climate change affects vulnerability of important tree species, vegetation types, and resources of concern (box 6.1). We have integrated modeling results with a detailed synthesis of climate change literature for western North America.

This assessment is focused on vegetation types listed in table 6.1, where the vulnerability of each vegetation type is inferred from the aggregate vulnerability of its dominant species (table 6.2). Vulnerability is also considered with respect to heterogeneous landscapes, including both vegetation disturbance and land use history.

All projections of future conditions contain uncertainty (box 6.2). Uncertainty can result from a lack of information or from a disagreement about what is known or predictable. Uncertainty can also result from known and unknown errors. It may have many sources, including quantifiable errors in data, ambiguously defined concepts or terminology, and uncertain projections of human behavior. Uncertainty can be represented by quantitative measures (e.g., a range of values) or by qualitative statements (e.g., judgment of a team of experts).

Climate Change Assessment Techniques

Ecologists have invested considerable effort to project the effects of climate change on ecosystem processes across various scales (Clark et al. 2001; Joyce et al. 2014; Schumacher et al. 2006). Using traditional field methods to explore climate change response is difficult because of the complex interactions between ecological processes, disturbance, and climate at multiple temporal and spatial scales (McKenzie et al. 2014).

Four techniques exist to assess and project the effects of climate change on vegetation and related resource concerns. First, **expert opinion** involves experts in the fields of climate change, ecology, and vegetation dynamics qualitatively assessing what will happen to vegetation under various climate change scenarios. Second, **field assessment** involves monitoring or remote sensing to monitor vegetation change as the climate warms. Field sampling involves establishing plots across the landscape, detecting change between plot measurements, and correlating these changes to climate data. Demographic studies track individuals over time, rather than using plot-scale inventories, to understand the role of climate relative to other factors. The U.S. Department of Agriculture Forest Service (USFS) Forest Inventory and Analysis database, the only demographic dataset in the IAP region, has not been analyzed for the interaction of vegetation and climate. Although field assessment techniques are the most reliable and useful, they are often intractable because of the large areas and long time periods for which sampling is needed to detect changes.

Third, **statistical analysis can be used to create empirical models** that project climate change response. Many studies that project habitat, range, or occupational shifts of tree species from climate warming use species distribution models (SDMs; also called bioclimatic envelope models or niche models) to project future geographic ranges (Hansen and Phillips 2015; Iverson and Prasad 2002; Warwell et al. 2007). However, SDMs are inherently flawed for projecting future species distributions because they rely on recent or historical climate-species relationships, resulting in predictions of potential species habitat, not actual species distribution (Iverson and McKenzie 2013). One of the biggest limitations of this approach is that most species distributions are not in equilibrium with climate, thereby causing SDMs to miss areas favorable for a species but where the species is currently absent. In addition, SDMs do not include critical ecological processes (e.g., reproduction,

Table 6.1—Vegetation types included in the IAP vulnerability assessment.

Vegetation type[a]	Description
Subalpine pine forest	Forest communities dominated or co-dominated by bristlecone, limber, and/or whitebark pine for long periods of time. Other co-dominant trees may include subalpine fir, Engelmann spruce, white fir, and aspen.
Subalpine spruce-fir forest	Upland forest communities in which the most shade-tolerant tree capable of occupying the site is subalpine fir, Engelmann spruce, and/or blue spruce. Major seral species include lodgepole pine, aspen, and Douglas-fir.
Mesic mixed conifer forest	Upland forest communities where the most shade-tolerant tree capable of occupying the site is grand fir, white fir, Shasta red fir, mountain hemlock, or Sierra lodgepole pine. Major seral species include lodgepole pine, Douglas-fir, ponderosa pine, Jeffery pine, and aspen.
Dry mixed conifer forest	Upland, lower montane, forest communities where the most shade-tolerant tree capable of occupying the site is Douglas-fir, white fir, or limber pine; and woodland species such as curl-leaf mountain mahogany, Gambel oak, bigtooth maple, pinyons, and junipers are usually present. Ponderosa pine is a major seral species. Lodgepole pine is absent. Aspen is sometimes an important seral species.
Aspen-mixed conifer forest	Upland forest communities where the most shade-tolerant tree capable of occupying the site is a conifer species but aspen is (or was) an important component due to periodic disturbances. Following a disturbance, conifers can return to dominance in less than 150 years.
Persistent aspen forest	Upland forest communities dominated by aspen in which succession to conifer dominance is not possible or takes longer than 150 years.
Ponderosa pine forest	Upland forest communities where ponderosa pine is the only forest tree species capable of occupying the site, or where natural under-burning periodically eliminates other conifers and maintains ponderosa pine dominance.
Riparian forest	Forest communities occurring adjacent to water bodies or around seeps and springs. They may be dominated by any of the species listed above in addition to cottonwoods, willows, alders, birch, or nonnative trees such as saltcedar and Russian olive.

[a] Vegetation types are those used by the U.S. Forest Service Intermountain Region.

tree growth, competitive interactions, disturbance) (Iverson and McKenzie 2013; Watling et al. 2012).

Finally, the most effective technique uses **modeling to assess climate-mediated vegetation responses** (Gustafson 2013; Iverson and McKenzie 2013; McKenzie et al. 2014), incorporating projected future climate into ecological models to simulate climate change effects (Baker 1989; He et al. 2008; Keane et al. 2004; Merriam et al. 1992; Perry and Millington 2008). Many existing models simulate ecological change at broad (global, regional) and fine (point, ecosystem, stand) scales (Bugmann 2001; Cramer et al. 2001). However, models focused on large spatial scales (50–500 square miles) are best suited for projecting climate change effects because most ecosystem processes operate and most management decisions are made at large scales (Cushman et al. 2007; Littell et al. 2011; McKenzie et al. 2014).

To realistically model species composition changes, a mechanistic, process-driven simulation approach is needed to emphasize physical drivers of vegetation dynamics that are directly related to climate (Falk et al. 2007; Gustafson 2013; McKenzie et al. 2014). However, mechanistic model design is complex, containing detailed parameterization of species life histories and physiologies, interacting disturbance factors, and high-resolution modeling over large areas (Lawler et al. 2006). Dynamic global vegetation models operate at scales from regional (hundreds of miles) to global (degrees of latitude and longitude), projecting aggregates of species as life forms or plant functional types, which may not be directly relevant for resource managers (Bachelet et al. 2003; Bonan 2008; Neilson et al. 2005). Most of these models project shifts to more drought-tolerant and disturbance-tolerant species in a warmer climate. In some models, increased water-use efficiency in trees, induced by elevated carbon dioxide (carbon dioxide fertilization), may offset this general shift in vegetation as forests expand into areas where the climate is currently too dry (Bachelet et al. 2003).

Ecosystem models that accurately project climate change effects must simulate disturbances, vegetation, climate, and their interactions across multiple spatial scales (Purves and Pacala 2008), but few models simulate ecosystem processes with the mechanistic detail needed to realistically represent important interactions (Keane et al. 2015b; Riggs et al. 2015) (table 6.2). For example, direct interactions between climate and vegetation may be more realistically represented by simulating the daily dynamics of carbon (photosynthesis, respiration), water (evapotranspiration), and nutrients at the plant level than by simulating vegetation development

Box 6.1—Summary of the Primary Effects of Climate Change on Vegetation Types in the IAP Region

Syntheses of autecological information, empirical data, and modeling were used to identify expected responses of forest vegetation in the IAP region through the end of the 21st century, summarized here for vegetation types (table 6.1)

Subalpine Pine Forest

Highly vulnerable

- Whitebark pine will be especially vulnerable, because warming is expected to exacerbate existing stressors (white pine blister rust, mountain pine beetle, fire exclusion).
- Limber pine, Engelmann spruce, and white fir may grow faster with less snowpack (longer growing season), although limber pine could be stressed by more bark beetles.
- Great Basin and Rocky Mountain bristlecone pines growth may decrease but with high variability among locations.
- Quaking aspen will be minimally affected by a warmer climate, especially compared to aspen at lower elevations.

Subalpine Spruce-Fir Forest

Moderately vulnerable

- Subalpine fir, Engelmann spruce, and blue spruce may grow faster in the upper subalpine zone because of less snowpack (longer growing season).
- Lodgepole pine will be more susceptible to mountain pine beetle.
- Quaking aspen will be minimally affected by a warmer climate, especially compared to aspen at lower elevations.
- Douglas-fir could increase at the lower end of the subalpine zone.
- Increased wildfire could reduce the distribution of all subalpine species except aspen.

Mesic Mixed Conifer Forest

Moderately vulnerable; some winners, some losers

- Douglas-fir, ponderosa pine, and Jeffrey pine (early seral, fire tolerant) may become relatively more common than other (late seral) species that are less fire tolerant, but they will probably grow slower.
- Shasta red fir will grow slower, and distribution may decrease because of increased wildfire.
- Lodgepole pine and quaking aspen, which regenerate rapidly after wildfire, will persist across the landscape, possibly with increased stress from insects and pathogens.

Dry Mixed Conifer Forest

Moderately vulnerable; some winners, some losers

- Curl-leaf mountain-mahogany, Gambel oak, and bigtooth maple can cope with both drier soils (drought tolerant) and increased wildfire (vigorous sprouting), and they may become more abundant in some locations.
- Two-needle pinyon and singleleaf pinyon are sensitive to long periods of drought combined with insects, and they may have reduced growth and some mortality; frequent wildfire may reduce abundance.
- Limber pine may be challenged by a combination of mountain pine beetles, white pine blister rust, and increasing wildfire.
- Douglas-fir and white fir growth will decrease; white fir will be less abundant if wildfire frequency increases.

Aspen-Mixed Conifer Forests

- *Moderately vulnerable, depending on vegetation*
- Mature spruce-fir forest will become less common if wildfire frequency increases.
- At higher elevations, early-seral species such as quaking aspen will become more abundant and possibly more widely distributed.
- At lower elevations, ponderosa pine will persist, and quaking aspen and Gambel oak will become more abundant.

Box 6.1—*continued.*

- Changes in species distribution and abundance will depend on topography (north vs. south aspect, canyons vs. side slopes, etc.).

Persistent Aspen Forests

Moderately vulnerable, depending on vegetation

- Mature spruce-fir forest will become less common if wildfire frequency increases.
- Aspen will maintain dominance because of its ability to sprout after wildfire.
- At lower elevations, ponderosa pine will persist, and quaking aspen and Gambel oak will become more abundant.
- Douglas-fir will probably persist because it has relatively high drought and fire tolerance, but will grow slower.

Montane Pine Forests

Moderately vulnerable

- Ponderosa pine will maintain and probably increase dominance over associated species that are less tolerant of drought and wildfire, but it may grow slower.
- Limber pine and bristlecone pine will probably persist at higher elevations where fuel loads are low.
- If bark beetles become more prevalent, they could increase stress and mortality in pine species, especially during drought periods.

Riparian Forests

Highly vulnerable

- Vegetation dominance will transition to species that are more tolerant of seasonal drought, including ponderosa pine and other deep-rooted conifers.
- Hardwood species that rely on periodic high water levels for regeneration will become less common.
- Riparian forests associated with small or transient water sources (e.g., springs) will be more susceptible than forests near large water sources (e.g., rivers). Low-elevation riparian forests near small water sources will be more susceptible than high-elevation forests with persistent snowpack.
- Saltcedar will persist in riparian areas because it is more drought tolerant than native vegetation, but tamarisk beetle is a promising biocontrol.

annually using state-and-transition modeling approaches (Keane et al. 2015a).

Forest Vegetation Responses to Climate

The effects of climate change on forest vegetation are likely to be driven primarily by vegetation responses to altered disturbance regimes, and secondarily through direct effects on vegetation through shifts in regeneration, growth, and mortality (Dale et al. 2001; Flannigan et al. 2009; Temperli et al. 2013) (box 6.3). Effects on vegetation caused by a changing climate (Chapter 3) will vary over different spatial and temporal scales. Trees will respond to reduced water availability, higher temperatures, and changes in growing season in different ways, but because trees are stationary organisms, altered vegetation composition and structure will be the result of changes in plant processes and responses to disturbance. This section discusses responses of trees and other forest vegetation to projected climate.

Individual Plant Effects

There are several important modes of response of plants to changing climates (Joyce and Birdsey 2000). The first is changes in **productivity**, which could increase in some locations because of increasing temperatures, longer growing seasons, and improved water-use efficiency (Aston 2010; Joyce 1995). The window of successful **seedling establishment** will change (Ibáñez et al. 2007), and increasing drought and high temperatures may narrow the time for effective regeneration in low-elevation forests and widen the window in high-elevation forests. Climate may directly cause **tree mortality** through the effects of increased temperature on moisture stress in trees. Extreme climatic events, such as late growing-season frosts and high winds causing breakage and blowdowns, may increase because of projected increases in climatic variability (Notaro 2008), and these events may cause mortality (Joyce et al. 2014; Vanoni

Table 6.2—Dominant tree species in each vegetation type (see table 6.1) in each IAP subregion. Indicator species are shown in bold text.

Vegetation type[a]	Middle Rockies	Greater Yellowstone	Uintas and Wasatch Front	Plateaus	Great Basin	Intermountain Semi Desert
Subalpine pine forest	PNV[b] **Whitebark pine**	PNV **Whitebark pine**	PNV **Whitebark pine** **Limber pine**	PNV **Limber pine** **GB bristlecone pine**[c]	PNV **Limber pine** **GB bristlecone pine**	
Subalpine spruce-fir forest	PNV **Subalpine fir** **Engelmann spruce** Seral Lodgepole pine Douglas-fir Western larch	PNV **Subalpine fir** **Engelmann spruce** Seral Lodgepole pine Douglas-fir	PNV **Subalpine fir** **Engelmann spruce** Seral Lodgepole pine Douglas-fir	PNV **Subalpine fir** **Engelmann spruce** **Blue spruce** Seral Douglas-fir	PNV **Subalpine fir** **Engelmann spruce** **Blue spruce** Seral Lodgepole pine Douglas-fir	
Mesic mixed conifer forest	PNV **Grand fir** **Douglas-fir** Seral **Lodgepole pine** Douglas-fir Ponderosa pine **Western larch**	PNV **Douglas-fir** Seral **Lodgepole pine**	PNV **White fir** **Douglas-fir** Seral **Lodgepole pine** Douglas-fir	PNV **White fir** **Douglas-fir** Seral Douglas-fir Ponderosa pine	PNV **White fir** **Sierra white fir** **Shasta red fir** **Mountain hemlock** **Sierra lodgepole pine** Seral **Sierra lodgepole pine** **Western white pine** Jeffrey pine Ponderosa pine	
Dry mixed conifer forest	PNV **Douglas-fir** **Grand fir** Seral Ponderosa pine Douglas-fir	PNV **Douglas-fir** **Limber pine** Seral Limber pine	PNV **White fir** **Douglas-fir** Seral **Ponderosa pine** **Gambel oak** **Curl-leaf mtn.-mahogany** **Bigtooth maple** **Rocky Mtn. juniper**	PNV **White fir** **Douglas-fir** Seral **Ponderosa pine** **Gambel oak** **Curl-leaf mtn.-mahogany** **Bigtooth maple** **Utah juniper** **Two-needle pinyon**	PNV **White fir** **Sierra white fir** **Douglas-fir** Seral **Ponderosa pine** **Jeffrey pine** **Gambel oak** **Curl-leaf mtn.-mahogany** **Bigtooth maple** **Utah juniper** **Singleleaf pinyon**	

Table 6.2—*Continued*.

Vegetation type[a]	Middle Rockies	Greater Yellowstone	Uintas and Wasatch Front	Plateaus	Great Basin	Intermountain Semi Desert
Aspen-mixed conifer forest	PNV Subalpine fir Engelmann spruce Grand fir Douglas-fir Seral **Aspen** Lodgepole pine Douglas-fir Ponderosa pine	PNV Subalpine fir Engelmann spruce Douglas-fir Seral **Aspen** Lodgepole pine Douglas-fir	PNV Subalpine fir Engelmann spruce White fir Douglas-fir Seral **Aspen** Lodgepole pine Douglas-fir Ponderosa pine Gambel oak Curl-leaf mtn.-mahogany Bigtooth maple	PNV Subalpine fir Engelmann spruce Blue spruce White fir Douglas-fir Seral **Aspen** Douglas-fir Ponderosa pine Gambel oak Curl-leaf mtn.-mahogany Bigtooth maple	PNV White fir Sierra white fir Shasta red fir Seral **Aspen** Sierra lodgepole pine Jeffrey pine Western juniper	
Persistent aspen forest	None	PNV **Aspen** Subalpine fir Engelmann spruce Douglas-fir Seral **Aspen** Lodgepole pine	PNV **Aspen** Subalpine fir Engelmann spruce White fir Douglas-fir Seral **Aspen** Lodgepole pine	PNV **Aspen** Subalpine fir Engelmann spruce Blue spruce White fir Douglas-fir Seral **Aspen** Douglas-fir Ponderosa pine Gambel oak Curl-leaf mtn. mahogany Bigtooth maple	PNV **Aspen** White fir Sierra white fir Shasta red fir Seral **Aspen** Sierra lodgepole pine Jeffrey pine Western juniper	PNV **Aspen** (snow pockets)
Montane pine forest	PNV Douglas-fir **Ponderosa pine** Grand fir **Limber pine** Seral **Ponderosa pine** Douglas-fir **Limber pine**	PNV **Limber pine** Douglas-fir Seral **Limber pine**	PNV **Limber pine** **Ponderosa pine** Douglas-fir White fir **GB bristlecone pine** Seral **Limber pine** **GB bristlecone pine** **Ponderosa pine**	PNV **Limber pine** **GB bristlecone pine** **Ponderosa pine** Douglas-fir White fir Seral **Limber pine** **GB bristlecone pine** **Ponderosa pine**	PNV **Limber pine** **GB bristlecone pine** **Ponderosa pine** **Jeffrey pine** Douglas-fir White fir Shasta red fir Seral **Limber pine** **GB bristlecone pine** **Ponderosa pine** **Jeffrey pine** Douglas-fir	

Table 6.2—*Continued*.

Vegetation type[a]	Middle Rockies	Greater Yellowstone	Uintas and Wasatch Front	Plateaus	Great Basin	Intermountain Semi Desert
Riparian forest	PNV Subalpine fir Engelmann spruce Grand fir Douglas-fir Ponderosa pine Aspen Black cottonwood White alder Sitka alder Thinleaf alder Water birch	PNV Subalpine fir Engelmann spruce Blue spruce Douglas-fir Aspen Lodgepole pine Narrowleaf cottonwood Black cottonwood Balsam cottonwood Water birch Thinleaf alder Boxelder Crack willow	PNV Subalpine fir Engelmann spruce Blue spruce Douglas-fir Ponderosa pine Aspen Lodgepole pine Narrowleaf cottonwood Fremont cottonwood Water birch Thinleaf alder Boxelder Velvet ash Crack willow Salt cedar	PNV Subalpine fir Engelmann spruce Blue spruce White fir Douglas-fir Ponderosa pine Aspen Narrowleaf cottonwood Fremont cottonwood Water birch Thinleaf alder Boxelder Velvet ash Crack willow Salt cedar	PNV Subalpine fir Engelmann spruce Blue spruce White fir Sierra white fir Shasta red fir Sierra lodgepole pine Douglas-fir Jeffrey pine Ponderosa pine Aspen Lodgepole pine Narrowleaf cottonwood Black cottonwood Lanceleaf cottonwood Water birch Thinleaf alder	

[a] Vegetation types are those used by the U.S. Forest Service Intermountain Region.
[b] PNV indicates potential natural vegetation.
[c] "GB bristlecone pine" indicates Great Basin bristlecone pine.

et al. 2016). There will also be disruptions in **phenology** in a warmer climate, with some plants suffering damage or mortality when phenological cues and events are mistimed with new climates (e.g., flowering during dry portions of the growing season) (Cayan et al. 2001). In addition, the **genetic limitation** of species or trees to respond to climate change will vary greatly among species and populations (Hamrick 2004). For example, species restricted to a narrow range of habitat conditions may become maladapted to new climates (St. Clair and Howe 2007).

Plants can respond to climate-mediated changes in different ways (Aitken et al. 2008). Direct effects of temperature at the cellular level may increase photosynthesis and respiration (Waring and Running 1998). Photosynthesis rates increase with temperature up to an optimum and decline thereafter, although potential effects on tree growth vary by species and local soil and moisture conditions. In the IAP region, any decrease in tree growth would be expected to occur at low elevations, whereas some trees at high elevations may have increased growth. Respiration increases with temperature, and respiration occurs even when stomata are closed, so high temperatures coupled with low water availability may result in high respirational losses with few photosynthetic gains (Ryan et al. 1995).

Increased atmospheric carbon dioxide levels may also directly modify physiological growth processes at the cellular level. Water-use efficiency may increase for some conifer species, potentially compensating for lower water availability (Waring and Running 1998). Leaf biomass is usually the first to increase as plants attempt to optimize photosynthesis by growing more leaf tissue (i.e., leaf area), although increased leaf area can be transitory depending on available water and nitrogen. Higher atmospheric carbon dioxide levels and temperatures can also interact to increase growth, especially if warmer temperatures are closer to temperature optima for photosynthesis.

Another direct effect of warming temperatures is longer growing seasons (Cayan et al. 2001; McKenzie et al. 2009). In addition, future climate may be more variable, affecting dormancy regulation, bud burst, and early growth (Hanninen 1995; Harrington et al. 2010). Plant phenological cues may be disrupted or triggered inappropriately because of high weather variability, a response that may be fatal for seedlings. Warmer temperatures may reduce growing-season frosts in mountain valleys, thereby allowing more frost-susceptible species, such as ponderosa pine (*Pinus ponderosa*) to exist in habitats currently occupied by lodgepole pine (*Pinus contorta* var. *latifolia*), subalpine fir (*Abies lasiocarpa*), and Engelmann spruce (*Picea engelmannii*). Increased temperatures may result in decreased winter chilling, which could result in delayed bud burst, reduced flowering, and reduced seed germination (Chmura et al. 2011).

Box 6.2—Uncertainty and Climate Change Effects on Vegetation

Global Climate Models (GCMs) that project rapidly warming climates have a high degree of uncertainty. Although it is clear that increasing atmospheric carbon dioxide will cause a significant increase in temperature (IPCC 2007), uncertainty exists about the magnitude and rate of climate change (Roe and Baker 2007; Stainforth et al. 2005). This uncertainty is generally higher for climate projections made at fine resolutions and for longer time periods (Knutti and Sedlacek 2013). The range of possible projections of future climate from GCMs (anywhere from a 1.6 to 8 ^{o}C increase in global average annual temperature) is much greater than the variability of climate over the past 3 centuries (Stainforth et al. 2005), and the variability across GCMs is greater than the variability in each model's climate projections.

Because it is impossible to know whether society will respond to climate change by employing technological innovations to minimize carbon dioxide emissions or to mitigate its effects, most GCMs also simulate a range of scenarios that capture different strategies and socioeconomic policies to deal with climate change, introducing yet another source of uncertainty. Moreover, it is the high variability of climate extremes, not the gradual change of average climate, that will drive most ecosystem responses to disturbance and plant dynamics—and these rare, extreme events are the most difficult to project (Easterling et al. 2000).

Yet another source of uncertainty is introduced when we try to project how the Earth's vegetation and ecosystems will respond to climate change (Araujo et al. 2005). Mechanistic ecological simulation of climate, vegetation, and disturbance dynamics across landscapes is still evolving (Keane and Finney 2003; Sklar and Costanza 1991; Walker 1994). Many current ecosystem simulation models are missing important direct interactions of disturbance, hydrology, and land use with climate that will affect plant distributions (Notaro et al. 2007). Little is known about the interactions among climate, vegetation, and disturbance, and interactions among different disturbance regimes (e.g., fire and beetles) could create novel landscape behaviors. It is also difficult to determine how plant and animal reproduction, growth, and mortality will respond to changing climate (Gworek et al. 2007; Ibanez et al. 2007; Keane et al. 2001; Lambrecht et al. 2007). These modeling uncertainties greatly increase as projections are made further into the future and at finer spatial scales (Xu et al. 2009).

Uncertainties need to be considered when using this assessment for analysis, planning, and project management. Sometimes there is less uncertainty in implementing conventional restoration designs than in designing restoration or treatment plans that attempt to account for climate change effects. For example, including climate change in restoration of western larch ecosystems may be more straightforward than for ponderosa pine ecosystems. Because all climate effects will be manifest in different ways on different landscapes, there is no "one-size-fits-all" prescription that can be adopted everywhere.

Much of the water used by trees in mountain forests comes from snowmelt, so amount and duration of snowpack influence regeneration and growth patterns of tree species and forest communities. Warmer temperatures will cause earlier snowmelt, leading to an earlier start of the growing season, and longer periods of low soil moisture during the rest of the growing season. In contrast, less snowpack will create longer growing seasons in subalpine communities where cold and snowpack duration limit tree regeneration and growth, potentially facilitating increased productivity (Peterson and Peterson 2001) and regeneration (Woodward et al. 1994).

Climate change can indirectly affect vegetation by altering mycorrhizal dynamics (Amaranthus et al. 1999). Many trees, particularly in the seedling and sapling stages, need mycorrhizae to survive, especially in areas with chronic water shortage (Mohatt et al. 2008; Walker et al. 1995). Migration of tree species to more favorable sites in future climates may be governed by the ability of mycorrhizae to also populate these areas (Lankau et al. 2015). Mycorrhizal responses following wildfire are important because fire is expected to increase significantly in a warmer climate (Chapter 8). Establishment of trees in burned areas can be delayed for decades or even centuries (Little et al. 1994), as both mycorrhizae and trees revegetate the area (Schowalter et al. 1997).

Migrating to a new site has historically been the main response of plants to climate change (Huntley 1991), requiring that species have the ecological ability to quickly occupy available sites and the genetic capacity to survive and reproduce successfully (Davis et al. 2005). Most tree species in the IAP region are long lived and genetically diverse, so they can survive wide fluctuations of weather, but the interaction of increasing drought and modified disturbance regimes will play a role in the future distribution and abundance of forest species (Allen et al. 2010) (Chapter 8).

A warmer climate is expected to facilitate upward shifts in the elevation distribution of plant species. For example, Lenoir et al. (2008) found that some plant species have moved upward in elevation at a rate of 100 feet per decade, but it is unclear whether such shifts will drive long-term changes in forest communities. For example, wildfire plays a dominant role in most ecosystems in western North America, and increasing wildfire frequency and extent may overwhelm potential shifts in forest species distribution. The potential for tree populations to migrate may vary among diverse mountain ranges, depending on local biophysical conditions.

Box 6.3—How Do Climate Change Vulnerability Assessments and Adaptation Inform Ecological Restoration?

In an ideal sense, *ecological restoration* is defined as the practice of reestablishing historical plant and animal communities in a given area and the renewal of ecosystem and cultural functions necessary to maintain these communities now and into the future (Egan and Howell 2001). However, this ideal may be difficult to manage because: (1) little is known about historic conditions, (2) many key species may already be lost, (3) some efforts may be prohibitively expensive, and (4) future climates will create novel ecosystems. As a result, The Society for Ecological Restoration has opted for a definition that states that ecological restoration is "the process of renewing and maintaining ecosystem health."

The U.S. Forest Service manual direction (FSM 2020) includes objectives and a policy for restoration:

- *Restore and maintain ecosystems* that have been damaged, degraded, or destroyed by reestablishing the composition, structure, pattern, and ecological processes.
- *Manage for resilient ecosystems* that have a greater capacity to withstand stressors, absorb and recover from disturbances, and reorganize and renew themselves, especially under changing and uncertain environmental conditions.
- *Achieve long-term ecological sustainability* and provide a broad range of ecosystem services to society.

The Forest Service emphasizes ecosystem restoration across all National Forest System lands with the goal of attaining resilient ecosystems. All strategic plans, including the Forest Service Strategic Plan and land management plans, must include goals and objectives to sustain the resilience and adaptive capacity of aquatic and terrestrial ecosystems by reestablishing, maintaining, or modifying their composition, structure, function, and connectivity. The goals and objectives must be established within this framework as defined by laws, Indian treaties and Tribal values and desires, and regulations. The goals and objectives must also consider public values and desires, social concerns, economic sustainability, the historical range of variability, ecological integrity, current and likely future ecological capabilities, a range of climate and other environmental change projections, the best available scientific information, and technical and economic feasibility to achieve desired conditions for National Forest System lands.

A primary element of an integrated approach is to identify and eliminate or reduce stressors that degrade or impair ecosystems. Restoration activities should also take into account social and ecological influences at multiple scales and incorporate the concept of a dynamic system and ecological trajectory. Some ecosystems may have been altered to such an extent that reestablishing components of the historical range of variability may not be ecologically or economically possible. Therefore, goals and activities can focus on restoring the underlying processes that create functioning ecosystems.

Functional restoration, an alternative concept used in the Forest Service, is defined as the "restoration of abiotic and biotic processes in degraded ecosystems." Functional restoration focuses on underlying processes that may be degraded, regardless of the structural condition of the ecosystem. As contrasted with ecological restoration that tends to seek a historical reference condition, functional restoration focuses on dynamic processes that drive structural and compositional patterns. Functional restoration aims to restore functions and improve structures with a long-term goal of restoring interactions between function and structure. However, a functionally restored system may look quite different than the historical reference condition in terms of structure and composition. In this case, disparities cannot be easily resolved, because a threshold of degradation has been crossed, or environmental drivers (e.g., climate) that influenced structural and compositional development have changed.

Reproduction

Cone and seed crops of some tree species could be affected by climate change (Ibáñez et al. 2007; LaDeau and Clark 2001). Low-elevation, xeric forests may have fewer and smaller cone crops because of increased stand density and water stress. Cone crops may also have a lower percentage of viable seed because of increased stress. Infrequent cone crops coupled with low seed production may cause reduced regeneration in recently burned areas, in some cases resulting in dominance of nonforest vegetation. The opposite may be true in higher, colder environments, where increased temperatures will increase growing season length and thereby increase potential for more cone crops with more seeds. Spruce-fir communities may produce so much seed that they overwhelm regeneration of other conifers, especially after mixed-severity fires. Species such as whitebark pine (*Pinus albicaulis*) and lodgepole pine have unique cone characteristics; whitebark pine cones require birds for seed dispersal, and lodgepole pine cones may be serotinous and opened only by fire.

Growth and Mortality

Climate adversely affects growth and mortality through decreased water availability, resulting in shorter effective growing seasons (Bugmann and Cramer 1998; Chmura et al. 2011; Keane et al. 2001; Williams et al. 2010). Extended droughts require conifers to close stomata longer to conserve water. Ponderosa pine and limber pine (*Pinus flexilis*) have excellent stomatal control, and stomata can remain closed for long periods of time; Douglas-fir (*Pseudotsuga menziesii*) has poor stomatal control, which can drive leaf water potentials to low values and contribute to physiological damage (Sala et al. 2005). If photosynthetic production cannot exceed respiration demands, then plants become stressed.

If physiological damage is high enough, carbon storage in plant cells may decline as a result of stomatal closure and insufficient carbon assimilation to meet demands for tissue maintenance. In addition, lack of water for uptake, especially while stomata are open, can greatly reduce hydraulic conductance (McDowell et al. 2008; Sevanto et al. 2014). Both of these physiological responses to low water supply, which typically occur during prolonged drought, can substantially reduce vigor, making weakened trees more susceptible to other stresses. In the most extreme cases, the ultimate outcome is tree mortality, often facilitated by bark beetles or other insects.

In mesic ecosystems in the IAP region, a warmer climate may enhance growth and decrease mortality (Wu et al. 2011). Earlier growing seasons with ample moisture, as projected for some forests, may promote increased productivity. This will be especially true at higher elevations where cold temperatures, not moisture, limit tree growth. Increased biomass will also amplify competition between species, thereby favoring shade-tolerant individuals in the absence of disturbance. Increased biomass could also reduce resistance to forest insect and diseases (Chapter 8).

Regeneration

Microsite conditions required for successful establishment of tree species are typically rare, so seed germination and survival, especially for seeds that are wind dispersed, are rarely successful (Anderson and Winterton 1996). Suitable moisture conditions must persist for long periods of time for seed germination and early seedling growth. In dry forests, most of the successful regeneration occurs in years when soils are moist for an adequate time and heating at the soil level does not kill developing leaves and stems. A warmer climate may decrease the frequency of high-regeneration years, and regeneration may become rare on the driest sites. In contrast, regeneration may be enhanced by warming at high elevation because earlier snowmelt will provide more time for seedlings to survive and grow (Butler 1986).

During mild winters, seed chilling requirements may not be met for some species, thereby reducing germination. In addition, germination may be delayed to drier times during the growing season. For example, Nitschke and Innes (2008) found that in a warmer climate, chilling requirements were not met for most low-elevation tree species in British Columbia. High soil temperatures can stress both germinants and established seedlings (Rochefort et al. 1994). Climate change may also affect the dispersal properties of seeds. For example, rodent and bird species that disperse seeds may shift habitats because of climate-mediated changes (Tomback 1998). Longer and drier summers and autumns suggest that seed dispersal may occur when the ground and litter are dry and unsuitable for seed germination and establishment (Neilson et al. 2005).

Genetics and Species Adaptation

Climate affects plant phenotypes and is an agent of natural selection. Plant adaptations to local environments have often developed a **clinal** (or continuous) response to abiotic and biotic factors. In addition, **ecotypic** (or discontinuous) response to environmental gradients may play an important role, depending on local soils and topography. Therefore, a combination of clinal and ecotypic environmental gradients determines long-term plant survival and persistence across the landscape.

Natural selection, migration, genetic drift, and mating system determine species genetic composition. Thus, the ability of plant populations to respond to climate change is influenced by underlying patterns of genetic variation. Molecular markers can reveal significant genetic diversity and divergence among populations. Populations may diverge because of fire, volcanic activity (Hansen 1949), glaciation (Hamrick 2004), seed dispersal agents (Lorenz and Sullivan 2009), and pollinator history. Plants that are pollinated by insects or rely on animals to disperse seed are more vulnerable to climate change than plants with wind-dispersed seed, because of the requirement for interaction with another organism.

Genetic diversity allows species to adapt to changing environments, colonize new areas, occupy new ecological niches, and produce substantial and robust progeny that persist in the long term (Ledig and Kitzmiller 1992). Populations within a species adapt to environmental change over time. Species and populations of plants most vulnerable to climate change are typically (1) rare species or genetic specialists, (2) species with limited phenotypic plasticity, (3) species or populations with low genetic variation, (4) populations with low dispersal or colonization potential, (5) populations at the trailing edge of a species range, (6) populations at the lower-elevation limit of their distribution, and (7) populations threatened by habitat loss, fire, insects, or disease (Spittlehouse and Stewart 2003; St. Clair and Howe 2011). The ability of a species to respond to environmental change is closely tied to its adaptive strategy (e.g., specialist or generalist) (table 6.3), mechanisms that shape its genetic structure, and the rate of environmental change.

Fragmentation is a critical issue for plant populations because isolation and small populations promote inbreeding and loss of genetic diversity (Broadhurst et al. 2008; Potter et al. 2015). Gene flow from adjacent populations can increase the rate of adaptation by introducing genetic variation that is preadapted to warmer or drier climates (Aitken et al. 2008). This knowledge allows resource managers to select an appropriate population or seed source to increase the likelihood of desired revegetation or restoration (box 6.4).

Table 6.3—Summary of attributes characterizing plant species' adaptive strategies.[a]

	Adaptive strategy	
Attributes	**Specialist**	**Generalist**
Factor controlling phenotypic expression of adaptive traits	Genotype	Environment
Mechanisms for accommodating environmental heterogeneity	Genetic variation	Phenotypic plasticity
Range of environments where physiological processes function optimally	Small	Large
Slope of clines for adaptive traits	Steep	Flat
Partitioning of genetic variation in adaptive traits	Mostly among populations	Mostly within populations

[a] Modified from Rehfeldt (1994).

Box 6.4—Using Historical Range and Variability to Assess and Adapt to Climate Change

To effectively implement ecosystem-based management, land managers often find it necessary to obtain a reference, or benchmark, to represent the conditions that describe fully functional ecosystems (Cissel et al. 1994; Laughlin et al. 2004). Contemporary conditions can be evaluated against this reference to determine status, trend, and magnitude of change, and to design treatments that provide society with valuable ecosystem services while returning declining ecosystems to a more sustainable condition (Hessburg et al. 1999; Swetnam et al. 1999). Reference conditions are assumed to represent the dynamic character of ecosystems and landscapes, varying across time and space (Swanson et al. 1994; Watt 1947).

The concept of *historical range and variability* (HRV) was introduced in the 1990s to describe past spatial and temporal variability of ecosystems (Landres et al. 1999), providing a spatial and temporal foundation for planning and management. HRV has sometimes been equated with “target” conditions (Harrod et al. 1999), although targets can be subjective and somewhat arbitrary, representing only one possible situation from a range of potential conditions (Keane et al. 2009). HRV encompasses a full range of conditions that have occurred across multiple spatial and temporal scales.

HRV represents a broad historical envelope of possible ecosystem conditions—burned area, vegetation cover type area, patch size distribution—that can provide a time series of reference conditions. This assumes that:

- Ecosystems are dynamic, not static, and their responses to changing processes are represented by past variability
- Ecosystems are complex and have a range of conditions within which they are self-sustaining, and beyond this range they transition to disequilibrium (Egan and Howell 2001)
- Historical conditions can serve as a proxy for ecosystem health
- Time and space domains that define HRV are sufficient to quantify observed variation
- Ecological characteristics being assessed for an ecosystem or landscapes match the management objective (Keane et al. 2009).

The use of HRV has been challenged because a warmer climate may permanently alter the environment of ecosystems beyond what was observed under historical conditions (Millar et al. 2007a), particularly altered disturbance processes, shifts in plant species distribution, and hydrologic dynamics (Notaro et al. 2007). However, a critical evaluation of possible alternatives suggests that HRV is still a viable approach in the near term because it has relatively low uncertainty.

An alternative to HRV is projecting future landscape characteristics in a changing climate using complex empirical and mechanistic models. However, the range of projections for future climate from commonly used GCMs is quite broad (Chapter 3; Stainforth et al. 2005). Additional uncertainty accrues from unknown technological advances, behavioral adaptations, and human population growth (Schneider et al. 2007). Moreover, variability of climate extremes, not the gradual change of average climate, will drive most ecosystem response to climate-mediated disturbance and plant dynamics (Smith 2011). Despite these uncertainties, it will be useful to quantify *future range and variability* (FRV) for landscapes where it is feasible and appropriate (Araujo et al. 2005; Keane et al. 2009).

Given cumulative uncertainties, time series of HRV may have lower uncertainty than simulated projections of future conditions, especially because large variations in past climates are already captured in the time series. It may be prudent to wait until simulation technology has improved enough to create credible FRV landscape pattern and composition. In the meantime, attaining HRV would be a significant improvement in the functionality of most ecosystems in the IAP region, and would be unlikely to result in negative outcomes from a management perspective. As with any approach to reference conditions, HRV is useful as a guide, not a target, for restoration and other management activities.

Some species may not be able to migrate quickly enough to keep pace with projected rates of climate change (30–300 feet per year) (Davis 1989; Malcolm et al. 2002). Slow rates of migration may be further impeded by landscape fragmentation (Davis and Shaw 2001; Davis et al. 2005). Therefore, adaptation may be a more important response to climate change than migration. Some authors suggest that long-lived species with high levels of genetic variation can respond favorably to climate change (Hamrick 2004; Hamrick et al. 1992). However, others dispute the ability of forest trees to adapt or migrate and suggest trees may be restricted by their long lifespans, generation intervals, and juvenile phases (Etterson and Shaw 2001; Jump and Peñuelas 2005; Parmesan 2006). Because plant populations are genetically adapted to local climates, the climatic tolerance of individual populations will be critical.

Adaptive strategies for conifers in the IAP region are well documented (Rehfeldt 1994). Differences in adaptive strategy can be characterized by varietal modifications (e.g., *Pinus ponderosa* var. *ponderosa* versus var. *scopulorum*), different elevations, and variable geography. For example, *P. ponderosa* var. *ponderosa* is characterized as having an intermediate (neither generalist nor specialist) adaptive strategy, but at high elevation it has a specialist strategy (genetic variation is organized into numerous local populations, finely tuned to site-specific gradients). Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) is characterized as having a specialist adaptive strategy, but at high elevation it has a generalist adaptive strategy (genetic variation is organized into one or a few populations capable of surviving, growing, and reproducing over a broad range of environments) (Rehfeldt 1989). A generalist adaptive strategy is considered more beneficial for responding to climate change (table 6.3).

Patterns of adaptive variation in other native plants (shrubs, forbs, grasses, sedges) are both clinal and ecotypic. These patterns involve multiple life forms (annual, biennials, perennials) and different ploidy levels (multiple copies of DNA, such as 4X, 6X, or 8X), where 2X is the base level, in which one copy of DNA is inherited on both the maternal and paternal sides. Grasses are largely generalists and less vulnerable to climate change, although ecotypic variation can overlie the generalist adaptive strategy. Forbs, which are mostly insect pollinated and coupled with longer growing seasons and changes in phenology, are considered more vulnerable to climate change than trees and grasses.

Stressors: Biotic and Abiotic Disturbances

A warming climate will rarely be the direct agent of change for tree species and communities. Most changes in vegetation will occur in response to disturbance or some combination of other stressors to climate change (Keane et al. 2015a; McKenzie et al. 2009; Peterson et al. 2014a, b). The biggest changes across the IAP region are likely to be altered water balance and increasing disturbances such as wildfire, insects, and nonnative species (Chapter 8). Disturbances in combination with other stressors (e.g., drought) will create disturbance regimes in which multiple factors interact to modify ecosystem structure and function (Iverson and McKenzie 2013; McKenzie et al. 2009).

Wildfire is pervasive throughout forest ecosystems in western North America and was historically a dominant landscape disturbance agent in the IAP region. Fire exclusion since the 1920s has disrupted annual occurrence, spatial extent, and cumulative area of wildfires, resulting in increased surface fuel loads, tree densities, and ladder fuels, especially in low-elevation, dry conifer forests. Wildfire regimes, defined by fire frequency, annual area burned, severity, and pattern, are greatly influenced by variability in landscape environmental conditions including vegetation distribution, climate, weather, and topography (McKenzie et al. 2011). Regionally, years with high area burned are correlated with drought, so if drought increases as expected, area burned is expected to increase significantly (McKenzie et al. 2004; Peterson et al. 2014a).

Fire history determines composition and structure of most forests in the IAP region. At the lowest and driest elevations, frequent surface fires historically consumed litter and dead wood and killed seedlings and smaller trees. Fuel accumulations over several decades indicate that future fires may be larger and more intense and may cause higher rates of tree mortality than historical fire (box 6.3). Fire exclusion has not affected fire regimes as much where fires were historically infrequent because of relatively cool, wet conditions (e.g., high elevation) (Romme and Despain 1989; Schoennagel et al. 2004). However, earlier onset of snowmelt, predicted to occur with changing regional climate, will reduce fuel moisture, making these systems flammable for longer periods of time and potentially leading to increased area burned (Miller et al. 2009).

Fire exclusion has resulted in increased tree regeneration and denser forest canopies, coupled with accumulation of understory and canopy fuels in dry forests (Ferry et al. 1995; Keane et al. 2002) (fig. 6.1). These conditions create competition for water, light, and nutrients, making trees in fire-excluded forests susceptible to mortality from biotic and abiotic stressors, such as insects (Anderegg et al. 2012; Wikars and Schimmel 2001), drought (Allen et al. 2010), and fire (Hood et al. 2007).

Native insects and diseases naturally occur throughout forest cover types of the IAP region (Chapter 8). The level of insect and disease activity fluctuates with the availability of host material, stand conditions, environmental factors, and abundance of parasites and predators. These agents typically occur at endemic levels within forest ecosystems and affect mature and weakened trees.

Climate and forest composition and structure influence insect activity and outbreaks. Mountain pine beetle (*Dendroctonus ponderosae*) is an integral component of forest ecosystem processes because of its role in stand

Figure 6.1—Area where fire has been excluded for many decades. Dense stands of ponderosa pine and other species create fuel ladders that can facilitate crown fires (photo: U.S. Forest Service).

thinning and redistribution of resources and nutrients. It is responsible for tree mortality across large areas (Logan et al. 2003), causing significant ecological and economic impacts. Many bark beetle life history traits that influence population success are temperature dependent (Bentz and Jönsson 2015); warming temperatures have directly increased bark beetle-caused tree mortality in some areas of western North America (Safranyik et al. 2010; Weed et al. 2015) (fig. 6.2). Temperature increases will affect tree distribution and tree vigor (Chapman et al. 2012; Hart et al. 2013). Therefore, future bark beetle-caused tree mortality will depend not only on the spatial distribution of live host trees and heterogeneity of future landscapes but also on the ability of beetle populations to adapt to changing conditions.

Fungal diseases, dwarf mistletoes (*Arceuthobium* spp.), root diseases, needle casts and blights, and abiotic diseases affect forest ecosystems, although the effects of climate change on forest diseases are difficult to project. The effects of climate change on root disease contribute significantly to mortality and loss of tree vigor, although little is known about climate-disease relationships. Climate-mediated changes to forest tree diseases will be dictated by

Figure 6.2—Stand containing lodgepole pine killed by mountain pine beetle. This insect has killed lodgepole pine across large areas of western North America, including the Intermountain Adaptation Partnership region, during the past 20 years. Chronic damage from the beetle may become more common in a warmer climate (photo: U.S. Forest Service).

disease and host tree responses to new climates and their interactions (Sturrock et al. 2010). Interactions among biotic diseases, abiotic stressors, and host species will drive future pathogen outbreaks.

Soil characteristics, aspect, elevation, and forest stand structure contribute to effective moisture availability for tree establishment and growth, helping to shape spatial patterns of forests. Global climate models (GCMs) indicate that the IAP region will have longer, warmer summers (Chapter 3). Seral species such as ponderosa pine, which can establish on bare soil where high surface temperatures (up to 150 °F) exclude other species, have deep roots that can reach water and avoid competition with shallow-rooted species. In the absence of disturbance, shade-tolerant tree species can establish and grow in the understory, allowing them to take up water from the nutrient-rich soil surface. Leaf surface area increases over time, with leaf areas in excess of 6 square feet per square foot of soil surface area in some forests. Transpiration also increases over time, with the potential to deplete soil water needed to keep trees hydrated throughout the summer.

Climate Change Assessment for Tree Species

Here we assess vulnerability for tree species, vegetation types, and resources of concern in the IAP region, based on (1) ecological characteristics, (2) disturbance interactions, (3) current and historical conditions, and (4) potential climate change responses (table 6.4). Most of the material in this section was derived from published literature, although observational information is included for context. Scientific literature on climate change effects is limited for some species and forest types, making it necessary in some cases to augment the literature with expert knowledge to develop inferences.

Tree Species

Tree species in the IAP region will respond to climate change through modification, contraction, and expansion. First, a species could increase or decrease in productivity in situ within its current range because of increasing temperatures and adequate precipitation (**modification**, or acclimatization). Second, a species may diminish or be extirpated, if conditions change enough to become inhospitable to that species (Allen et al. 2010) (**contraction**). Finally, a species could migrate to areas that are more conducive to establishment and growth (Johnstone and Chapin 2003) (**expansion**). Any species can have multiple modes of response to climate change, and most species will respond to future climates via all three modes.

Application of these three modes to determine future species dynamics requires integration of variability and scale. For example, assessment of species migration requires a long temporal scope to evaluate species range shifts (Prentice et al. 1991). A tree species could become

Table 6.4—Categories used to assess vulnerability of species and vegetation types.

Evaluation category	Description	Example
Habitat, ecosystem function, or species	Specific biophysical or social entity of interest	Whitebark pine
Broad-scale climate change effect	Overarching change in climate that is expected to affect a resource	Warming temperatures
Current condition, existing stressors	Current status of resource relative to desired conditions, including factors that are reducing the quality or quantity of the resource	Reduced abundance, wildfire, mountain pine beetle, white pine blister rust
Sensitivity to climatic variability and change	Specific sensitivity of a habitat, species, or ecosystem function that responds to climate	Low ability to compete with encroaching conifers
Expected effects of climate change	How specific habitat, species, or ecosystem function is expected to respond to climate change (develop inferences from model projections and known responses to climatic variability)	Regeneration may be reduced by combination of warming and low seed availability
Adaptive capacity	Ability to adjust to climate change, to moderate potential damages, or to cope with the consequences; usually more appropriate for species than for systems and processes	Variable: unable to compete with other tree species, but bird-mediated seed dispersal allows rapid colonization of burned areas
Exposure	The extent to which each species' physical environment will change	High

established in a “new” environment made suitable by climate change, such as subalpine tree expansion, but variability in climate may prevent long-term establishment. In addition, shifts in species distribution and abundance will be governed primarily by disturbance, not competition, so disturbance adaptations will be more important than climatic niches.

Most of the information on vulnerability of tree species to climate change was derived from recent summaries on projected climate change effects (Bollenbacher 2012; Devine et al. 2012; Keane et al. 2015a) and older literature on autecology and silviculture (Burns and Honkala 1990; Minore 1979). The following summaries integrate genetic, morphological, ecological, and disturbance characteristics to project how a tree species will respond to a warmer climate.

In general, the literature is inconsistent on the response of tree species to climate change. Results from SDMs often differ from other sources that include gap modeling, mechanistic ecosystem simulation, and field data summaries. As a result, we do not emphasize SDM results in assessment evaluations. Most climate change studies project few species changes after moderate warming (e.g., B1, B2, A1B, RCP 4.5 scenarios) but major species shifts under the most extreme emissions scenarios (e.g., A1, RCP 8.5). Timeframe also affects inferences about vulnerability. Management timeframes of 10 to 50 years are not long enough to effectively evaluate changes in wildfire, native insects, and tree growth because ecosystem response to disturbance may require two to five times the disturbance return interval. Finally, projections by GCMs vary, so the magnitude and rate of climate change, especially by the end of the 21st century, are uncertain (but are always considerably warmer). We have confidence in these projections at broad spatial scales, but less confidence for specific locations.

Douglas-fir (Pseudotsuga menziesii)

(Middle Rockies, Southern Greater Yellowstone, Uintas and Wasatch Front, Plateaus, Great Basin and Semi Desert subregions)

Autecology

Douglas-fir (fig. 6.3) is found throughout the IAP region, growing in pure and mixed conifer stands (Hermann and Lavender 1990), often associated with ponderosa pine, Jeffrey pine (*Pinus jeffreyi*), grand fir (*Abies grandis*), subalpine fir, and quaking aspen (*Populus tremuloides*). Regeneration is most successful where Douglas-fir is seral (Ryker and Losensky 1983), and seedling growth is strongly limited by moisture and competing vegetation. Douglas-fir is intermediate in shade tolerance, tolerating drought better than most competitors (except for ponderosa pine and Jeffrey pine) by keeping stomata open to extract soil water at low soil water potentials (Sala et al. 2005; Stout and Sala 2003). The species exhibits high genetic differentiation, which is strongly associated with geographic or topographic features (Rehfeldt 1978). Seed sources on south aspects have adaptive characteristics for a shorter growing season and drier soils and may survive under drought stress better than seedlings from north aspects.

Disturbance Interactions

Mature Douglas-fir is resistant to fire injury because of its thick bark, deep main roots, and high crowns (Ryan and Reinhardt 1988). Ponderosa pine and western larch can survive fire across all life stages, so on sites with frequent fires where Douglas-fir is associated with these other species, its cover is usually kept low by fire (Agee 1991). Douglas-fir is subject to damage from a variety of agents that may increase under future climates (Hermann and Lavender 1990), including Douglas-fir beetle

Figure 6.3—Douglas-fir. Growth of Douglas-fir in the Intermountain Adaptation Partnership region is expected to decrease in a warmer climate (photo: C. Restaino, used with permission).

(*Dendroctonus pseudotsugae*), western spruce budworm (*Choristoneura occidentalis*), and Douglas-fir tussock moth (*Orgyia pseudotsugata*). The latter two insects attack trees of all ages at periodic outbreak intervals, often resulting in severe defoliation during outbreak years. Armillaria (*Armillaria solidipes*) and annosus (*Heterobasidion annosum*) root diseases may intensify in infection and widen in distribution to cause high tree mortality. Annosus root disease is particularly lethal in Douglas-fir (Hagle 2003). Of the many heart rot fungi (more than 300) attacking Douglas-fir, the most damaging and widespread is red ring rot (*Porodaedalea pini*).

Historical and Current Conditions

Historical frequent wildfire kept Douglas-fir from becoming established on some dry sites where it was associated with ponderosa pine. The cumulative effects of fire exclusion and logging have allowed Douglas-fir to become more dominant across some portions of the IAP region, often with high stem densities in fire-excluded stands. This has created areas where both canopy and surface fuels are high (Keane et al. 2002), predisposing Douglas-fir forests to future crown fires. In addition, these dense stand conditions have contributed to decreased vigor, which makes species susceptible to western spruce budworm and Douglas-fir beetle outbreaks.

Climate Change Responses

Some studies suggest that Douglas-fir distribution will increase in a warmer climate (Morales et al. 2015) and that growth will increase (Soulé and Knapp 2013), although a recent study provides convincing evidence that growth will decrease throughout its range (Restaino et al. 2016). It is likely that multiple factors will contribute to reduced distribution and vigor of Douglas-fir forests in some locations. Increased heat loading following severe wildfires is expected to be more common in the future, and may reduce Douglas-fir regeneration at lower-elevation sites and on south aspects (Kemp 2015). Douglas-fir may also face increasing competition from ponderosa pine, which is more drought tolerant (Stout and Sala 2003), and it may not have the genetic potential to rapidly migrate to more conducive sites (Aitken et al. 2008). In addition, Douglas-fir could have less resistance to the native insects previously mentioned if it is chronically stressed by low soil moisture. Increased wildfires, coupled with adverse effects of fire exclusion, could reduce tree survival in the future and make trees more susceptible to Douglas-fir beetle (Hood and Bentz 2007; Hood et al. 2007). Klopfenstein et al. (2009) projected that the range of Armillaria root rot will remain constant in a warmer climate, and if areas where Douglas-fir is maladapted increase, susceptibility to root rot could also increase. With limited genetic diversity at low to middle elevations and a more generalist strategy at higher elevations (St. Clair and Howe 2007), Douglas-fir may retract from the driest portions of its range.

Grand Fir (Abies grandis)

(Middle Rockies subregion)

Autecology

Grand fir is found on a wide variety of sites, including stream bottoms, valleys, and mountain slopes in the Middle Rockies of the IAP region (Foiles et al. 1990), typically in association with other conifer species. Grand fir grows best on rich soils of valley bottoms but also grows well on shallow exposed soils of mountain ridges, if moisture is adequate (Antos and Shearer 1980). Grand fir is either an early- or late-seral species, depending on site moisture (Ferguson and Johnson 1996). On productive mesic sites, it grows rapidly to compete with other seral species in the overstory, but other conifer species can outcompete it. On drier sites, it is the most shade-tolerant species and can dominate the understory. Grand fir can also share dominance with subalpine fir, especially in narrow valley bottoms, where it can exert dominance in lower elevational zones (Antos and Shearer 1980). Grand fir has high shade tolerance but low drought tolerance. It forms associations with ectomycorrhizae and arbuscular mycorrhizae, which may allow it to outcompete some shade-tolerant conifers. It has low frost tolerance but can tolerate fluctuating water tables.

Disturbance Interactions

Grand fir is susceptible to fire damage in moist creek bottoms but is more resistant on dry hillsides where roots are deeper and bark is thicker (Ryan and Reinhardt 1988). Wildfires that burn grand fir stands are stand replacing or mixed severity, generating sufficient heat to kill even mature trees (Arno 1980; Arno et al. 2000). Grand fir is susceptible to Armillaria and annosus root diseases, which can cause high levels of tree mortality (Hagle et al. 2003). Numerous insects attack grand fir, including western spruce budworm and Douglas-fir tussock moth, which cause widespread defoliation, top kill, and mortality. The western balsam bark beetle (*Dryocoetes confusus*) and fir engraver (*Scolytus ventralis*) are the principal bark beetles that attack grand fir (Foiles et al. 1990).

Historical and Current Conditions

Fire exclusion has increased grand fir on both dry and mesic sites, and higher tree densities have stressed grand fir, making it more susceptible to root rot and insect attacks. Therefore, the condition of most grand fir stands depends on the last severe fire; if fire exclusion has caused grand fir to dominate in both the overstory and understory, then these stands are usually stressed because of high densities and increased root rot and insects. However, in early-seral stands where high grand fir regeneration has not yet occurred, an increase in fir is likely with continued fire exclusion.

Climate Change Responses

On dry sites, increased drought and longer growing seasons will exacerbate stress caused by competition, resulting in high mortality of grand fir, mainly from insects and disease. Nitschke and Innes (2008) used a gap model to project major declines in grand fir, and Coops and Waring (2011) used a mechanistic model to simulate a nearly 50 percent decrease in the range of grand fir compared to historical distributions. However, increased productivity may lead to increased grand fir populations in locations with higher soil moisture (Aston 2010; Urban et al. 1993). As noted earlier, increased densities may also lead to increased stress. Longer fire seasons and high fuel loadings from fire exclusion will probably lead to large, severe fires that may reduce grand fir in drier locations. In summary, although grand fir is often stressed by high stem densities, the species is likely to tolerate changes in climate and remain on the landscape at levels that are closer to historical conditions rather than its current abundance.

Shasta Red Fir (Abies magnifica)

(Great Basin and Semi Desert subregion)

Autecology

Shasta red fir grows best in areas with cold, wet winters and warm, dry summers (Lanner 1983; Oosting and Billings 1943; Rundel et al. 1977). The growing season in these areas is short, with snow often on the ground in July (Barbour 1988; Barbour et al. 1991; Holland 1986; Mitchell and Moir 1976). Red fir can be found growing at lower elevations in canyons and other protected places where significant cold air drainage keeps soil and air temperatures low (Parker 1984). The species also occurs at high elevation on mountain ranges that continue in active formation, where it thrives on young, xeric soils. Red fir has a high frost tolerance and low drought tolerance. It is a late-seral species nearly everywhere it is found. Although red fir grows best in full sunlight, it can survive and grow for long periods in relatively dense shade.

Disturbance Interactions

Shasta red fir sustains moderate damage from low-severity fires but is often killed by mixed-severity fires (Atzet and Wheeler 1982). Openings created in mixed red fir and white fir (*Abies concolor*) stands in the Sierra Nevada tend to regenerate more readily to red fir (Parker 1986). Red fir is susceptible to windthrow after partial cutting, especially when marginal codominant and lower crown classes are left as the residual stand (Gordon 1973). Root diseases such as annosus root rot contribute significantly to lack of wind firmness. Other diseases that reduce tree vigor include dwarf mistletoe and cytospora (*Cytospora* spp.) canker, which, in turn, make trees susceptible to fir engraver attack.

Historical and Current Conditions

Native Americans used Shasta red fir forests for hunting mule deer (*Odocoileus hemionus*) and for other sources of food and materials during summer. Mining, logging, water diversions, railroad development, and sheep grazing altered some lower-elevation fir forests during the late 19th and early 20th centuries (Meyer n.d.). Burning was used to promote growth of grasses and forbs and to remove fuel and young trees from the understory (McKelvey and Johnston 1992), thus reducing fir regeneration. Starting in the 1950s, timber harvest and extensive road infrastructure began in portions of red fir forest, with silvicultural techniques that create even-aged stands being implemented (Potter 1998). By the 1990s, silvicultural practices emphasized shelterwood cutting and uneven-aged silvicultural systems (Laacke and Tappeiner 1996). Despite this history of resource use, red fir is largely undisturbed in many higher-elevation and isolated locations.

Climate Change Responses

Shasta red fir is expected to sustain moderate effects from a warmer climate. If snowpack decreases as expected, a longer growing season may increase growth at higher elevations. Regeneration could also improve under these conditions. Lower-elevation populations may grow more slowly where soil moisture is limited in summer. Red fir is typically found in forests with mixed-severity fire regimes, so if wildfire becomes more frequent than historical records indicate, especially where fuel loadings are elevated, fire severity could cause crown fires with high mortality in younger trees (older trees have thick bark and high crowns). Increased fire could produce a more open forest structure over decades to centuries.

Subalpine Fir (Abies lasiocarpa)

(Middle Rockies, Southern Greater Yellowstone, Uintas and Wasatch Front, Plateaus, Great Basin and Semi Desert subregions)

Autecology

Although widely distributed, subalpine fir grows within a narrow range of mean temperatures of 25 to 40 °F, with average January temperatures of 5 to 25 °F. Cool summers, cold winters, and deep winter snowpack are more important than precipitation in determining where it grows. Subalpine fir ranges from lower valleys to the upper subalpine zone in the IAP region, typically mixed with other species, most notably Douglas-fir and Engelmann spruce. Subalpine fir is shade tolerant; partial shade usually favors seedling establishment and early survival (Knapp and Smith 1982). It is relatively intolerant of drought, and seedlings can be killed by lengthy droughts. It is a prolific seeder, often having large cone crops every

2 to 3 years (Alexander et al. 1990), and although dense mats of seedlings can occur, they are also susceptible to many herbivores and pathogens.

Disturbance Interactions

Subalpine fir is highly susceptible to fire damage because of thin bark, shallow roots, and low, dense crowns (Ryan and Reinhardt 1988). Even low-intensity fire can cause mortality, and frequent fires can eliminate subalpine fir from both the overstory and understory, thereby maintaining more fire-adapted species such as lodgepole pine (Little et al. 1994; Murray et al. 1995; Wadleigh and Jenkins 1996). In spruce-fir forests, the most important insects are western spruce budworm and western balsam bark beetle (*Drycoetes confusus*). Fir broom rust (*Melampsorella caryophyllacearum*) and wood rotting fungi are responsible for most disease losses, but root and butt rots may be important locally. Decades of intense competition, coupled with a period of moderate to severe drought, can cause mortality in subalpine fir stands.

Historical and Current Conditions

Effects of fire exclusion have not yet become manifest in most subalpine fir ecosystems because of historically infrequent fire and slow successional advancement. However, abundance of subalpine fir has increased in some landscapes (Keane et al. 1994). These dense stands have become stressed from competitive interactions, resulting in susceptibility to disturbances and drought. If these stands continue to escape fire, the seed sources of co-located, fire-adapted species may be eliminated, and high-elevation sites could be converted to grass and shrublands (Keane 2001). In addition, if fire is excluded from these dense forests, fuels will accumulate, inevitably leading to high-severity fires (Keane 2001; Morgan et al. 1994b). Recent USFS Forest Health Monitoring data in the IAP region indicate that dieback of subalpine fir is occurring in some locations, attributed to a complex of drought, insects, and pathogens.

Climate Change Responses

Because subalpine fir is adapted to moist growing conditions, it is likely to respond poorly to increasing temperatures and drought (Alexander et al. 1990; Brunelle et al. 2005; Whitlock and Bartlein 1993). However, it is a good competitor and may be able to expand its range at treeline (Little et al. 1994; Rochefort et al. 1994; Villalba et al. 1994) and increase growth in a longer growing season (Peterson et al. 2002). Seedling establishment may be the bottleneck for subalpine fir establishment in the future because the species needs long periods of high moisture for germination and seedling establishment (Urban et al. 1993), and years that meet these conditions may be less frequent in the future. If stand densities increase, competitive stress will increase, making fir more vulnerable to insects, disease, and abiotic factors. If wildfire increases where subalpine fir is dominant, abundance would decrease from the direct effects of higher temperature. Subalpine fir is likely to shift across the high mountain landscape, with expansion balancing retraction, although fire, disease, and insects may limit abundance.

White Fir (Abies concolor var. concolor)

(Uintas and Wasatch Front, Plateaus, Great Basin and Semi Desert subregions)

Autecology

White fir is distributed throughout most of the American Southwest, from canyon bottoms and ravines up to ridgetops. It is a dominant, late-seral component of some habitat types in Utah and develops best on gentle slopes (Laacke 1990), although the rooting habit is adaptable to depth of the soil profile. It can survive for long periods as a suppressed tree in the understory, then respond with rapid growth if light becomes available. Within mixed conifer forests, white fir tends to achieve dominance on moist sites, especially if long fire return intervals provide the opportunity for it to mature to a point at which it is moderately fire tolerant. White fir is sensitive to frost damage (Laacke 1990), and is susceptible to windthrow following partial cutting.

Disturbance Interactions

In mixed conifer forests with an intact low-severity fire regime, white fir rarely attains dominance because it is more fire sensitive than its associates (Agee 1982; Alexander et al. 1984). Thus, many white fir habitat types are in mid-seral stages, with various species dominating the overstory and white fir dominating the reproductive size classes. White fir mistletoe (*Phoradendron bolleanum* subsp. *pauciflorum*) and white fir dwarf mistletoe (*Arceuthobium abietinum* f. sp. *concoloris*) damage white fir, causing spike tops, loss of vigor, and increased susceptibility to bark beetles (Bega 1978). White fir is susceptible to a number of decay fungi including annosus root disease, Armillaria root disease, laminated root rot (*Phelllinus weirii*), yellow cap fungus (*Pholiota limonella*), Indian paint fungus (*Echinodontium tinctorium*), and white pocket rot (*Phellinus mini*). Fir engraver beetle causes major losses throughout the range of white fir (Wilson and Tkacz 1996).

Historical and Current Conditions

White fir, which has historically been dominant on wetter sites and codominant in drier mixed conifer forests, has increased in abundance in areas where fire has been excluded. In some cases, the understory in fire-excluded stands is dense, and surface fuels are high, conditions conducive to a crown fire (Dahms and Geils 1997; McKelvey and Johnston 1992). If dense stands escape fire, the seed sources of other fire-adapted species may be eliminated, and some sites may have increased dominance of grass and shrublands (Keane 2001). White fir mortality following wildfire is often

100 percent, although associated species such as ponderosa pine and Douglas-fir often survive. White fir has never been a primary timber species, although it has been logged in some places. It was often left uncut where more valued species were removed, becoming the residual dominant.

Climate Change Responses

White fir has high shade tolerance but low drought tolerance, so low soil moisture will have the greatest effects in well-drained soils and on south aspects. Sudden temperature increases during May and June can cause damage nearly identical to that of spring frosts, which may be an issue for some fir populations. A modeling study in California suggested that effects of climate change on white fir will be moderate (Battles et al. 2008), and although this may be true in the IAP region, wildfire will play a major role in its future distribution and abundance. White fir is typically found in forests with low-severity and sometimes mixed-severity fire regimes, so if fire becomes more frequent than historically, especially where fuel loadings are elevated, fire severity could cause crown fires with high mortality rates. Over decades to centuries, increased fire could produce a more open forest structure with fewer white fir in both the canopy and understory.

Rocky Mountain Juniper (Juniperus scopulorum)

(Uintas and Wasatch Front subregion)

Autecology

Rocky Mountain juniper grows in dry, sub-humid climates. It is a drought-enduring species with a shallow but fairly extensive lateral root system. Rocky Mountain juniper is normally a component of early-seral or near late-seral vegetation. It is relatively shade tolerant during the seedling and sapling stages, but it later becomes more intolerant and is unable to endure excessive shade. In Utah, junipers have been observed occupying sagebrush stands under certain conditions; twoneedle pinyon (*Pinus edulis*) generally follows and tends to replace juniper. Pinyon-juniper communities may encroach into grasslands that have been overgrazed or disturbed. Once established, Rocky Mountain juniper competes well with understory vegetation for water and nutrients.

Recent paleobotanical studies indicate the macroclimate covering much of the Rocky Mountain juniper range has changed from mesic to more xeric conditions. Juniper is generally less drought resistant than other juniper species, and high temperatures are not favorable for regeneration or growth. Rocky Mountain juniper was present in western Nebraska and the Laramie Basin of Wyoming as recently as 1,000 years BP, with some trees over 50 inches in diameter (Tauer et al. 1987; Van Devender 1987).

Disturbance Interactions

Rocky Mountain juniper is susceptible to loss from erosion simply because it is often established on exposed sites where soils are readily eroded. It is susceptible to death or injury from fire, primarily because the bark is thin, and the lower branches contain volatile oils and normally extend to the ground (Hepting 1971; Noble 1990; Sieg 1997). Rocky Mountain juniper has a compact crown when young, and because it grows slowly, is susceptible to fire for the first 20 years or more (Crane 1982; Fischer and Clayton 1983; Hansen and Hoffman 1988; Mitchell 1984; Mueggler 1976; Stanton 1974). As trees mature, they develop thicker bark and a more open crown, allowing them to potentially survive surface fires. Large-diameter junipers have been documented to survive four to six fires.

Postfire reestablishment is solely by seed (Floyd et al. 2000), and animal transport of seeds is an important factor (Paysen et al. 2000). Regeneration is often high after old trees burn (Stanton 1974; Wright 1972). Frequent fires in pinyon-juniper habitat can maintain a grassland setting, and the absence of fire will allow conversion to woodlands (Gruell 1986). After fire in pinyon-juniper, junipers usually establish first, followed by pinyon pine, which may eventually replace juniper on higher-elevation sites (Holland 1990). The nonnative annual cheatgrass (*Bromus tectorum*) has become increasingly common in the understory over the past few decades, providing abundant fine surface fuels and increasing the potential for more frequent wildfires (Shinneman and Baker 2009).

Historical and Current Conditions

Rocky Mountain juniper was a source of fuel (charcoal) for the mining industry between the 1860s and 1920s (Young and Budy 1979), and it has been used extensively for firewood, fence posts, and other needs, with local deforestation occurring in some locations. In some lower-elevation sites, juniper has been cut or removed from the landscape through chaining and herbicides to encourage the growth of grasses and forage for livestock grazing. Persistent woodlands of Rocky Mountain juniper, pinyon pine, or a mixture of both are found where local soils and climate are favorable, and wildfire has been infrequent (Romme et al. 2009). Pinyon-juniper savannas are found where local soils and climate are suitable for both trees and grasses, and low-severity fires have been relatively frequent. Wooded shrublands are found where local soils and climate support a shrub community, but trees have increased during moist climatic conditions and periods without wildfire. Large increases in juniper density have occurred in portions of all types of pinyon-juniper vegetation, which may have been driven by factors such as natural range expansion, livestock grazing since the 1880s (which reduced fuels and probably decreased fire frequency), fire exclusion, climatic variability, and carbon dioxide fertilization (Romme et al. 2009).

Climate Change Responses

Rocky Mountain juniper is drought tolerant, and reduced soil moisture is not expected to have a significant effect on its abundance and distribution, although its growth and expansion into adjacent shrub-steppe systems could be slowed. The future of Rocky Mountain juniper will largely depend on spatial and temporal patterns of wildfire, which is expected to increase in frequency (Floyd et al. 2004). Junipers can generally survive low-severity fire if they are at least 20 years old, so if fires occur more frequently than that, tree mortality will be high. After an initial fire, accumulation of surface fuels and tree regeneration could be slow because of moisture limitations, resulting in a sparse canopy and disconnected fuels (Rocca et al. 2014). The long-term condition of juniper is complicated by nonnative annual grasses, especially cheatgrass, which increases surface fuels and fire frequency.

Utah Juniper (*Juniperus osteosperma*)

(Plateaus, Great Basin and Semi Desert subregions)

Autecology

Utah juniper is a late-seral species in several pinyon-juniper, sagebrush (*Artemisia* spp.)-grassland, and shrub-steppe habitats. Utah juniper tolerates dry soils (Hickman 1993; Lanner 1983; Meeuwig and Bassett 1983), commonly growing on alluvial fans and dry, rocky hillsides (Barney and Frischknecht 1974; Hitchcock and Cronquist 1973; Pieper 1977; Shantz and Piemeisel 1940) with shallow, alkaline soils (Bunderson et al. 1985). Utah juniper is shade intolerant (Meeuwig and Bassett 1983); it is a late-seral species in areas where stands are open and regeneration can occur without competition for light. Utah juniper has a taproot that extends deep into the soil, responding to low nutrient levels in the soil by developing extensive fine roots. Juniper competes more efficiently for soil moisture than do herbaceous understory plants, and is more likely to maintain a stable population as understory plants decrease (Austin 1987; Everett et al. 1983; Springfield 1976).

Disturbance Interactions

Utah juniper is generally not fire tolerant, although trees more than 4 feet tall are capable of surviving low-intensity fires (Bradley et al. 1992; Springfield 1976). Cheatgrass has become increasingly common in the understory over the past few decades, continually providing abundant fine surface fuels on and increasing the potential for more frequent wildfires (Shinneman and Baker 2009).

Historical and Current Conditions

Utah juniper was a source of fuel (charcoal) for the mining industry between the 1860s and 1920s (Young and Budy 1979), and has been used extensively for firewood, fence posts, and other needs, with local deforestation in some locations. In some lower-elevation locations, juniper has been removed from the landscape through chaining and herbicides to encourage growth of grasses and forage for livestock grazing. Persistent woodlands of juniper or pinyon pines, or a mixture of both, are found where local soils and climate are favorable, and wildfire has been infrequent (Romme et al. 2009). Pinyon-juniper savannas are found where local soils and climate are suitable for both trees and grasses, and low-intensity fires are relatively frequent. Wooded shrublands are found where local soils and climate support a shrub community, but trees have increased during moist climatic conditions and periods without wildfire. Large increases in juniper density have occurred in portions of all types of pinyon-juniper vegetation, which may have been driven by factors such as natural range expansion, livestock grazing (since the 1880s, which reduced fuels and probably decreased fire frequency), fire exclusion, climatic variability, and carbon dioxide fertilization (Romme et al. 2009).

Climate Change Responses

Utah juniper is drought tolerant, and reduced soil moisture is not expected to have a significant effect on its abundance and distribution, although growth may decline even as it spreads into adjacent shrub-steppe systems. The future of Utah juniper will largely depend on spatial and temporal patterns of wildfire, which is expected to increase in frequency (Floyd et al. 2004). Junipers can generally survive fire only if they are tall enough for the crown to escape flames. Following an initial fire, accumulation of surface fuels and tree regeneration will probably be slow because of moisture limitations, resulting in a sparse canopy and disconnected fuels (Rocca et al. 2014). The long-term condition of juniper is complicated by nonnative annual grasses, especially cheatgrass, which increases surface fuels and fire frequency.

Western Larch (*Larix laricina*)

(Middle Rockies subregion)

Autecology

Western larch grows in relatively cool, moist forests in the Middle Rockies portion of the IAP region (Habeck 1990; Schmidt and Shearer 1990), typically associated with several other conifer species. It is often found in locations that have relatively high snowfall, and is rarely found in xeric sites (Gower et al. 1995). Cone and seed production is abundant when trees are older than 30 years, with good seed crops occurring every 10 to 14 years (Owens 2008). Seed germinates best on seedbeds exposed by burning or mechanical scarification (Antos and Shearer 1980; Beaufait et al. 1977; Schmidt 1969; Shearer 1976), and young seedlings grow fast on suitable sites, although drought reduces seedling survival (Schmidt and Shearer 1995). Shade intolerant, larch grows fast with tall, open crowns, allowing it to outcompete other species on mesic sites (Milner 1992). It is moderately drought tolerant and can survive seasonal drought, but performs poorly when droughts last more than 2 years.

Disturbance Interactions

Western larch depends on open-canopy, high-light environments and mineral soil seedbeds created by fire for successful regeneration (Schmidt et al. 1976). It can survive intense fire because of thick bark (Ryan and Reinhardt 1988), high crowns, deep roots, and epicormic branch production (Fiedler and Lloyd 1995; Harrington 2012; Schmidt and Shearer 1995; Schmidt et al. 1976), often surviving crown fires that kill other species (Marcoux et al. 2015). Seeds are wind dispersed across large burns, and if mature lodgepole pine occurs with larch, regeneration may be dominated by both species (Hopkins et al. 2013).

Western dwarf mistletoe (*Arceuthobium campylopodum*) is a damaging, parasitic plant of larch (Schmidt and Shearer 1990). It infects seedlings and persists throughout the life of the tree, causing reduced growth, water loss, and deformities. Cool, wet springs favor foliar diseases such as larch needle cast (*Meria larisis*), which, in turn, can reduce cone production. Larch needle blight (*Hypodermella laricis*), brown trunk rot (*Fomitopsis officinalis*), and red ring rot (*Phellinus pini*) are also important pathogens. Western spruce budworm and the nonnative larch casebearer (*Coleophora laricella*) are the two most serious insect pests (DeNitto 2013; Schmidt and Fellin 1973). Although neither insect causes substantial mortality, episodic outbreaks can cause severe defoliation and reduce growth and cone production (Schmidt et al. 1976).

Historical and Current Conditions

Western larch was formerly an important timber species, but extensive logging during the 20th century removed many of the large larches, reducing its dominance on the landscape (Arno 2010). Reduced seed sources for regeneration and fire exclusion have reduced burned mineral soil seedbeds where larch can regenerate. Continued fire exclusion has increased stand densities and increased surface fuel loads, which will make future fires more intense than they have been historically. Considerable effort is underway to increase the distribution and abundance of western larch in locations where it was previously more common.

Climate Change Responses

Western larch may be susceptible to a warmer climate because of its narrow geographic and elevation distribution and its uncertain association with wildfire. If fire increases, larch may have a colonization advantage, as long as fire mortality is moderate and mature trees remain to serve as seed sources. Without seed sources, regeneration may require assistance from management through planting. If fire exclusion continues, stand densities will increase and larch may be outcompeted by shade-tolerant competitors, making it more susceptible to insects and disease. When dense stands burn, crown fires may kill older, seed-producing trees (Hopkins et al. 2013). Keane et al. (1996) simulated major declines for western larch under fire exclusion and moderate climate change, but found it increased as more fire was allowed to burn over many decades. Larch can take advantage of changes in productivity in colder sites, as long as these areas burn with low intensity and larch survives the fires to provide seed for regeneration.

Great Basin Bristlecone Pine (Pinus longaeva) and Rocky Mountain Bristlecone Pine (P. aristata)

(Uintas and Wasatch Front, Plateaus, Great Basin and Semi Desert subregions)

Autecology

Great Basin bristlecone pine occurs in montane, subalpine, and treeline communities from 7,200 to 12,000 feet elevation (Hickman 1993; Lanner 1999), typically in multi-aged stands (Bradley et al. 1992). It grows in pure stands at treeline and in the upper subalpine zone, and is codominant with limber pine at lower elevations (Critchfield and Allenbaugh 1969; Vasek and Thorne 1977). Great Basin bristlecone pine is drought tolerant (Bare 1982; Tang et al. 1999), occurring in climates that are cold in winter and dry in summer. It establishes quickly in open mesic sites (Hawksworth and Bailey 1980), but competes poorly for water and nutrients, and is usually excluded from productive sites (Beasley and Klemmedson 1973; Hiebert 1977).

Rocky Mountain bristlecone pine occurs from 8,200 to 11,000 feet elevation (FNAA 2009) and is common on steep, dry, south- or west-facing slopes. It grows in cold, continental climates, with precipitation patterns influenced by summer monsoons bringing afternoon rain. Rocky Mountain bristlecone pine is commonly found on unproductive sites with nutrient-poor, acidic soils. This species often occurs in pure stands or mixed with limber pine.

Disturbance Interactions

As a thin-barked species (Zavarin and Snajberk 1973), Great Basin bristlecone pine is adapted to survive only low-intensity surface wildfires, although fire is infrequent at high-elevation sites (Bradley et al. 1992). White pine blister rust (*Cronartium ribicola*) is present in some stands, but it rarely has a significant effect on populations. Most high-elevation pines eventually die from root rot decay or soil erosion, which exposes and kills roots (Lanner 1999). Small wildfires may kill a few trees.

Wildfires are common in Rocky Mountain bristlecone pine sites, but are usually small in extent and cause minimal damage because patchy stand structure and low fuel loadings limit fire spread (Crane 1982). Although fire is not a major disturbance factor, Rocky Mountain bristlecone pine is favored in early postfire succession because it is a shade-intolerant seral species (Baker 1992; Schoettle 2003). Blister rust has been recorded in this species only recently (Blodgett and Sullivan 2004) and is rarely observed in the IAP region.

Historical and Current Conditions

Great Basin bristlecone pine and Rocky Mountain bristlecone pine are located at high elevation in relatively inaccessible locations. Because these species have no commercial value, they generally remain undisturbed by human activity and exist in intact subalpine forests and woodlands.

Climate Change Responses

Great Basin bristlecone pine and Rocky Mountain bristlecone pine are tolerant of cold temperatures and deep snowpack in winter, low soil moisture in summer, and high winds. Therefore, they are expected to be moderately vulnerable to climate change, with considerable variation among sites. A recent study showed that Great Basin bristlecone has a threshold at 60 to 250 vertical feet below treeline, above which trees have a positive growth response to temperature (Salzer et al. 2014). Growth chronologies from 250 feet or more below treeline had a change in climate response and did not correlate strongly with temperature-sensitive chronologies developed from trees growing at upper treeline. At the highest sites, trees on south-facing slopes grew faster than trees on north-facing slopes. High growth rates on the south aspect have declined since the mid–1990s, suggesting that temperature may no longer be as limiting to growth. Therefore, increasing warmth may lead to a divergence between growth and temperature at previously temperature-limited sites. Neither species of bristlecone pine is expected to change in distribution and abundance significantly during the 21st century. Increased wildfire could affect Rocky Mountain bristlecone pine in mixed-species stands with high surface fuels, but not in higher-elevation locations where trees are scattered and fuels are low.

Jeffrey Pine (Pinus jeffreyi)

(Great Basin and Semi Desert subregion)

Autecology

Jeffrey pine is shade intolerant and drought adapted, occupying low- to mid-elevation, dry forests (Minore 1979). It is both an early- and late-seral species, often associated with other conifer species on moist sites. Moisture typically limits growth, especially in summer, and distribution of Jeffrey pine on drier sites is limited by available soil moisture, which, in turn, is affected by soil texture and depth. Jeffrey pine tolerates dry soil conditions by efficiently closing stomata to avoid water loss and xylem cavitation (Sala et al. 2005), tolerating intense drought, and drawing groundwater at low soil water potentials. Jeffrey pine is associated with several species of ectomycorrhizae, giving it the capacity to survive in dry environments. Soil texture, plant competition, and seedbed conditions reduce seed germination and limit seedling survival and growth, although it can often germinate under moisture stress (Oliver and Ryker 1990).

Disturbance Interactions

Disturbance plays a major role in Jeffrey pine forests. The most damaging of the tree-killing insects are several species of *Dendroctonus* (Oliver and Ryker 1990), followed by ips beetles, all of which are native and present naturally in many stands. Dwarf mistletoe is widespread in Jeffrey pine stands but rarely fatal. Bark beetles can cause extensive mortality given availability of preferred host stand conditions. Jeffrey pine has a high capacity to survive fire (Minore 1979; Ryan and Reinhardt 1988), and wildfire favors the growth of large (thicker bark) Jeffrey pine by killing its primary competitors and small-diameter Jeffrey pines (Arno 1988; Steele et al. 1986).

Historical and Current Conditions

Fire exclusion, mining, timber harvest, and livestock grazing have contributed to reductions in distribution and abundance of Jeffrey pine. Changes in fire regime have altered the composition and structure of many dry forests, with area burned by surface fires decreasing and crown fires increasing in many areas (Hann et al. 1997). Landscapes where fire has been excluded for many decades typically have high stand densities and surface fuel loadings, setting the stage for future crown fires.

Climate Change Responses

Jeffrey pine is expected to be relatively tolerant of increasing temperatures and longer droughts. This species has high phenotypic plasticity and is therefore adapted to drought, although regeneration may decrease if precipitation decreases or becomes more variable. Some studies project an increase in distribution for ponderosa pine in western North America (Hansen et al. 2001; Morales et al. 2015; Nitschke and Innes 2008) that may be true for Jeffrey pine as well. Advancing competition resulting from fire exclusion, increased wildfire extent and intensity, and potential increases in mountain pine beetle, western pine beetle (*Dendroctonus brevicomis*), several *Ips* species, and western pine shoot borer (*Eucosma sonomana*) will dictate the future of Jeffrey pine. If fires are too frequent, established regeneration will not grow above the lethal scorch height. Increasing wildfire extent and severity (crown fires) could also eliminate the mature Jeffrey pine trees that provide seed sources for populating future burns.

Limber Pine (Pinus flexilis)

(Middle Rockies, Southern Greater Yellowstone, Uintas and Wasatch Front, Plateaus, Great Basin and Semi Desert subregions)

Autecology

Limber pine is a shade-intolerant, early-seral species (Steele 1990) that is slow growing but long lived. It occupies xeric sites across a wide range of elevations (Jackson et al. 2010). Because it is easily killed by fire, the species is found in fire-protected sites (e.g., rocky outcrops) with infrequent fires of low severity (Steele 1990). It can be associated with a wide range of other conifer species and quaking aspen (Langor 2007; Steele 1990). It is associated with both ectomycorrhizae and arbuscular mycorrhizae that facilitate its ability to exist in extremely dry environments. Limber pine seedlings are poor competitors with grass, but grow reasonably well on rocky substrates and with shrubs. Limber pine has difficulty competing with encroaching species on productive mesic sites and is often succeeded by Douglas-fir and subalpine fir. Its seeds are dispersed by rodents and by Clark's nutcracker (*Nucifraga columbiana*), which relies on pine seeds as a food source and caches them throughout the subalpine zone (Lanner 1980; Lanner and Vander Wall 1980).

Disturbance Interactions

Thin bark and low crowns make limber pine susceptible to damage from wildfire. It is also susceptible to white pine blister rust, and some stands in newly infected areas are currently undergoing high mortality (Smith et al. 2013). Limber pine also facilitates the expansion of currant (*Ribes* spp.) into traditional grasslands (Baumeister and Callaway 2006), thus increasing rust infections and subsequent mortality. Mountain pine beetle (Jackson et al. 2010) and severe dwarf mistletoe infections can cause mortality. Porcupine (*Erethizon dorsatum*) damage is prevalent in some areas.

Historical and Current Conditions

Fire exclusion has allowed limber pine to expand its range from fire-protected sites into areas where frequent fires historically restricted it (Arno and Gruell 1983; Brown and Schoettle 2008). Expansion into some grass and shrub rangelands has facilitated expansion of other species as well (e.g., Douglas-fir) (Baumeister and Callaway 2006; Jackson et al. 2010). Some of the newly established limber pine forests have suffered recent mortality from white pine blister rust, mountain pine beetle, and red belt (*Fomitopsis pinicola*) (Jackson et al. 2010; Langor 2007; Taylor and Sturdevant 1998). Increasing wildfire extent has also affected some stands.

Climate Change Responses

Limber pine has a generalist adaptive strategy with broad phenotypic plasticity (Devine et al. 2012; Feldman et al. 1999), so it is expected to be moderately vulnerable to climate change. The ability of limber pine to occupy shallow, infertile soils and tolerate periods of drought will confer resistance to warmer temperatures and drought. Reduced snowpack could increase growth of limber pine at higher elevations by lengthening the growing season (Aston 2010). However, warmer temperatures could also reduce soil moisture for seed germination and seedling growth, and lack of ectomycorrhizal associations could inhibit establishment in some locations (Coop and Schoettle 2009). Increasing wildfire extent and intensity may impact some limber pine stands in the future, causing higher mortality and reducing encroachment into grasslands.

Lodgepole Pine (Pinus contorta var. latifolia, P.c. var. murrayana)

(Middle Rockies, Southern Greater Yellowstone, Uintas and Wasatch Front, Great Basin and Semi Desert subregions)

Autecology

Lodgepole pine has broad ecological amplitude and environmental tolerance, including both the *murrayana* variety in the western portion of the IAP region and the *latifolia* variety elsewhere in the region (Lotan and Critchfield 1990). It grows well on gentle slopes and in basins but is also found on steep slopes and shallow soils. It is shade intolerant but highly tolerant of frost and drought. Lodgepole pine grows in pure stands and in association with many other conifer species, including subalpine fir, Engelmann spruce, Douglas-fir, and western larch (Steele et al. 1983). It can be either early or late seral, depending on location. Its ability to remain on xeric landscapes is enhanced by its association with many types of mycorrhizae. Lodgepole pine is generally a prolific seed producer, and the prevalence of cone serotiny in most individuals of the *latifolia* variety promotes rapid regeneration following wildfire (Hardy et al. 2000).

Disturbance Interactions

Fire plays a critical role in lodgepole pine forest succession (Brown 1973; Lotan et al. 1984). Mature lodgepole pine appears to be able to survive low-intensity fire, despite having thin bark (Ryan and Reinhardt 1988). In many cases, natural regeneration is prolific via abundant seed from serotinous cones (Lotan and Perry 1983; Nyland 1998), although drought is a common cause of mortality in first-year seedlings. Mountain pine beetle has played a significant role in the dynamics of lodgepole pine ecosystems. Beetles and wildfire create an important stress complex for lodgepole pine in some locations (Brown 1973; Geiszler et al. 1980), but can also act independently (Axelson et al. 2009; Moran and Corcoran 2012).

Historical and Current Conditions

Advancing succession associated with fire exclusion is contributing to replacement of lodgepole pine by subalpine fir in some areas of the IAP region. Concurrent increases in recently burned areas are creating new lodgepole stands, some of which may become very dense. Increased drought in these dense stands may exacerbate stress from other factors, including competition and insects. Warming temperatures have contributed to unprecedented mountain pine beetle outbreaks in lodgepole pine in western North America, including in the IAP region, causing 100 percent mortality in many mature lodgepole pine stands (Carroll et al. 2003; Jenkins et al. 2008; Page and Jenkins 2007).

Climate Change Responses

Longer drought periods and warmer temperatures in drier lodgepole pine forests may cause decreased growth and regeneration, perhaps resulting in a transition to more xeric tree species. Chhin et al. (2008) and Nigh (2014) projected that growth will decrease in moderate future warming, but the species probably has sufficient genetic capacity to compensate for this loss. Given that lodgepole pine is a generalist and capable of regenerating and growing in a wide range of environments, it is likely that any reduction in lodgepole pine dominance in dry sites would occur only under extreme warming scenarios over many decades to centuries.

In high-elevation subalpine systems where seasonal drought is not a problem, a warmer climate may increase productivity (Aston 2010; Johnstone and Chapin 2003). Wang et al. (2006) found major increases in lodgepole pine productivity under future climates with moderate warming, but decreased productivity and perhaps local extinctions were associated with extreme warming. Romme and Turner (1991) projected increases in the lodgepole pine zone in the Greater Yellowstone Area under moderate warming. Lodgepole pine could migrate into upper subalpine areas where it is currently excluded by cold, windy conditions (Hamann and Wang 2006; Romme and Turner 1991). The *latifolia* variety is well adapted to increased fire occurrence, depending on level of serotiny (Turner et al. 1999), although if fire is too frequent, it could be eliminated from sites where fire returns before established seedlings and saplings become reproductively mature (Larson et al. 2013). Projected increases in climatic conditions that facilitate mountain pine beetle outbreaks (higher reproductive rates) (Bentz et al. 2010) could reduce the abundance of lodgepole pine in some landscapes (Creeden et al. 2014; Gillette et al. 2014) (Chapter 8), especially where fire has been excluded (Temperli et al. 2013).

Ponderosa Pine (Pinus ponderosa var. ponderosa, P.p. var. scopulorum)

(Middle Rockies, Uintas and Wasatch Front, Plateaus, Great Basin and Semi Desert subregions)

Autecology

Ponderosa pine is shade intolerant and drought adapted, occupying low-elevation, dry forests (Minore 1979), and is both an early- and late-seral species, often associated with Douglas-fir and grand fir on moister sites. In the IAP region, Pacific ponderosa pine (var. *ponderosa*) extends from the central mountains of Idaho to the east side of the Sierra Nevada in Nevada. The Rocky Mountain variety (var. *scopulorum*) extends from the eastern mountains of Nevada to the central and northern mountains of Utah. (Note that Washoe pine [*P. p.* subsp. *washoensis*], which is found in a few locations in the Great Basin and northeastern slope of the Sierra Nevada, is no longer considered a discrete subspecies and is not included in the assessment.) For both the Pacific and Rocky Mountain varieties, moisture typically limits growth, especially in summer, and distribution of ponderosa pine on drier sites is limited by available soil moisture, which, in turn, is affected by soil texture and depth. Ponderosa pine seedlings are susceptible to frost damage, which can exclude this species from low valleys (Shearer and Schimidt 1970). Ponderosa pine tolerates dry soil conditions by efficiently closing stomata to avoid water loss and xylem cavitation (Sala et al. 2005), tolerating intense drought, and drawing groundwater at low soil water potentials.

Cone crop periodicity in ponderosa pine varies greatly, but it is a poor seed producer in some areas. Natural regeneration is sporadic and is best when a heavy seed crop is followed by favorable weather in the next growing season (Heidmann 1983; Shearer and Schmidt 1970). The Rocky Mountain variety is highly inbred, and its vulnerability could be further compromised with limited gene flow between populations (Potter et al. 2015). Soil texture, plant competition, and seedbed conditions reduce seed germination and limit seedling survival and growth, although ponderosa pine can often germinate under moisture stress (Oliver and Ryker 1990). Young seedlings are susceptible to cold night temperatures and deep frosts, and trees occasionally suffer winter desiccation in drying winds.

Disturbance Interactions

Disturbance plays a major role in sustaining ponderosa pine forests. Over 100 species of insects attack the Pacific variety, and over 50 species attack the Rocky Mountain variety. The most damaging of the tree-killing insects are several species of *Dendroctonus* (Oliver and Ryker 1990), followed by ips beetles, both of which are present naturally in all stands. Dwarf mistletoe is widespread but rarely fatal. In the absence of fire or another disturbance that reduces stem density, bark beetles can cause extensive tree mortality. Ponderosa pine has a high capacity to survive fire, better than all of its competitors except western larch (Minore 1979; Ryan and Reinhardt 1988). Thus, wildfire favors the growth of large-diameter ponderosa pine by killing its primary competitors and small-diameter ponderosa pines (Arno 1988; Steele et al. 1986).

Historical and Current Conditions

Wildfire historically promoted ponderosa pine dominance across most low-elevation savannas because of its high resistance to fire, including high-intensity fire. Fire exclusion, mining, timber harvest, and livestock grazing caused major reductions in ponderosa pine forests (Jain and Graham 2005). Changes in fire regime altered the composition and structure of the remaining dry forests (Hann et al. 1997), with area burned by surface fires decreasing (Page and Jenkins 2007), mean fire return interval increasing, and crown fires increasing (Hann et al. 1997). Mid-seral structures have increased, often containing dense stands of small ponderosa pine, Douglas-fir, and grand fir. The proportion of dry forests occupied by late-seral, single-storied ponderosa pine has declined significantly, and Douglas-fir or grand fir is often common in the understory.

Climate Change Responses

Ponderosa pine is expected to be relatively tolerant of increasing temperatures and longer droughts. The Rocky Mountain variety has relatively high phenotypic plasticity and is therefore better adapted to drought, although regeneration may decrease if precipitation decreases or becomes more variable. Morales et al. (2015) projected an 11 percent increase in the range of ponderosa pine in the western United States, and Nitschke and Innes (2008) used gap modeling to project replacement of dry Douglas-fir with ponderosa pine in British Columbia. Hansen et al. (2001) projected that the range of ponderosa pine will expand in the western United States, whereas most other tree species ranges will decrease. Although species distribution models suggest that the range of ponderosa pine may decrease (Bell et al. 2014; Franklin et al. 1991; Gray and Hamann 2013) and rise in elevation (Crimmins et al. 2011) in a warmer climate, these projections are questionable because they do not consider on-the-ground growth processes and competition.

Advancing competition resulting from fire exclusion, increased wildfire extent and severity, and the potential for increased susceptibility to insects in warmer, drier conditions will dictate the future of ponderosa pine in the IAP region (Hann et al. 1997; Miller and Keen 1960; Negrón and Fettig 2014). If fires are too frequent, regenerating trees will not grow above the lethal scorch height and will not reach maturity. Increasing wildfire severity could also eliminate mature ponderosa pine trees that provide seed sources for populating future burns.

Singleleaf Pinyon (Pinus monophylla)

(Great Basin and Semi Desert subregion)

Autecology

Singleleaf pinyon is adapted to a wide variety of sites. It usually grows on pediments; dry, rocky slopes; ridges; and alluvial fans between 4,500 and 7,500 feet elevation (Lanner 1999; Stephenson and Calcarone 1999). It is frost resistant, drought tolerant, and shade intolerant (Lanner 1983), typically growing on shallow, well-drained, low-fertility soils, although it has been found on more productive soils as well (Evans 1988; Gottfried and Severson 1993; Gottfried et al. 1995). Pinyon pine typically grows in association with juniper species, where juniper dominates lower elevations of their range and pinyon the upper. Pinyon-juniper woodlands typically progress toward increased tree density and canopy cover over time (Everett 1985; Meeuwig et al. 1990; Short and McCulloch 1977; West et al. 1975), often expanding into adjacent grass and shrublands (Burwell 1998; West et al. 1975). Understory species make up a small portion of the total biomass in denser stands, although they may be important forage species and typically persist following disturbance (Everett and Koniak 1981).

Disturbance Interactions

In the Great Basin, there is evidence of both frequent, low-intensity fires carried by once-abundant perennial grasses, and less frequent, local stand-replacement fires during extreme conditions. Fires burned in irregular patterns, producing a mosaic of burned and unburned landscape. On high-productivity sites where sufficient fine fuels existed, fires burned every 15 to 20 years, and on less productive sites with patchy fuels, fire intervals were 50 to 100 years or longer. Fire frequency in singleleaf pinyon communities varies with fuel loads and ignition source, which, in turn, vary with habitat type, aspect, topography, stand history, and climatic conditions (Gruell 1999; Paysen et al. 2000). Cheatgrass has become increasingly common in the understory over the past few decades, continually providing abundant fine surface fuels and increasing the potential for more frequent wildfires (Shinneman and Baker 2009).

Pinyon dwarf mistletoe (*Arceuthobium divaricatum*) can cause extensive damage (Hawksworth and Wiens 1972), leaving trees susceptible to insect attack. Pinyon blister rust (*Cronartium occidentale*) occurs extensively on *Ribes* species in most western States but infects singleleaf pinyon only sporadically (Stillinger 1944), occasionally girdling small trees. Black stain root disease (*Ophiostoma wageneri*) occasionally kills singleleaf pinyon (Smith 1967b; Wagener and Mielke 1961). The disease spreads by root contact, and infection is confined to xylem in the roots and lower trunk. Pinyon ips (*Ips confusus*) is commonly found in pinyon woodlands, with outbreaks occurring when trees are stressed (Chapter 8).

Historical and Current Conditions

Singleleaf pinyon was a source of fuel (charcoal) for the mining industry between the 1860s and 1920s (Young and Budy 1979), and it has been used extensively for firewood and other uses, with local deforestation in some locations. In some lower-elevation locations, pinyon has been removed from the landscape to encourage the growth of grasses and forage for livestock grazing. Persistent woodlands of pinyon pine or juniper species, or a mixture of both, are found where local soils and climate are favorable, and wildfire has been infrequent (Romme et al. 2009). Pinyon-juniper savannas are found where local soils and climate are suitable for both trees and grasses, and low-intensity fires have been relatively frequent. Large increases in junipers have occurred in portions of pinyon-juniper woodlands (Romme et al. 2009). Damage to cryptobiotic crusts has caused erosion in some pinyon-juniper woodlands.

Climate Change Responses

Singleleaf pinyon is drought tolerant, and reduced soil moisture is not expected to have a significant effect on its abundance and distribution, although its growth may decrease over time. It is not as drought tolerant as the juniper species with which it is associated, and may decrease in abundance where the species compete. However, it may be able to outcompete ponderosa pine at higher elevations.

The future of singleleaf pinyon will largely depend on spatial and temporal patterns of wildfire, which is expected to increase in frequency (Floyd et al. 2004). Pinyon is only moderately fire tolerant and is easily engaged in crown fires because of low crowns and high concentrations of volatile chemicals. After an initial fire, accumulation of surface fuels and tree regeneration is likely to be slow (unless Gambel oak [*Pinus gambelii*] is present) because of moisture limitations, resulting in a sparse canopy and disconnected fuels (Rocca et al. 2014). If fire frequency is high in areas where pinyon is codominant with ponderosa pine, the latter species will become more common and pinyon will become less common. The long-term condition of juniper is complicated by nonnative annual grasses, which increase surface fuels and fire frequency. Insects, especially pinyon ips, will also be an important stressor, especially during extended droughts.

Twoneedle Pinyon (Pinus edulis)

(Plateaus subregion)

Autecology

Pinyon-juniper woodlands are found between the low plains covered by grassland, desert shrub, or chaparral vegetation and the high mountains just below the zone dominated by either submontane shrubs or ponderosa pine. They grow best on higher, wetter sites of the woodland zone, just below ponderosa pine (Fowells 1965; Jameson et al. 1962). Twoneedle pinyon grows in semiarid to arid climates, often associated with oneseed juniper (*Juniperus monosperma*) and Utah juniper. Pinyon is drought tolerant and shade intolerant, and seedlings require extra moisture or shade until their elongating taproots reach deeper substrates (Mitchell 1984). The extensive root system of established pinyons and relatively rapid rate of root elongation, especially of young seedlings, enhance the ability of pinyon to survive in dry environments.

Disturbance Interactions

Small pinyon pines are sensitive to fire and may be killed by low-intensity fire (Floyd et al. 2000; McCulloch 1969), whereas larger trees tend to be somewhat resistant to surface fire because foliage is high enough above the ground to avoid crown scorch or other damage (Dwyer and Pieper 1967; Wittie and McDaniel 1990). Cheatgrass has become increasingly common in the understory over the past few decades, continually providing abundant fine surface fuels and increasing the potential for more frequent wildfires (Shinneman and Baker 2009). Foliage diseases include needle casts (*Elytroderma deformans*, *Bifusella saccata*) and needle rusts (*Coleosporium jonesii*, *C. crowellii*) (Fowells 1965; Hepting 1971). Pinyon blister rust and pinyon dwarf mistletoe damage stems; the latter species is considered the major pathogen of pinyon.

Historical and Current Conditions

Pinyon-juniper woodland expansion since the time of settlement has been attributed to several factors, including a warming climate, fire exclusion, increased populations of seed-dispersing birds and mammals, and reduced competition from grasses resulting from overgrazing by livestock (Everett 1987; Jameson 1970). In the absence of wildfire, fuels have accumulated in some stands, especially in more mesic sites, increasing the possibility of crown fire. Hazardous fuels reduction, including prescribed burning, has been used in some locations.

Climate Change Responses

Twoneedle pinyon is drought tolerant, and reduced soil moisture is not expected to have a significant effect on its abundance and distribution, although its growth may decrease over time. It is not as drought tolerant as juniper, and may decrease in abundance where the species co-occur. However, it may outcompete ponderosa pine at higher elevations. Since 2000, twoneedle pinyon at low-elevation sites in northern New Mexico has suffered significant mortality associated with extended drought and pinyon *Ips* (Breshears et al. 2009) (Chapter 8), and although similar mortality has not been widespread in Utah, it may be possible during long droughts. If pinyon mortality increases in the future, juniper would probably become more dominant.

The future of twoneedle pinyon will largely depend on spatial and temporal patterns of wildfire, which is expected to increase in frequency (Floyd et al. 2004). Pinyon pine is only moderately fire tolerant, and it is easily engaged in crown fires because of low crowns and high concentrations of volatile chemicals. After an initial fire, accumulation of surface fuels and tree regeneration will probably be slow (unless Gambel oak is present) because of moisture limitations, resulting in a sparse canopy and disconnected fuels (Rocca et al. 2014). If fire frequency is high in areas where pinyon pine is codominant with ponderosa pine, the latter species will become more common and pinyon pine will become less common. The long-term condition of juniper is complicated by nonnative annual grasses, which increase surface fuels and fire frequency. Insects, especially pinyon *Ips*, will also be an important stressor, especially during extended droughts.

Western White Pine (Pinus monticola)

(Great Basin and Semi Desert subregion)

Autecology

Western white pine occupies the extreme western Great Basin portion of the IAP region and is typically associated with other conifer species. It is limited by moisture at lower elevations and by temperature at higher elevations. Western white pine grows on a variety of sites, but is more common along moist creek bottoms, lower benches, and northerly slopes. Seedling establishment is favored by partial shade in severe sites (Graham 1990) but minimal shade on northern slopes. Once established, it grows best in full sun. Seedlings have low drought tolerance, and first-year seedlings are subject to mortality from high surface temperatures on exposed sites. White pine attains dominance only after wildfire or in silvicultural systems that favor it. A generalist species with broad climate and environmental tolerances (Devine et al. 2012), western white pine adapts to different conditions through phenotypic plasticity and selective genetic differences.

Disturbance Interactions

Historically, white pine forests originated from wildfires, especially stand-replacing burns, but they were also maintained by frequent low-intensity fires (Barrett et al. 1991). When mature, white pine has thick bark and a high crown, which make it tolerant of fire. White pine blister rust has greatly decreased survival and vigor of white pine (Fins et al. 2002; Harvey et al. 2008), virtually eliminating this species in some locations. Armillaria root rot causes foliar chlorisis and root mortality, as well as reduced growth. Annosus root disease and laminated root rot also cause reduced vigor and some mortality. Bark beetles attack western white pine, killing groups of trees in mature forests, especially those weakened by blister rust (Chapter 8).

Historical and Current Conditions

Western white pine stands were previously more dominant in western North America (Harvey et al. 2008). It is much less abundant in mixed conifer forests as a result of logging, fire exclusion, and blister rust (Fins et al. 2002). This decline will probably continue to reduce abundance, and in some cases, cause local extirpation in the absence of assertive restoration.

Climate Change Responses

Western white pine may be well adapted to a warmer climate in some portions of its range (Loehman et al. 2011). It can disperse seeds into burned areas, which are likely to increase in the future, and a warmer climate may increase its productivity in some locations. However, the prevalence of white pine blister rust will make it difficult for white pine to persist in most forests (Fins et al. 2002; Harvey et al. 2008), and it is expected to continue to decline throughout much of its range.

Whitebark Pine (Pinus albicaulis)

(Middle Rockies, Southern Greater Yellowstone, Uintas and Wasatch Front subregions)

Autecology

Whitebark pine is an important component of upper subalpine forests in the IAP region (Arno and Hoff 1990). It supports unique components of floral and faunal diversity and promotes community development and stability (Tomback and Achuff 2010; Tomback et al. 2001). It is a long-lived tree, tolerates moderate shade (Minore 1979), grows slowly, and tolerates long periods of drought (Callaway et al. 1998). In the absence of wildfire, whitebark pine is replaced by subalpine fir and Engelmann spruce in some locations (Arno and Hoff 1990). Whitebark pine has a mutualistic relationship with Clark's nutcracker, which caches and disperses seeds (Tomback 1982, 1983). Whitebark pine is genetically diverse (Keane et al. 2012), allowing it to exist across many environments.

Disturbance Interactions

Whitebark pine fire regimes are complex and variable in space and time (Morgan et al. 1994b). Most fires in the upper subalpine zone burn in mixed-severity patterns that facilitate long-term survival of the species (Keane et al. 1994). Mountain pine beetle can damage mature stands, often causing high mortality. White pine blister rust is also damaging, preventing tree development and often causing mortality. Whitebark pine has some resistance to white pine blister rust, and although efforts at developing rust-resistant seed for regenerating burned and treated areas hold promise, restoration will need to occur at large spatial scales to be effective.

Historical and Current Conditions

Whitebark pine, a candidate species for listing under the U.S. Endangered Species Act (USFWS 2011), has been declining since the early 20th century from the combined effects of mountain pine beetle-caused mortality, fire exclusion, and spread of white pine blister rust (Schwandt 2006; Tomback and Achuff 2010) (fig. 6.4). Within the last decade, outbreaks of mountain pine beetle and increasing damage and mortality from blister rust have resulted in cumulative whitebark pine losses that have altered high-elevation community composition and ecosystem processes throughout much of western North America.

Climate Change Responses

Although whitebark pine was able to persevere through climatic variability in the past, it will be highly exposed to future climate change because of its confined distribution to upper subalpine environments. It is expected to continue to decline in abundance and vigor in a warmer climate, not because it is poorly adapted to an altered climate, but because it is experiencing so much stress from blister rust and mountain pine beetle that regeneration capability is greatly reduced (Bartlein et al. 1997; Bentz et al. 2016; Devine et al. 2012). In some cases, whitebark pine populations are so low that Clark's nutcracker is acting more as a seed predator than a seed disperser (Keane and Parsons 2010; Leirfallom et al. 2015). A warmer climate is expected to exacerbate this decline in most locations.

Figure 6.4—Whitebark pine. This species, which has been subjected to mortality from white pine blister rust for decades, may be more susceptible to mountain pine beetles in a warmer climate (photo: J. Beck, National Park Service).

Blue Spruce (Picea pungens)

(Middle Rockies, Southern Greater Yellowstone, Uintas and Wasatch Front, Plateaus, Great Basin and Semi Desert subregions)

Autecology

The shallow roots of blue spruce restrict it to moist sites where water is close to the surface (Lanner 1983). Blue spruce occurs at middle elevations on montane streambanks, well-drained floodplains, first-level terraces, ravines, intermittent streams, and gentle slopes (Fechner 1985; Hess and Alexander 1986; Lanner 1983). Spruce grows in cool climates that are sub-humid to humid and characterized by low summer temperatures and low winter precipitation. It is a pioneer species in riparian communities that are subject to periodic disturbances, such as scouring and flooding (Baker 1990; Fechner 1990; Szaro 1990). It is a shade-tolerant, mid- to late-seral species in montane and subalpine zones (Baker 1988; Schmidt and Larson 1989).

Disturbance Interactions

Blue spruce is easily killed by fire (Jones 1974; Wright and Bailey 1982). Insects and disease reduce growth, viability, and vigor of spruce (Fechner 1985; Walters 1978) (Chapter 8). Heart and root rots, cone rusts, nematodes, snow molds, canker, and tip blight can reduce the vigor of spruce (Fechner 1990; Nelson and Krebill 1982) and can cause mortality in older, low-vigor trees.

Historical and Current Conditions

Because blue spruce is located at high elevation and has no commercial value for timber, it has been relatively free of human influence, except in stands where it may have been associated with harvest of other species, such as Engelmann spruce. Western spruce budworm has killed patches of spruce and often other species in some locations, but this appears to be a normal occurrence in older, low-vigor stands.

Climate Change Responses

Climate change may reduce the functionality of riparian and wet meadow locations where blue spruce is commonly found. Therefore, its distribution and abundance could decrease locally if growth and vigor decline over time. Wildfire is currently uncommon in blue spruce communities, but if it becomes more frequent in a warmer climate, blue spruce will decrease in abundance because of fire. If fire frequency is high enough, spruce may not achieve dominance in the overstory.

Engelmann Spruce (Picea engelmannii)

(Middle Rockies, Southern Greater Yellowstone, Uintas and Wasatch Front, Plateaus, Great Basin and Semi Desert subregions)

Autecology

Engelmann spruce is widely distributed and is a major component of high-elevation forests in the IAP region (Alexander and Shepperd 1990) It occupies very cold environments in some locations. It is shade tolerant, although not as much as its common associate subalpine fir. This species is not drought tolerant, especially as a seedling (Alexander and Shepperd 1990), but tolerates frost and seasonal standing water. Pure Engelmann spruce is found in wet areas, but the species is usually mixed with other conifer species in upland locations. Seeds germinate in a variety of substrates, including litter and decomposed humus. Following establishment, survival is favored by adequate soil moisture, cool temperatures, and some shade.

Disturbance Interactions

Engelmann spruce is highly susceptible to fire injury and death, but some large spruce can survive severe burns (Bigler et al. 2005; Wadleigh and Jenkins 1996). It survives fire better than its primary associate, subalpine fir (Ryan and Reinhardt 1988). Surviving spruce can provide abundant seed in burned areas, although the subsequent forest may or may not be dominated by both spruce and other species (e.g., subalpine fir) (Pfister et al. 1977). Engelmann spruce is susceptible to windthrow, especially after timber harvest and thinning. Several insect species are associated with Engelmann spruce (Chapter 8).

Historical and Current Conditions

Recent trends in Engelmann spruce forests across the IAP region are unclear. Advancing succession during many decades of fire exclusion has probably increased spruce abundance in subalpine and upper subalpine landscapes. But logging and fire have reduced spruce at lower elevations, where it occurs in seasonally wet areas and frost pockets. Several locations throughout the IAP region with mature Engelmann spruce have sustained extensive mortality from spruce beetle (*Dendroctonus rufipennis*) outbreaks.

Climate Change Responses

Some losses of Engelmann spruce are likely in drier portions of its range, especially in seasonally moist sites that will be drier in the future. Some mortality may have already occurred from recent drought (Liang et al. 2015). Higher temperatures can increase growth in some locations (Luckman et al. 1984) and reduce growth in other locations (Alberto et al. 2013). If wildfire frequency increases, it will probably reduce the extent of mature spruce, although it readily establishes following wildfire. Spruce beetle can cause greater stress in a warmer climate, especially in mature stands (Bentz et al. 2010). Although Engelmann spruce is sensitive to climate, it will probably persist in high-elevation landscapes, because of its genetic capacity to adapt to climatic variability by taking advantage of suitable microsites (Jump and Peñuelas 2005).

Quaking Aspen (Populus tremuloides)

(Middle Rockies, Southern Greater Yellowstone, Uintas and Wasatch Front, Plateaus, Great Basin and Semi Desert subregions)

Autecology

Quaking aspen is abundant in the IAP region, with its distribution limited by water availability and growing-season temperature. Aspen stems are relatively short lived and maintained by disturbance (Mueggler 1985; Rogers 2002), although belowground genets of aspen clones can survive for millennia. It is shade intolerant and sprouts aggressively following disturbance (usually fire), which kills most of the live stems, thus stimulating vegetative propagation (suckering) (Bartos 1978) and facilitating rapid reoccupation of the site. This species has substantial phenotypic variation, as evidenced by varied foliar morphology, stem morphology, and phenology among different clones.

Disturbance Interactions

Browsing of post-disturbance suckers by ungulates—including elk (*Cervus elaphus*), moose (*Alces alces*), and cattle—frequently damages seedlings and sprouted stems (Eisenberg et al. 2013; White et al. 1998), and in some cases mature trees, thus increasing susceptibility to insects and pathogens. Wildfire can kill aboveground stems (Bartos 1998) but also promotes new seedlings and suckering by eliminating conifers (Campbell and Bartos 2001; Shepperd et al. 2001). Following disturbance, aspen dominates a site for 40 to 80 years; thinning from insects and disease and succession (shading) by conifers eventually reduce aspen abundance (Mueggler 1985; Rogers 2002). Hypoxylon canker (*Hypoxylon mammatum*) causes significant damage in some locations (Perala 1990). Young trees can be killed by small rodents and mammals (Eisenberg et al. 2013).

Historical and Current Conditions

Since around 1970, aspen has been in a period of general decline that may be at least partly attributed to wildfire exclusion, allowing plant succession to proceed toward conditions that ordinarily exclude aspen (Campbell and Bartos 2001; Frey et al. 2004). Recent episodes of aspen dieback ("sudden aspen decline") have been superimposed on this general decline; the epidemiology begins with death of branch tips and progresses to death of mature trees and eventually death of entire clones (Frey et al. 2004). Dieback is suspected to be caused by periods of drought (Worrall et al. 2013). The worst symptoms are generally found at lower elevations.

Climate Change Responses

Seral aspen communities will respond to a warmer climate differently than mature aspen communities (Rice et al. 2017). Aspen on warmer sites could suffer high mortality because of increasing water deficit (Hogg and Hurdle 1995; Ireland et al. 2014). Extreme droughts (Frey et al. 2004) and high temperatures (Perala 1983) are of special concern, especially at the margins of aspen distribution at low elevation, and may weaken trees enough that insects and pathogens can cause tree mortality (Rice et al. 2017). Increased wildfire frequency, particularly on moist sites, is likely to favor aspen regeneration in the future by removing conifers. If future wildfires are severe, however, they may kill shallow root systems and locally extirpate aspen. In some locations, declining stands may have little regeneration because of ungulate herbivory (Rogers et al. 2013).

Fremont Cottonwood (Populus fremontii)

(Southern Greater Yellowstone, Uintas and Wasatch Front subregions)

Lanceleaf Cottonwood (Populus × acuminata)

(Great Basin and Semi Desert subregion)

Narrowleaf Cottonwood (Populus angustifolia)

(Southern Greater Yellowstone, Uintas and Wasatch Front, Plateaus, Great Basin and Semi Desert subregions)

Balsam Cottonwood (Populus balsamifera)

(Middle Rockies subregion)

Autecology

The four cottonwood species in the IAP region—Fremont cottonwood, lanceleaf cottonwood, narrowleaf cottonwood, and balsam cottonwood—grow primarily in seasonally wet to moist open-canopy sites, typically along streams and rivers. Cottonwood often dominates riparian communities on alluvial sites from 4,000 to 6,000 feet elevation, with other hardwood species, shrubs, and grasses in the understory. Cottonwood is shade and drought intolerant, requiring access to the water table during most of the growing season (Rood et al. 2003). High streamflows facilitate seedling establishment through scouring and deposition of alluvial sediments for germination of windborne seeds. High numbers of seedlings often become established after a flood, but thin over time. Seedlings and saplings are frequently injured and sometimes killed by early or late frosts (DeBell 1990).

Disturbance Interactions

Cottonwood is somewhat fire tolerant owing to its thick bark and high branches. It is a weak stump sprouter, but rarely regenerates from suckers (Brown 1996). Cottonwood can resprout and survive low-intensity fires in the short term (Gom and Rood 1999), but fire injuries can introduce diseases that weaken and sometimes kill trees (Borman and Larson 2002). Several insects attack cottonwood. Many fungal species cause decay in cottonwood, but only brown stringy heart rot (*Spongipellis delectans*) and yellow laminated butt rot (*Pholiota populnea*) cause significant damage. Russian olive (*Elaeagnus angustifolia*) and saltcedar (*Tamarix* spp.) are aggressive nonnative trees that can outcompete cottonwood in some locations, particularly during or after drought (Shafroth et al. 2002).

Historical and Current Conditions

Cottonwood species are well distributed within their respective habitats in the IAP region, although degradation of riparian areas by grazing and other land uses have damaged some trees and the functional integrity of the riparian system. Russian olive and saltcedar have displaced cottonwoods in many locations, thus altering local hydrological function, because the nonnative species take up more water than native species. Biological control releases of the nonnative northern tamarisk beetle (*Diorhabda carinulata*) in the Southwest, starting in the 1990s, have caused rapid mortality and decline in vigor in many saltcedar populations (Sher and Quigley 2013; Tracy and Robbins 2009).

Climate Change Responses

As snowpack declines and melts earlier with warming temperatures, there will be reduced, attenuated river flows, along with a possible shift in timing of peakflows. These shifts may decrease germination and establishment of young cottonwoods, depending on the relative timing of floods and seed production (Whited et al. 2007). Altered hydrological flow, which can also be caused by withdrawal for human use, will affect both floodplain interaction and water available to cottonwoods, which, in turn, can affect recruitment and establishment of seedlings (Auble and Scott 1998; Beschta and Ripple 2005). Upland conifers can potentially establish in the riparian zone if the local water table has dropped, increasing competition with cottonwoods. Long-term transport of seeds provides cottonwood with an effective mechanism for regeneration across large landscapes, conferring some resilience to future climate.

Sitka Alder (Alnus viridis subsp. sinuata)

(Middle Rockies subregion)

Thinleaf Alder (Alnus incana subsp. tenuifolia)

(Middle Rockies, Southern Greater Yellowstone, Uintas and Wasatch Front, Plateaus, Great Basin and Semi Desert subregions)

White Alder (Alnus rhombifolia)

(Middle Rockies subregion)

Autecology

Sitka alder and thinleaf alder are small, deciduous trees or shrubs found on a wide range of soils and wide range of elevations. Sitka alder is usually multistemmed and bushy, forming dense thickets. White alder is a deciduous, medium to large tree found on a variety of soils typically near permanent streams at low to mid-elevations. All species are found on moist, cool sites, typically riparian areas or other locations where a reliable water source is available; for example, Sitka alder is often located in avalanche tracks. These species are associated with other hardwood and shrub species, mixed with or intermittent with overstory conifer species. All species are moderately shade tolerant (Haeussler and Coates 1986). Seeds require a moist mineral soil for germination, which normally takes place in the spring. Thinleaf alder can also propagate by cloning (Hall 1973). All alder species fix nitrogen through their association with actinomycetes.

Disturbance Interactions

Many sites occupied by alder species are subject to periodic flooding. Although tops may be damaged or killed, all species can sprout from root crowns. Wind-dispersed seeds readily germinate on alluvial soils exposed by floods or covered by sediment, and on bare soil created by wildfire, avalanches, and soil slumps. Alders have thin bark, and stems are easily killed by fire. Although alder can be killed by severe fire (Barro et al. 1989), it can also sprout following top kill by fire (Fischer and Bradley 1987). Although alder wood is resilient and somewhat limber, avalanches can damage Sitka alder and thinleaf alder, which often reproduce by sprouting (Oliver et al. 1985).

Historical and Current Conditions

Alders have rarely been disturbed by human activity because they have no timber value. They have been subjected to some stress in riparian areas that have been disturbed by water withdrawals or livestock grazing.

Climate Change Responses

In general, higher temperatures are not expected to have significant direct effects on alder species because alders are usually located in riparian areas that are buffered from temperature increases. However, smaller riparian areas may become drier in a warmer climate, especially if they rely on adjacent snowpack. Lower levels of soil moisture could reduce the vigor of alder and other species. Increased frequency of wildfire may be a significant stressor for white alder because it may not sprout vigorously after fire (Fryer 2014), possibly making associated species more competitive. Sitka alder and thinleaf alder can sprout after wildfire, so increased disturbance will probably not affect their distribution and abundance.

Velvet Ash (Fraxinus velutina)

(Uintas and Wasatch Front, Plateaus subregions)

Autecology

Velvet ash (also called desert ash or Arizona ash) is a deciduous tree with spreading branches and a rounded crown (if it has sufficient sunlight) that grows up to 30 feet tall when mature. It is found in riparian areas in canyons and along streambanks in desert mountains of southern Utah and southern Nevada above 3,000 feet elevation. Velvet ash grows in a variety of substrates, including alkaline soils. The presence of this species in the desert generally indicates a permanent underground water supply. It is shade intolerant, regenerates through wind dispersal of winged seeds, and can sprout from the base when damaged.

Disturbance Interactions

Velvet ash is easily top-killed by fire, but stumps can sprout vigorously following fire and mechanical damage and can attain prefire heights in 8 years (Winkel and Syzdek 2015). North American ash populations are at substantial risk from the introduction of emerald ash borer (*Agrilus planipennis*), which has now reached as far west as Colorado. Large-scale mortality of ash trees, as a result of borer infestations, would probably result in significant modifications in the composition and successional dynamics of many natural forests (MacFarlane and Meyer 2005) (Chapter 8).

Historical and Current Conditions

Little is known about the historical distribution or uses of velvet ash. It has no commercial value for timber but may have been used for firewood in some locations. Its populations are probably mostly intact, except where riparian areas have been modified.

Climate Change Responses

As soil moisture declines in a warmer climate, marginal riparian sites for velvet ash may become less favorable for regeneration and survival of young trees. With increases in fire frequency, there are likely to be increased vegetative regeneration and decreased production of seedlings following fire; fire would probably kill seeds on or near the soil surface, restricting seedling recruitment to surviving seed-producing trees. Low-intensity fires may promote regeneration by thinning stands and stimulating sprouting. Increased temperatures may promote ash seedling and mature tree growth by increasing soil temperatures. Browsing pressure on ash may increase with increased drought, as upland grasses and forbs desiccate and senesce earlier, or are replaced by less palatable species.

Water Birch (Betula occidentalis)

(Middle Rockies, Southern Greater Yellowstone, Uintas and Wasatch Front, Plateaus, Great Basin and Semi Desert subregions)

Autecology

Water birch is primarily a riparian species, occurring near waterways, wet swales, marshes, ravines, bogs, and moist woodlands (Arno and Hammerly 1977; Welsh et al. 1987). Water birch is common along streams in steep areas of the IAP region, especially in coarse-textured, moist to wet soils (Sutton and Johnson 1974). Although common in semiarid climates (Arno and Hammerly 1977), water birch is not particularly drought tolerant (Merigliano 1996) but is moderately shade tolerant and flood tolerant. In the Great Basin, riparian habitats with water birch are found in upland habitats ranging from mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyana*) shrublands (Manning and Padgett 1989) to fir forests (Lanner 1983).

Disturbance Interactions

Water birch often forms clumps by sprouting from the base of the trunk (Harrington 1964). Sprouts can develop after top kill by flooding or other physical injury (Hansen et al. 1995; Skinner et al. 2006) or without aboveground damage (Lanner 1983). This species can regenerate quickly following damage and disturbance.

Historical and Current Conditions

Little is known about the historical distribution and use of water birch. It has little commercial value but is sometimes used for firewood and fence posts. Birch is used as browse by ungulates, including livestock, to some extent. Birch stems may have increased in some areas where American beaver (*Castor canadensis*) populations were reduced or extirpated.

Climate Change Responses

Water birch adapts well to a wide range of climate and water availability (Disalvo and Hart 2002). As soil moisture declines with a warmer, drier climate, marginal riparian sites for birch may become less favorable for regeneration and survival of young trees. With increased fire frequency, there are likely to be better vegetative regeneration and decreased production of seedlings following fire events. Fire would probably kill seeds on or near the soil surface, restricting seedling recruitment to surviving seed-producing trees. Low-intensity fires may promote regeneration by thinning stands and stimulating sprouting. Birch productivity may benefit from increased temperatures because seedling and mature tree growth may increase with increasing soil temperatures. Browsing pressure may increase with increased drought, as upland grasses and forbs desiccate and senesce earlier, or are replaced by less palatable species.

Boxelder (Acer negundo)

(Southern Greater Yellowstone, Uintas and Wasatch Front, Plateaus subregions)

Autecology

Boxelder is a fast-growing and fairly short-lived hardwood that grows in riparian and palustrine communities. It generally grows on moist sites along lakes and streams, on floodplains, and in low-lying wet places where its shallow root system can find abundant moisture (Lanner 1983). Resilient to climate extremes (Preston 1948), boxelder is drought tolerant once established and can withstand short periods of flooding (Sutton and Johnson 1974). It is moderately shade tolerant but does not reproduce in its own shade. Boxelder roots are shallow and spreading, except in deep soils (Preston 1948; Sutton and Johnson 1974). It tolerates a wide range of soils but grows more vigorously in well-drained soils (Medina 1986).

Disturbance Interactions

Boxelder grows on moist bottomland sites, which are seldom subject to burning. This thin-barked species is easily injured by fire (Van Dersal 1938), regenerating via sprouting and seeds. It produces large annual crops of wind-dispersed seeds that germinate on a wide variety of soils. It also sprouts from the root crown, stump, or exposed roots following top kill by mechanical damage (Hansen and Hoffman 1988; Nix and Cox 1987). Verticillium wilt (*Verticillium albo-atrum*) is the only notable disease that kills boxelder, although it is also susceptible to stem canker caused by eutypella canker (*Eutypella parasitica*). Boxelder bugs (*Boisea trivittata*) infest boxelder trees and other maples, but do not cause significant damage.

Historical and Current Conditions

Boxelder was used for windbreaks and erosion control in many parts of the West. It has no commercial value but is sometimes used for firewood. It is used as browse by ungulates, and although it is unpalatable to livestock, the animals may damage stems while seeking shade. It is possible that boxelder stems have increased in some areas where American beaver populations were reduced or extirpated (Dieter and McCabe 1989). It is probably mostly intact from an ecological perspective.

Climate Change Responses

Boxelder exists across a broad range of soils and topographic locations, but as soil moisture declines in a warmer climate, marginal riparian sites may become less favorable for regeneration and survival of young trees. With increased fire frequency, there are likely to be increased vegetative regeneration and decreased production of seedlings following fire. Fire is likely to kill seeds on or near the soil surface, restricting seedling recruitment to surviving seed-producing trees. Low-intensity fires may promote regeneration by thinning stands and stimulating sprouting. Boxelder productivity may benefit from increased temperatures because seedling and mature tree growth may increase with increasing soil temperatures. Browsing pressure on boxelder may increase with increased drought, as upland grasses and forbs desiccate and senesce earlier, or are replaced by less palatable species.

Figure 6.5—Gambel oak sprouts vigorously following wildfire, as shown in both the foreground and background. The distribution and abundance of this species may increase in a warmer climate, replacing conifers as a dominant species in some locations (photo by Heath Haussamen, used with permission).

Gambel Oak (Quercus gambelii)

(Uintas and Wasatch Front, Plateaus, Great Basin and Semi Desert subregions)

Autecology

Gambel oak is a small deciduous tree or large shrub that is widespread in foothills and lower mountain locations of the IAP region. The tree typically grows at between 3,000 and 10,000 feet elevation, where average annual precipitation is 10 to 24 inches. Oak height is typically 10 to 30 feet depending on soil type and water availability. Branches are irregular and crooked, making them flexible enough to bend without breaking when covered with snow. Deep roots, xeromorphic leaves, and efficient water transport contribute to the high drought tolerance of Gambel oak (Kolb and Stone 2000), which grows in both pure stands and associated with ponderosa pine, pinyon pine, and other hardwood tree and shrub species. In most of its range, Gambel oak regeneration depends more on sprouting than establishment from seed (Clary and Tiedemann 1986; Larsen and Johnson 1998).

Disturbance Interactions

Gambel oak responds to fire by vegetative sprouting from its lignotuber and rhizomes, and even the stems can survive low-intensity fires (Harper et al. 1985) (fig. 6.5). Fire frequency in oak stands depends on accumulation of fuels by both oak and associated species (Mitchell 1984). Following wildfire, sprouts continue to grow, and natural thinning occurs, adding dead stems to the fuel bed. In the absence of fire, sprouts form young poles. At the pole stage, fires cause 100 percent stem mortality, either creating openings within stands for resprouting or cycling back to a grass-forb stage. In the absence of fire, Gambel oak stands reach maturity in 60 to 80 years. Dense understories of oak may serve as ladder fuels that carry fire to overstory conifers, increasing fire risk to adjacent species. Fire in some ponderosa pine stands can convert to thickets of Gambel oak, initiating a Gambel oak successional stage after the competing ponderosa pine overstory is removed (Dick-Peddie and Moir 1970). Late-spring frosts that kill oak leaves can cause extreme fire behavior later in the summer; the dead leaves tend to cling to the stem and act as dry aerial fuels (Jester et al. 2012). Many insects and diseases are associated with Gambel oak.

Historical and Current Conditions

Gambel oak acorns have been an important food for Native Americans for thousands of years, and the species is widely used for firewood. Oak density has been reduced in some areas with herbicides, mechanical treatments, and prescribed burning, typically to reduce fire hazard and protect overstory species such as ponderosa pine. In some areas where multiple wildfires have occurred in the past 30 years, oak appears to be increasing in dominance through sprouting and mortality of conifers (e.g., Adams and Dockter n.d.) combined with slow regeneration of the overstory.

Climate Change Responses

Gambel oak is very tolerant of low soil moisture, providing an advantage in a warmer climate with more droughts. Oaks sprout readily following wildfire, and with an expected increase in fire in the future, oaks may retain dominance or codominance in most locations. Being adapted to both drought and fire will improve the competitive status of oak with co-occurring tree species such as ponderosa pine and pinyon pines and probably with other shrub species, except at the lowest elevations where shrub-steppe systems dominate. Therefore, it is likely that Gambel oak will increase in abundance and possibly distribution in a warmer climate with more fire.

Curl-Leaf Mountain Mahogany (Cercocarpus ledifolius)

(Uintas and Wasatch Front, Plateaus, Great Basin and Semi Desert subregions)

Autecology

Curl-leaf mountain mahogany is a drought-tolerant, somewhat shade-tolerant, slow-growing tree or tall shrub (Lacey and Mosley 2002; Lanner 1983) found at 4,000 to 8,000 feet elevation in the IAP region (Brotherson 1990), typically in scattered patches and in extensive pure stands on dry, rocky slopes between conifer and desert steppe communities (Munz 1973; Stubbendieck et al. 1992). The root system is shallow and spreads widely (Sutton and Johnson 1974), typically in shallow to deep, well-drained, low-fertility sandy loam soils (Davis 1990; Hickman 1993).

Disturbance Interactions

Wildfires usually cause mortality of curl-leaf mountain mahogany, although older plants with thick bark may survive low-intensity fires (Gruell et al 1985; Martin and Johnson 1979). Postfire regeneration is primarily by seedling establishment (Gruell et al. 1985), and sprouting after fire is rare (Tisdale and Hironaka 1981). Several species of insects, including mountain-mahogany looper (*Iridopsis clivinaria*), feed on mountain mahogany, but do not generally cause significant damage.

Historical and Current Conditions

Curl-leaf mountain mahogany was used by Native Americans to make bows and other small implements. Euro-Americans first used it as fuel for mining in the 1860s. The species provides forage for ungulates and wildlife. Livestock can damage productivity where grazing is heavy (Smith 1967a). Fire exclusion has facilitated increased mountain mahogany abundance and successful regeneration in some locations (Gruell 1982; Kay 2003), allowing it to compete with more fire-adapted species. Mountain mahogany is occasionally killed with herbicides, mechanical removal, or prescribed fire to improve range quality or reduce fuel bed continuity.

Climate Change Responses

Curl-leaf mountain mahogany is drought tolerant, so it should continue to be productive in a warmer climate with more droughts, especially compared to other species. However, if wildfire frequency and extent increase as expected, it will be at a disadvantage because it is not fire tolerant and does not regenerate by sprouting. If wildfire is sufficiently frequent, new seedlings may be successively killed, thus reducing the abundance of mountain mahogany across fire-prone landscapes.

Bigtooth Maple (Acer grandidentatum)

(Uintas and Wasatch Front, Plateaus, Great Basin and Semi Desert subregions)

Autecology

Bigtooth maple is an important component of montane riparian communities in the IAP region (Fitzhugh et al. 1987; Moir 1982), typically located in canyons, in ravines, along mountain streams, and on lower slopes (Alexander et al. 1984; Cronquist et al. 1997) at 4,000 to 7,000 feet elevation. It is more abundant in the bottom than in the top of snowmelt drainages. In Idaho, it grows on hillsides, below springs and seeps, and on secondary floodplains of narrow canyon drainages (Hall and Hansen 1997). It is found on upper slopes in the Wasatch Mountains, although it is more common on mesic, north-facing slopes than on drier south-facing slopes (Dina and Klikoff 1973; Ehleringer et al. 1992). Bigtooth maple is drought tolerant (Sorenson et al. 1984; Sutton and Johnson 1974) and cold hardy, and tolerates summer temperatures above 100 °F (Sorenson et al. 1984).

Disturbance Interactions

Although bigtooth maple can be top-killed by fire, plants can survive by sprouting from the root crown (Bradley et al. 1992; Harper et al. 1992). In a severe burn, this species is likely to be killed (Harper et al. 1992). Smaller stems are more likely to be killed by fire, clearing areas for new tree seedlings and sprouts from surviving larger trees.

Historical and Current Conditions

Little is known about the historical distribution and use of bigtooth maple. It has no economic value except as firewood. The species is used for forage and cover by native ungulates and for cover by livestock (Hall and Hansen 1997). Bigtooth maple is useful for restoration of sites where vegetation has been denuded because it establishes deep roots, even in infertile soils (Barker 1977).

Climate Change Responses

Because bigtooth maple is drought tolerant, its productivity may be relatively stable in a warmer climate, especially because it is located in canyons and other places where water is typically present. As soil moisture declines in a warmer climate, marginal riparian sites for maple may become less favorable for regeneration and survival of young trees. With increased fire frequency, there are likely to be increased vegetative regeneration and decreased production of seedlings in some locations. Low-intensity fires may promote regeneration by thinning stands and stimulating sprouting. Browsing pressure on maple could increase with increased drought, as grasses and forbs desiccate and senesce earlier, or are replaced by less palatable species.

Crack Willow (Salix fragilis)

(Southern Greater Yellowstone, Uintas and Wasatch Front, Plateaus subregions)

Autecology

Crack willow is native to Europe and western Asia, where it is found in riparian habitats, usually growing beside rivers and streams and in marshes and wet meadows. It grows in similar habitats in the IAP region. The tree grows rapidly to a height of 30 to 60 feet, occasionally reaching 90 feet. Stem fragments are spread by water, and suckers spread locally. Crack willow outcompetes native species in riparian sites and forms dense, often pure stands along channels (Czarapata 2005), in some cases causing blockages, flooding, and structural changes in waterways (Weedbusters n.d.). This species is susceptible to wind, ice, and snow damage.

Disturbance Interactions

Crack willow responds favorably to periodic flooding. Broken twigs and branches can take root readily, enabling the species to colonize new areas as broken twigs fall into waterways and can be carried some distance downstream. Crack willow is assumed to respond to wildfire like most willow species, by sprouting from the root crown following top kill.

Historical and Current Conditions

Crack willow is now well established in many riparian areas in the IAP region. It was planted for erosion control and water uptake in some locations where rapid plant growth was desired. Although a nonnative species, crack willow is not listed as a noxious weed in any State in the IAP region, and it provides habitat for native bird species.

Climate Change Responses

As soil moisture declines in a warmer climate, marginal riparian sites for crack willow may become less favorable for regeneration and survival of young trees. With increased fire frequency, there are likely be increased vegetative regeneration and decreased production of seedlings in some locations. Even if this species is inhibited somewhat by a warmer climate, it is unclear whether native species could outcompete it.

Saltcedar (Tamarix spp.)

(Uintas and Wasatch Front, Plateaus subregion)

Autecology

Saltcedar (five species) is a nonnative, shrub-like tree with numerous large basal branches and a deep, extensive

Figure 6.6—Saltcedar. This species has caused widespread damage in riparian areas, although the recently introduced tamarisk beetle is a promising biocontrol (photo: M. Mejia, Bureau of Land Management).

root system that extends to the water table and is capable of extracting water from unsaturated soil layers. Saltcedar is found on lakeshores, in riparian floodplain habitats, on seasonally submerged sites, and in fine fluvial substrates (Diggs et al. 1999; Welsh et al. 1987). It is competitively superior to most native species under dry, saline conditions (Stromberg 1998; Vandersande et al. 2001), and few species can tolerate the understory environment (Brotherson and Winkel 1986) (fig. 6.6). Saltcedar is less sensitive to changes in groundwater availability than native riparian trees with which it is commonly associated. Greater tolerance of water stress can lead to saltcedar dominance on relatively dry riparian sites (Horton et al 2001; Smith et al. 1998; Stromberg 1998). Seedlings establish as flood waters recede, leaving moist deposits of bare soil along riparian corridors. Its small, wind- and water-dispersed seeds make it ideally suited as a pioneer species on these sites. Saltcedar is also early seral after fire (Busch and Smith 1993; Stuever et al. 1997). It is listed as a noxious weed in Nevada.

Disturbance Interactions

Evidence for specialized adaptation to wildfire in saltcedar remains unclear, despite its efficient postfire recovery—it is usually top-killed by fire but sprouts readily from the root crown (Busch 1995). Flammability increases with accumulation of dead and senescent woody material within the plant. When plants burn under high fuel loads, fire tends to be more severe, increasing the likelihood of killing the root crown of some individuals (Hohlt et al. 2002). Saltcedar plants can have many stems and high rates of stem mortality, resulting in a dense accumulation of dead, dry branches. Fire hazard peaks in tamarisk stands at 10 to 20 years of age (Ohmart and Anderson 1982). With a combination of flood suppression, water stress, and invasion by saltcedar, wildfires have replaced floods as the primary disturbance factor in many southwestern riparian systems.

Historical and Current Conditions

Saltcedar was introduced in North America in the 1800s, spreading rapidly in the southwestern and intermountain western United States in the 1920s, and altering the ecology and hydrology of riparian areas in this broad region. Control of saltcedar has proven to be challenging. Cutting, burning, and herbicides have been used in various combinations to reduce saltcedar populations, but treatments need to be conducted at large spatial scales to make a significant difference (Racher and Mitchell 1999). Biological control releases of the nonnative northern tamarisk beetle in the Southwest, starting in the 1990s, have caused rapid mortality and decline in vigor in many saltcedar populations (Sher and Quigley 2013; Tracy and Robbins 2009). The success of the beetle as a biological control agent is aiding the recovery of previously suppressed native riparian species. However, because the endangered southwestern willow flycatcher (*Empidonax traillii extimus*) now uses saltcedar as habitat, concern exists about beetles causing the loss of flycatcher habitat, and introduction of beetles has been restricted in some locations.

Climate Change Responses

Saltcedar is more drought tolerant and more efficient at obtaining water than most native species with which it is associated in riparian areas, so it is not expected to be vulnerable to a warmer climate. It also sprouts readily after wildfire, so it will be able to persist in a warmer climate with more fire. Despite efforts to control saltcedar, it would appear to be a permanent fixture in many riparian systems regardless of climate change.

Climate Change Assessment for Forest Vegetation Types

Vegetation types are broad species assemblages used to identify the geographic distribution of vegetation in the USFS Intermountain Region (table 6.1). These types are used to characterize broad landscapes for mapping, planning, and various aspects of vegetation management, but do not have specific spatial definitions. Here we describe the likely response of forest vegetation types to climate change, based on the preceding species descriptions (box 6.3).

Subalpine Pine Forest

Subalpine forests dominated by whitebark pine will be highly vulnerable in a warmer climate, primarily because this species is already subjected to considerable stress from white pine blister rust and mountain pine beetle (Chapter 8). As a result, populations are in decline and reproductive capacity is limited, even when germination conditions are suitable. In areas where wildfire has been excluded for many decades, subsequent fuel loading may create intense future fires that lead to mortality of mature trees. Decline in whitebark pine would have cascading effects on other species that eat its seeds, especially Clark’s nutcracker. Subalpine forests in which bristlecone pine is a major component are mostly in dry locations that could become increasingly stressed by low soil moisture, which would reduce growth.

Other subalpine forests are expected to be moderately affected by a warmer climate. Limber pine, subalpine fir, Engelmann spruce, and white fir may all have increased growth in the upper subalpine zone because of a longer, snow-free growing season. These species may migrate to higher elevations where conditions are suitable, although this would be a slow process over many decades. If wildfire increases in the subalpine zone, especially where it has been excluded in the past, crown fires may be prevalent, quickly eliminating mature trees across the landscape. Limber pine is challenged by mountain pine beetle and white pine blister rust (Chapter 8). Quaking aspen found in subalpine forests will be minimally affected by a warmer climate, especially compared to aspen at lower elevations.

Subalpine Spruce-Fir Forest

Spruce-fir forest will be moderately vulnerable to a warmer climate. Subalpine fir, Engelmann spruce, and blue spruce may all have increased growth in the upper subalpine zone because of a longer, snow-free growing season, so overall productivity could increase. These species may migrate to higher elevations where conditions are suitable, although this would be a slow process over decades to centuries. If wildfire increases in the subalpine zone, especially where it has been excluded in the past, crown fires may be prevalent, quickly eliminating mature trees across the landscape.

Often a seral species in spruce-fir forests, lodgepole pine is a host of mountain pine beetle. Bark beetle outbreaks in Engelmann spruce and lodgepole pine are often severe and can accelerate succession in areas of high tree mortality (Chapter 8). Most subalpine species are fire intolerant, but because most lodgepole pine populations have serotinous cones and the potential for rapid, dense regeneration, it is likely to persist in high-elevation landscapes. Quaking aspen in subalpine forests will be minimally affected by a warmer climate, especially compared to aspen at lower elevations. Where Douglas-fir is a seral species, it could increase in distribution and abundance where sufficient soil water is available. In addition, Douglas-fir is more fire tolerant than any of its associates, so it may become more common if fire increases.

Mesic Mixed Conifer Forest

The composition of mesic mixed conifer forest varies greatly across the IAP region, with site conditions and species assemblages determining vulnerability to climate change. In general, late-seral forests may become increasingly susceptible to wildfire, especially where fire has been excluded for many decades and fuel loads are elevated. Shasta red fir has some fire tolerance, but other firs and lodgepole pine are subject to high mortality from intense fires. The firs are intolerant of low soil moisture, so as snowpack declines and summer temperature increases, growth and productivity will probably decrease, except on north aspects.

Douglas-fir, ponderosa pine, and Jeffrey pine have high tolerance to fire and can survive mixed- severity fires. Therefore, if wildfire extent and intensity increase in the future (Chapter 8), these species may become relatively more common, and late-seral species may become less common. Douglas-fir, ponderosa pine, and Jeffrey pine are all tolerant of dry soils, so they are likely to persist across the landscape, but their growth rates will probably decrease. Lodgepole pine and quaking aspen, which are also common in this forest type, both respond to wildfire with rapid, abundant regeneration and are expected to persist across the landscape, possibly with increased stress from insects and pathogens (Chapter 8).

Dry Mixed Conifer Forest

The composition of dry mixed conifer forest varies across the IAP region, with site conditions and species assemblages determining vulnerability to climate change. Located in lower-elevation montane sites, often on steep slopes and shallow soils, this forest type contains some of the most drought-tolerant species in the region. Common seral species include ponderosa pine, which is fire tolerant and regenerates well after fire, and quaking aspen, which sprouts heavily and reproduces after fire. The woodland species curl-leaf mountain mahogany, Gambel oak, and bigtooth maple are drought tolerant, and the latter two sprout vigorously after fire. Therefore, a major component of mixed conifer forest is expected to be able to cope with both drier soils and increased wildfire.

Twoneedle pinyon and singleleaf pinyon are drought tolerant, and although intense fire typically kills them, they can usually regenerate successfully if competition is minimal. Singleleaf pinyon at its lowest elevational extent in northern New Mexico has undergone significant mortality from prolonged drought and pinyon engraver beetles during the past 15 years (Floyd et al. 2009) (Chapter 8), so this species may be susceptible to increasing drought in the future. Limber pine, which is considered late seral in these forests, is drought tolerant, but may be challenged by mountain pine beetle, white pine blister rust, and increasing (usually fatal) wildfire (Chapter 8).

Other species such as Douglas-fir and white fir are not nearly as drought tolerant as other mixed conifer species. Their growth will probably decrease in a warmer climate, and although Douglas-fir has relatively high fire tolerance, white fir tolerates fire only when it has large-diameter and thick bark. In a warmer climate with more fire, it will be increasingly difficult for these conifer species to compete with early-seral and woodland species that are more tolerant of both drought and fire. Therefore, it is likely that early-seral species will become more dominant in the future, and late-seral species will become less common and perhaps confined to north aspects and valley bottoms.

Aspen-Mixed Conifer Forest

The composition of this forest type is diverse, distinguished by the prominent role of quaking aspen as an early-seral species, often in combination with other conifer and woodland species. Response to climate change will depend on associated species, ranging from high to low elevation, and from north to south aspects. Increased wildfire frequency and extent will be the primary factor determining future composition and structure of aspen-mixed conifer forests.

Most of the higher-elevation, late-seral species in this forest type (firs, Engelmann spruce) are readily killed by fire, especially when immature. If wildfire reaches into the subalpine zone, it is likely that mature spruce-fir forests will become less common, or will persist only on northern slopes and in valley bottoms. Therefore, early-seral species, especially aspen, will attain increasing dominance because of their ability to resist fire or regenerate after it occurs. This will also be true at lower elevations in this forest type, where species such as ponderosa pine can readily survive intense fires, and other species such as aspen and Gambel oak sprout aggressively after fire. Productivity in these systems will probably be lower in a warmer climate with more fire. But the more fire-tolerant species will persist, especially in drier locations, where they can outcompete species that are susceptible to drought and fire.

Persistent Aspen Forest

Quaking aspen can persist for many decades in some forests in the IAP region, where productivity is relatively low and conifer species do not compete well. Succession proceeds slowly in persistent aspen forests, even in the absence of wildfire, especially at the higher elevations of the subalpine zone. The late-seral species in this forest type (firs, spruces) are readily killed by fire, especially when immature. Consequently, if wildfire reaches into the subalpine zone, it is likely that mature spruce-fir forests will become less common, or will persist only on northern slopes and in valley bottoms. Therefore, aspen will maintain dominance because of its ability to sprout aggressively after fire.

This will also be true at lower elevations in this forest type, where species such as ponderosa pine can readily survive intense fires, and other species such as aspen and Gambel oak sprout aggressively after fire. Douglas-fir will probably persist at some locations on the landscape because it has relatively high drought tolerance and fire tolerance. Productivity in these systems will probably be lower in a warmer climate with more fire. But the more fire-tolerant species will persist, especially in drier locations, where they can outcompete species that are susceptible to drought and fire.

Montane Pine Forest

Ponderosa pine is a dominant species in drier montane locations throughout much of the IAP region. Several other conifer species are included in this forest type, but are rarely as abundant as ponderosa pine, except in wetter locations (north aspects, valley bottoms). Ponderosa pine is persistent in these systems because it is tolerant of drought and very tolerant of fire. Consistently drier soils will cause this species to grow slower, but mortality will be rare unless drought lasts for several consecutive years and biotic agents cause additional stress (Chapter 8).

The expected increase in frequency and extent in a warmer climate will favor ponderosa pine over its less fire-tolerant competitors, thus ensuring dominance in most forests. But limber pine and bristlecone pine will probably persist at higher elevations, where fuel loads are typically low. An exception might be in areas where fire exclusion has increased stand density and fuel loads conducive to crown fires, but even then, regeneration of ponderosa pine will probably be sufficient to maintain dominance after fire. If insects become more prevalent in a warmer climate (Chapter 8), they could increase stress and mortality in pine species, especially during drought periods.

Riparian Forest

Riparian forests are distributed throughout the IAP region, adjacent to lakes, streams, seeps, springs, and high water tables. Vegetation is extremely diverse, including a broad range of conifer and hardwood species. Many of these species occur only in riparian systems, providing habitat for numerous wildlife species. In some lower-elevation, drier locations, nonnative saltcedar and Russian olive have been present, and, in some cases, dominant for many decades, displacing native species and reducing available groundwater.

Riparian systems will be one of the most vulnerable vegetation types in a warmer climate because they depend on reliable water supply. Higher temperatures will accelerate evapotranspiration as soils dry faster and as vegetation takes up water earlier and faster during the growing season. Both surface and subsurface water flows will decrease if snowpack decreases and melts earlier, precluding recharge during dry summers (Chapter 4). At a minimum, this will alter vegetation dominance to species that are more tolerant of seasonal drought, including ponderosa pine and other deep-rooted conifers. Hardwood species that rely on periodic high water levels for regeneration could become less common. Riparian forests associated with small or transient water sources (e.g., springs) will be more susceptible than forests near large water sources (e.g., rivers). Low-elevation riparian forests near small water sources will be more susceptible than high-elevation forests that have long duration of snowpack.

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Chapter 7: Effects of Climate Change on Nonforest Vegetation

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Introduction

Nonforest ecosystems, as they are addressed in this chapter, contain woodland, shrubland, herbaceous, wetland, or riparian vegetation types. They are estimated to occupy over 30 million acres and 50 percent of the U.S. Department of Agriculture Forest Service (USFS) Intermountain Region (table 7.1). These diverse ecosystems range in elevation from desert floors to mountain peaks above 11,000 feet and occupy a wide variety of sites, from deep and highly productive soils to very shallow nonproductive soils. Other than riparian and wetland ecosystems, nonforest vegetation types tend to occur in more arid environments or are otherwise controlled by edaphic features such as soil depth, drainage, or chemical (saline) characteristics.

The diversity and varied conditions of nonforest ecosystems in the Intermountain Adaptation Partnership (IAP) region present challenges for studying the effects of climate change. These ecosystems have been exposed to a wide variety of uses and impacts, resulting in varied ecological conditions across landscapes. Some ecosystems will be less resilient to environmental changes such as increasing carbon dioxide and other greenhouse gases, warming temperatures, and altered amount and timing of seasonal and annual precipitation. The objective of this chapter is to provide insight into the climate change vulnerability of nonforest ecosystems in the IAP region. Climate change vulnerability can be defined as the degree to which a system is susceptible to and unable to cope with adverse effects of climate change (IPCC 2007). This information is intended to provide a basis for developing adaptation actions to increase resilience of nonforest ecosystems in the IAP region (Chapter 14).

Vulnerability Assessment Methods

Climate change vulnerability is a function of the exposure of a system, its sensitivity, and its adaptive capacity (IPCC 2007). In a climate change context, exposure can be thought of as the degree, duration, or extent of deviation in climate to which a system is exposed. Sensitivity is the degree to which a system is affected, either positively or negatively and directly or indirectly, by climate-related stimuli (IPCC 2007). Adaptive capacity is the ability of a system to adjust to climate change (including climatic variability and extremes) by moderating potential damages, taking advantage of opportunities, or coping with the consequences (IPCC 2007).

In considering the potential vulnerability of nonforest ecosystems to the effects of climate change in the IAP region, we modeled our assessment on work done by NatureServe (Comer et al. 2012) for the Mojave and Sonoran Deserts. NatureServe evaluated sensitivity of ecosystems to the direct effects of climate change, as well as their resilience to climate change (based on landscape condition, invasive species, and adaptive capacity). The combined relative ratings for sensitivity and resilience were used to determine climate change vulnerability by the year 2060 for each vegetation cover type.

For our nonforest vegetation vulnerability assessment, a team of experts evaluated sensitivity and adaptive capacity (as already defined). Adaptive capacity incorporates factors such as landscape condition, characteristic species and genetic diversity, and occurrence of invasive species. For example, degraded landscape condition, loss of native species and genetic diversity, and high abundance of invasive species would lower the adaptive capacity of an ecosystem. We relied on published literature and expert evaluations to establish a broad rating system that included five categories for evaluating the sensitivity and adaptive capacity of the vegetation cover types discussed in this report (table 7.2). We also developed numerical vulnerability scores, which combined sensitivity and adaptive capacity (e.g., a value of 5 was used for high sensitivity and low adaptive capacity and a value of 1 was given to low sensitivity and high adaptive capacity) (table 7.2). This system creates some transparency in the assessment process and provides a means to update the assessment with new information as it becomes available.

Vulnerability of Nonforest Ecosystems to Climate Change

Many of the rangelands in the IAP region have sustained, at one time or another, unmanaged livestock grazing. In 1902, Albert Potter, a staff member under Gifford Pinchot,

Table 7.1—Amount of non-forest vegetation cover types in the IAP region, developed from LANDFIRE data.

	IAP Region	Middle Rockies	Southern Greater Yellowstone	Uintas and Wasatch Front	Plateaus	Great Basin and Semi Desert
	Percent					
Forest	49.3	62.0	65.5	55.4	45.6	15.0
Non-forest	50.7	38.0	34.5	44.6	54.4	85.0
Pinyon-juniper shrublands and woodlands	12.6	0.0	0.0	4.9	29.2	37.0
Oak-maple woodlands	2.2	0.0	0.1	9.7	4.4	0.5
Mountain-mahogany woodlands	2.1	0.1	0.0	2.3	3.2	6.1
Mountain big sagebrush shrublands	13.0	17.9	12.0	13.4	3.5	11.4
Dry big sagebrush shrublands	6.5	2.3	0.5	5.4	3.3	20.2
Mountain shrublands	2.2	3.7	2.8	1.4	1.4	0.3
Dwarf sagebrush shrublands	1.2	0.7	0.0	0.3	4.3	1.6
Blackbrush shrublands	0.5	0.0	0.0	0.0	0.1	2.2
Salt desert shrublands	0.3	0.0	0.1	0.4	0.3	1.1
Grasslands	4.3	9.9	2.1	1.0	0.7	1.9
Subalpine forb	2.5	1.6	7.9	2.4	1.5	0.6
Alpine	1.6	0.5	5.7	1.6	1.0	0.3
Riparian	1.3	0.5	1.6	1.9	1.5	1.8
Wetland	0.6	0.7	1.6	0.0	0.0	0.2

the first USFS chief, evaluated the conditions of forests and rangelands in Utah (Prevedel and Johnson 2005). Potter's diary provides detailed descriptions of the effects of unmanaged sheep and cattle grazing on the vegetation and soils of the forest reserves throughout Utah at that time (Potter 1902). As he traveled from northern to southern Utah, Potter often referred to lands that were "heavily grazed" and "heavily stocked" and described lands that were "badly tramped out" and "bare of vegetation." These historical uses often led to a change in site potential and ecological states. Degraded ecological condition from unmanaged grazing, combined with landscape fragmentation, will render many sites less resilient to changing climate. These sites have lost their diversity in species, structure, and genetic composition, and many plants on these sites have decreased vigor, lowering their ability to respond to and cope with the direct (e.g., increased temperatures) and indirect effects (e.g., increased fire) of climate change.

Other primary management concerns in the IAP region include invasive species and uncharacteristic fire regimes, or fire regimes (intensity, severity, extent, and timing of fire) that differ from those before Euro-American settlement. Many low-elevation sagebrush habitats now have significantly shortened fire return intervals (Balch et al. 2013). Increasing dominance by invasive cool-season, annual grasses has created a positive feedback cycle, characterized by frequent fire followed by increased dominance of annual grasses creating fuel conditions that facilitate combustion (Balch et al. 2013). The invasive species of greatest concern is cheatgrass (*Bromus tectorum*), although other invasive annuals such as medusahead (*Taeniatherum caput-medusae*) are growing concerns throughout the region. The expansion of these and other species may be supported by elevated atmospheric carbon dioxide concentrations, increased area burned, and increased soil disturbance (Chambers et al. 2014; Nowak et al. 2004). In addition, the frequent-fire cycle may be exacerbated by wetter and warmer winters, which promote cool-season grass growth (fuel production), increased fuel levels and continuity, and increased area burned (if ignitions occur) (Bradley et al. 2016). Where improper grazing occurs, it can also accelerate annual grass invasion, resulting in changes in the fire cycle, especially in the drier sagebrush types.

Land use legacies, coupled with changing climate, pose unique challenges for managers in the region. Potential interactions between land use change, management, and climate change are not well understood, but the extent to which ecosystem resilience has been affected by human

Table 7.2—Vulnerability ratings for sensitivity and adaptive capacity of non-forest cover types in the IAP region, based on published literature and expert evaluations by a team of scientists.

	Sensitivity rating	Sensitivity score	Adaptive capacity rating	Adaptive capacity score	Combined score	Vulnerability
Alpine	H	5	L	5	10	Very High
Dry big sagebrush shrublands	H	5	L	5	10	Very High
Low-elevation riparian	H	5	L-M	4	9	High-Very High
Subalpine forb communities	H	5	M	3	8	High
Persistent pinyon-juniper woodlands	H	5	M	3	8	High
High-elevation riparian	M-H	4	L-M	4	8	High
Mountain-mahogany woodlands	M	3	L-M	4	7	Moderate-High
Mountain big sagebrush shrublands	M	3	L-M	4	7	Moderate-High
Mountain grasslands	M	3	L-M	4	7	Moderate-High
Salt desert shrublands	M	3	L-M	4	7	Moderate-High
Mid-elevation riparian	M-H	4	M	3	7	Moderate-High
Blackbrush	L-M	2	L	5	7	Moderate-High
Dwarf sagebrush shrublands	M-H	4	M-H	2	6	Moderate
Sprouting sagebrush	M	3	M	3	6	Moderate
Oak-maple woodlands	L-M	2	M	3	5	Low-Moderate
Mountain shrublands	L-M	2	M-H	2	4	Low-Moderate

uses will ultimately affect the ability of those ecosystems to respond to changing climate.

Climate change projections for the IAP region (Chapter 3) indicate that average annual minimum and maximum temperatures are likely to increase by 5 to 12 °F, mean annual precipitation will remain the same or increase slightly, extreme events (e.g., drought and extreme precipitation events) will occur more frequently and be more severe, and concentrations of carbon dioxide and other greenhouse gases in the atmosphere will continue to increase through the end of the 21st century. Minimum daily temperatures in the Great Basin in the 20th century increased more than maximum temperatures (Chambers 2008). In addition, these increased minimum daily temperatures have resulted in longer frost-free periods. Projections vary somewhat by subregion, but even where precipitation is projected to increase slightly, higher temperatures are likely to lead to greater effective drought and soil water deficit.

Despite increased moisture stress, net primary productivity (NPP) of vegetation in the IAP region may increase with warming temperatures due to greater water-use efficiency associated with carbon dioxide fertilization effects (Reeves et al. 2014). Projections suggest that there will be a greater increase in NPP in the northern cooler and wetter portions of the IAP region (Southern Greater Yellowstone and Middle Rockies subregions). A short decline in NPP will precede a smaller increase in NPP in the southern warmer and drier portions of the region (Plateaus and Great Basin and Semi Desert subregions) (fig. 7.1). However, the capacity to respond to carbon dioxide fertilization varies greatly among and within plant functional groups, suggesting that changes in NPP will not be expressed uniformly by species within plant communities. Ecosystem response to climate change throughout the IAP region will vary with local site characteristics (e.g., water holding capacity, soil characteristics) and ecological condition.

Paleoecological studies have shown that species respond individualistically and at different rates with changing climates, resulting in reshuffling species associations and novel community combinations (Delcourt and Delcourt 1981; Williams and Jackson 2007). Thus, each species is likely to respond differently to future climatic changes and carbon dioxide fertilization (Anderson and Inouye 2001), depending on physiological tolerances and the competitive ability of the species. Consequently, we are likely to see new vegetation communities in the IAP region under changing climate. However, because vegetation types, or groups of associated species, are widely known and provide a convenient unit of assessment, we discuss climate change effects by vegetation type, highlighting likely species-level responses.

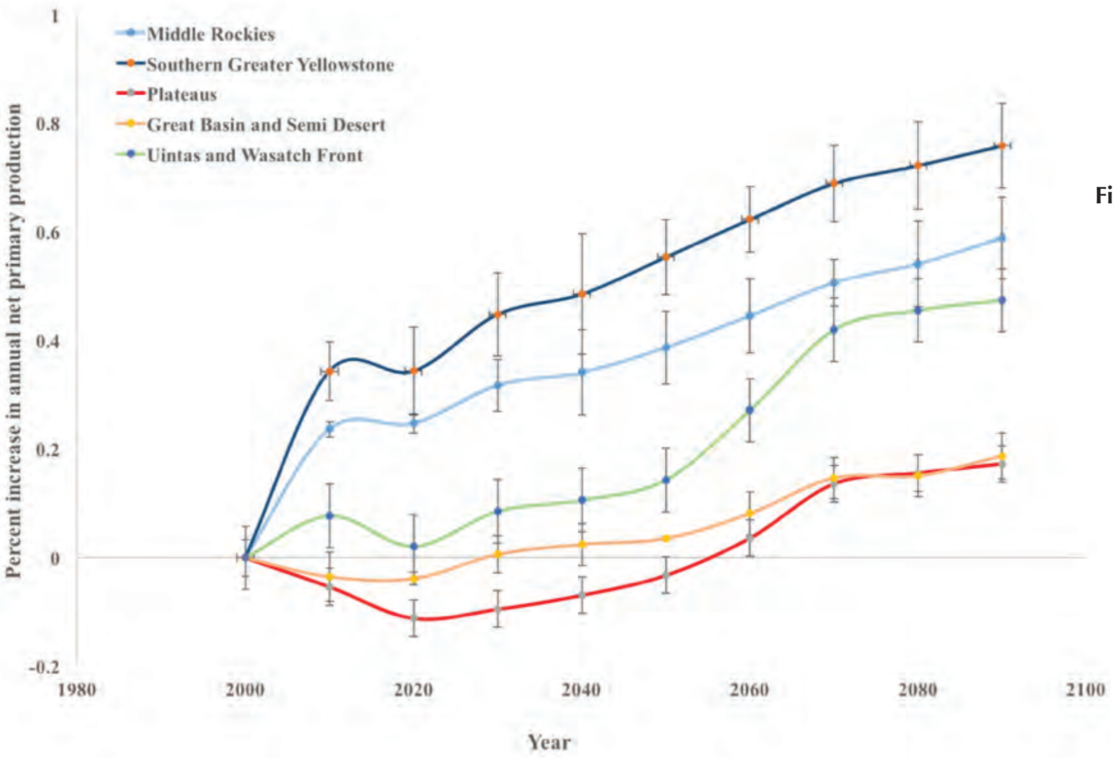

Figure 7.1—Average and standard deviation of net primary production under the A1B, A2, and B2 climate change scenarios for five subregions in the Intermountain Adaptation Partnership region (data from Reeves et al. [2014]).

Woodland Ecosystems

Woodland ecosystems include vegetation stands with at least 10 percent cover of tree species that are typically less than 40 feet tall at maturity, and often less than 16 feet tall on relatively harsh sites. Woodlands, in general, are more abundant in Utah and Nevada than in Idaho or Wyoming (table 7.1). Three woodland types are included in this assessment: persistent pinyon-juniper, oak-maple, and mountain mahogany. Persistent pinyon-juniper woodlands are those dominated by pinyon pine (*Pinus edulis, P. monophylla*) or juniper, either in combination or as individual species. Oak-maple woodlands are dominated by Gambel oak (*Quercus gambelii*) or bigtooth maple (*Acer grandidentatum*), or both; mountain mahogany woodlands are dominated by curl-leaf mountain mahogany (*Cercocarpus ledifolius*). These woodland types generally occur on mid-elevation sites (but can be found on south-facing slopes at higher elevations) and are found on a wide variety of soils.

Persistent Pinyon-Juniper Woodlands

Three general pinyon-juniper vegetation types have been defined based on canopy structure, characteristics of the understory, and historical disturbance regimes (Romme et al. 2009): persistent pinyon-juniper woodlands, wooded shrublands, and pinyon-juniper savannas. Pinyon-juniper savannas are uncommon in the IAP region and are not described here. Persistent pinyon-juniper woodlands are those that were historically dominated by pinyon (singleleaf pinyon [*Pinus monophylla*] or twoneedle pinyon [*P. edulis*]) or juniper, or both, and where fire was rare, usually because of poor soil conditions and low surface fuel levels and continuity. Wooded shrublands are characterized by a dominant shrub component (most notably mountain big sagebrush [*Artemisia tridentata* ssp. *vaseyana*] and Wyoming big sagebrush [*A. t.* ssp. *wyomingensis*], but wooded shrublands also occur in dwarf sagebrush ecosystems). The density of pinyon and juniper in various combinations increases and decreases over time in response to climate and disturbance, including fire and insect outbreaks.

Only those plant communities that historically occurred as tree-dominated sites for a majority of time under pre-Euro-American natural disturbance regimes are included in our persistent pinyon-juniper woodlands discussion. Many sites now dominated by pinyon pines or junipers, or both, were historically dominated by sagebrush or other shrubby species because of more frequent fire and lack of grazing, and these are not included in the woodlands discussion. They are, however, included in the discussions of the shrubland landscapes they now occupy.

In many areas where Wyoming big sagebrush, mountain big sagebrush, black sagebrush (*Artemisia nova*), and low sagebrush (*Artemisia arbuscula*) species historically dominated the landscape, expansion by pinyon pine and juniper, and to a lesser extent, other conifers, is occurring (Miller and Tausch 2001). In advanced stages of expansion, dense woodlands completely replace shrubland communities, and these changes are commonly attributed to a lengthening of fire-free intervals associated with 20th-century fire suppression. However, livestock grazing and climatic conditions favorable for tree establishment in the early 20th century also affected vegetation (Miller and Tausch 2001). Burkhardt and Tisdale (1969) found that western juniper (*Juniperus occidentalis*) had more than doubled its distribution between the

1860s, when Euro-American settlement of the West began, and the time of their study about 100 years later. Miller et al. (2008) found that 50 to 75 percent of the sagebrush-steppe communities in portions of Idaho, Oregon, Nevada, and Utah supported expansion of western juniper, Utah juniper (*Juniperus osteosperma*), or singleleaf pinyon by 1920. This rate of expansion has decreased, possibly because of a reduction in the rate of establishment (Miller et al. 2008).

To determine the degree to which pinyon-juniper woodlands have expanded in the Intermountain Region, we compared LANDFIRE biophysical setting (BpS) (LANDFIRE 2008) and existing vegetation type (EVT) (LANDFIRE 2012) data for the acreage dominated by sagebrush shrublands and pinyon-juniper woodlands and shrublands. The BpS layer represents vegetation cover types that may have been present before Euro-American settlement. This layer is based on both the current physical environment (NatureServe's ecological systems classification [Comer et al. 2003]) and an approximation of historical disturbance regimes. The EVT layer is an approximation of existing land cover types that relies on decision tree models, field data, Landsat imagery, elevation, and biophysical gradient data as predictors of vegetation.

Table 7.3 shows the difference in acres of pinyon-juniper woodlands and shrublands and sagebrush shrublands between the BpS and EVT layers for each IAP subregion, estimating change in dominance of sagebrush and pinyon-juniper dominated landscapes in the Intermountain Region since Euro-American settlement. It indicates that pinyon-juniper has increased the most in the Great Basin and Semi Desert subregion. Pinyon-juniper has also increased, but to a lesser degree, in the Plateaus and the Uintas and Wasatch Front subregions.

Vegetation Type Description and Distribution

Persistent pinyon-juniper woodlands are dominated by singleleaf pinyon or twoneedle pinyon, and by western juniper or Utah juniper in various combinations. Persistent juniper woodlands occur throughout the Great Basin and Semi Desert, Plateaus, and Uintas and Wasatch Front subregions,

Table 7.3—LANDFIRE-derived estimates (percent of the landscape) of change in dominance of sagebrush and pinyon-juniper dominated landscapes in the Intermountain Region since Euro-American settlement. The biophysical settings (BpS) layer (LANDFIRE 2008) represents the vegetation cover type that may have dominated the landscape prior to Euro-American settlement. The existing vegetation type (EVT) layer (LANDFIRE 2012) is an approximation of existing land cover types that relies on decision tree models, field data, Landsat imagery, elevation, and biophysical gradient data as predictors of vegetation.

Subregion and cover type	BpS	EVT	Difference (EVT – BpS)
	Percent		
Middle Rockies			
Pinyon-juniper woodlands and shrublands	0.0	0.0	0.0
Sagebrush shrublands	100.0	100.0	
Southern Greater Yellowstone			
Pinyon-juniper woodlands and shrublands	0.0	0.2	+0.2
Sagebrush shrublands	100.0	99.8	
Uintas and Wasatch Front			
Pinyon-juniper woodlands and shrublands	4.5	20.4	+15.9
Sagebrush shrublands	95.5	79.6	
Plateaus			
Pinyon-juniper woodlands and shrublands	48.1	72.2	+24.1
Sagebrush shrublands	51.9	27.8	
Great Basin and Semi Desert			
Pinyon-juniper woodlands and shrublands	0.3	52.7	+52.4
Sagebrush shrublands	99.7	47.3	

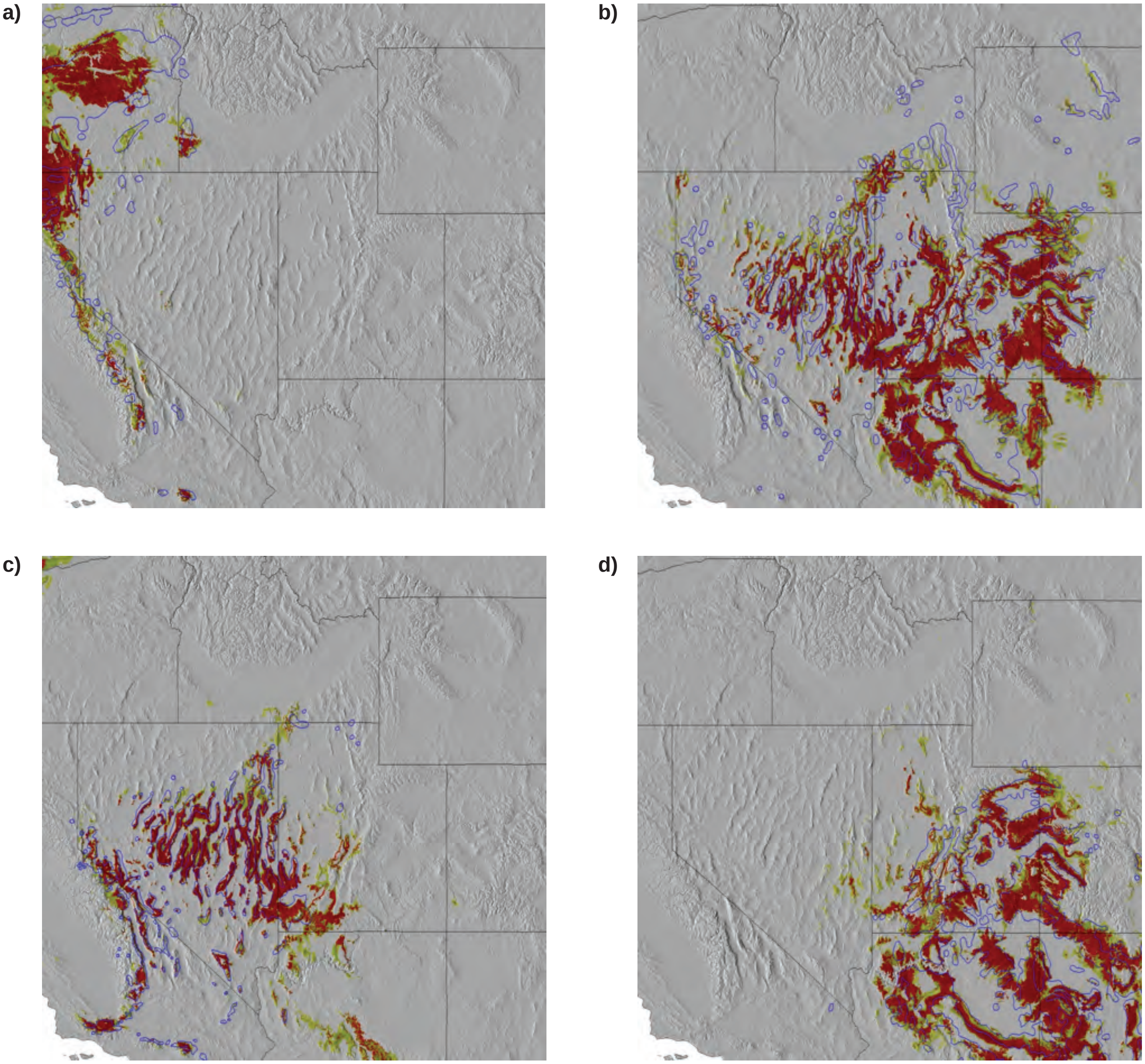

Figure 7.2—Modeled distribution of juniper and pinyon pine species in the Intermountain Adaptation Partnership region: (a) western juniper, (b) Utah juniper, (c) singleleaf pinyon, and (d) twoneedle pinyon. Data are from USDA FS (2017). Model projections to 2090 are based on two global circulation models (HadCM3GGa1, CGCM2_ghga), assuming an increase in greenhouse gas emissions of 1 percent per year since 1990 (see Rehfeldt et al. [2006]).

but are relatively insignificant in the Middle Rockies and Southern Greater Yellowstone subregions (fig. 7.2). In the IAP region, persistent pinyon-juniper woodlands generally make up between 2 and 10 percent of the total woodland areas in any given geographic area (Miller et al. 1999), but they are particularly abundant on portions of the Colorado Plateau at lower elevations (Romme et al. 2009).

Species composition of pinyon-juniper woodland varies across the IAP region. Western juniper occurs along the western edge of the Great Basin and Semi Desert subregion in southwestern Idaho and northwestern Nevada (fig. 7.2a). Utah juniper is the most common tree in the Great Basin and Semi Desert subregion, and is widely distributed throughout the Plateaus, and Uintas and Wasatch Front subregions; it is much less abundant in the Middle Rockies and Southern Greater Yellowstone subregions (Lanner 1983) (fig. 7.2b). Singleleaf pinyon is mostly limited to woodlands in the California, Nevada, and extreme southwestern Utah portions of the Great Basin and Semi Desert subregion (fig. 7.2c). A few disjunct populations occur in other National Forest lands in Utah, notably in the Mollens Hollow Research Natural Area on the Logan District of the Uinta-Wasatch-Cache National Forest. Twoneedle pinyon occurs at lower elevations of National Forests in the Plateaus subregion and in adjacent landscapes of the Uintas and Wasatch Front subregion (fig. 7.2d).

Figure 7.3—Utah juniper. The presence of very old Utah juniper suggests that this rocky site would only rarely develop a grassy understory capable of carrying a surface fire (from Tausch and Hood [2007]).

Pinyon-juniper woodlands often occur on rocky upland sites with shallow and coarse-textured soils that support sparse herbaceous vegetation cover (fig. 7.3). Curl-leaf mountain mahogany may be a codominant or subdominant woodland species. Immediately after disturbance, these sites are dominated by shrubs, grasses, or forbs, or a combination, which may persist for long periods of time.

The age of many pinyon and junipers in persistent stands throughout the West suggests that natural stand-replacement fires of mixed to high severity may be infrequent to rare, averaging 100 to 500 years (Bauer and Weisberg 2009; Miller et al. 1999; Romme et al. 2009). Low-intensity surface fires had a very limited role in affecting stand structure and dynamics in most persistent woodlands historically; most fires were high-severity, stand-replacement fires (Romme et al. 2009). However, fire history is often difficult to measure in these ecosystems because of the lack of fire scar evidence in many pinyon-juniper ecosystems (Baker and Shinneman 2004).

Sensitivity to Climate Change: High

Occupying the transition zone between mesic forests at higher elevations and xeric environments too dry for trees at lower elevations, pinyon-juniper woodlands may be highly sensitive to changes in temperature and precipitation (Romme et al. 2009). Climate envelope model projections for species dominant in pinyon-juniper woodlands indicate a significant contraction of this type in Nevada and Utah (classified as Great Basin conifer forest by Rehfeldt et al. 2012). The likely causes of these projected contractions include higher temperatures and increasing drought stress.

In addition to the direct effects of climate change, pinyon-juniper woodlands may be sensitive to the indirect effects of climate change, including increased area burned (McKenzie et al. 2004) and insect outbreaks (Romme et al. 2009). For example, a major pinyon pine mortality event in 2002–2004 in Colorado, Arizona, New Mexico, and Utah resulted from high temperatures, drought, and bark beetle outbreaks (Romme et al. 2009). Fire directly causes tree mortality, and warm and dry conditions after fires may also inhibit tree regeneration, affecting species composition and long-term vegetation trajectories (Floyd et al. 2015).

As a result of these sensitivities to the direct and indirect effects of warming, persistent pinyon-juniper woodlands are rated as highly sensitive to climate change (table 7.2). However, Utah juniper, which is the most common juniper in the region, has been observed moving downslope into communities currently dominated by sagebrush. At the same time, pinyon pines have been observed moving upslope. It is unclear which novel communities will form in a changing climate, but some new communities that include juniper and possibly pinyon are likely to remain, at least on portions of the landscape.

Adaptive Capacity: Moderate

Persistent pinyon-juniper woodlands are a complex set of ecosystems with a high degree of variation among sites (Romme et al. 2009). Many sites on which this vegetation type occurs have relatively low abundance of invasive species, and because many sites with persistent pinyon-juniper woodlands occur in well-protected, rocky areas with relatively little pressure from livestock grazing and other human uses, their ecological condition has not been degraded. However, with climate change, they may be affected by invasive species from adjacent plant communities, specifically invasive annual grasses such as cheatgrass, particularly at the lower-elevation ecotones (Chambers et al. 2014). Cheatgrass invasion significantly shortens fire return intervals (Chambers et al. 2014) and could cause major ecological change in these woodlands. For this reason, the adaptive capacity of pinyon-juniper woodlands is rated as moderate (table 7.2).

Vulnerability to Climate Change: High

The vulnerability of persistent pinyon-juniper is high because of high sensitivity to the direct and indirect effects of climate change and moderate adaptive capacity (table 7.2). Comer et al. (2012) found that the vulnerability of Great Basin pinyon-juniper woodlands in the Mojave Desert, south of the Great Basin, was moderate, because although these ecosystems were highly sensitive to climate change (they are projected to contract with warming), their adaptive capacity was also high. In our assessment, we gave greater importance to the effects of climate change on adjacent landscapes that would indirectly affect the resilience of the persistent pinyon-juniper woodlands, leading to a vulnerability rating of high.

Oak-Maple Woodlands

Vegetation Type Description and Distribution

Oak-maple woodlands are dominated by mature stands of bigtooth maple or Gambel oak, or both, under natural disturbance regimes. These woodlands are most abundant in the Uintas and Wasatch Front subregion and are also found in the Plateaus subregion (table 7.1, fig. 7.4). Gambel oak is more widespread in the Plateaus subregion, occurring over a greater range of elevations, but generally does not extend north of Brigham City in northern Utah. Bigtooth maple, on the other hand, extends through central Utah into the Southern Greater Yellowstone subregion. Although characteristic of these woodlands, both species (especially Gambel oak) occur as subdominant components of mountain shrubland communities, and boundaries between these vegetation types are sometimes arbitrary.

Historical fire regimes in oak-maple woodlands are not well understood because of a lack of physical evidence such as fire scars (Kaufmann et al. 2016). However, these woodlands are well adapted to fire. Immediately after disturbance, these sites are dominated by shrubs, grasses, or forbs. Both dominant tree species, as well as many of the associated shrubs and herbaceous species, sprout from the root crown following top kill, so postdisturbance grass-forb dominance is short lived.

Sensitivity to Climate Change: Low to Moderate

Climate envelope model projections show a slight restriction of current habitats of Gambel oak and an expansion of its climate envelope into Idaho and Montana by 2060; a few of these models show expansion into eastern Nevada as well (Rehfeldt et al. 2006). During that same time period, some models indicate an expansion of the bigtooth maple climate envelope into eastern Idaho and Montana, although the distribution throughout much of its current range decreases. For these reasons, we have determined that this vegetation type has a low to moderate sensitivity to the effects of climate change (table 7.2).

Adaptive Capacity: Moderate

Gambel oak and bigtooth maple sprout after fire, and can easily reestablish following disturbance (Engel 1983). In addition, there are many species associated with Gambel oak or bigtooth maple communities (Simonin 2000; Tollefson 2006), many of which sprout following fire. This diversity of fire-adapted species provides these communities with significant adaptive capacity. However, adaptive capacity

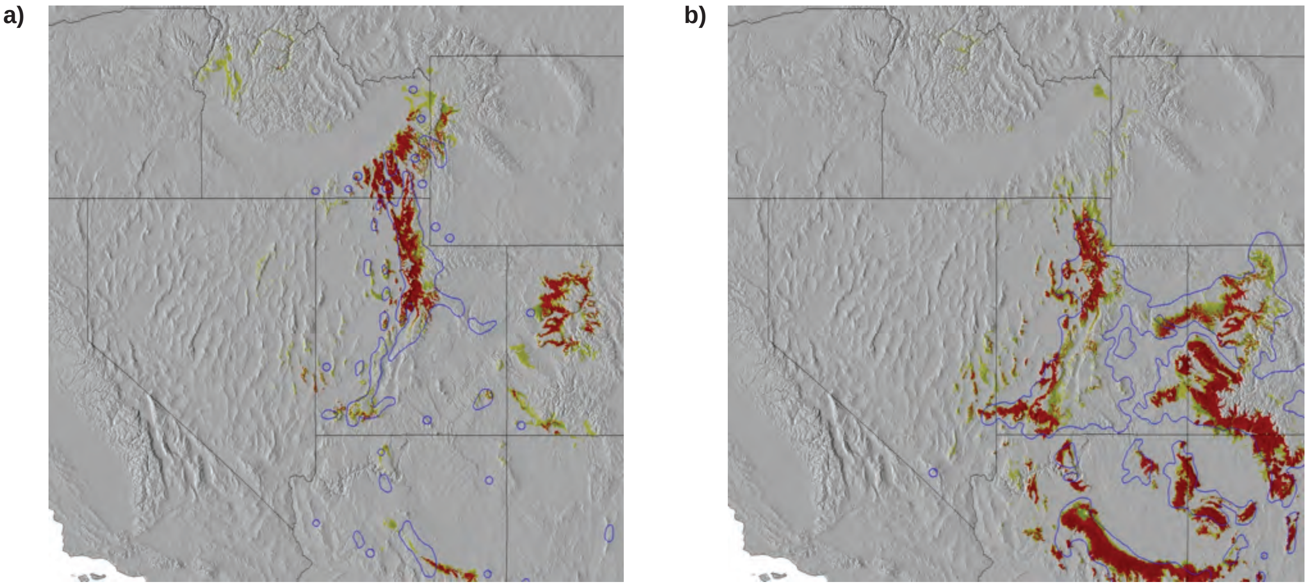

Figure 7.4—Modeled distribution of (a) bigtooth maple and (b) Gambel oak in the Intermountain Adaptation Partnership region. Data are from USDA FS (2017). Model projections to 2090 are based on two global circulation models (HadCM3GGa1, CGCM2_ghga), assuming an increase of greenhouse gas emissions of 1 percent per year since 1990 (see Rehfeldt et al. [2006]).

of these ecosystems is affected to some degree by the number of invasive species capable of invading following disturbance, which can lower species diversity and alter fire regimes. This type is given a moderate adaptive capacity rating because of the potential for invasive species establishment (table 7.2).

Vulnerability to Climate Change: Low to Moderate

The vulnerability of oak-maple woodlands is rated as low to moderate because of the low to moderate sensitivity and moderate adaptive capacity to climate change (table 7.2). Although the current locations of these woodlands may change over time, the amount of land covered by this vegetation type may increase to some degree outside its current distribution.

Mountain Mahogany Woodlands

Vegetation Type Description and Distribution

Curl-leaf mountain mahogany woodlands typically occur throughout the IAP region in isolated patches on warm, rocky ridges and on other sites with dry, coarse-textured soils, primarily on western or southern exposures (Davis and Brotherson 1991). These woodlands are most common in the Great Basin and Semi Desert, Plateaus, and Uintas and Wasatch Front subregions (table 7.1). Historically, this type was restricted to rocky areas that were probably protected from fire, but curl-leaf mountain mahogany, like pinyon-juniper (although to a lesser extent), has expanded because of fire exclusion in habitats where frequent fires historically kept it in check (Davis and Brotherson 1991). Most often, curl-leaf mountain mahogany is killed by fire, and regeneration is only by seed (Gruell et al. 1985). However, early postfire recolonization by mountain mahogany is facilitated by seeds that are well adapted for wind dispersal. Consequently, this species is often among the first nonsprouting shrubs and trees to reoccupy a burn when unburned plants provide a seed source nearby. Curl-leaf mountain mahogany can survive for long periods (Riegel et al. 2006), and on sites that have sustained long fire-free periods, mahogany trees have been found to be over 400 years old (Dealy 1975).

Sensitivity to Climate Change: Moderate

Climate envelope models project a significant restriction in the climate envelope of curl-leaf mountain mahogany (Rehfeldt et al. 2006). The species occurs across a broad elevational gradient (7,000–11,000 feet), which suggests some resilience to climate change. Curl-leaf mountain mahogany is often found on soils that have low fertility (Gucker 2006) or contain calcium carbonates (although this trait does not seem to be as evident in the Great Basin as elsewhere in its distribution) (Gonella and Neel 1995). These traits, combined with relatively high predation of its seeds (Dealy 1979), suggest the species may not be a good competitor. However, the affinity of the species for poor soils suggests it is tolerant of poor conditions, and it could potentially expand into areas where other species become less competitive in warmer and drier conditions. For these reasons, and because of the similarity of some mountain mahogany woodland sites to those of persistent pinyon-juniper woodland sites, the sensitivity of these woodlands is rated as moderate (table 7.2).

Adaptive Capacity: Low to Moderate

The lack of fire since the early 1900s has allowed curl-leaf mountain mahogany to expand to some degree and occupy new habitats. Livestock grazing has also been largely absent from these woodland communities because of the difficult terrain and sparse forage (USDA FS 2013). However, abundance of invasive species has increased in some of these communities, potentially affecting fire return intervals and resilience. In addition, this vegetation type generally does not have a high level of site diversity. For these reasons, and because the species grows slowly and does not sprout following fire, the adaptive capacity of mountain mahogany woodlands is rated as low to moderate (table 7.2).

Vulnerability to Climate Change: Moderate to High

The vulnerability of mountain mahogany woodlands to climate change is rated moderate to high because of the moderate sensitivity rating and the low to moderate adaptive capacity rating (table 7.2). These communities are limited to specific sites and have few places where they can expand.

Shrubland Ecosystems

Shrubland ecosystems are vegetation communities with at least 10 percent cover of shrub species that are generally less than 6.5 feet tall at maturity, and often less than 1.5 feet tall on relatively harsh sites. Shrubland ecosystems include those dominated by dwarf and big sagebrush or a variety of upland shrub species, as well as all salt desert communities. The term shrub-steppe is often applied to shrubland ecosystems when herbaceous understory vegetation (generally perennial grasses and forbs) is sufficiently abundant to co-dominant. Mountain big sagebrush shrubland (shrub-steppe) is the most common shrubland type in the IAP region. Mountain big sagebrush and dry big sagebrush shrublands make up nearly 40 percent of the nonforest vegetation in the IAP region (table 7.1). As already noted (table 7.3), much of the area historically dominated by these shrublands, as well as other sagebrush-dominated shrublands, has been invaded by pinyon pine or juniper. Mountain shrublands, though present throughout the region, are more extensive in the northern subregions (Middle Rockies and Southern Greater Yellowstone). Dry big sagebrush shrublands are most abundant on National Forest lands in the Great Basin and Semi Desert subregion. Dwarf sagebrush shrublands also occur throughout the region, but are most abundant in the Plateaus subregion. Blackbrush and salt desert shrublands occupy only minor portions of National Forest lands in the region, but are more widespread on adjacent landscapes at lower elevations in the Plateaus and Great Basin and Semi Desert subregions.

Various species and varieties of sagebrush have been combined into four unique sagebrush types because of similarities in environments they inhabit, plant structure, or response to disturbances. These sagebrush types are:

- **Mountain big sagebrush shrublands**—Mountain big sagebrush and Bonneville big sagebrush (*Artemisia tridentata* ssp. *vaseyana* × *wyomingensis*).
- **Dry big sagebrush shrublands**—Wyoming big sagebrush and basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*).
- **Sprouting sagebrush shrublands**—Mountain silver sagebrush (*A. cana* ssp. *viscidula*), snowfield sagebrush (*A. spiciformis*), and threetip sagebrush (*A. tripartita*). Timberline sagebrush (*A. rothrockii*) is endemic to the Sierra Nevada in California and has very limited distribution within the region. Thus, it is not addressed in any detail in this report.
- **Dwarf sagebrush shrublands**—Low sagebrush, black sagebrush, scabland sagebrush (*A. rigida*), Bigelow sagebrush (*A. bigelovii*), Owyhee sagebrush (*A. papposa*), budsage (*A. spinescens*), and pygmy sagebrush (*A. pygmaea*).

Although Wyoming and various low-growing sagebrush species are common throughout the region, mountain big sagebrush communities occupy the greatest area of USFS lands (table 7.1). Wyoming and basin big sagebrush types were aggregated because of similarities in life history traits, and because they represent critical habitats for many species of birds and wild and domestic ungulates. However, basin big sagebrush occupies sites with deeper soils (often on alluvial fans). These conditions tend to increase available moisture, with higher coverage by perennial bunchgrasses, suggesting these sites may be more resilient and resistant to various threats (Chambers et al. 2013). Similarly, the low or dwarf sagebrush species were combined for their common physical structure, unique habitats they represent, and similar life histories. Finally, all sprouting sagebrush species were combined because of their similar response to fire.

Overall, about 10 percent of the sagebrush-steppe of the Southwest and Intermountain West has been converted to dryland or irrigated agriculture (Noss et al. 1995). Over 99 percent of the remaining sagebrush-steppe has been affected by livestock, and about 30 percent of that area has been heavily grazed. In addition, much of the sagebrush in the IAP region contains annual invasive species, with impacts concentrated in lower-elevation, more xeric sagebrush landscapes (Miller et al. 2011). Various nonnative perennial species, such as crested wheatgrass (*Agropyron cristatum* and *A. desertorum*), intermediate wheatgrass (*Thinopyrum intermedium*), smooth brome (*Bromus inermis*), and forage kochia (*Bassia prostrata*), have been seeded for forage, fire breaks, or erosion control throughout the region. These species now dominate large areas, and continue to be seeded during postfire rehabilitation across much of the region despite some concerns for impacts on native species diversity (Davies et al. 2013; Lesica and Deluca 1996).

Effects of Climate Change

Several recent studies modeled the effects of climate change on sagebrush shrublands in the western United States (Balzotti et al. 2016; Bradley 2010; Schlaepfer et al. 2012; Still and Richardson 2015). Each of these studies concluded that climate change is likely to have significant effects on sagebrush ecosystems. Climate change risk to sagebrush is most pronounced in southern Nevada because decreased summer precipitation and increased temperatures there could make current sagebrush habitat climatically unsuitable in the future (Bradley 2010; Schlaepfer et al. 2012). Still and Richardson (2015) projected a 39 percent loss of the climate suitable for Wyoming big sagebrush across its range in the West. Neilson (2005) projected a loss of 12 percent of all current sagebrush habitat with each 1.8-°F increase in temperature, and the southern limit of suitable climate for many sagebrush species may shift to the northern Great Basin.

Sagebrush species, however, commonly hybridize, which has been shown to provide greater ability to adapt to changing environments (Hoffman and Sgrò 2011; McArthur 2000). In addition, all major species of sagebrush included in this discussion have both diploid and polyploid populations (McArthur 2000). Polyploids are smaller with slower growth rates that make them better adapted to stressful environments than their diploid relatives (Sanderson et al. 1989). Sagebrush, as a complex, may have greater ability to adapt to climate change than other associated taxa. It is impossible, however, to understand what effect new genotypes could have on future generations of sagebrush, how quickly they may develop, and how emergence of new genotypes may affect their ability to occupy sites that are becoming increasingly warmer and drier.

Mountain Big Sagebrush Shrublands

Vegetation Type Description and Distribution

Mountain big sagebrush plant communities occur throughout the IAP region and are generally found at elevations between 4,500 and 10,200 feet on moderately deep to deep, well-drained soils and on sites that are more cool and mesic than those associated with Wyoming big sagebrush plant communities (Blaisdell et al. 1982; Tueller and Eckert 1987; West et al. 1978; Winward 1980; Winward and Tisdale 1977). Mountain big sagebrush communities are dominated by mountain big sagebrush or xeric big sagebrush for long periods of time under historical disturbance regimes. Basin big sagebrush, snowfield sagebrush, mountain silver sagebrush, or threetip sagebrush may also occur as minor components in this vegetation type. Other shrub taxa, such as yellow rabbitbrush (*Chrysothamnus viscidiflorus*), rubber rabbitbrush (*Ericameria nauseosa*), mountain snowberry (*Symphoricapos oreophilus*), Woods' rose (*Rosa woodsii*), Saskatoon serviceberry (*Amalenchier alnifolia*), and chokecherry (*Prunus virginiana*) may be present at subdominant levels. Except where degraded by chronic overgrazing, the herbaceous understory of mountain big sagebrush communities supports a rich variety of perennial grasses and forbs that are critical for system resilience and wildlife habitat, and codominates even in late-seral communities. Natural fire regimes maintain spatial and temporal mosaics of herb-dominated to shrub-dominated patches in various stages of succession, and prevent conversion to conifer forests or woodlands.

Historically the presettlement fire return intervals for mountain big sagebrush were relatively short, (35–80 years) (Heyerdahl et al. 2006; Kitchen and McArthur 2007; Miller et al. 2001) compared to Wyoming big sagebrush (more than 100 years) (Baker 2006; Lesica et al. 2007). On cooler, more mesic sites, fire-free intervals have increased to between 50 and 150 years. The lack of fire, combined with the effects of livestock herbivory, has caused much of the increase in pinyon pines and juniper, with a consequent loss of herbaceous and shrub cover throughout much of the range of mountain big sagebrush (Crawford et al. 2004; Miller and Rose 1999).

Sensitivity to Climate Change: Moderate

Mountain big sagebrush shrublands have moderate sensitivity to climate change. Sensitivity to climate change varies with elevation, with lower-elevation stands more sensitive than those at higher elevations (Balzotti et al. 2016). Mountain big sagebrush growth is dependent on temperature, precipitation, and maximum snow depth (Poore et al. 2009). Winter precipitation has the strongest relationship with growth (Poore et al. 2009). At higher elevations growth is positively correlated with temperature, but lower elevations may experience decreased growth with warming. Likewise, production in higher-elevation vegetation communities may increase in the future (Reeves et al. 2014). Given that increased temperatures and a reduction in snowpack are likely with climate change, mountain big sagebrush growth rates are likely to decrease at lower elevations but could be improved at temperature-limited sites toward the higher end of the species distribution, thus potentially having significant and asymmetric effects on sagebrush cover.

Adaptive Capacity: Low to Moderate

Adaptive capacity of mountain big sagebrush shrublands is rated as low to moderate (table 7.2), depending on elevation and site conditions, land use history, fire suppression, and abundance of invasive species. A few areas of mountain big sagebrush shrublands have been converted to agricultural lands, and most of those that remain are used for domestic livestock grazing because of the palatable herbaceous undergrowth. Those that have had chronic improper grazing typically have high sagebrush canopy cover and low vigor of native herbaceous species, and thus may have invasive plant species present in varying amounts. In intact mountain big sagebrush shrublands, species and functional type diversity may confer resilience to climate change.

Mountain big sagebrush is easily killed by fire and does not resprout; postfire recovery is from seed that survives fire or disperses from unburned areas. Although recovery for mountain big sagebrush is often rapid (15–35 years) (Kitchen and McArthur 2007; Nelson et al. 2014), longer recovery times (50–150 years) are expected if residual seed are absent or if seedlings fail to establish from the short-lived seed bank (Baker 2006, 2011; Nelson et al. 2014). Postfire recovery is currently problematic on warmer and drier sites and may become a problem on cooler and moister sites in the future if the frequency and intensity of fires increase as projected (Abatzoglou and Kolden 2013). Regeneration of big sagebrush postfire is strongly linked to winter and spring precipitation (Nelson et al. 2014), which is not projected to change significantly in the IAP region (Chapter 3).

With increased fire severity and frequency, there is likely to be a shift in community composition to dominance by fire-adapted shrub and herbaceous species and possibly nonnative species. Fire-adapted shrub species (e.g., rubber rabbitbrush, yellow rabbitbrush, mountain snowberry, Wood's rose, Saskatoon serviceberry, chokecherry) may increase in abundance following fire (Fischer and Clayton 1983; Smith and Fischer 1997). In addition, more spring and winter precipitation and increased minimum temperatures may facilitate the establishment of nonnative annual grasses (particularly cheatgrass, which germinates in winter to early spring) or other invasive species, although this pattern is seldom observed in the cooler, moister mountain big sagebrush communities with healthy herbaceous understories.

Overall, mountain big sagebrush shows higher adaptive capacity than Wyoming big sagebrush, but is likely to be stressed somewhat by drought as climate patterns change (Balzotti et al. 2016). Compositional shifts in herbaceous species are likely. Mountain big sagebrush may be able to persist on mesic sites (Chambers et al. 2013), but mountain big sagebrush communities may be subject to upslope pressure from woodland tree species (unless disturbance or disturbance surrogates are used to reset successional processes). Conifer expansion, especially by juniper and pine species, into sagebrush communities is especially pronounced in the Great Basin (Miller et al. 2008). Interruptions to wildfire cycles and favorable climatic periods, combined with other factors, have led to the proliferation of trees, often occurring in sagebrush sites that previously did not support trees. Consequently, land cover type has gradually shifted from shrubland to woodland across numerous sites (Miller et al. 2011). These transitions significantly reduce resilience to changing climates, as the increased abundance of trees negatively affects soil moisture available for perennial herbaceous species. Conversely, mountain big sagebrush could expand into drier persistent aspen stands, as these areas are likely to be negatively affected by climate change (Chapter 6). This species is well adapted to the soils on which these aspen stands occur, and this replacement is already occurring in some areas.

Subspecies of big sagebrush can hybridize or undergo polyploidization, offering greater genetic diversity and potentially providing the species with the capacity to undergo selection and adapt to shifting climatic regimes (Poore et al. 2009). Garrison et al. (2013) found that what has been called Bonneville big sagebrush (Garrison 2006; McArthur and Sanderson 1999; Rivera et al. 2011; Winward 2004) has been shown to be a hybrid between mountain big sagebrush and Wyoming big sagebrush. This hybrid is found in southeastern Idaho and extreme northern Utah. Hybridization creates a greater level of uncertainty regarding the future distribution of this subspecies, as well as all other species and varieties of sagebrush. The ability of the expected new hybrids to survive on changing habitats under future climates is poorly understood at this time. Bonneville big sagebrush has also been observed in southern Utah, where it occupies sites ecologically similar to Wyoming big sagebrush. Hybridization contributes to the evolution of sagebrush (McArthur and Sanderson 1999), which may at least maintain morphologically similar sagebrush communities in the future.

Vulnerability to Climate Change: Moderate to High

Vulnerability of mountain big sagebrush shrublands varies from moderate to high because of the broad elevational range at which mountain big sagebrush occurs, and because of the wide range in current conditions of these shrubland communities (table 7.2). Factors contributing to the vulnerability of these communities include livestock grazing, expansion of pinyon-juniper shrublands, altered wildfire regimes, and nonnative invasive species, including cheatgrass and seeded forage species.

Dry Big Sagebrush Shrublands

Vegetation Type Description and Distribution

Dry big sagebrush shrublands are those dominated by Wyoming big sagebrush, basin big sagebrush, Parish big sagebrush (*A. t.* ssp. *parishii*), or sand sagebrush (*A. filifolia*) for long periods of time under historical disturbance regimes. Small amounts of threetip sagebrush may also occur in this vegetation type. The perennial herbaceous understory is less productive and less diverse in this vegetation type than in mountain big sagebrush-steppe and may be codominant or subdominant in intact communities.

Wyoming big sagebrush occurs throughout the IAP region in locations where winter or spring precipitation is sufficiently reliable to support spring growth; it is often found in areas receiving 8 to 16 inches of precipitation annually (Welsh et al. 2008). It typically grows in the warm, dry conditions of valleys and foothills, generally below 6,500 feet elevation (Welsh et al. 2008; Winward and Tisdale 1977), and often below National Forest boundaries. Soils on which Wyoming big sagebrush occurs are often underlain by an argillic, caliche, or silica layer (Miller et al. 2011). Basin big sagebrush also occurs throughout the region, but most of its habitat has been converted to agricultural use and other development because it typically occurs in valley bottoms on highly productive soils. Surviving stands are common in the deep soils of canyon bottoms and other areas of soil aggradation. Sand sagebrush is limited in the IAP region to southern Utah and possibly the Spring Mountains of southern Nevada. Parish big sagebrush is found on the Bridgeport District of the Humboldt-Toiyabe National Forest (central Nevada). Small populations also occur in southern Utah (Shultz 2006).

Sensitivity to Climate Change: High

Climate change is projected to have significant effects on dry big sagebrush shrublands, and these ecosystems are highly sensitive to a changing climate (table 7.2). Projections suggest potential loss of more than one-third of the climatically suitable area of Wyoming sagebrush by 2050 (Still and Richardson 2015). Amount and timing of precipitation control seeding establishment at low elevations because soil water content primarily controls seedling survival (Nelson et al. 2014; Poore et al. 2009; Schlaepfer et al. 2014). Conditions suitable for seedling establishment are infrequent under contemporary climatic conditions and are likely to become less frequent with climate change. Thus, these ecosystems remain vulnerable to drought, and sagebrush establishment is likely to be more difficult as years with adequate snowfall become less frequent (Meyer and Warren 2015). Even after seedling establishment, drought and increased summer temperature can affect survival and growth of adult plants because growth is positively correlated with winter precipitation and winter snow depth (Poore et al. 2009). Hence, if drought events increase in frequency and severity in the future, big sagebrush biomass and the abundance and diversity of perennial grasses and forbs may decrease.

Adaptive Capacity: Low to Moderate

Adaptive capacity of dry big sagebrush ecosystems to climate change is low (table 7.2) because of the effects of historical grazing on the composition and structure of these warmer and drier sites, fragmentation with conversion to agricultural uses (Noss et al. 1995), and oil and gas development, which is prominent in the IAP in the Uinta Basin of eastern Utah. Prior to Euro-American settlement in the West, much of the land occupied by Wyoming big sagebrush shrubland had understories dominated by spatially discontinuous perennial grasses. These communities carried fires only when humidity was low and winds were high, or after several wet years when fine fuels could accumulate (Hull and Hull 1974; Mensing et al. 2006; Vale 1975). These fire-free intervals were relatively long in comparison to other more mesic sagebrush-dominated sites, often 100 to 200 years or more. Where perennial bunchgrasses and shrubs have been lost to improper livestock grazing and invasion by annual grasses, fire frequency has increased dramatically, to more than double that of sagebrush shrublands with intact, native understory in the Great Basin (Balch et al. 2013). Observations of increased fire frequencies were reported as early as the early to mid–1900s after these annual grasses had invaded much of the Intermountain West (Pickford 1932; Piemeisel 1951; Robertson and Kennedy1954).

Strong negative relationships exist between cover of cheatgrass and perennial native grasses and forbs in Wyoming big sagebrush shrublands (Anderson and Inouye 2001; Chambers et al. 2014; West and Yorks 2002). Chambers et al. (2007) found that on relatively intact sites, native perennial herbaceous vegetation resprouted after fire, which then limited the growth and reproduction of cheatgrass. About 15 percent cover of perennial native herbaceous species is required to prevent an increase of medusahead or cheatgrass following fire or management treatments in these shrublands (Chambers et al. 2014; Davies et al. 2008).

The genetic variability within these species of sagebrush, how that variability is spread across the distribution of the species, and the relationship of this variability to climate change effects on the species are of critical importance (Chaney et al. 2017). Cytotypic variation, or individuals within a species that have different chromosomal factors (e.g., diploid versus tetraploid) than others within the same species, may be as important as subspecific variation in explaining adaptation and functional diversity within the big sagebrush complex (Brabec et al. 2016).

Research has also shown that minimum temperatures play a bigger role in the probability of sagebrush survival than water-related responses (Brabec et al. 2016; Chaney et al. 2017). In common garden studies, Chaney et al. (2017) found greater survival from cytotypes collected from regions with greater seasonal differences in temperature and higher summer precipitation (interior regions of the continent) than those collected from regions with moderate winter temperatures and drier summers. They also found that Wyoming big sagebrush had a greater physiological avoidance and resistance to freezing than mountain big sagebrush. These differences may have been the result of a greater insulating effect of snow cover at higher elevations where mountain big sagebrush occurs, and the resulting differences in the need to adapt to cold temperatures by the more exposed Wyoming big sagebrush. The importance of integrating genetic diversity into our understanding of the adaptive capacity of all sagebrush species is becoming more evident as the research in this area begins to evaluate how these cover types will respond to climate change.

Vulnerability to Climate Change: Very High

Dry big sagebrush shrublands have a very high vulnerability to climate change because of high sensitivity and low adaptive capacity (table 7.2). Evidence of this is found in the loss of this type across large areas of southern Utah in response to the 2002–2003 drought. Dry big sagebrush shrublands occupying lower elevations of the Great Basin are expected to be some of the most vulnerable to climate change. Western Wyoming, eastern Idaho, and higher elevations in the Great Basin are predicted to retain or gain climatically suitable areas for the most abundant component of dry big sagebrush shrublands, Wyoming big sagebrush (Still and Richardson 2015). Although suitable Wyoming big sagebrush habitat is projected to expand in some areas within and beyond the IAP region, its overall distribution is projected to decrease by at least 39 percent (Still and Richardson 2015). The distances between current and projected future habitats capable of supporting Wyoming big sagebrush often exceed the estimated migration rate of 6 to 19 miles per century (McLachlan et al. 2005; Yansa 2006). Thus, this species may lose significantly more habitat to climate change than it can gain (Still and Richardson 2015) without active assistance.

Sprouting Sagebrush Shrublands

Vegetation Type Description and Distribution

Sprouting sagebrush shrublands include communities dominated by mountain silver sagebrush, snowfield sagebrush, threetip sagebrush, or timberline sagebrush. These species are all capable of sprouting from the root crown following fire or other form of top kill, and because of their ability to sprout, a postdisturbance stage dominated by grasses and forbs is short lived.

Mountain silver sagebrush occurs through most of the IAP region (fig. 7.5), commonly on heavy soils in riparian terraces and in areas with high snowpack in mountainous areas (McArthur 2000). In the Sierra Nevada, similar sites are occupied by Bolander silver sagebrush (*A. cana* ssp. *bolanderi*) (Shultz 2006). In some areas around the Greater Yellowstone Area, silver sagebrush has replaced lodgepole pine (Jakubos and Romme 1993).

There is some disagreement on the distribution of threetip sagebrush in the literature. Shultz (2006) describes this variety as occurring in portions of Idaho, Nevada, and Wyoming, whereas Winward (2004) includes northern Utah in the distribution of this variety. Much of its habitat has been converted to agriculture because of the productive soils on which it occurs. Remaining populations are isolated throughout its presettlement distribution (Shultz 2006).

Timberline sagebrush is a California endemic and is uncommon in the IAP region (fig. 7.5). It occurs in deep soils along forest margins of the Sierra Nevada in California and Nevada (McArthur 2000), and collections on or near the Bridgeport District in Humboldt-Toiyabe National Forest appear to generally be above 10,000 feet elevation (Jepson Flora Project 2016). Because it is rare in the region, we did not include it in this assessment.

Snowfield sagebrush occurs at high elevations in the IAP region throughout northern and central Utah, western Wyoming, central and southeastern Idaho, and the eastern Sierras. It typically occurs at higher elevations than, or as inclusions within, mountain big sagebrush shrublands in areas where snow depth and subsequent soil moisture are higher. However, it is included here because of its ability to sprout in response to fire.

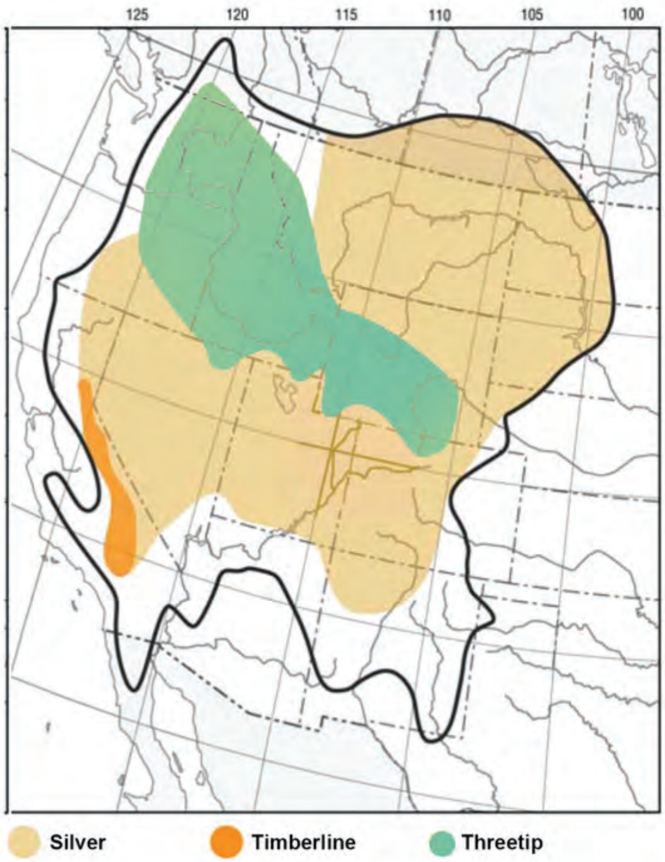

Figure 7.5—Distribution of silver sagebrush, timberline sagebrush, and threetip sagebrush in the western United States (from Mahalovich and McArthur [2004]).

Sensitivity to Climate Change: Moderate

Warmer and drier climates will negatively affect the vigor and abundance of sprouting sagebrush species, which are adapted to more mesic conditions. Although these species can sprout following disturbance, they also reproduce by seed. Like other sagebrush species, however, seed viability is short for many species, including silver sagebrush (Romo and Young 2002). Seed viability is likely to be negatively affected by increased temperatures, prolonged droughts, and irregular precipitation patterns. For these reasons, the sensitivity of sprouting sagebrush shrublands is rated as moderate (table 7.2).

Adaptive Capacity: Moderate

All three subspecies of sagebrush in these communities sprout after fire. In addition, silver sagebrush spreads by underground rhizomes (Schultz and McAdoo 2002) and therefore can recover more quickly than other species of sagebrush following disturbance. These factors, when combined with the more mesic habitat conditions, led to a rating of moderate adaptive capacity (Balch et al. 2013) (table 7.2).

Vulnerability to Climate Change: Moderate

Sprouting sagebrush shrublands have been given a moderate climate change vulnerability rating because of their moderate sensitivity and adaptive capacity to climate change (Balch et al. 2013) (table 7.2). Although the sagebrush species in this type can sprout, their higher dependence on soil moisture than other sagebrush shrublands makes them vulnerable to increasing temperatures and drought. In addition, increased fire frequency and severity (particularly in threetip sagebrush communities) may cause a shift in community composition to dominance by fire-adapted herbaceous or nonnative species. Other fire-adapted shrub species (e.g., rubber and yellow rabbitbrush) may increase, particularly following fire. Nonnative invasive species respond favorably after fire, and if present, may increase in cover and density. Understory composition in both silver and threetip sagebrush communities may possibly shift to more xeric grassland species (e.g., bluebunch wheatgrass [*Pseudoroegneria spicata*], needle-and-thread [*Hesperostipa comata*]), which are better adapted to warmer and drier conditions. Sprouting sagebrush species may shift landscape position to sites with more moisture and cooler temperatures (e.g., higher-elevation, lower landscape position, and northeast aspects).

Dwarf Sagebrush Shrublands

Vegetation Type Description and Distribution

Dwarf sagebrush shrublands are those communities dominated by low sagebrush (including the subspecies low sagebrush [*A. a.* ssp. *arbuscula*], alkali sagebrush [*A. a.* ssp. *longiloba*], cleftleaf low sagebrush [*A. a.* ssp. *thermopola*], and Lahontan sagebrush [*A. a.* ssp. *longicaulis*]), black sagebrush, Bigelow sagebrush, Owyhee sagebrush, scabland sagebrush, or pygmy sagebrush. These dwarf sagebrush shrublands occur across a broad elevational range, often on sites with shallow or rocky soils, or on soils with high clay content. The abundance and diversity of perennial grasses and forbs vary but are generally similar to or less than those associated with dry big sagebrush shrubland communities. Fires were rare historically because fine fuels are typically low, but when fires occur, the grass-forb stage can persist for long periods of time on harsh sites or where erosion occurs after fire (Young 1983). Pinyon and juniper may invade on the more mesic sites in the absence of disturbance. Some sites are susceptible to invasion by introduced annual grasses, and where this occurs, fire frequency often increases.

Dwarf sagebrush species occur throughout the IAP region (fig. 7.6). Black sagebrush and one or more varieties of low sagebrush are found throughout most of the region. Bigelow sagebrush occurs in the southern portions of Utah and Nevada. Scabland and Owyhee sagebrush are limited to the western and southern portions of Idaho, and northeastern Nevada. Lahontan sagebrush is generally restricted to northwestern Nevada and adjacent areas in California and Oregon. Pygmy sagebrush is uncommon but is locally abundant in east-central and eastern Nevada, western Utah, and the Uinta Basin of northeastern Utah (Ulev 2005).

Low, Bigelow, and black sagebrush occur across a broad geographic and elevational range. Black sagebrush generally occurs between 4,600 and 8,500 feet elevation in the

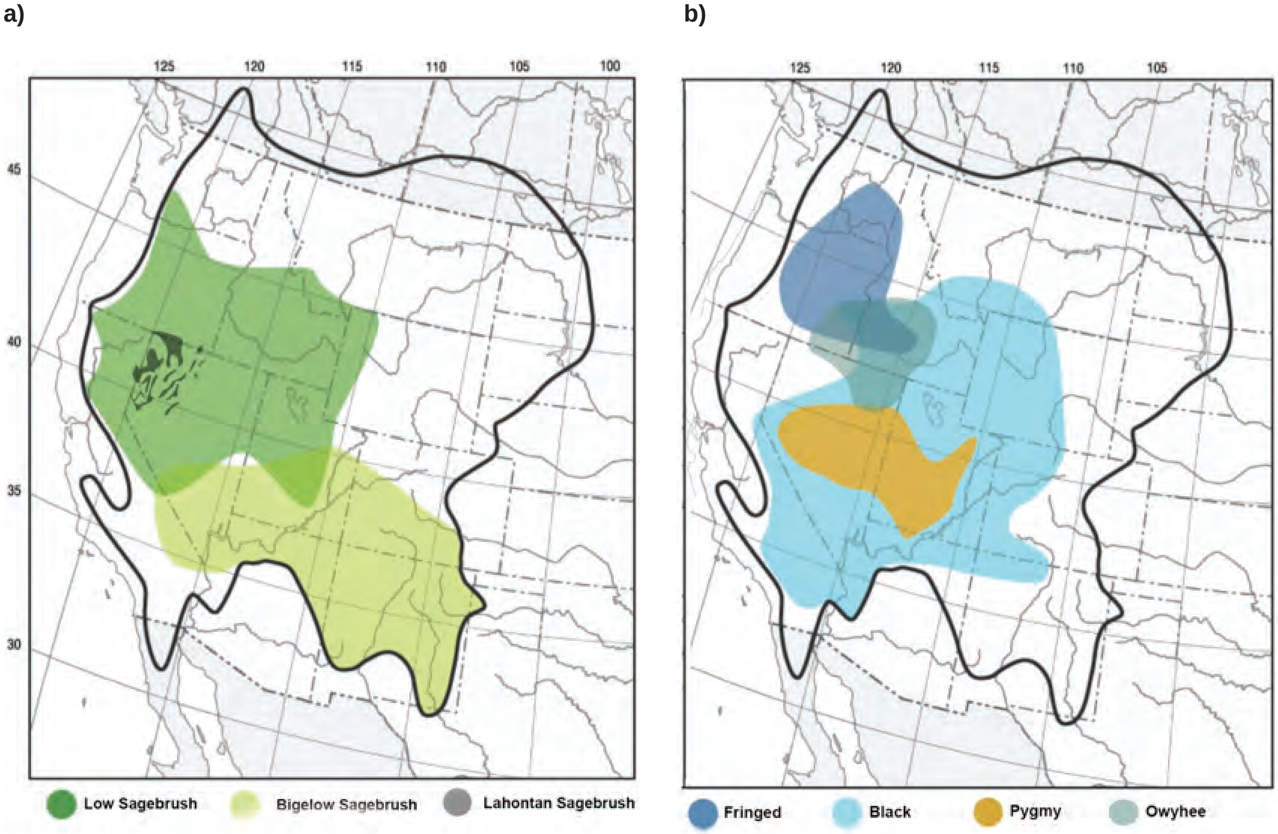

Figure 7.6—Distribution of low sagebrush species in the western United States: (a) low, Bigelow, and Lahontan sagebrush; and (b) fringed, black, pygmy, and Owyhee sagebrush (from Mahalovich and McArthur [2004]).

Intermountain West, and up to 11,000 feet in Nevada (Fryer 2009). Low sagebrush ranges from 2,300 feet to over 11,000 feet in Nevada (Steinberg 2002), but tends to occur primarily above 8,000 feet in a band across central Nevada, from Ely to Bridgeport. Bigelow sagebrush ranges in elevation between 3,000 and 7,000 feet in Nevada and Utah (Howard 2003). Scabland and pygmy sagebrush have a narrower distribution, but elevational range for pygmy sagebrush is 5,000 to 11,000 feet in Nevada (Ulev 2005). Pygmy, Bigelow, scabland, and alkali sagebrush grow in edaphically limited habitats, and all other dwarf sagebrush species generally occur on shallow or rocky soils, making them more resistant to cheatgrass dominance, and therefore more resistant to the large or severe fires to which other sagebrush shrublands have been subjected.

Sensitivity to Climate Change: Moderate to High

All low-growing sagebrush species are likely to be negatively affected by higher temperatures and increased periods of drought. As with all sagebrush species, seed viability of dwarf sagebrush species is short and their dependence on spring soil moisture will make them susceptible to prolonged droughts and to changes in climate that may otherwise affect the timing and amount of spring moisture. Increases in fire, coupled with drought, could inhibit regeneration of the dwarf sagebrush species, particularly on harsh sites (Young 1983).

Adaptive Capacity: Moderate to High

Dwarf sagebrush shrublands are likely to have a moderate to relatively high adaptive capacity to climate change (table 7.2). Species in these shrublands have broad distributions and occur over a wide elevational range in the IAP region. Adaptive capacity may be moderated, however, because of the relatively low productivity characterizing these species, especially where other risk factors (e.g., nonnative annual grasses) are present. Sites dominated by scabland sagebrush occur over a narrower range in elevation (McWilliams 2003), and thus it may be more susceptible to the effects of climate change because alternative suitable sites may not be available.

None of the dwarf sagebrush species can sprout following fire, with the possible exception of hybrids between black and silver sagebrush; sprouting is thought to be a heritable trait in crosses between nonsprouting and sprouting sagebrush species (McArthur 1994). Hybridization may play a role in increasing adaptive capacity of other dwarf sagebrush species to the effects of climate change. In central Nevada, black sagebrush commonly forms hybrids at all elevations. Lahontan sagebrush is a putative stable hybrid between low sagebrush and Wyoming big sagebrush (McArthur and Sanderson 1999).

Vulnerability to Climate Change: Moderate

Dwarf sagebrush shrublands are rated as moderately vulnerable because sensitivity and adaptive capacity are rated as moderate to high (table 7.2). Climate change is likely to result in shifts in the distribution of conditions suitable to support the dwarf sagebrush species in the region. All dwarf sagebrush species are intolerant of fire, and most do not sprout following fire. Because of the low productivity of these sites, however, cheatgrass may not be able to establish on harsh sites (Chambers et al. 2013). Thus, these ecosystems may be more likely to resist a significant change in fire regimes. However, these sites will be exposed to higher temperatures and more erratic precipitation patterns, reducing the ability of seedlings to establish during unfavorable years.

Mountain Shrublands

Vegetation Type Description and Distribution

Mountain shrublands are typically associated with mountain big sagebrush shrublands, oak-maple woodlands, and pinyon-juniper woodlands, as well as montane and subalpine forests. They can occur as large patches within wooded and forested landscapes. Combinations of species such as chokecherry, serviceberry (*Amelanchier alnifoli*a), snowberry, currant (*Ribes* spp.), rose (*Rosa* spp.), maple (*Acer* spp.), sumac (*Rhus* spp.), ceanothus (*Ceanothus* spp.), Scouler willow (*Salix scouleriana*), elderberry (*Sambucus* spp.), thimbleberry (*Rubus parviflorus*), alderleaf mountain mahogany (*Cercocarpus montanus*), bitterbrush (*Purshia tridentata*), wild crab apple (*Peraphyllum ramosissimum*), and mountain ash (*Sorbus scopulina*) are common. Mountain big sagebrush is also common as a subdominant element. Species dominating the overstory of these shrublands are typically adapted to a wide range of elevations (table 7.4). In addition to the wide variety of shrub species, there is an even greater diversity of associated perennial herbaceous species that occur in the understory.

Sensitivity to Climate Change: Low to Moderate

High species diversity, coupled with the broad elevational range over which these communities occur, is likely to result in relatively low sensitivity of mountain shrublands to climate change (table 7.2). Though not directly related to the IAP region, studies in Alberta, Canada, found little change in the spring flowering response of either serviceberry or chokecherry between 1936 and 2006 (Beaubien and Hamann 2011). However, declining snowpacks, more frequent and severe droughts, and warmer temperatures may cause hotter fires and, at the same time, sites may become drier, causing variable amounts of mortality, depending on site conditions.

Adaptive Capacity: Moderate to High

Montane shrublands were historically maintained by relatively frequent fire (approximately every 30 years or less) (Smith and Fischer 1997), and most montane shrubs sprout following fires. Stressors to these shrublands include fire exclusion and resulting conifer encroachment, browsing by both native wildlife and domestic livestock, and insects and disease. As noted earlier, the diversity of species in these communities is often very high. However, there is the potential that more frequent and severe fires will decrease resilience. Loss of topsoil and creation of hydrophobic (water-repellent) soils after frequent, hot fires, can lead to loss of species over time (DeBano 1981; Wellner 1970). As sites become drier, there may be a shift away from mesic species to more xeric and fire-adapted shrubs, such as rubber rabbitbrush, yellow rabbitbrush, bitterbrush, and mountain big sagebrush.

Vulnerability to Climate Change: Low to Moderate

Of all the ecosystems in the IAP region, montane shrublands appear to have the lowest vulnerability to climate change (table 7.2) because of high species diversity, high sprouter diversity, wide range in elevation, and broad distribution of dominant overstory species. Even with increasing temperatures and uncertain precipitation, species of the

Table 7.4—Elevation ranges of species that dominate or codominate the overstory of mountain shrublands in the IAP region.

Species	Elevation	Source
	Feet	
Saskatoon serviceberry (*Amelanchier alnifolia*)	4,000-9,500	Welsh et al. (2008)
Utah serviceberry (*Amelanchier utahensis*)	3,000-9,000	Welsh et al. (2008)
Birchleaf mountain-mahogany (*Cercocarpus montanus*)	3,900-9,800	Cronquist et al. (1997)
Chokecherry (*Prunus virginiana*)	3,100-10,170	Johnson (2000)
Skunkbush sumac (*Rhus trilobata*)	2,900-7,700	Pendleton et al. (1989)
Thimbleberry (*Rubus parviflorus*)	4,700-9,000	Gucker (2012)
Scouler willow (*Salix scouleriana*)	Sea level-10,000	Anderson (2001)
Mountain snowberry (*Symphoricarpos oreophilus*)	4,000-10,000	Aleksoff (1999)

montane shrublands are probably the most capable of expanding into niches at higher elevations and onto adjacent, more mesic portions of the landscapes in which they occur.

Blackbrush Shrublands

Vegetation Type Description and Distribution

Blackbrush shrublands are very limited on National Forest lands in the IAP region, occurring at the lowest elevations on the southern edge of the region in the Spring Mountains National Recreation Area in Humboldt-Toiyabe National Forest and on the Moab District in Manti-La Sal National Forest. Distinct ecotypes of blackbrush (*Coleogyne ramosissima*) occur in the region: one entering the Great Basin and Semi Desert subregion from the adjacent Mojave Desert to the south, and the other in the Plateaus subregion (Richardson and Meyer 2012; Richardson et al. 2014). Communities are dominated by blackbrush with jointfir (*Ephedra* spp.), burrobush (*Ambrosia dumosa*), hedgehog cactus (*Echinocereus* spp.), spiny menodora (*Menodora spinosa*), various goldenbush species (*Ericameria* spp.), prickly pear (*Opuntia* spp.), Apache plume (*Fallugia paradoxa*), and others sometimes present as subdominants. Historically, interspaces in these communities were probably mostly bare, even during years of higher precipitation, because of competition from blackbrush (Brooks et al. 2007). Perennial grasses and seral shrubs probably occurred sporadically in areas where blackbrush cover was low (Brooks et al. 2007).

Sensitivity to Climate Change: Low to Moderate

As a long-lived, stress-tolerant shrub, blackbrush has relatively low sensitivity to the direct effects of climate variability in the absence of disturbance (Kitchen et al. 2015). It sheds its microphyllous leaves in response to drought stress, is well adapted to high temperatures (Munson et al. 2011; Summers et al. 2009), and occurs on shallow soils with a rooting system that allows it to capture soil water opportunistically (Schwinning et al. 2005, 2008).

Adaptive Capacity: Low

There is a high level of genetic differentiation between populations of blackbrush that occur in the Mojave Desert (those of the Spring Mountains in southern Nevada) and those of the Colorado Plateau (Dixie and Manti-La Sal National Forests), which has implications for population persistence and migration in response to climate change (Richardson and Meyer 2012; Richardson et al. 2014). Pendleton et al. (2015) found records that indicate blackbrush has the ability to migrate in response to changes in climate, but that the rate at which climate change is expected to occur may preclude natural migration because of its episodic recruitment. In addition, blackbrush communities have little resistance to invasive plant species and very low resilience to the fires accompanying the increase in invasive annual grasses. Large areas of blackbrush in the Mojave Desert, where red brome (*Bromus rubens*) has increased significantly, have burned in the past decade (Pendleton et al. 2015). Blackbrush does not sprout after fire, and the species is not regenerating in these burned areas (Pendleton et al. 2015).

Vulnerability to Climate Change: Moderate to High

Despite the low sensitivity of blackbrush to the direct effects of climate change, vulnerability is rated as moderate to high (table 7.2) because of its lack of resistance to invasion by exotic species and its inability to resprout following fire. With increased area burned under changing climate (Abatzoglou and Kolden 2013), a loss of dominance by blackbrush is likely to occur, dominance by invasive annual grasses will increase, and a subsequent increase in fire frequency and size may occur with increased horizontal fuel continuity.

With climate change, there may be some expansion of blackbrush communities onto adjacent sites that are currently higher in elevation or on sites that have somewhat higher available soil moisture. This expansion is more probable in the Plateaus subregion, where invasive species have had less impact on fire and existing blackbrush communities, and where some evidence exists for contemporary blackbrush migration (Kay 2015). Expansion is much less likely on National Forest lands close to the Mojave Desert, where replacement of blackbrush by invasive species is already resulting in net loss of the blackbrush vegetation type.

Salt Desert Shrublands

Vegetation Type Description and Distribution

North American salt desert shrublands are dominated by a mixture of drought- and salt-tolerant (halophytic) shrub, sub-shrub, and herbaceous species and occupy landscapes too dry or too salty to support sagebrush. Salt desert shrublands are a minor component on National Forest lands in the IAP region, occurring primarily in the Utah and Nevada portions of the region (fig. 7.7), where their distribution on National Forest lands is limited to lower elevations. However, this type is extensive on adjacent lands managed by the Bureau of Land Management in Nevada and Utah as well as outside the region in southeastern Wyoming.

Salt desert shrublands are dominated primarily by species belonging to the Chenopod plant family, such as greasewood (*Sarcobatus* spp.), fourwing saltbush (*Atriplex canescens*), shadscale (*A. confertifolia*), Gardner saltbush (*A. gardneri*) and close relatives, mat saltbush (*A. corrugata*), winterfat (*Krascheninnikovia lanata*), gray molly (*Bassia americana*), spiny hopsage (*Grayia spinosa*), iodine bush (*Allenrolfea occidentalis*), and seepweed (*Sueda* spp.), along with a variety of other shrub species (Blaisdell and Holmgren 1984). Perennial grasses are often codominant, with the relative importance of warm and cool-season species dependent on the reliability of seasonal moisture for the sites. Common warm season grasses can occur in areas with warm, wet summers, which occur where salt desert shrublands are found in the extreme southern portions of the region. Cool-season

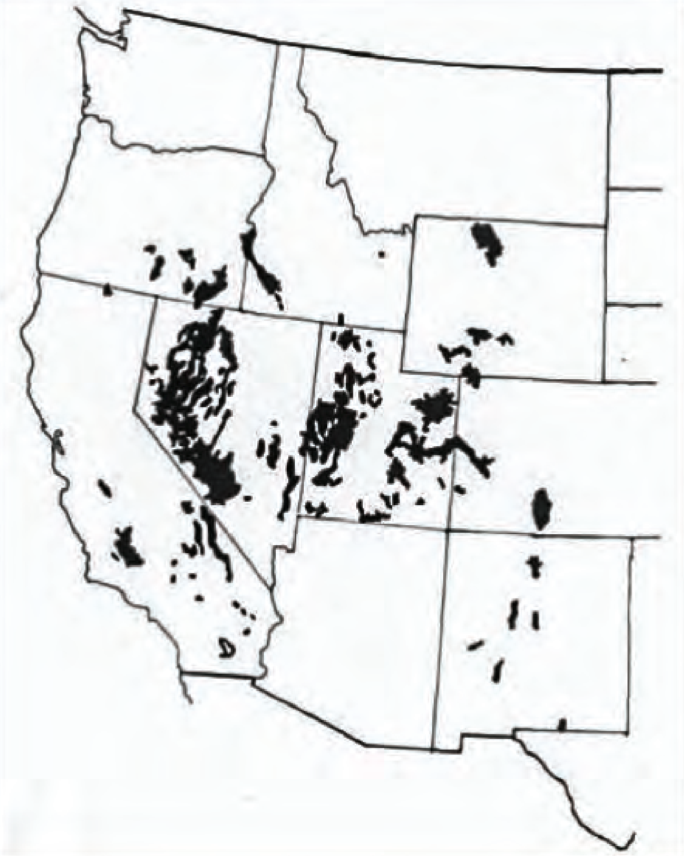

Figure 7.7—Distribution of salt desert shrublands in the western United States (derived from West [1983]).

grasses can occur elsewhere in the region, where spring is typically cooler and wetter (Paruelo and Lauenroth 1996). In the southern salt desert shrublands, warm season grasses include galleta grass (*Pleuraphis jamesii*), blue grama (*Bouteloua gracilis*), alkali sacaton (*Sporobolus airoides*), sand dropseed (*Sporobolus cryptandrus*), and saltgrass (*Distichlis spicata*). Common cool-season grasses include Indian ricegrass (*Achnatherum hymenoides*), squirreltail (*Elymus elymoides*), Salina wildrye (*Leymus salinus*), needle-and-thread grass (*Hesperostipa comata*), and purple three-awn (*Aristida purpurea*). A diverse mixture of native forbs responds opportunistically to variability in the timing and amount of precipitation and support a rich diversity of desert pollinators. Total plant cover in these communities is typically 20 percent or less, and height of shrubs is usually less than 1.5 feet (West 1983).

Cheatgrass establishment in dry salt desert communities is limited by low and sporadic precipitation (Meyer et al. 2001), but has been observed to be increasing. With increasing cheatgrass comes the potential for impacts from fire, which was not historically a significant disturbance factor (West 1994).

Sensitivity to Climate Change: Moderate

Many of the species associated with salt desert shrublands have wide ecological distributions and are tolerant of a wide range of climatic conditions. Species typically combine various morphological and physiological attributes (such as small, heavily protected leaves, high root-to-shoot ratios) that enable them to tolerate stress with others (such as seed and shoot dormancy) that facilitate stress avoidance. The effects of climate change on these plant communities will include both positive and negative shifts for individual species. However, the plant communities are likely to be relatively insensitive to the direct effects of climate change.

Adaptive Capacity: Low to Moderate

Many of the species that characterize salt desert ecosystems are fire intolerant (Chambers et al. 2013; Meyer et al. 2001). With the introduction of nonnative annual grasses, an increase in fine fuels may allow for increased area burned (West 1994), which would likely decrease the abundance of many characteristic species in this type. Disturbed salt desert shrublands are particularly susceptible to invasion by nonnative halophytic species such as halogeton (*Halogeton glomeratus*) and Russian thistle (*Salsola* spp.). Halogeton is a succulent summer annual that quickly spreads and establishes in disturbed areas (such as roadways and livestock watering areas) within intact perennial communities. It is a prolific seed producer, and seeds may remain in the soil seed bank for 10 years or more (Cronin and Williams 1966). Once established, halogeton prevents natural regeneration of native shrubs, such as winterfat (Eckert 1954; Harper et al. 1996; Kitchen and Jorgensen 1999) and Gardner saltbush (Goodrich and Zobell 2011). Today, halogeton stands are frequently found adjacent to remnant winterfat communities throughout the Great Basin (Kitchen and Jorgensen 2001).

Vulnerability to Climate Change: Moderate to High

With moderate sensitivity and low to moderate adaptive capacity, salt desert shrublands have moderate to high vulnerability to climate change (table 7.2). Risks of direct and indirect (i.e., fire) effects of introduced species render the vulnerability of this vegetation type relatively high to the combination of future impacts. Climate change is expected to result in more extreme precipitation events (West 1994). The combination of wet years and the fertilization effects of increased atmospheric carbon dioxide may result in an increase in annual grasses, which will in turn be more likely to fuel wildfire (Bradley et al. 2016; Salo 2005; Smith et al. 1987). Most of the dominant woody species in salt desert shrublands are poorly adapted to fire, and they will be vulnerable to increases in fire frequency.

Alpine Forblands and Grasslands

Alpine forblands and grasslands include communities dominated by either a variety of broadleaf forb species or by grasses, as well as the wide variety of species that occur in alpine ecosystems. Edaphic and climatic factors in these communities inhibit the establishment or significant growth of woody species.

Alpine Communities

Vegetation Type Description and Distribution

Alpine ecosystems occur at the highest elevations above treeline in the IAP region, at elevations generally above 8,000 feet in the northern portions to over 11,000 feet in the south. Although relatively small in area, they have high aesthetic value and high visitor and recreational use. They are possibly the ecosystems in the IAP region that are most at risk from the effects of climate change because of their shrinking habitat. These high-elevation locations are characterized by a very short growing season. Alpine plant communities are diverse and complex across the IAP region (Hayward 1952) and can include a variety of growth forms, including upland krummholz, shrubland, grassland, and herbaceous communities, herbaceous wetlands, and sparsely vegetated bedrock and scree communities (NatureServe 2013). These diverse types have been combined here because of the relatively small area they cover within the region, and because they are expected to have similar (negative) responses to climate change.

Sensitivity to Climate Change: High

The length and depth of snow cover, which are strongly correlated with mean temperature and precipitation, are key factors controlling alpine ecosystems (Beniston 2003). Snow cover provides frost protection for alpine plants in the winter, as well as the water supply in spring. Reduced snowpack with warming is likely to cause major changes in alpine plant communities (Gottfried et al. 2012). Alpine plants may be at greater risk from competition from plant species that are adapted to warmer temperatures and longer growing seasons. Research from the European Alps showed a significant increase in species richness in alpine ecosystems with the invasion of plants from lower altitudes (Pauli et al. 2003). It will be essential to account for new competitive interactions among species to better predict the responses of individual alpine species and entire communities to climate change (Alexander et al. 2015).

Adaptive Capacity: Low

The adaptive capacity of plant species in alpine ecosystems to climate change is likely to be low (table 7.2) because they have limited geographic space into which they can expand, and they are isolated communities (Alo and Wang 2008). In addition, the physiological traits that allow their persistence in alpine climates also reduce their ability to adapt to changing climates. The fate of individual species in a changing climate is likely to depend on their individual ecophysiological responses to the direct effects of increased temperatures and carbon dioxide levels, as well as the indirect effects of rising temperatures, such as the length of the snow-free period (Pauli et al. 2003).

The introduction of mountain goats (*Oreamnos americanus*), a nonnative species, to nearly every mountain range in Utah with alpine vegetation and the Ruby Mountains in Nevada has the potential to impact existing native vegetation, introduce noxious and invasive weeds, and result in a significant reduction of ground cover. As a result, there is potential for loss of native plants from trampling and subsequent soil erosion, further decreasing the capacity of alpine plant communities to adapt to climate change.

Vulnerability to Climate Change: Very High

The composition and distribution of alpine ecosystems will be affected by decreasing snowpack. For high-elevation vegetation, climate change may affect seed germination and survival by modifying moisture availability and therefore result in reduced plant success. Specific effects will depend on vulnerability thresholds of the characteristic species and the rate and magnitude of changes over time (Beniston 2003). In addition, climate change could lead to a mismatch between plant flowering and pollinator emergence (Parmesan 2006), which could adversely affect both plants and pollinators.

Alpine communities often have a relatively high number of endemic species because they are isolated (Beniston 2003), meaning that highly endemic alpine biota will have a disproportionately high risk of extinction (Parry et al. 2007). Local extinctions of otherwise widespread alpine species such as arctic gentian (*Gentianodes algida*) and alpine chaenactis (*Chaenactis douglasii* var. *alpina*) have already occurred in portions of Idaho because of habitat loss and fragmentation (USEPA 1998). Warming temperatures and longer growing seasons are likely to allow more competitive shrubs, trees, and herbs to expand upslope from adjacent ecosystems and potentially outcompete existing alpine vegetation (Alexander et al. 2015).

Mountain Grasslands

Vegetation Type Description and Distribution

Grasslands are areas where grasses and grass-like species dominate and trees and shrubs have no more than a minor presence. Forbs are typically present, although forb abundance and diversity vary, and forbs are subdominant to grasses. Grasslands that occur on the mid- to high-elevation landscapes are composed primarily of perennial cool-season bunchgrasses. Typical species for higher elevations include slender wheatgrass (*Elymus trachycaulus*), mountain brome (*Bromus carinatus*), needlegrasses (*Achnatherum* spp.), and blue grasses (*Poa*). Dominant species at middle elevations may include bluebunch wheatgrass, Idaho fescue (*Festuca idahoensis*), and Hood sedge (*Carex hoodii*). On many sites that have transitional winter- and summer-dominant weather patterns, a mixture of cool and warm season grasses can coexist.

Boulder Top Mountain on the Aquarius Plateau in Dixie National Forest has broad landscapes dominated by a low-growing fescue that was historically included in the sheep fescue (*Festuca ovina*) complex. Welsh et al. (2008) note that there are native forms of *Festuca ovina*, whereas another database (NRCS 2017) indicates that this species is entirely introduced. The ecosystems on the Aquarius Plateau appear to be native grasslands and are treated as such here.

These apparent native grassland communities occur on one of the largest contiguous flat-top landscapes above 11,000 feet elevation in the IAP region. Youngblood (1980) also recognized grassland communities on the Bridger-Teton National Forest dominated by spike fescue (*Leucopoa kingii*), bluebunch wheatgrass, and Idaho fescue. This important cover type is very limited in distribution in the IAP region.

Sensitivity to Climate Change: Moderate

Determining the sensitivity of grasslands to climate change is complex. As noted earlier, cool-season grasses occur in areas with cool, wet springs, which occur throughout most of the IAP region. Warm season grasses occur in areas with warm, wet summers, which occur at lower elevations in the southern portion of the IAP region (Paruelo and Lauenroth 1996). Some studies, based solely on projected increases in temperature, suggest that grasslands dominated by cool-season grasses may decline and that grasslands dominated by warm season grasses could, at the same time, expand into those environments. To further complicate this assessment, the increased atmospheric carbon dioxide favors cool-season grasses and enhances biomass production. However, warming favors warm season grasses because of increased water-use efficiency (Morgan et al. 2004, 2007). For these reasons, we cautiously rank sensitivity of these ecosystems as moderate (table 7.2).

Adaptive Capacity: Low to Moderate

The adaptive capacity of these grassland communities is rated as low to moderate because of historical impacts, and inherent adaptive capacity of species dominating these sites (table 7.2). Many low-elevation grasslands have been converted to agricultural use. Those grasslands that remain, particularly at lower elevations, are often highly disturbed, fragmented, and frequently occupied by many nonnative invasive plant species (Finch 2012). More frequent or severe fire associated with climate change may encourage further expansion of invasive species in grasslands, especially at lower elevations where adjacent landscapes are dominated by annual grasses (Bradley et al. 2016).

Vulnerability to Climate Change: Moderate to High

With moderate climate sensitivity and low to moderate resilience, these cool-season grass-dominated communities are rated as having a moderate to high vulnerability to climate change (table 7.2). Although some studies suggest that cool-season grasses will respond positively to increased carbon dioxide levels, other models show that these same species will decline because of increasing temperatures. Warm season grasses have been shown to be favored by increased temperatures alone because of increased water-use efficiency (Morgan et al. 2004, 2007); thus, they may have a competitive advantage over cool-season grasses and could expand into the region from warmer and drier climates to the south. Increasing fire would also encourage more invasive species in grasslands (Bradley 2009; D’Antonio and Vitousek 1992), converting many warmer and drier systems to invasive annual grasslands.

Subalpine Forb Communities

Vegetation Type Description and Distribution

Subalpine forb communities are upland communities dominated by non-grass herbaceous species, commonly called forbs (Ellison 1954; Shiflet 1994). Grasses are typically present but are subdominant (Shiflet 1994). If present, trees and shrubs constitute only a minor element of these communities (Ellison 1954). Subalpine forb communities occur at moderate to high elevations (7,000–11,000 feet) where forb growth and reproduction are favored by topographic, edaphic, and climatic conditions (Shiflet 1994). Mean annual precipitation is 25 to 40 inches. These communities can be found in various patch sizes, from small subalpine meadows to a dominant vegetation type covering miles of ridgetops and gentle slopes. They are most extensive in areas where midsummer thunderstorms of late July to mid-August coincide with the prime flowering season in the subalpine zone. Subalpine forb communities merge into mountain sagebrush-steppe, subalpine conifer forest, and aspen forest ecosystems and share numerous species with each (Ellison 1954).

Subalpine forb communities are limited in the IAP region (fig. 7.8). Subalpine forb communities are especially prominent on the Wasatch Plateau in central Utah (Ellison 1954), in the Teton Range of the Idaho-Wyoming border, and in the Wind

Figure 7.8—Distribution of tall subalpine forb communities (in orange) in the Intermountain Adaptation Partnership region. Forested area is shown in green (from U.S. Forest Service, http://www.fs.fed.us/wildflowers/beauty/Tall_Forb/what.shtml).

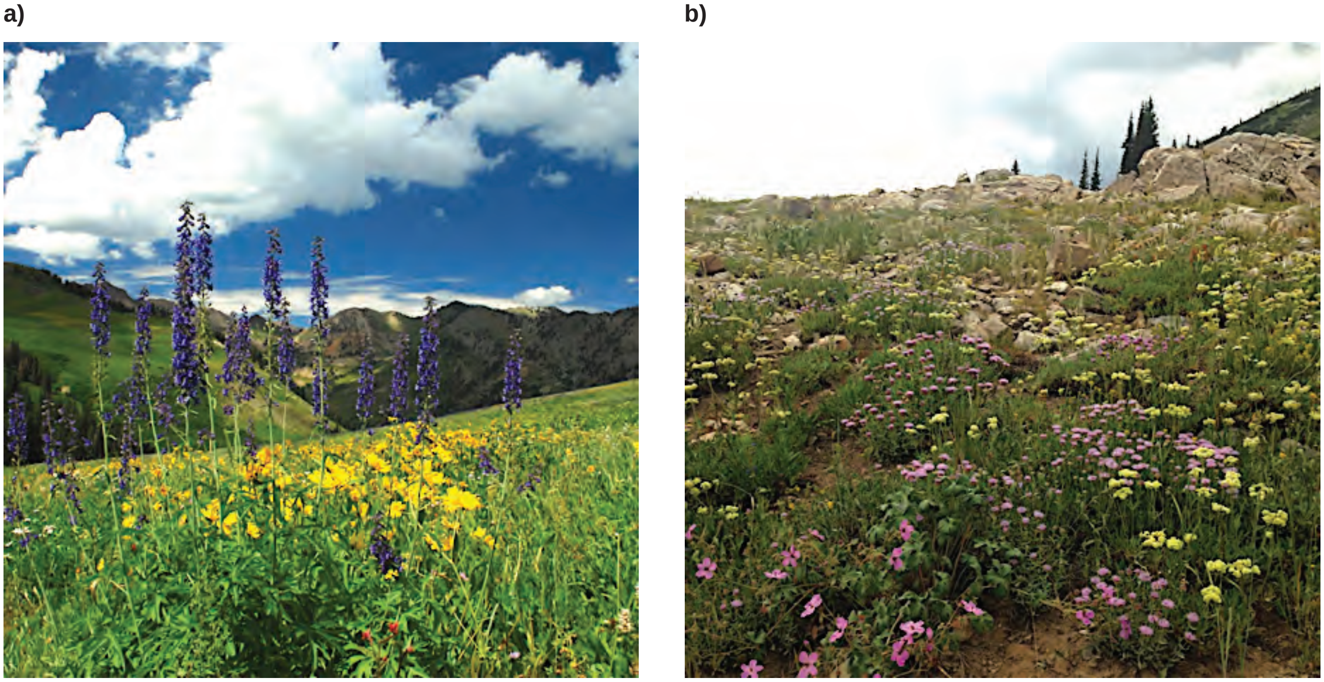

Figure 7.9—Subalpine forb communities in the Intermountain Adaptation Partnership region: (a) a subalpine tall forb community occurring on deep, productive soils, and (b) a subalpine low forb community occurring on shallow, well-drained soils (photos: W. Padgett, U.S. Forest Service).

River Range of western Wyoming (Gregory 1982). These communities have also been found in the Jarbidge Mountains and Ruby Mountains of northern Nevada (Lewis 1971, 1975; Loope 1970) and in small amounts elsewhere in the region.

Subalpine forb communities are characterized by high vascular plant species diversity. For example, 54 forb genera (65 native, mostly perennial species) representing 22 families are found on 30 acres of the Elk Knoll Research Natural Area administered by the Manti-La Sal National Forest (unpublished records on file at the USFS, Shrub Sciences Laboratory, Provo, Utah). In addition to forbs, 11 grass and 11 shrub species are found at subdominant to incidental levels.

Subalpine forb communities include species assemblages classified as tall forb, which are typically associated with deep soils (fig. 7.9a) (Shiflet 1994), as well as assemblages of short forbs that occur on well-drained, typically shallow and rocky soils (fig. 7.9b). In addition, there are a variety of mixed and intermediate phases that combine elements of each. Common tall forb species include false hellebore (*Veratrum californicum*), false springparsley (*Pseudocymopterus montanus*), western sweetroot (*Osmorhiza occidentalis*), licorice root (*Ligusticum filicinum*), biscuit root (*Lomatium* spp.), valerian (*Valeriana* spp.), one-flower helianthella (*Helianthella uniflora*), showy goldeneye (*Viguiera multiflora*), geraniums (*Geranium* spp.), peavine (*Lathryus* spp.), lupines (*Lupinus* spp.), American vetch (*Vicia americana*), elk weed (*Fraseria speciosa*), larkspur (*Delphinium* x*occidentale*), columbine (*Aquilegia* spp.), jacobsladder (*Polemonium foliosissimum*), bluebells (*Mertensia* spp.), asters (*Symphiotrichum* spp.), and paintbrushes (*Castilleja* spp.), among many others. Common shorter forbs include various buckwheats (*Eriogonum* spp.), yarrow (*Achillea millifolium*), agoseris (*Agoseris* spp.), scarlet gilia (*Ipomopsis aggregata*), beebalm (*Mondardella* spp.), cinquefoil (*Potentilla* spp.), penstemons (*Penstemon* spp.), groundsels (*Packera* spp.), and paintbrushes (*Castilleja* spp.). Common grasses include slender wheatgrass, mountain brome, Porter brome (*Bromus porteri*), bluegrass (*Poa* spp.) and needlegrasses.

Sensitivity to Climate Change: High

Species that occur in subalpine forb communities occur across a broad elevational range and occupy a wide variety of habitats, but little literature is available regarding the specific requirements for the establishment and maintenance of these ecosystems. Soil characteristics are critical for preservation of the tall forb assemblages (Lewis 1993). Where those deep soils have eroded, the type has been compromised and in some cases, sites are no longer capable of maintaining species that once dominated (Shiflet 1994). These communities respond to summer rainfall, and it is unclear whether these precipitation events will increase or decrease in frequency and amounts with changing climate. However, higher temperatures will lead to reduced soil moisture and are likely to alter the conditions necessary to support these unique ecosystems. Although species in these communities may be able to move to higher elevations with warming, lack of soil development at higher elevations may prevent their establishment.

Adaptive Capacity: Moderate

Many acres of this cover type have been degraded or lost because of historical livestock grazing at unsustainable levels (Ellison 1954; Lewis 1993; McArthur et al. 2013). Heavy grazing has resulted in a loss of productive topsoil in many places, which limits the establishment and growth of many dominant native species (Shiflet 1994). On the Wasatch Plateau of central Utah, Lewis (1993) found significant improvement in conditions once livestock were removed from sites that had lost tall forb species through excessive grazing in the late 1800s. This is not always the case; intensive grazing by livestock and subsequent loss of topsoil can result in establishment of species such as tarweed (*Madia glomerata*) that can remain in place for years (Shiflet 1994). Because much of the area in subalpine forb communities is in a degraded condition, adaptive capacity is rated as moderate (table 7.2).

Vulnerability to Climate Change: High

Although some subalpine forb communities may be able to move higher in elevation where current alpine environments occur, the lack of soil development at higher elevations may support only the lower-growing species found in this vegetation cover type. In some areas, such as the Wasatch Plateau in central Utah, the tall forb communities occur at the highest elevations of the plateaus, and therefore the vulnerability to the communities is high to very high. In addition, increased drought stress with higher temperatures is likely to stress species in these communities. The overall vulnerability of this type to climate change is therefore high (table 7.2).

Riparian and Wetland Communities

Riparian and wetland communities occupy about 1 percent of the land surface in the Great Basin (Sada 2008), and they very likely occupy about that same percentage of the landscape throughout the IAP region. Though the area in these types is relatively small, they have very high species diversity and support a variety of ecosystem functions (Naiman and Dècamps 1997). From high to low elevation, riparian and wetland communities throughout the region have been subjected to relatively high impacts from human uses, including road construction, land development, conversion to agricultural uses, and changes in stream discharge because of dam construction and water diversions. In addition, these areas have been affected by intensive use by domestic livestock, beaver removal, and nonnative species (Sada 2008).

Riparian and wetland communities are described by elevation in this report. This organization was chosen because of differences in stream size, localized climates, species composition and associated structure, and processes such as erosion, transport, and deposition that dominate these communities at different elevations. Historical and current impacts and threats and predicted responses to climate change also tend to vary by elevation.

High-elevation areas often have smaller and steeper stream channels, with some large snowmelt- and spring-fed wetlands. Where stream systems are characterized by steep gradients, they tend to be dominated by erosional processes. Riparian and wetland vegetation composition and sometimes structure vary with elevation (Engelhardt et al. 2015).

Middle elevations often have larger stream channels with lower gradients. They are dominated by transport processes, moving sediments from higher elevation to lower-elevation stream channels. Riparian and wetland vegetation composition and structure are highly variable, with trees, low and tall shrubs, and herbaceous species.

Low elevations have the largest channels and are often dominated by depositional processes. Most streams are alluvial and armored by riparian vegetation. Historically, the largest cottonwood gallery forests and natural wetlands occurred at lower elevations. Low-elevation riparian areas have a highly variable vegetation structure and contain trees, low and tall shrubs, and herbaceous species.

Across elevations, wetlands can vary in size and are dependent on water availability and site characteristics (e.g., valley bottom and associated stream type). Species composition varies with elevation. Upper-elevation wetlands are typically dependent on snowpack and snowmelt to sustain their water supply. They are often characterized by herbaceous species (sedges and rushes) but may also have low-growing willows as a community dominant. Drainage and development have eliminated many lower-elevation wetlands.

All riparian areas can be influenced by beaver activity, which results in ponding and flooding because of dam building. Historically, beaver occurred throughout the IAP region, except in the Great Basin. Much has been written on the hydrological and ecological roles that beaver populations play in riparian ecosystems (Jenkins and Busher 1979). Beaver dams can reduce peak discharge and stream velocity, and they can reduce sediment flows by increasing deposition in the ponded areas (Collen and Gibson 2001). Beaver dams also spread water over broad areas, expanding habitat for riparian and wetland species (Pollock et al. 2003). The widespread removal of beaver has resulted in significant changes to stream hydrology, geomorphology, and ultimately the ability of valley bottoms to support healthy and diverse riparian and wetland ecosystems (Pollock et al. 2003). The introduction or reintroduction of beaver, however, does not always have a significant positive effect (Rosell et al. 2005). Locations for reintroductions must be carefully considered.

Sensitivity

Watershed geomorphic and hydrological characteristics, as well as climatic factors such as temperature, precipitation type, and precipitation amount, influence the volume and timing of streamflows (Patten 1998). Whereas base flow conditions result from the gradual release of groundwater and snowmelt, periodic flooding can result from either rapid spring snowmelt or high-intensity summer thunderstorms. The distribution, health, composition, and maintenance of riparian communities depend on volume and timing of streamflows (Auble et al. 1994; Poff et al. 1997; Scott et al. 1996, 1997; Stromberg 1993; Stromberg and Patten 1995).

The Great Basin and Semi Desert and Plateaus subregions are among the driest areas in the western United States. Climate change is likely to have the greatest effects in these relatively hot and dry portions of the region (Perry et al. 2012). Water availability is projected to decrease because of increased drought, earlier runoff, and lower late-spring and summer streamflows. High flows required for channel maintenance will be reduced. Plant community composition and structure will be affected by increased water stress, and drought-tolerant species are likely to replace riparian and wetland species. In addition, geomorphic and hydrological processes and dynamics that have been responsible for riparian and wetland ecosystem development at lower elevations have already been affected by construction of dams and water diversions in most places.

Adaptive Capacity

From high to low elevations, most riparian and wetland systems have been altered from historical conditions, resulting in changes in stream geomorphic and hydrological processes, including stream downcutting and channel straightening. Stream discharge has been reduced because of dam construction and water diversions. These changes have decreased water availability to riparian ecosystems because of greatly reduced floodplain access and recharge. Riparian areas and wetlands have also been affected by domestic livestock grazing, road construction, and nonnative species (Sada 2008).

Riparian systems are inherently driven by frequent disturbances, in particular seasonal floods or high water flows (Kauffman 2001). These flows affect the movement and deposition of sediment and large woody debris (Nakamura et al. 2000). The flow regime of riparian systems is of primary importance in maintaining their ecological integrity (Poff et al. 1997). The magnitude, frequency, duration, timing, and rate of change of streamflows directly and indirectly affect water quality, energy sources, physical habitat, and the biotic interactions within the stream systems. The modification of any one of these can have a cascading effect on ecological integrity.

Changes in flow regimes, whether through climate change or through human-caused alterations such as those from water diversions and dams, impact the amount, season, and timing of flows. This can substantially alter associated riparian and wetland species because of their dependence on fluvial geomorphic process, surface water, and groundwater (Merritt et al. 2010; Nilsson and Berggren 2000; Poff et al. 1997). Floods are responsible for erosion, transport, and deposition of sediments, as well as the amounts and location of vegetation and debris. Many dominant riparian species, such as cottonwoods and willows, are pioneer species that depend on these events to provide bare, moist substrates necessary for seed germination and plant establishment (Cooper et al. 2003; Scott et al. 1996; Stella et al. 2011).

Vulnerability

Factors considered in characterizing the vulnerability of each riparian and wetland vegetation type to climate change include regeneration success, response to disturbance (changes in amount, timing, and location of runoff), and plant life history traits.

High-Elevation Riparian and Wetland Communities

Vegetation Type Description and Distribution

High-elevation riparian and wetland communities include forests, shrublands, and herbaceous communities occurring in meadows, adjacent to streams and water bodies, or around seeps and springs. High-elevation wetland sites are often associated with bogs, fens, springs, and streams at low-gradient sites, such as glacial cirque floors and slumps, or around small lakes and ponds proximal to high ridgelines. These communities generally occur above 8,500 feet elevation throughout the IAP region. As noted previously, upper-elevation streams are erosional in nature, providing sediments to their connected systems.

Forest communities occur near the boundary between high- and mid-elevation riparian and wetland communities and can include species such as aspen and conifers, including subalpine fir (*Abies lasiocarpa*) and spruce (*Picea* spp.); cottonwoods generally do not occur at these elevations. Low-growing willows such as Wolf's (*Salix wolfii*) and plainleaf (*S. planifolia*) can dominate broad meadows, along with other shrubs such as resin birch (*Betula glandulosa*) and bog blueberry (*Vacinnium occidentale*). Some tall willows, such as Drummond's (*Salix drummondiana*), may also occur. High-elevation sedges (e.g., *Carex aquatilis*, *C. illota*, *C. limosa*, *C. scopulorum*, *C. luzulina*) can dominate these wetland and riparian systems, along with tufted hairgrass (*Deschampsia cespitosa*) and alpine bentgrass (*Agrostis humilis*).

Existing stressors in high-elevation riparian and wetland communities include drought, livestock grazing (particularly domestic sheep), and grazing by both introduced ungulates (e.g., mountain goats), and large populations of native ungulates. In addition, recreational uses can be significant, especially in areas adjacent to high populations and relatively easy access. Roads in the valley bottoms are a major factor affecting erosional processes. Improper all-terrain vehicle use can also cause severe soil and vegetation damage, particularly in seasonally wet riparian areas, meadows, and peatlands.

Sensitivity to Climate Change: Moderate to High

Warming temperatures and reduced snowpack may result in the loss of high-elevation riparian and wetland habitats, resulting in drier, less productive systems. With rising temperatures, frigid snow- and water-dependent ecosystems in the upper portions of watersheds will have very little room to move upslope. Elevating temperatures will increase competition from riparian species now occurring at lower elevations, and smaller snowpacks will increase competition from upland species that occupy drier sites.

Adaptive Capacity: Low to Moderate

Although these ecosystems have been less impacted by humans than mid- and low-elevation riparian and wetland communities, existing stressors still include drought, livestock grazing, introduced ungulates (e.g., mountain goats), and large populations of native ungulates, as well as some recreational uses. There tend to be few invasive species in these high-elevation ecosystems, and because of historically late seasonal snow cover and associated later plant growth, these ecosystems have had shorter grazing seasons by domestic livestock. Like riparian and wetland species of mid- to lower elevations, nearly all tree species occurring in these areas sprout following fire. These combined factors result in a low to moderate adaptive capacity for these communities (table 7.2).

Vulnerability to Climate Change: High

High-elevation riparian and wetland communities have a high vulnerability to climate change because of moderate to high sensitivity and low to moderate adaptive capacity (table 7.2). Mid-elevation riparian and wetlands communities are likely to move higher in elevation with warming climate. Systems currently in place are in danger of losing their water source, and soil moisture is likely to be reduced as snowpack amount and duration decrease.

Mid-Elevation Riparian and Wetland Communities

Vegetation Type Description and Distribution

Mid-elevation riparian and wetland communities include forests, shrublands, and herbaceous communities occurring adjacent to streams, in wet meadows, and surrounding water bodies, or proximal to seeps and springs. These communities generally occur between 5,500 and 8,500 feet throughout the IAP region. As noted earlier, mid-elevation streams transport sediments from these and higher-elevation riparian areas to the lower-elevation systems.

Mid-elevation riparian communities may be dominated by a variety of tree, shrub, and herbaceous species. Tree species, such as narrowleaf cottonwood (*Populus angustifolia*), quaking aspen (*P. tremuloides*), western river birch (*Betula occidentalis*), and thinleaf alder (*Alnus incana*) occur in these areas. Conifer species dominating adjacent landscapes, such as Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), Engelmann spruce (*Picea engelmannii*), and blue spruce (*P. pungens*) may also occur at stream edges. Shrubs include mid-elevation willows, such as Booth's willow (*Salix boothii*), Drummond's willow, shining willow (*S. lucida* subsp. *caudata*), and dusky willow (*S. melanopsis*), and a variety of herbaceous meadow and wetland species. At the lower range of these communities, Nebraska sedge (*Carex nebrascensis*) can dominate meadows, along with tufted hairgrass.

Sensitivity to Climate Change: Moderate to High

Riparian areas, because of their high water tables, have some of the highest capacity to adapt to changing climates. However, as snowpacks are reduced and seasonality of runoff changes, the amount of water available for subsurface storage is likely to be reduced. Increasing temperatures will increase competition from invasive and riparian species from lower elevations, and reduced water tables will increase competition from adjacent upland species. Thus, the species composition of these riparian areas could change considerably in a changing climate.

Adaptive Capacity: Moderate

Adaptive capacity of these mid-elevation riparian and wetland ecosystems is moderate (table 7.2) and may be less in areas subjected to a wide variety of human influences. Historically, these ecosystems were affected by heavy livestock grazing. In addition, these areas have been used as locations for road construction, concentrated recreational uses, and several other developments. Many nonnative invasive species, such as Canada thistle (*Cirsium arvense*), nodding plumeless thistle (*Carduus nutans*), scotch thistle (*Onopordum acanthium*), and bull thistle (*Cirsium vulgare*), occur in these habitats. Waterways provide a means for dispersing these species widely. Because of the high level and variety of human impacts on these riparian ecosystems, many of these mid-elevation communities have lost resilience. These systems typically have high fuel moisture and are not very susceptible to wildland fire. When fires occur, however, they often move from adjacent upland communities into these environments (Dwire and Kauffman 2003).

Vulnerability to Climate Change: Moderate to High

Climate change vulnerability of mid-elevation riparian and wetland communities is rated as moderate to high because these communities have moderate to high sensitivity and moderate adaptive capacity to the effects of climate change (table 7.2). Mid-elevation riparian plant species may have the ability to move upward in elevation, but where resilience has been compromised by human uses, these systems may not be able to easily adjust to changes in their environment. Invasive species that already dominate many mid-elevation sites are likely to expand their dominance. As riparian areas become drier, upland species will continue to expand into these sites.

Low-Elevation Riparian and Wetland Communities

Vegetation Type Description and Distribution

Low-elevation riparian and wetland communities include forests, shrublands, and herbaceous communities occurring adjacent to streams and water bodies, in meadows, or around seeps and springs. These communities generally occur below about 5,500 feet throughout the IAP region. Lower-elevation streams are generally where sediments from mid- and upper-elevation sources are deposited.

These riparian communities may be dominated by a variety of tree, shrub, and herbaceous species. Tree species include narrowleaf cottonwood, lanceleaf cottonwood (*Populus* ×*acuminata*), Fremont cottonwood (*P. fremontii*), black cottonwood (*P. balsamifera* ssp. *trichocarpa*), and box elder (*Acer negundo*), as well as a wide variety of nonnative tree species. Shrubs include a wide variety of willows, such as yellow willow (*Salix lutea*), Geyer willow (*S. geyeriana*), Booth willow, Pacific willow (*S. caudata*) and narrowleaf willow (*S. exigua*). Beaked sedge (*Carex utriculata*), Nebraska sedge, and Baltic rush (*Juncus arcticus*) grow at many elevations, but are typically common at lower elevations. Low-elevation wetland and riparian communities are limited in their occurrence on National Forest System lands throughout the region because most of these habitats occur near or below the forest boundaries.

Sensitivity to Climate Change: High

Although riparian and wetland species at lower elevations in the IAP region may not be adapted to increasing temperatures, species from adjacent geographic areas could replace species that currently dominate these ecosystems. However, the low-elevation riparian and wetland communities are more likely to be affected by decreased flows and water availability through continued diversions. In addition, the timing of water availability (because of lower snowpacks) is likely to affect species with high water demands throughout the summer. Changes in the amount and timing of runoff events could greatly impact water tables and soil moisture relationships and eliminate much of the riparian and wetland habitats that remain at these lower elevations. Much has been written on the hydrological requirements for the germination of various cottonwoods and willows (Auble and Scott 1998; Mahoney and Rood 1998; Siegel and Brock 1990; Young and Clements 2003). The connections among changes in climate, hydrology (timing and amount of flows), and the ability of these species to continue to germinate and establish are only now being investigated (Gori et al. 2014; Smith and Finch 2016; Stromberg et al. 2010). However, climate change has the potential to greatly affect the ability of these woody riparian dominant species to germinate and establish in the future; accordingly, low-elevation riparian and wetland ecosystems are rated as highly sensitive to climate change (table 7.2).

Adaptive Capacity: Low to Moderate

Many low-elevation riparian and wetland communities have been degraded from a wide variety of human influences (e.g., fig. 7.10), such as road construction, concentrated recreational uses, and other development. These areas have also been subjected to excessive, unmanaged livestock grazing, especially in the past. Management efforts by Federal agencies since the early 1980s have focused on reducing impacts and improving conditions of these systems.

As a result of historical land uses, many nonnative invasive species occur in these habitats. For example, these areas have had some of the greatest increases in nonnative invasive woody species, such as tamarisk (*Tamarix chilensis*, *T. ramosissima*) and Russian olive (*Elaeagnus angustifolia*), as well as nonnative invasive herbaceous species. Many of these herbaceous species are listed as noxious. Many low-elevation wetlands in the region have become dominated by the nonnative common reedgrass (*Phragmites australis*) (fig. 7.11). Purple loosestrife (*Lythrum salicaria*) can also invade wetlands and replace existing native wetland species.

Vulnerability to Climate Change: High to Very High

The direct effects of reduced flows and changes in timing and duration of spring runoff because of climate change will reduce resilience in low-elevation riparian and wetland communities, and thus their vulnerability to climate change is rated as high to very high (table 7.2). These systems have also been affected by upstream diversions of water and wetland drainage, and by livestock grazing, development, road construction, and concentrated recreational uses. Additional pressures on these already vulnerable ecosystems could have significant effects in the future.

Figure 7.10—Heavily grazed riparian area. Heavy livestock grazing in riparian areas inhibits regeneration and growth of woody riparian species such as cottonwoods and willows (photo: W. Padgett, U.S. Forest Service).

Figure 7.11—Common reedgrass that has invaded and dominated low-elevation wetlands along the Great Salt Lake in northern Utah (photo: W. Padgett, U.S. Forest Service).

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Climate Change Vulnerability and Adaptation in the Intermountain Region

Part 1

GTR-375

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Climate Change Vulnerability and Adaptation in the Intermountain Region

Part 2

Forest Service

Rocky Mountain Research Station

General Technical Report
RMRS-GTR-375

April 2018

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Abstract

The Intermountain Adaptation Partnership (IAP) identified climate change issues relevant to resource management on Federal lands in Nevada, Utah, southern Idaho, eastern California and western Wyoming, and developed solutions intended to minimize negative effects of climate change and facilitate transition of diverse ecosystems to a warmer climate. U.S. Department of Agriculture Forest Service scientists, Federal resource managers, and stakeholders collaborated over a 2-year period to conduct a state-of-science climate change vulnerability assessment and develop adaptation options for Federal lands. The vulnerability assessment emphasized key resource areas—water, fisheries, vegetation and disturbance, wildlife, recreation, infrastructure, cultural heritage, and ecosystem services—regarded as the most important for ecosystems and human communities.

The earliest and most profound effects of climate change are expected for water resources, the result of declining snowpacks causing higher peak winter streamflows, lower summer flows, and higher stream temperatures. These changes will in turn reduce fish habitat for cold-water fish species, negatively affect riparian vegetation and wildlife, damage roads and other infrastructure, and reduce reliable water supplies for communities. Increased frequency and magnitude of disturbances (drought, insect outbreaks, wildfire) will reduce the area of mature forest, affect wildlife populations (some positively, some negatively), damage infrastructure and cultural resources, degrade the quality of municipal water supplies, and reduce carbon sequestration. Climate change effects on recreation, a major economic driver in the IAP region, will be positive for warm-weather activities and negative for snow-based activities. IAP participants developed adaptation options that can be implemented in planning, project management, monitoring, and restoration as climate-smart responses to altered resource conditions.

***Keywords**:* adaptation, climate change, ecological disturbance, Intermountain Adaptation Partnership, resilience, science-management partnership, vulnerability assessment

Front cover photo: top: Hiking trail near Lake Mary dam and reservoir, Uinta-Wasatch-Cache National Forest, photo U.S. Forest Service.

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Summary

The Intermountain Adaptation Partnership (IAP) is a science-management partnership with a wide variety of participants across the U.S. Department of Agriculture, Forest Service Intermountain Region, which spans Nevada, Utah, southern Idaho, eastern California, and western Wyoming. The partnership includes the Forest Service Intermountain Region, and Pacific Northwest and Rocky Mountain Research Stations; National Park Service Climate Change Response Program; North Central Climate Science Center; Desert, Great Basin, Great Northern, and Southern Rockies Landscape Conservation Cooperatives; the University of Washington; Native American tribes; and dozens of other stakeholder organizations. These organizations and other IAP participants worked together over 2 years to identify climate change issues relevant to resource management on Forest Service and National Park Service lands in the IAP region, and to find solutions that could help to minimize the negative effects of climate change and facilitate the transition of ecosystems to a warmer climate. The IAP provided education, conducted a climate change vulnerability assessment, and developed adaptation options for managing resources of the 12 national forests (Ashley, Boise, Bridger-Teton, Caribou-Targhee, Dixie, Fishlake, Humboldt-Toiyabe, Manti-La Sal, Payette, Salmon-Challis, Sawtooth, Uinta-Wasatch-Cache [plus Curlew National Grassland]) and 22 National Park Service units in the IAP region.

The IAP region is characterized by high ecological diversity. Vegetation types include mixed conifer forest, dry ponderosa pine forest, subalpine forest, sagebrush, grasslands, alpine tundra, and wetlands. Ecosystems in the IAP region produce water, fish, timber, wildlife, recreation opportunities, livestock grazing, and other ecosystem services, providing a socioeconomic foundation based on natural resources. The geographic and ecological diversity of the region, especially on Federal lands, contributes significantly to the economic sustainability of human communities, linking Federal resource management with local livelihoods.

The effects of climate change on each resource area in the IAP region are synthesized from the available scientific literature and analyses and are based on available climate change projections (Chapter 3). Highlights of the vulnerability assessment and adaptation options for each resource area are summarized next.

Water and Soil Resources

Climate Change Effects

Lower snowpack and increased drought will result in lower base flows, reduced soil moisture, wetland loss, riparian area reduction or loss, and more frequent and possibly more severe wildfire. April 1 snow water equivalent and mean snow residence time are sensitive to temperature and precipitation variations. Warmer (usually lower elevation) snowpacks are more sensitive to temperature variations, whereas colder (usually higher elevation) snowpacks are more sensitive to precipitation. Warmer locations will experience more runoff in winter months and early spring, whereas colder locations will experience more runoff in late spring and early summer. In both cases, future peakflows will be higher and more frequent.

Lower snowpacks will cause significantly lower streamflow in summer, and reduce the rate of recharge of water supply in some basins. Annual water yields, which are affected by annual precipitation totals (heavily influenced by winter and spring precipitation in the western part of the region) and summer evapotranspiration, will generally be lower. Although declining snowpacks will occur throughout the region, snowpacks at higher elevations (Uinta Mountains, Teton and Wind River Ranges, and some central Idaho ranges) may not change much through the late 21st century. Carbon content in soils will decrease in areas where decomposition rate and wildfire frequency increase, and soil erosion will be accelerated by intense fires.

Adaptation Options

Primary adaptation strategies focus on expanding water conservation; increasing water storage, managing for highly functioning riparian areas, wetlands, and groundwater-dependent ecosystems; and developing policies for water rights. Adaptation tactics include: (1) using drought-tolerant plants for landscaping, managing livestock water improvements efficiently, and educating the public about water resource issues and conservation; (2) decommissioning and improving road systems, improving grazing management practices, and promoting and establishing American beaver populations; (3) managing vegetation to reduce forest density and hazardous fuels; (4) modifying dam and reservoir operation to improve water storage, and improving streamflow and runoff forecasts; and (5) maintaining and protecting soil cover and cryptobiotic crusts, using grazing management systems that promote healthy root systems in plants, and promoting native plant species diversity.

Fish and Other Aquatic Species

Climate Change Effects

A combination of higher stream temperature, low streamflow in summer, and higher peakflow at other times of the year will create a significant stress complex for cold-water fish species. Habitats that provide the restrictive thermal requirements of juvenile bull trout are rare, and little evidence exists for flexibility in habitat use. The length of connected habitat needed to support a bull trout population varies with local conditions, but current estimates suggest a minimum of 20 to 30 miles contingent on water temperature, nonnative species presence, and local geomorphic characteristics. Juvenile cutthroat trout occupy a broader thermal and stream size niche than bull trout. They also appear to persist in smaller habitat patches. Nonetheless, they require cold-water habitat patches exceeding 3 to 6 miles. Increased frequency and extent of extreme events will be especially stressful for bull trout and cutthroat trout, except at higher elevations, where habitat will remain favorable. Both species may in some cases be able to adjust their life histories to accommodate altered habitat, although the potential for this adaptive capacity is unknown. From the mid- to late-21st century, the vast majority of suitable cold-water fish habitat will be on Federal lands.

Rocky Mountain tailed frogs have long generation times and low fecundity, so increased summer droughts and wildfires, as well as extreme floods and postfire debris flows may threaten some populations. Sensitivities are similar for Idaho giant salamanders. Western pearlshell mussels have a broad geographic range, which reduces their vulnerability, although lower streamflow and higher stream temperatures are expected to be stressful in some locations. Springsnails are expected to be highly vulnerable because they require particular hydrological conditions, specific and stable temperature regimes, and perennial flows. Yosemite toads, already in decline, will be sensitive to reduced duration of ephemeral ponds for breeding in spring. Sierra Nevada yellow-legged frogs will be sensitive to less reliable availability of perennial water bodies needed for multiyear metamorphosis and maturation.

Adaptation Options

Primary adaptation strategies focus on increasing resilience of native fish species by restoring structure and function of streams, riparian areas, and wetlands; monitoring for invasive species and eliminating or controlling invasive populations; understanding and managing for community-level patterns and processes; and conducting biodiversity surveys to describe current baseline conditions and manage for changes in the distribution of fish and other aquatic species. Adaptation tactics include reconnecting floodplains and side channels to improve hyporheic and base flow conditions, ensuring that passage for aquatic organisms is effective, accelerating restoration in riparian areas, maintaining or restoring American beaver populations, managing livestock grazing to restore ecological function of riparian vegetation, removing nonnative fish species, maintaining or increasing habitat connectivity, and increasing the resilience of forests to wildfire.

Vegetation and Ecological Disturbances

Climate Change Effects

Increased temperature is expected to cause a gradual change in the distribution and abundance of dominant plant species. Increased ecological disturbance, driven by higher temperatures, is expected to cause near-term effects on vegetation structure and age classes, and will facilitate long-term changes in dominant vegetation. In forest ecosystems, native and non-native insects are expected to be significant stressors in a warmer climate; in fact, this appears to be already occurring. In all vegetation types, an increase in the frequency and extent of wildfire will be a significant stressor, especially where large fuel accumulations exist. Nonnative plant species will likely continue to expand in most vegetation types, especially in rangelands, potentially displacing native species and altering fire regimes. A combination of these and other stressors (stress complexes), exacerbated by climate, may accelerate the rate of change in vegetation assemblages, and reduce productivity and carbon storage in most systems. Riparian areas may be especially sensitive as a warming climate causes hydrological regimes to change, reducing the timing and amount of water available in summer. Climate change effects on specific forest types include:

- Subalpine pine forest—Most subalpine tree species will be moderately affected by a warmer climate, although bristlecone pine could undergo stress in the driest locations. Whitebark pine will be vulnerable because it is already stressed from white pine blister rust and mountain pine beetles. If wildfire increases, crown fires may quickly eliminate mature trees across the landscape.

- Subalpine spruce-fir forest—This forest type will be moderately vulnerable. Subalpine fir and Engelmann spruce may have increased growth in a longer growing season. Bark beetles will be a stressor for Engelmann spruce. If wildfire increases, crown fires may quickly eliminate mature trees across the landscape. Quaking aspen will be minimally affected by a warmer climate.

- Mesic mixed conifer forest—Late-seral forests will be susceptible to wildfire, especially where fuel loads are high. Douglas-fir, ponderosa pine, and Jeffrey pine, which have high fire tolerance, may become more common, and late-seral species less common. Growth rates of most species will decrease. Lodgepole pine and quaking aspen will persist, perhaps with increased stress from insects and pathogens.

- Dry mixed conifer forest—Most species in mixed conifer forest (ponderosa pine, Gambel oak, quaking aspen) can cope with dry soils and wildfire. Growth of less drought-tolerant species (Douglas-fir, white fir) will decrease. With increased fire frequency, early-seral species will become more common, and late-seral species less common.

- Aspen mixed conifer forest—Increased wildfire frequency and extent will determine future composition and structure of this forest type. Conifers at higher elevations (mostly not fire resistant) will become less common, confined to northern slopes and valley bottoms. Quaking aspen and Gambel oak will attain increasing dominance because of their ability to sprout vigorously after fire, outcompeting species susceptible to drought and fire.

- Persistent aspen forest—Conifers at higher elevation (mostly not fire resistant) will become less common, confined to northern slopes and valley bottoms. Quaking aspen will attain increasing dominance because of its ability to sprout vigorously after fire, outcompeting species susceptible to drought and fire. Douglas-fir will persist in locations with sufficient soil moisture. Overall productivity will probably decrease.

- Montane pine forest—Ponderosa pine will persist in this forest type because it is drought tolerant and fire tolerant, outcompeting other species following wildfire, but will grow more slowly. Limber pine and bristlecone pine will probably persist at higher elevations where fuel loads are low. If insect outbreaks are more prevalent in a warmer climate, they could increase stress in pine species, especially during drought.

- Riparian forest—This is a highly vulnerable forest type because it depends on a reliable water supply. Vegetation dominance may shift to species that are more tolerant of seasonal drought, including ponderosa pine and other deep-rooted conifers. Hardwoods could become less common. Riparian forests associated with small or transient water sources will be especially vulnerable, especially at lower elevations.

Nonforest

In nonforest ecosystems, increasing frequency and duration of drought are expected to drive direct changes on soil moisture, which will reduce the vigor of some species, causing mortality or making (mostly woody species) more susceptible to insects and pathogens. Increasing frequency and extent of wildfire will be a major stressor for species that regenerate slowly following fire, especially non-sprouting vegetation (e.g., most sagebrush species). The dominance of nonnative plant species, especially annual grasses (e.g., cheatgrass), will be enhanced by increasing disturbance and will themselves encourage more frequent fire—a significant change in the ecology of most vegetation assemblages. Although productivity may increase in some grasslands, most other nonforest ecosystems will experience lower productivity. Most native species are expected to persist if they can move to favorable portions of the landscape and are sufficiently competitive. Climate change effects on specific nonforest vegetation include:

- Pinyon-juniper shrublands and woodlands—These woodlands are sensitive to chronic low soil moisture during prolonged droughts (to which pinyon pines are more sensitive than junipers), increased insect outbreaks that follow drought stress, and increased frequency and extent of wildfire. These species will persist across the landscape, although the distribution and abundance of species may change.

- Oak-maple woodlands—Gambel oak and bigtooth maple, the dominant species in these woodlands, are widely distributed and both sprout heavily following wildfire. As a result, their vulnerability is expected to be relatively low, and Gambel oak in particular may become more dominant as wildfire frequency and extent increase across the landscape.

- Mountain mahogany woodlands—These woodlands, which are dominated by curl-leaf mountain mahogany, are expected to be moderately vulnerable. This species is slow-growing and does not sprout following wildfire, so regeneration of disturbed sites may be slow, especially where nonnative species are common. However, mountain mahogany is capable of growing on low-fertility soils, so it will continue to be competitive with other species.

- Mountain big sagebrush shrublands—Vulnerability varies from moderate to high because of the broad elevation range at which mountain big sagebrush occurs, and because of the wide range in current conditions. Livestock grazing, expansion of pinyon pine and juniper species, altered wildfire regimes, and nonnative invasive species are significant stressors. These factors may be exacerbated by a warmer climate, especially in drier habitats.

- Dry big sagebrush shrublands—Vulnerability is high, as evidenced by significant mortality that occurred during recent drought. Conditions suitable for seedling establishment are infrequent under current climatic conditions and are likely to become less frequent in a warmer climate. Lower elevations of the Great Basin are especially vulnerable, whereas sagebrush in wetter locations may be able to persist.
- Sprouting sagebrush shrublands—Warmer, drier climate will negatively affect the vigor and abundance of sprouting sagebrush species, which are adapted to more mesic conditions. These species can sprout following wildfire, but seed viability is short and unreliability of spring soil moisture will make them susceptible to prolonged droughts. Overall vulnerability is moderate, and regeneration will be critical to long-term persistence across the landscape.
- Dwarf sagebrush shrublands—All low-growing sagebrush species are likely to be negatively affected by higher temperatures and increased periods of drought. Seed viability is short and their dependence on spring soil moisture will make them susceptible to prolonged droughts and to altered timing and amount of spring moisture. Increased wildfire frequency, coupled with drought, could inhibit regeneration on drier sites.
- Mountain, blackbrush, and salt desert shrublands—These shrublands have low to moderate vulnerability, depending on their location relative to soil moisture availability. Many of these shrublands have relatively high species diversity—some are well-adapted to periodic drought and some may be able to migrate to higher elevations. Salt desert communities at lower elevations may be vulnerable to drought and are intolerant of wildfire.
- Alpine communities—The composition and distribution of alpine ecosystems will be affected by decreasing snowpack, altering plant vigor and regeneration. Specific effects will depend on vulnerability thresholds of diverse species and the rate and magnitude of changes over time. Some species may be able to persist or migrate to suitable habitat, but the lower extent of some communities will be compromised by tree establishment.
- Mountain grasslands—The vulnerability of cool-season grass-dominated communities is moderate to high. Warm-season grasses are favored by higher temperatures, providing an opportunity for spread into mountain grasslands from lower-elevation and more southern locations. Increased wildfire frequency will facilitate more nonnative invasive species, decreasing the dominance and vigor of natives.
- Subalpine forb communities—Higher temperatures and increasing drought make this vegetation type highly vulnerable in many locations. Although some subalpine forb communities may be able to move higher in elevation, shallow soil profiles may support only lower-growing species. Tall forb communities at the highest elevations on plateaus (e.g., Wasatch Plateau) are particularly vulnerable.
- Riparian and wetland communities—Most of these communities are highly vulnerable, especially those at lower elevations where soil conditions are already affected by periodic drought. Reduced summer streamflow and groundwater will create significant stress for some dominant plant species, although high species diversity in many locations ensures some long-term persistence, perhaps with lower functionality.

Adaptation Options

Primary adaptation strategies for forest vegetation focus on promoting disturbance-resilient species, maintaining low tree densities, promoting species and genetic diversity, promoting diversity of forest structure, and increasing knowledge about climate change effects for agency land managers and stakeholders. Tactics include conducting thinning treatments, favoring disturbance-resilient species in thinnings, planting potential microsites with a mixture of species, collecting seed for postfire reforestation, and reducing density through prescribed fire and managed wildfire. Maintaining and restoring stream channels, and protecting vegetation through appropriate livestock management can be applied in riparian areas.

Primary adaptation strategies for nonforest vegetation focus on restoring resilience to and maintaining healthy and intact woodlands, shrublands, and grasslands, increasing management actions to prevent invasive species, and maintaining and restoring natural habitat. Tactics include using mechanical treatments, prescribed fire, using integrated weed management, implementing fuels reduction projects, using ecologically based invasive plant management, implementing livestock management that reduces damage to native perennial species, and maintaining or improving native plant cover, vigor, and species richness.

Terrestrial Animals

Climate Change Effects

The effects of climate change on terrestrial animal species are expected to be highly variable, depending on habitat conditions in specific locations and on the flexibility of animal life histories to accommodate altered conditions. Flammulated owl, wolverine, and greater sage-grouse are expected to be the most vulnerable to population declines, whereas Utah prairie dog and American three-toed woodpecker will be the least vulnerable. Most species will exhibit some sensitivity to altered phenology, habitat, and physiology. Species restricted to high elevations or surface water habitats will generally be vulnerable. Following are possible climate change effects on species of conservation concern.

- Black rosy finch—An alpine specialist, this species will suffer loss of habitat associated with shrinking snowfields and glaciers and possibly encroaching tree establishment, although it does have the capacity to migrate to other locations.
- Flammulated owl—Wildfire and insects will increase early-seral forest structure over time, conditions detrimental for this species, which prefers mature, open ponderosa pine and other semiarid forests with brushy understories.
- Greater sage-grouse—Degraded habitat caused by wildfire-induced mortality of mature sagebrush, in combination with increased dominance of pinyon-juniper woodlands, invasive annual species, and possible effects of West Nile virus will be significant challenges to this species.
- White-headed woodpecker—As long as sufficient mature coniferous forest habitat with pines as a seed source and dead trees for nesting remain, this species will be relatively resilient to a warmer climate because it can move readily to more favorable locations.
- American pika—This species will be vulnerable on isolated mountaintops and at low elevations where it is near its physiological tolerance. Populations in the southern Great Basin are the most vulnerable in the IAP region, but populations in other locations may be fairly resilient.
- Bighorn sheep—Different parts of the region, and thus different subspecies, will be subject to different population dynamics. Populations in the most arid, low-elevation locations and without access to dependable springs and forage will be most vulnerable.
- Canada lynx—This species will be vulnerable to reduced snowpack and prey availability (especially snowshoe hares), although interactions among climate, wildfire, and insect outbreaks may reduce late-seral forest habitat preferred for breeding.
- Fisher—The extent, quality, and connectivity of habitat for this species will probably decrease as increasing wildfire reduces late-seral forest habitat, although fishers can readily move from unfavorable to favorable habitat.
- Fringed myotis—This species could undergo some stress if water sources become less common or more transient, although its mobility and migratory nature allow it to respond to changing conditions.
- Northern Idaho ground squirrel—Increased vegetative productivity may benefit this species, although loss of snowpack, drought, disease, and nonclimatic factors (overgrazing, land development) may be significant stressors.

- Sierra Nevada red fox—With populations that are mostly small and isolated, this species may be affected by drought, wildfire, and insects that alter vegetation, and especially by reduced snowpack, which promotes higher populations of coyotes, a competitor for limited prey.
- Townsend's big-eared bat—This species uses a variety of habitats, conferring some resilience, although increasing wildfires and nonnative grasses could degrade habitats and reduce prey availability. Declining snowpack may also reduce the number and duration of water sources.
- Utah prairie dog—This species may be fairly resilient to a warmer climate, although population declines have been observed during prolonged periods of drought, which affects food and water availability.
- Wolverine—This species, already low in numbers, could be significantly affected by declining snowpack in its preferred high-elevation forest and alpine habitats, and possibly by altered vegetation composition over time.
- Boreal toad—Subject to recent population declines, this species is sensitive to water balance, so altered timing and duration of water availability could be stressors. The harmful chytrid fungus may or may not be affected by climate change, and trampling of riparian areas by livestock is locally damaging.
- Columbia spotted frog—Historical declines of this species may be exacerbated by alteration and fragmentation of aquatic habitats. Drought, warmer temperatures, and reduced snowpack will potentially alter breeding habitat, although spotted frogs will probably be resilient in areas with reliable water sources.
- Great Basin spadefoot—This species may be fairly resilient to a warmer climate because it occurs in a variety of vegetation types, has a flexible breeding season, and has high reproductive rates. Populations in the southern portion of its range and where it relies on ephemeral ponds may be more vulnerable.
- Prairie rattlesnake—This species has low fecundity, long generation times, and low dispersal, making it vulnerable to additional climate stresses such as wildfires and flooding. It will probably be more resilient in areas with sufficient microhabitats and low habitat fragmentation.

Adaptation Options

Primary adaptation strategies focus on improving riparian habitat through restoration, encouraging healthy beaver populations, retaining mature forest structure where possible, reducing nonnative plant species, maintaining quaking aspen habitat, and maintaining connectivity of habitat patches across the landscape. Adaptation tactics include removing hazardous fuels to reduce wildfire intensities, minimizing impacts from livestock grazing, using prescribed fire and conifer removal to promote aspen stands, removing cheatgrass and other invasive species from sagebrush systems, and minimizing impacts of recreation on species sensitive to human disturbance.

Outdoor Recreation

Climate Change Effects

Summer recreation (hiking, camping, bicycling) will benefit from a longer period of suitable weather without snow, especially during the spring and fall shoulder seasons. **Snow-based recreation** (downhill skiing, cross-country skiing, snowmobiling) will be negatively affected by a warmer climate because of less snow and more transient snowpacks. Ski areas and other facilities at lower elevations will be especially vulnerable. **Hunting and fishing** may be affected somewhat by a warmer climate, depending on specific location and activity. Hunting will be sensitive to temperature during the allotted hunting season and timing and amount of snow. Fishing will be sensitive to streamflows and stream temperatures associated with target species; if summer flows are very low, some streams may be closed to fishing. **Water-based recreation** (swimming, boating, rafting) will be sensitive to lower water levels. **Gathering forest products** for recreational and personal use (e.g., huckleberries, mushrooms) will be somewhat sensitive to the climatic conditions that support the distribution and abundance of target species, and to extreme temperatures and increased occurrence of extreme events (e.g., flooding, landslides).

Adaptation Options

Recreation participants are highly adaptable to changing conditions, although Federal agencies are not very flexible in modifying management. Primary adaptation strategies focus on transitioning management to shorter winter recreation seasons, providing sustainable recreation opportunities, increasing management flexibility and facilitating transitions to meet user demand and expectations, and managing recreation sites to mitigate risks to public safety and infrastructure. Adaptation tactics include collecting data on changing use patterns and demands, maintaining current infrastructure and expanding facilities in areas where concentrated use increases, educating the public about changing resource conditions, varying the permit season for rafting to adapt to changes in peak flow and duration, and determining which recreation sites are at risk from increased hazards.

Infrastructure

Climate Change Effects

Vulnerability of infrastructure can be assessed at three levels: (1) documentation of the type and quantity of infrastructure, (2) examination of infrastructure investments at the regional level, and (3) evaluation of infrastructure at local or smaller scales. Infrastructure risk can be proactively addressed by identifying assets that have a high likelihood of being affected by future climatic conditions and significant consequences if changes do occur. Roads and other infrastructure that are near or beyond their design life are at considerable risk to damage from flooding and geomorphic disturbance (e.g., debris slides). If road damage increases as expected, it will have a profound impact on access to Federal lands and on repair costs. Trails and developed recreation sites may also be sensitive to increased flooding and chronic surface flow, especially in floodplains. Buildings and dams represent large investments, and some may be at risk to an increased frequency of extreme events (wildfire, flooding).

Adaptation Options

Primary adaptation strategies focus on maintaining an accurate inventory of at-risk infrastructure components (e.g., buildings, roads), increasing resilience of the transportation system to increased disturbances (especially flooding), and ensuring that design standards are durable under the new conditions imposed by a warmer climate. Adaptation tactics include improving roads and drainage systems to survive higher peakflows and more flooding, conducting risk assessments of vulnerable roads and infrastructure, decommissioning roads where appropriate, documenting seasonal traffic patterns, emphasizing potential increases in extreme storm events when evaluating infrastructure inventory, fireproofing of buildings, and coordinating with partners whenever possible.

Cultural Resources

Climate Change Effects

Some aspects of climate change may exacerbate damage and loss of cultural resources, which are threatened by natural biophysical factors as well as human behaviors such as vandalism and illegal artifact digging. Increasing wildfire, flooding, melting of snowfields, and erosion can quickly displace or destroy artifacts before they have been identified and examined, potentially leading to the loss of thousands of items. In addition, large disturbances can change the condition of vegetation, streams, and other landscape features valued by Native Americans.

Adaptation Options

Adaptation strategies and tactics to protect cultural resources include improving inventories of the location of cultural resources, suppressing wildfires to protect specific sites, implementing fuels treatments in dry forests to reduce wildfire intensity, implementing protection strategies (e.g., stabilization, armoring, fireproofing) in areas prone to disturbances, monitoring areas affected by flooding and debris flows in mountain canyon and foothill areas, and applying vegetation management treatments designed to protect “first food” resources.

Ecosystem Services

Climate Change Effects

Ecosystem services provided to human communities from Federal lands will be affected by climate change in several ways:

- Timber and related products and services—Reduced growth rates in primary timber species will have a minimal effect on harvestable wood volume, although increased wildfires and insect outbreaks can reduce harvestable timber supply. Economic forces and policies will continue to dominate the wood products industry and employment, regardless of climate change.

- Grazing forage for domestic livestock and wildlife—Productivity may increase in some rangelands and decrease in others, so effects will vary spatially. Increased dominance of nonnative species (e.g., cheatgrass) will reduce range quality and support more frequent wildfires. Local erosion and encroaching urbanization will reduce the amount of available forage, regardless of climate change.

- Water quantity and quality—Declining snowpack will alter hydrological regimes annually and seasonally. Water yield is expected to decrease significantly by the 2040s and considerably more by the 2080s. The most sensitive watersheds are those already impaired or at risk, based on vegetation and soil conditions. Water quality may be affected by algal blooms and by erosion following wildfires.

- Ecosystem carbon—Ecosystems will increasingly be affected by disturbances (drought, wildfires, insects) that will remove living and dead vegetation, and, in turn, reduce carbon sequestration. If fires are as frequent as expected, forests may rarely attain a mature stand structure at lower elevations, thus limiting potential carbon sequestration.

- Pollination—Altered temperature and precipitation may lead to variable flowering phenology, which could reduce pollination by native insects such as bumblebees, and reduce native plant reproduction. Increased drought and extreme temperatures may impact pollinators already under stress from insecticides and increased dominance by nonnative plants.

Adaptation Options

Adaptation strategies for ecosystem services focus on availability and quality of forage for livestock, availability and quality of water, and habitat for pollinators. Adaptation strategies for grazing focus on increasing resilience of rangeland vegetation, primarily through nonnative species control and prevention. Adaptation tactics include flexibility in timing, duration, and intensity of authorized grazing as a tactic to prevent ecosystem degradation under changing conditions, as well as a more collaborative approach to grazing management.

Adaptation strategies for water focus on timing of water availability and quality of water delivered beyond Federal lands, assessments of potential climate change effects on municipal water supplies, and identifying potential vulnerabilities to help facilitate adaptive actions. Adaptation tactics include reducing hazardous fuels in dry forests to reduce the risk of crown fires, reducing other types of disturbances (e.g., off-road vehicles, unregulated livestock grazing), and using road management practices that reduce erosion.

Adaptation strategies for pollinators focus on improving pollinator habitat by increasing native vegetation and by applying pollinator-friendly best management. Adaptation tactics include establishing a reserve of native seed mixes for pollinator-friendly plants, implementing revegetation with plants beneficial to both pollinators and wildlife, and creating guidelines that would help managers incorporate pollinator services in planning, project analysis, and decisionmaking.

Conclusions

The IAP facilitated the most comprehensive effort on climate change assessment and adaptation in the United States, including participants from stakeholder organizations interested in a broad range of resource issues. It achieved specific elements of national climate change strategies for the U.S. Forest Service and National Park Service, providing a scientific foundation for resource management, planning, and ecological restoration in the IAP region. The large number of adaptation strategies and tactics, many of which are a component of current management practice, provides a pathway for slowing the rate of deleterious change in resource conditions. Rapid implementation of adaptation as a component of sustainable resource management will help to maintain critical structure and function of terrestrial and aquatic ecosystems in the IAP region. Long-term monitoring will help to detect potential climate change effects on natural resources, and evaluate the effectiveness of adaptation options that have been implemented.

Contents

Chapter 8: Effects of Climate Change on Ecological Disturbances

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Introduction

This chapter describes disturbance regimes in the Intermountain Adaptation Partnership (IAP) region, and potential shifts in these regimes as a consequence of observed and projected climate change. The term "disturbance regime" describes the general temporal and spatial characteristics of a disturbance agent (e.g., insects, disease, fire, weather, human activity, invasive species) and the effects of that agent on the landscape (tables 8.1, 8.2). More specifically, a disturbance regime is the cumulative effect of multiple disturbance events over space and time (Keane 2013). The shifting mosaic of diverse ecological patterns and structures, in turn, affects future patterns of disturbance, in a reciprocal, linked relationship that shapes the fundamental character of landscapes and ecosystems. Disturbance creates and maintains biodiversity in the form of shifting, heterogeneous mosaics of diverse communities and habitats across a landscape (McKinney and Lockwood 1999), and biodiversity is generally highest when disturbance is neither too rare nor too frequent on the landscape (Grime 1973).

Changing climate is altering the characteristics of disturbance agents, events, and regimes, with additional effects expected in the future (Dale et al. 2001). As described in other chapters in this report, climate change can alter the timing, magnitude, frequency, and duration of disturbance events, as well as the interactions of disturbances on a landscape. Interactions among disturbance regimes, such as the co-occurrence in space and time of bark beetle outbreaks and wildfires, can result in highly visible, rapidly occurring, and persistent changes in landscape composition and structure. Understanding how multiple disturbance interactions may result in novel and emergent landscape conditions is critical for addressing climate change effects and designing land management strategies that are appropriate for future climates (Keane et al. 2015).

We have summarized the following climate-sensitive disturbance agents present in the IAP region: wildland fires, insects, forest tree diseases, invasive plants, and geologic hazards. We discuss ways in which climate change will potentially affect each disturbance agent, and we include a discussion on how these disturbance agents may differ among the IAP subregions. Last, we discuss how disturbance agents may interact. Understanding how, when, where, and why climate change alters disturbance characteristics can help resource managers to anticipate future management challenges and identify where landscapes may shift into new and sometimes novel states.

Paleo-Ecological Overview

The effects of global environmental change are projected to alter the frequency and extent of landscape disturbances in the western United States, including wildfire and insect outbreaks (Flannigan et al. 2009; Raffa et al. 2008). In the IAP region, some conifer-dominated forests face an uncertain future from concomitant climate warming and intensifying disturbance regimes (Rehfeldt et al. 2006; Westerling et al. 2006). Recent studies suggest that unusually severe disturbances can promote transitions of high-elevation conifer-dominated forests to grasslands (Odion et al. 2010; Savage and Mast 2005). Retrospective ecological records derived from lake sediments and tree rings can help to establish baseline understanding about how ecosystem dynamics and disturbance regimes have responded and may respond during transitional climate periods involving changes in moisture and temperature.

The IAP region is topographically complex, with steep environmental gradients and vegetation ranging from sagebrush-steppe at low elevations to alpine tundra at the highest elevations. Between these extremes are forested zones that include pinyon-juniper woodlands, ponderosa pine parklands, montane forests of Douglas-fir (*Pseudotsuga menziesii*), and spruce-fir forests in the subalpine zone (Arno and Hammerly 1984).

The IAP region encompasses two distinct geologic provinces—the Great Basin and the Colorado Plateau— and many important physiographic, hydrological, and ecological linkages. The spatial pattern and seasonality of precipitation maximums throughout the region are heterogeneous and

Table 8.1—Area of forest land, by forest type group and primary disturbance class in the USFS Intermountain Region (2005-2014). This includes data from all forested Forest Inventory and Analysis (FIA) plots (n = 7,572) (2005–2014).

	Disturbance class											
Forest-type group	**None**	**Insect**	**Disease**	**Fire**	**Wild animals**	**Domestic animals**	**Weather**	**Vegetation**	**Other**	**Human**	**Geological**	**All land**[a]
	Thousand acres											
Pinyon-juniper	18,360	431	542	145	42	169	116	6	18	19	27	19,877
Douglas-fir	3,554	563	181	211	3	105	6	-	12	-	10	4,647
Ponderosa pine	1,185	17	44	117	-[b]	5	-	-	-	5	-	1,376
Fir-spruce-mountain hemlock	4,316	777	121	96	-	28	39	9	-	-	98	5,487
Lodgepole pine	1,818	566	100	129	-	26	6	-	-	-	-	2,647
Western larch	-	-	-	4	-	6	-	-	-	-	-	10
Other western softwoods	867	130	9	34	-	30	12	-	-	-	9	1,093
California mixed conifer	31	-	20	-	-	-	-	-	-	-	-	52
Elm-ash-cottonwood	97	-	3	3	-	1	-	-	-	-	-	106
Aspen-birch	2,244	157	240	157	4	18	19	-	-	5	10	2,857
Other hardwoods	3	-	-	-	-	-	-	-	-	-	-	3
Woodland hardwoods	3,235	27	23	170	3	24	38	-	7	-	1	3,531
Nonstocked	1,761	61	26	944	5	61	-	-	-	18	1	2,881
Total	37,476	2,732	1,316	2,015	58	476	237	15	37	47	159	44,572

[a] Columns and rows may not add to their totals due to rounding.
[b] Table cells without observations are indicated by "-".

Table 8.2—Area of forest land, by National Forest and primary disturbance class in the USFS Intermountain Region (2005-2014). This includes data from all forested Forest Inventory and Analysis (FIA) plots (n = 7,572) (2005–2014).

	Disturbance class											
National forest	**None**	**Insect**	**Disease**	**Fire**	**Wild animals**	**Domestic animals**	**Weather**	**Vegetation**	**Other**	**Human**	**Geological**	**All land**[a]
	Thousand acres											
Ashley	723	160	75	45	-[b]	-	-	-	-	-	-	1,004
Boise	1,424	80	34	182	5	7	-	-	-	5	-	1,739
Bridger-Teton	1,650	515	14	101	-	-	-	-	-	-	-	2,282
Dixie	1,255	88	23	92	6	4	18	-	-	-	-	1,489
Fishlake	1,009	15	16	34	-	1	-	-	-	-	-	1,077
Manti-La Sal	875	84	61	28	6	-	6	-	-	-	18	1,081
Payette	1,548	33	24	350	-	14	-	-	-	-	6	1,977
Salmon-Challis	1,850	662	79	362	-	104	12	9	6	-	17	3,103
Sawtooth	809	136	30	49	-	15	-	-	-	-	34	1,076
Caribou-Targhee	1,871	59	52	-	-	27	14	-	6	5	12	2,048
Humboldt-Toiyabe	3,047	113	137	119	-	24	24	-	-	5	15	3,487
Uinta-Wasatch-Cache	1,322	214	95	25	-	-	19	-	7	-	11	1,694
Total	17,388	2,164	645	1,392	18	199	94	9	19	16	115	22,063

[a] Columns and rows may not add to their totals due to rounding.

[b] Table cells without observations are indicated by "-".

temporally dynamic (Mock 1996; Mock and Brunelle-Daines 1999). Generally, in the southern portion of the IAP region, precipitation occurs during the summer via the North American Monsoon and during winter from Pacific frontal storms (Adams and Comrie 1997; Mitchell 1976). El Niño-Southern Oscillation (ENSO) is the primary driver of winter precipitation delivery, and ENSO varies in intensity and frequency over decadal to millennial timescales (Moy et al. 2002; Ropelewski and Halpert 1986). ENSO phase is an important control on fire regimes in the IAP region, with increased burning associated with the La Niña phase in the areas of the IAP region south of the 40 to 42° ENSO dipole transition zone (Brown et al. 2008; Schoennagel et al. 2005; Wise 2010).

Over millennial timescales, vegetation and disturbance regimes are shaped by climatic changes mediated by variations in incoming solar radiation (insolation), which result from subtle shifts in Earth-sun geometry. During the Holocene Thermal Maximum (HTM), which occurred 6,000 to 9,000 years BP, summers were warmer and winters were colder (Berger and Loutre 1991). Reconstructions of past environmental conditions help us to understand how past climates shaped plant communities and affected disturbance regimes. More specifically, lake sediment cores, which rely on the analysis of ecological proxy data, such as pollen and charcoal particles, facilitate reconstructions of forest composition and the frequency of past fire episodes. Chronologies for lake sediment records are produced through the analysis of radiometric isotopes, such as 210Pb/137Cs and 14C. In the IAP region, many paleo-environmental reconstructions have been done in subalpine environments, where perennial wetlands are more common than at lower-elevation sites.

The HTM is commonly emphasized in paleo-environmental reconstruction because of potential analogs for a warming 21st century. A summer temperature reconstruction from the Snake Range in western Nevada suggests that HTM warmth may have peaked 5,000 to 6,000 years BP (Reinemann et al. 2009). A calcite-based precipitation reconstruction from western Colorado, near the eastern margin of the IAP region, indicates that high-elevation HTM climate was dominated by high rainfall relative to snow, though this trend essentially reversed later in the period, when high-elevation sites were dominated by snowfall (Anderson 2011).

Despite long-term changes in seasonal temperature and precipitation regimes, upper-elevation sites in the IAP region have been dominated by Engelmann spruce (*Picea engelmannii*) for at least the last 9,000 years, with increasing abundances of subalpine fir (*Abies lasiocarpa*) and aspen (*Populus* spp.) beginning around 3,000 years BP (Morris et al. 2013). Fire regimes for this region are dynamic; the Aquarius Plateau recorded more frequent fires during the HTM period relative to recent millennia (Morris et al. 2013). On the other hand, sites located farther north (~40° N) near the ENSO dipole transition zone show essentially the opposite pattern, with reduced area burned during the HTM and increasing area burned toward present. In the IAP region, the quantity of moisture delivery during winter is modulated by ENSO. Because the fire season is strongly linked with snow cover (e.g., Westerling et al. 2006), shifts in the rates of biomass burning are apparent at sites located in the north and south of the ENSO dipole during the Holocene due to long-term dynamics of ENSO (Moy et al. 2002).

Wildland Fire

Wildland fire is defined in the 2009 Guidance for Implementation of Federal Wildland Fire Management Policy glossary as: "A general term describing any non-structure fire that occurs in the wildlands." Wildland fire includes both wildfires and prescribed fires. In contrast, wildfire is defined as: "An unplanned ignition of a wildland fire (such as a fire caused by lightning, volcanoes, unauthorized or accidental human-caused fires) and escaped prescribed fires" (USDA and DOI 2009). The terms "fire," "wildfire," and "wildland fire" are used throughout this document.

Wildland fire is an important overarching process that has significantly shaped the landscapes of the IAP region, dictating plant community structure and the direction and pace of ecosystem processes (Kitchen 2010). Historically, wildland fires maintained sagebrush-grass-forb-dominated landscapes in lower to mid-elevations, and lodgepole pine (*Pinus contorta* var. *latifolia*) and aspen-mixed conifer communities at mid- to high elevations. It maintained open understories in ponderosa pine (*Pinus ponderosa*) communities and created openings for other subalpine forest species to regenerate.

It is critical that we understand fire behavior, its ecological effects, and how human impacts on fuels and our environment have affected and continue to shape the roles that fire plays in our ecosystems. What are the relationships with wildland fire and vegetation cover types? How does climate change affect those relationships? How do fire and climate change affect carbon sequestration, and what is the importance of carbon sequestration in the IAP region? How do we manage risks associated with wildland fire, and how are the socioeconomics associated with wildland fire changing? These questions are important to consider for resource planning in the context of climate change.

Fire Regimes

The role of fire in ecosystems and its interactions with dominant vegetation is called a fire regime. Fire regimes can be defined by fire frequency (mean number of fires per time period), extent, intensity (measure of the heat energy released), severity (net ecological effect), and seasonal timing (Agee 1993). Fire regimes characterize the spatial and temporal patterns of fires and the impacts on ecosystems on the landscapes where they occur (Bradstock et al. 2002; Brown and Smith 2000; Keeley et al. 2009; Morgan et al. 2001). Understanding fire regimes is critical for understanding the

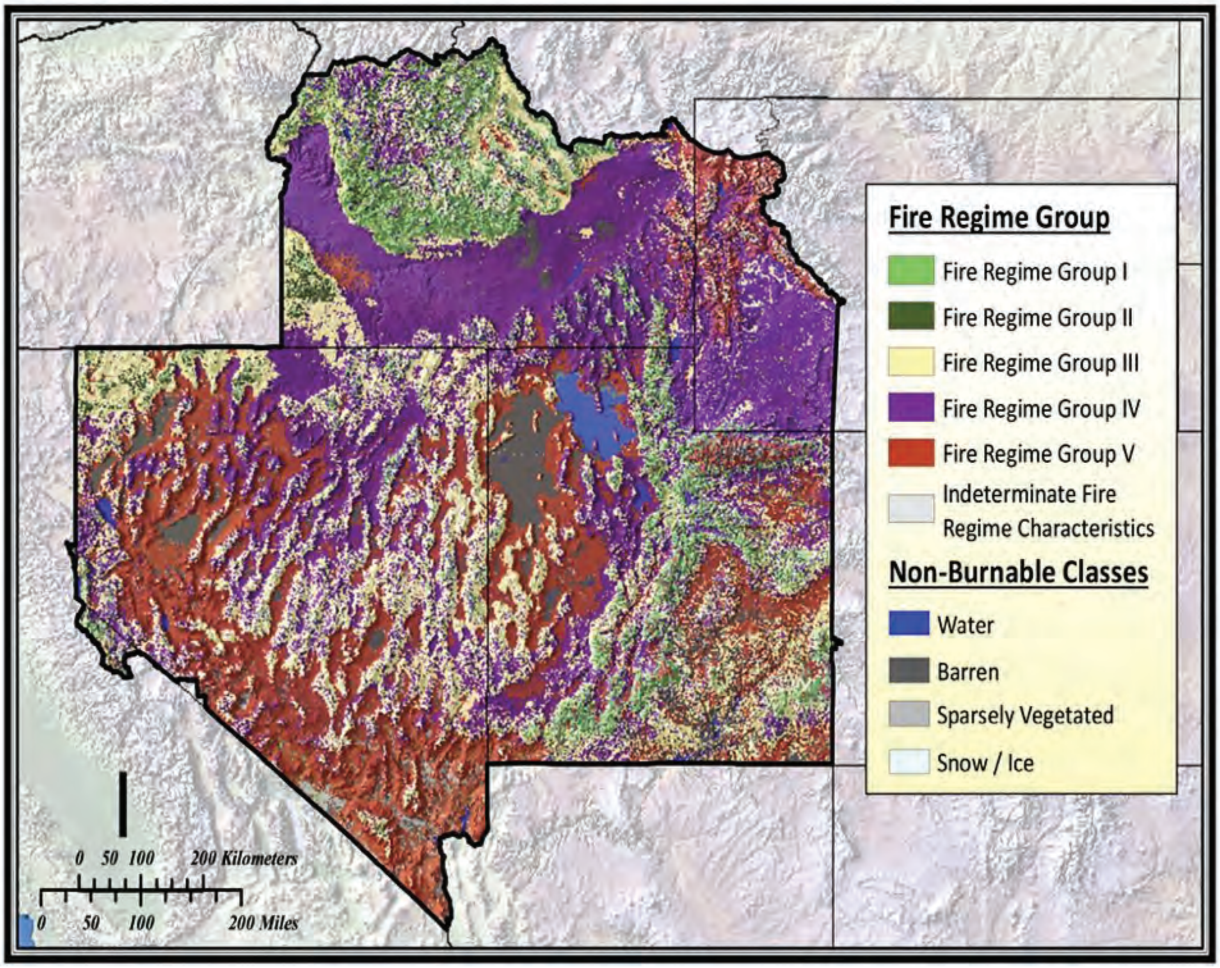


Figure 8.1—Distribution of LANDFIRE Fire Regime Groups in the Intermountain Adaptation Partnership region (Fire Regime Groups IVa and IVb have not been distinguished) (data described in Rollins [2009] and at https://www.landfire.gov/NationalProductDescriptions12.php).

role that climate change has on fire patterns (Brown et al. 2008; Grissino-Mayer and Swetnam 2000; Pechony and Shindell 2010; Schoennagel et al. 2004).

Fire regime groups, intended to characterize the presumed historical fire regimes, have been developed at a national scale (Hann et al. 2004) (see figure 8.1 for fire regimes in the IAP region). These groups are based on interactions among dynamic vegetation, fire spread, and fire effects, all in a spatial context. The natural (historical) fire regime groups are classified based on average number of years between fires (fire frequency), combined with the severity (amount of replacement) of the fire on the dominant overstory vegetation. Table 8.3 has been adjusted for the IAP region based on knowledge of local scientists and represents mean fire return intervals and severity groups that are more applicable to our geographic area (Kitchen 2015).

Low-severity, high-frequency fires representing **Fire Regime Group I** were once more typical in ponderosa pine forests at low elevations than they are today (fig. 8.2); fire suppression has reduced fire frequency in these forests (Stein 1988). Fires historically burned frequently enough to maintain low fuel loads and an open stand structure, producing a landscape in which fire-caused mortality of mature trees was relatively low (Agee 1998; Jenkins et al. 2011; Moritz et al. 2011). Adaptive traits, such as thick bark, also allowed mature ponderosa pines to survive many repeated fires over time.

Gambel oak (*Quercus gambelii*) communities were historically characterized by high-frequency, stand-replacing fires associated with **Fire Regime Group II** (fig. 8.3). Although insufficient historical data are available to adequately compare pre-Euro-American fire return intervals in Gambel oak communities to those of post-Euro-American settlement, there are accounts that Native Americans frequently burned these landscapes. The removal of Native Americans, as well as the introduction of domestic livestock grazing, led to a decrease in the number of ignitions and the spatial distribution of wildland fires in these ecosystems (Wadleigh et al. 1998). Today, many of these areas have a fire return interval of 35 to 200 years and would be classified as **Fire Regime Group IV**.

Table 8.3—Revised fire regime groups following LANDFIRE, with examples of cover types included in each group (numbers in parentheses developed by Hann et al. 2004).

Group	Mean fire return interval	Severity	Example cover types
I	<35 years (often <25 years)	Low (surface fires most common). Generally low-severity fires replacing <75% of the dominant overstory vegetation; can include mixed-severity fires that replace up to 75% of the overstory	Ponderosa pine; dry mixed conifer; aspen with mixed conifer
II	<35 years (often less than 25 years)	Mixed to high (high-severity fires replacing greater than 75% of the dominant overstory vegetation)	Gambel oak-maple; grasslands
III	35-80 (200) years	Mixed	Douglas-fir; western larch, lodgepole pine, and Douglas-fir; curl-leaf mountain mahogany; seral juniper and pinyon-juniper shrublands; riparian deciduous woodland; mesic mixed-conifer-aspen
IVa	35-80 (200) years	High	Lodgepole pine; Douglas-fir; mountain big sagebrush; Gambel oak-maple, curl-leaf mountain-mahogany, persistent aspen, mesic mixed conifer-aspen
IVb	81-200 (35) years	High	Wyoming big sagebrush; low and black sagebrush; lodgepole pine; persistent aspen; oak-maple; curl-leaf mountain-mahogany.
V	200+ years	Mixed to high (generally replacement-severity; can include any severity type in this frequency range)	Spruce-fir forests; salt desert shrub; persistent pinyon-juniper; juniper woodlands

Figure 8.2—Ponderosa pine forest on the east side of Boulder Mountain in Dixie National Forest, Utah. This forest type represents Fire Regime Group I, with high-frequency ground fires that maintain low understory fuels (photo: Wayne Padgett, U.S. Forest Service).

Figure 8.3—Regenerating Gambel oak along the Wasatch Front east of Farmington, Utah. This forest type represents Fire Regime Group II, with high-frequency, stand-replacing fires (photo: W. Padgett, U.S. Forest Service).

Generally, areas with mixed-severity fire with a return interval of 35 to 80 years, such as cool moist Douglas-fir and lodgepole pine types, are classified as **Fire Regime Group III**. Historically, patterns of fire intensity and frequency in cool moist Douglas-fir and lodgepole pine habitat types were driven by topography, weather, stand structure, and fuel loading. As a result, a range of fire behavior characteristics are represented in Fire Regime Group III, from light surface fire to stand-replacement fire, depending on conditions, thus creating a mixed-severity fire regime.

Historically, mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) was maintained by high-severity, stand-replacing fires of **Fire Regime Group IVa** (Miller et al. 2001). Today, the fire return interval in these communities is often much longer than it was historically, with associated juniper (*Juniperus* spp.) expansion replacing both sagebrush and their diverse herbaceous understory (Miller et al. 2001) (fig. 8.4).

Fire Regime Group IVb is representative of a variety of cover types in the IAP region, from Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) communities found at lower elevations to lodgepole pine forests in mountainous portions of the region. Lodgepole pine communities undergo large, stand-replacing fires (Romme 1982), and many, but not all, lodgepole pine trees can regenerate prolifically when heating from fires releases seed from serotinous cones (fig. 8.5) (Schoennagel et al. 2003).

Figure 8.4—Utah juniper establishment in a mountain big sagebrush-bunchgrass community in the Stansbury Mountains of central Utah (photo: W. Padgett, U.S. Forest Service).

Figure 8.5—Regeneration after fire in a lodgepole pine forest. Lodgepole pine forests are in Fire Regime Group IV, characterized by stand-replacing, high-severity fires with a 35- to 200-year fire return interval (photo: J. Peaco, National Park Service).

Figure 8.6—A recently burned spruce-fir forest on the north slope of the Uinta Mountains in northern Utah. This forest type represents Fire Regime Group V, with stand-replacing fires with a long (200 or more years) fire return interval (photo: Wayne Padgett, U.S. Forest Service).

High-severity fires that occur at intervals of 200 or more years representing **Fire Regime Group V** are typical in subalpine forests (fig. 8.6) and those of 1,000 or more years are typical of salt desert shrublands (fig. 8.7). In subalpine forests, fires tend to cause high mortality of mature trees because long intervals between fires result in dense, multistoried forest structures that are susceptible to crown fires (Agee 1998). There is little evidence that fires burned historically in salt desert shrublands, and they may have never burned until the introduction of invasive species, such as cheatgrass (*Bromus tectorum)*, to their understory (West 1994).

Wildland Fire Behavior

Fire behavior can be defined as the manner in which fuel ignites, flame develops, and fire spreads, as determined by the interactions of weather, fuels, and topography. A change in any one factor will alter the behavior of fires. Humans also play a significant role in the occurrence of fire in the conterminous United States (Hawbaker et al. 2013).

Figure 8.7—A salt desert shrubland near the La Sal Mountains in southeastern Utah. This cover type represents Fire Regime Group V, with stand-replacing fires with a long (200 or more years) fire return interval (photo: Wayne Padgett, U.S. Forest Service).

Climate and Weather

The terms "climate" and "weather" are often used interchangeably, and both affect wildland fires in direct and indirect ways. The difference between these is a matter of time; weather is what happens on a day-to-day basis, whereas climate is a measure of how weather and the atmosphere "behave" over a longer period of time (NASA 2005). Climate determines broad vegetation cover types that occur in any given area of the IAP region. Weather affects the seasonal and annual variability in fuel production in a particular landscape and expected fire behavior for that day. For example, unusually wet weather in the spring can increase fine fuel production.

The Plateaus subregion and southern portion of the Great Basin and Semi Desert subregion (fig. 1.1) are characterized by mild winters with long, hot, and typical monsoonal summer weather patterns. These monsoons are less pronounced and the temperatures are somewhat cooler, in the northern portion of the Great Basin and Semi Desert and the Uinta and Wasatch Front subregions. The Middle Rockies and Southern Greater Yellowstone subregions to the north have a maritime-influenced temperate climate with warm, dry summers and cool to cold and moist winters. These climates dictate the vegetation cover types dominating each subregion.

Weather as a driver of fire behavior is certainly the most dynamic of the three environmental conditions affecting fire behavior (weather, fuels, and topography). Wind, temperature, relative humidity, and precipitation, all features of weather, affect fire behavior. During the fire season, the amount and timing of precipitation largely determine availability of fine fuels, and short periods of dry weather are sufficient to precondition these systems to burn (Gedalof et al. 2005; Westerling and Swetnam 2003). Large fires are most strongly correlated with low precipitation, high temperatures, and summer drought (July through September) in the year of the fire (Littell et al. 2009).

Fuels

Fire regimes are also influenced by fuel structure, composition, continuity, and moisture content. These characteristics vary across vegetation and depend on the amount and configuration of live and dead fuel present at a site, environmental conditions that favor combustion, and ignition sources (Agee 1993; Krawchuk et al. 2009). Drier fuels can be ignited more easily, and a continuous layer of fuels can aid in the spread of fire. In some cases, high fuel moisture ultimately controls the extent and severity of fire (fig. 8.8).

Where rates of vegetation production outpace decomposition, sufficient biomass accumulates and is available to support fires, although higher-elevation regions with abundant fuels do not always have sufficiently dry conditions to sustain a fire. However, prolonged dry weather conditions (about 40 days without precipitation) can sufficiently dry live fuels and larger dead fuels to carry large, intense fires once they are ignited (Schoennagel et al. 2004). Wildland fuels lose moisture and become flammable in warm and dry summers typical throughout the IAP region; during this time there are ample sources of ignition from lightning strikes and humans. Therefore, the active wildfire season (period conducive to active burning) is in the summer, typically from late June through October, with shorter seasons at higher-elevation sites where snowpack can persist into July.

Fuels are generally less dynamic over time than the other drivers of fire behavior. Seasonal changes in annual and perennial grasses are a major driver of fuel conditions in grassland and shrublands, but in forests, changes in fuels, such as down woody fuels, are relatively slow; changes depend on the dead woody fuel size classes and decomposition rates, which vary by species.

Figure 8.8—Quaking aspen (*Populus tremuloides*) communities with high fuel moisture (in background). These stands helped to stop a fire on the north slope of the Uinta Mountains in northern Utah in fall 2002 (photo: Wayne Padgett, U.S. Forest Service).

Topography

There are strong interactions among topography, fuels, and weather. Aspect, elevation, and topographic features have affect moisture profiles across the landscape that directly affect vegetation and fuels. Slope steepness, aspect, valleys, ridges, chutes, and saddles all affect fire behavior differently. Rate of fire spread increases with slope steepness. Topographic features that channel fire tend to increase fire intensity, or the amount of energy release per unit time, whereas those that disperse energy tend to reduce fire intensity.

Human Effects on Historical Fire Regimes

Fires historically played a significant role in a variety of forest and nonforest types in the IAP region (Bartos and Campbell 1998; Gruell 1999; Heyerdahl et al. 2011; Miller and Tausch 2001). Wildland fire, as well as other disturbances such as insect outbreaks, disease, drought, invasive species, and storms, is part of the ecological history of both forest and nonforest ecosystems, influencing vegetation age and structure, plant species composition, productivity, carbon storage, water yield, nutrient retention, and wildlife habitat (Ryan and Vose 2012).

When comparing the historical to the current role of wildland fire on various ecosystems, we see significant change because of human influences (Kitchen 2015). Humans have affected fuels and ignition patterns in a variety of ways, including livestock grazing, introduction of invasive annual grasses, fire ignitions, fire suppression and exclusion, and landscape fragmentation, all of which affect the quantity and structure of fuels (Allen et al. 2002; Falk et al. 2011; Ogle and DuMond 1997; Pausas and Keeley 2014). Human activities have created either a “fire deficit” through fire suppression and exclusion, or a “fire surplus” through the addition of highly flammable invasive species to landscapes (Parks et al. 2015). Parks et al. (2015) noted that primarily nonforested portions of the western United States had a surplus of fires between 1984 and 2012 because of the abundance of cheatgrass (*Bromus tectorum*) in the Great Basin and red brome (*B. rubens*) in the Mojave Desert; the forested portions of the region experienced a deficit of fires because of fire exclusion.

Fire Deficit

Fire exclusion has increased the potential for crown fires in forests that historically had low-severity fire regimes (Agee 1998; Peterson et al. 2005) and in some forests with mixed-severity regimes (Taylor and Skinner 2003). Historically, ground or surface fires were frequent in ponderosa pine communities and maintained open understories. Fire exclusion since the 1920s has increased surface fuel loads, tree densities, and ladder fuels, especially in low-elevation, dry conifer forests (Schoennagel et al. 2004) (fig. 8.9). As a result, fires in these forests may be larger and more intense, and may cause higher rates of tree mortality than historical fires. In higher-elevation forests where fires were historically infrequent, fire exclusion has had minimal effects on fire regimes (Romme and Despain 1989; Schoennagel et al. 2004). The fire deficit has also resulted in the increase in pinyon pines and junipers (e.g., Utah juniper [*Juniperus osteosperma*] throughout the West) (fig. 8.10).

Increased Fire Frequency

Fire intervals for many sagebrush ecosystems of low to moderate productivity are perhaps 10 to 20 times shorter today than what is estimated for the pre-20th-century era (Peters and Bunting 1994; Whisenant 1990) because of the spread and dominance of invasive annual grasses, including cheatgrass (fig. 8.11). Cheatgrass invasion is not dependent upon livestock grazing. However, once cheatgrass was first introduced to the sagebrush-dominated rangelands in the early 1900s, it spread quickly into areas that had been grazed in the late 1800s (Young et al. 1987). Once a site is invaded by cheatgrass, it will not easily return to native perennial grass and forb dominance with exclusion of livestock grazing (Young and Clements 2007).

Livestock Grazing

Moderate levels of livestock grazing can be used to reduce fine fuel loading and subsequent fire severity in

Figure 8.9—High fuel loading in a ponderosa pine forest in Dixie National Forest in southern Utah as a result of decades of fire exclusion (photo: W. Padgett, U.S. Forest Service).

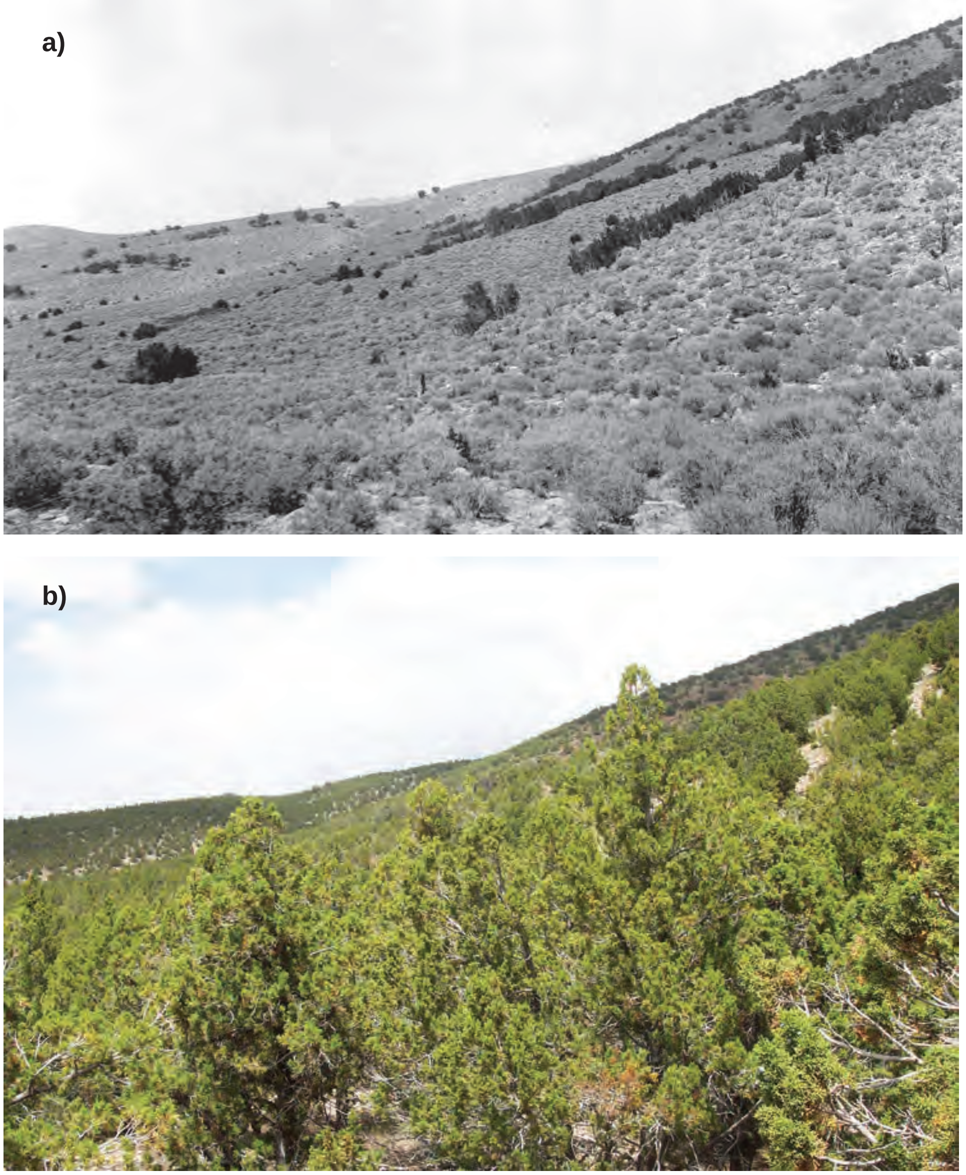


Figure 8.10—Big Creek Canyon on the west side of the Stansbury Mountains in north-central Utah in (a) 1901 and (b) 2004, showing an increase in Utah juniper in the mountain big sagebrush-Wyoming big sagebrush ecotone as a result of fire exclusion (left photo: G. K. Gilbert, U.S. Geological Survey; right photo: W. Padgett, U.S. Forest Service).

Figure 8.11—Cheatgrass and juniper establishment in a Wyoming big sagebrush community on lower slopes of the Stansbury Mountains in north-central Utah (photo: W. Padgett, U.S. Forest Service).

sagebrush-steppe plant communities and potentially other rangelands (Davies et al. 2010). However, grazing has been shown to change community composition over time, thereby influencing fuel characteristics (Chambers 2008). In some rangeland ecosystems, overgrazing and fire exclusion have caused the expansion of pinyon pine and juniper, with an associated increase in woody fuels in many sagebrush ecosystems (fig. 8.12); fire severity and size have increased as a result (Chambers 2008; Marlon et al. 2009).

Landscape Fragmentation

Practices such as timber harvest, road construction, and oil and gas development fragment the patterns of fuel loads on the landscape. In addition, sagebrush communities in the Intermountain West have been fragmented by conversion to agricultural uses and brush control projects (Kitchen and McArthur 2007). Fragmentation affects the spatial distribution and variation of fuel loads, which can in turn affect the susceptibility of a landscape to fire (Gould et al. 2008). Fragmented fuels can inhibit the spread of fire and ultimately contribute to the accumulation of fuels on the landscape (Sexton 2006).

Ignitions

On average, between 2002 and 2012, humans caused 24 percent of the fires in the U.S. Department of Agriculture Forest Service (USFS) Intermountain Region (fig. 8.14). A combination of human- and lightening-caused fires burned an average of 310,000 acres annually during that period, ranging from a low of 44,046 acres (2004) to 1,194,537 acres (2007) (FIRESTAT 2015) (fig. 8.13).

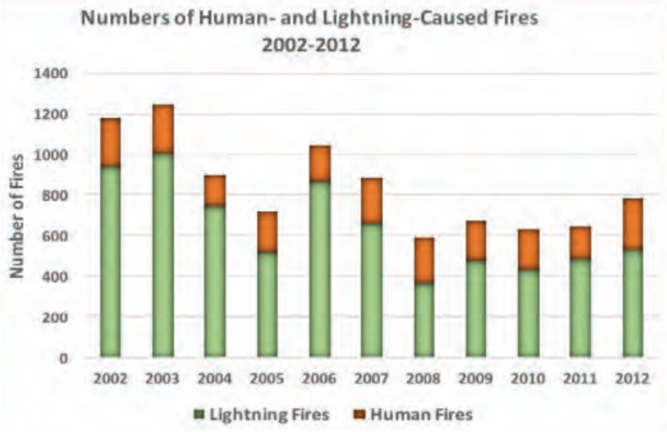


Figure 8.12—Number of human- and lightning-caused fires annually in the U.S. Forest Service Intermountain Region, 2002–2012 (data from FIRESTAT [2015]).

Climate Change and Wildland Fire

Climate controls the magnitude, duration, and frequency of weather events, which, in turn, drive fire behavior. In a warming climate, we are experiencing earlier snowmelt (Mote et al. 2005) and longer fire seasons (Westerling et al. 2006), and these trends are expected to continue. These changes are likely to result in increases in area burned, but fire activity will ultimately be limited by the availability of fuels (Brown et al. 2004; Flannigan et al. 2006; Loehman et al. 2011a; McKenzie et al. 2004; Torn and Fried 1992). Grissino-Mayer and Swetnam (2000) note that climate change may not result in simple linear responses in fire regimes. In some places in the IAP region, climate-driven changes in vegetation may lead to fuel limitations and lower fire area burned (McKenzie and Littell 2017).

Despite general agreement that warming temperatures will lead to increased area burned at broad scales in the western United States (McKenzie et al. 2004; Westerling et al. 2006), finer scale patterns are less certain. Projections

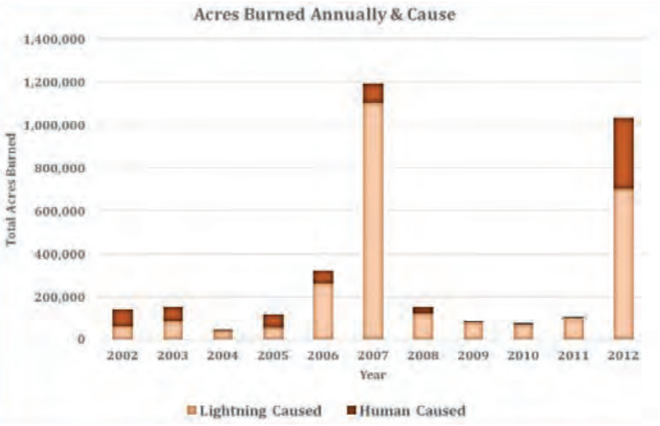


Figure 8.13—Wildfire area burned in the U.S. Forest Service Intermountain Region, 2002–2012 (data from FIRESTAT [2015]).

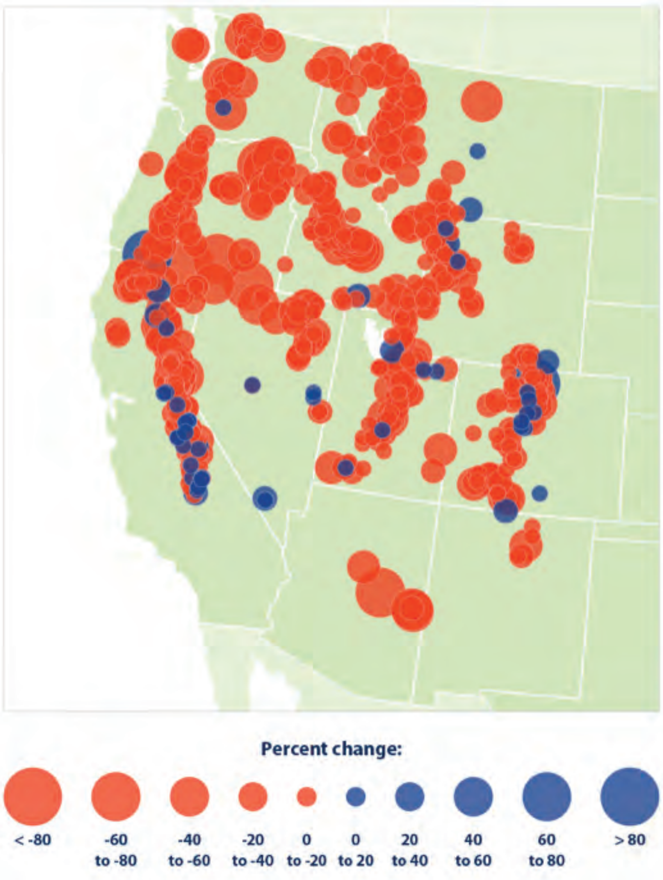


Figure 8.14—April 1 snow water equivalent in the western United States, 1955–2015 (from USEPA [2016]).

of future climate are somewhat uncertain at the regional and local scales that influence fire occurrence and behavior. For example, projections for future precipitation are characterized by both uncertainty and high variation (IPCC 2007; Littell et al. 2011). Although lightning and high wind events may increase in the future, thus increasing the potential for fire activity, confidence in these projections is low (Seneviratne et al. 2012).

Climate Change and Snowpack

Large and consistent decreases in snowpack have been observed throughout the western United States between 1955 and 2015 (fig. 8.14) (USEPA 2016). Although some individual stations in the 11 contiguous western States saw increases in snowpack, April 1st snow water equivalent declined at more than 90 percent of the sites measured. The average change across all sites amounts to a 23 percent decline. Declining snowpacks, when combined with other ongoing changes in temperature and drought, contributed to warmer, drier conditions that have fueled wildfires in parts of the western United States (Kitzberger et al. 2007; Westerling et al. 2006). Earlier onset of snowmelt reduces fuel moisture during the fire season, making a larger portion of the landscape flammable for longer periods of time (McKenzie et al. 2004; Miller et al. 2011a). This shift may be especially pronounced in mid- to high-elevation forested systems where fuels are abundant and snowpack can be limiting to fire (Westerling et al. 2006).

Climate Change and Fire Size and Severity

Changes in climate, especially drought and excessive heat, are linked to increased tree mortality, shifts in species distributions, and decreased productivity (Allen et al. 2010; van Mantgem et al. 2009; Williams et al. 2013). However, the most visible and significant short-term effects of climatic changes on forest ecosystems are caused by altered disturbance regimes, including insects and fire (Hicke et al. 2016). Large and long-duration forest fires have increased fourfold over the past 30 years in the West, and the length of the fire season has also increased (Westerling and Bryant 2008; Westerling et al. 2006). In addition, area burned increased between 1960 and 2015 (NIFC 2015) (fig. 8.15).

Analysis of fire data since 1916 for the 11 contiguous western States shows that for a temperature increase of 4 °F, annual area burned will be 2 to 3 times higher (McKenzie et al. 2004). The occurrence of very large wildfires is also projected to increase (Barbero et al. 2015; Stavros et al. 2014), as longer fire seasons combine with regionally dry fuels to promote larger fires. Fire severity over the long term will be dependent on vegetation changes and fuel conditions; if productivity is reduced and fuel loads are lower, fire severity may decrease in some systems (Parks et al. 2016).

Wildland Fire and Carbon Balance

In all vegetated ecosystems, there is a balance between the ability of the ecosystems to store (sequester) carbon and the release of carbon to the atmosphere with fire. Globally, forests and their soils contain the Earth's largest terrestrial carbon stocks. In the United States, forests and their soils represent 89 percent of the national terrestrial carbon sink (North and Hurteau 2011; Pacala et al. 2007; Pan et al. 2011). Forests in the western United States are estimated to account for 20 to 40 percent of the total annual carbon sequestration in the country (Pacala et al. 2001; Schimel and Braswell 2005). Carbon typically accumulates in forests (in woody biomass) and forest soils for decades to centuries until a disturbance event releases this stored carbon into the atmosphere (Goward et al. 2008).

Carbon Release

Wildland fires in forest ecosystems are one of the primary means for regulating carbon storage (sink) and emissions (Kasischke et al. 2000). Carbon is released to the atmosphere through wildland fires, but quantifying or projecting wildland fire emissions is difficult because their amount and character vary greatly from fire to fire, depending on biomass densities, quantity and condition of consumed fuels, combustion efficiency, and weather (Loehman et al. 2014; Sommers et al. 2014). The release

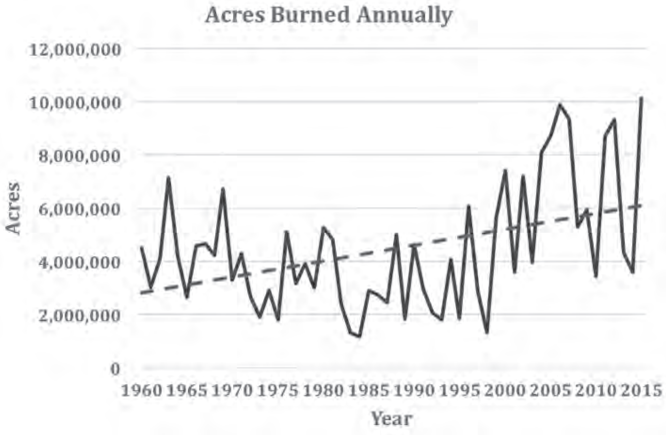


Figure 8.15—Wildfire area burned in the 11 contiguous Western States, 1960–2005 (data from NIFC [2015]).

of carbon from fires in forest ecosystems depends on climate and disturbance regime (Keith et al. 2009). Emissions measured from an individual fire event may not be characteristic of large-scale emissions potential, because of complex ecological patterns and spatial heterogeneity of burn severity within fire perimeters. Predisturbance productivity and conditions further affect the carbon emitted (Bigler et al. 2005; Dale et al. 2001; Falk et al. 2007).

High-severity fires typical of mid- to high-elevation forests in the IAP region may consume a large amount of aboveground biomass, resulting in an instantaneous pulse of carbon (i.e., the area affected becomes a carbon source to the atmosphere). However, these fires typically occur infrequently, and eventually carbon is recaptured by forest regrowth. Low-severity fires such as those that occur in low-elevation, dry forest types typically release less carbon per fire event (although total emissions depend on area burned) at more frequent intervals than with stand-replacing regimes. Low-severity fires favor long-lived and fire-resistant (or fire-tolerant) forest species that typically survive multiple fire events (Ritchie et al. 2007).

Carbon loss from wildland fire is balanced by carbon capture from forest regrowth over multiple decades, unless a lasting shift in dominant plant life form occurs or fire return intervals change (Kashian et al. 2006; Wiedinmyer and Neff 2007). This shift in balance has occurred in many of the low-elevation sagebrush communities that have been converted to cheatgrass (McArthur et al. 2009; Rau et al. 2011; Whisenant 1990). Wyoming big sagebrush communities, prior to Euro-American settlement, were composed of sagebrush and perennial grasses that were clumped in distribution and carried fire only under extreme weather conditions (low humidity and high windspeed). The invasion of cheatgrass into these communities increased fuel continuity, greatly increasing the frequency and extent of fire occurrences (West 1999; Young et al. 1972). Fire return intervals have decreased from between 50 and 100 years to less than 10 years because of cheatgrass invasion (Miller et al. 2011b; Whisenant 1990).

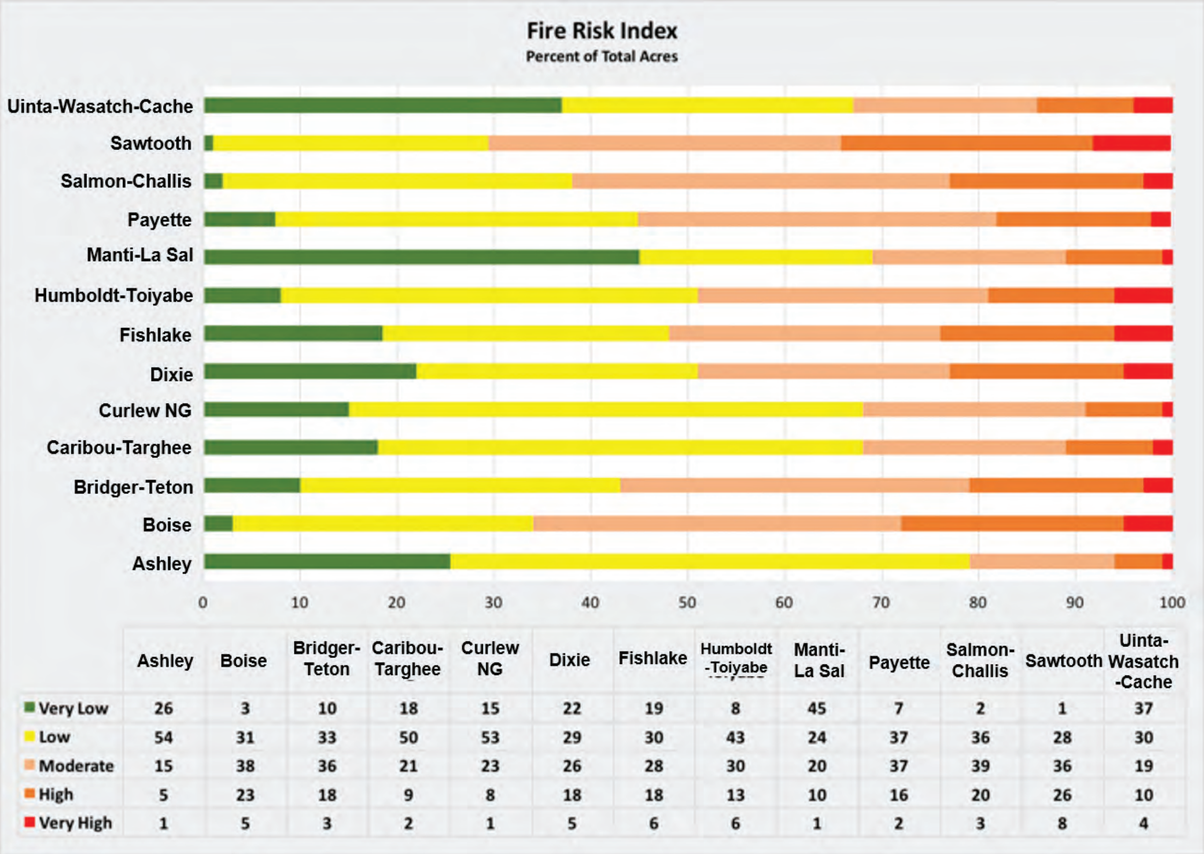
Carbon Sequestration

The potential for forests and rangelands to mitigate climate change depends on human activities such as land use and land management, and environmental factors such as vegetation composition, structure, and distribution; disturbance processes; and climate (Derner and Schuman 2007; Loehman et al. 2014). Although much has been written about the ability of forests to sequester carbon, less is written about the corresponding ability of rangelands, which also contribute to this ecosystem service. There are approximately 770 million acres of rangelands in the United States (Havstad et al. 2009); of these, half are on public lands in the West (Follet et al. 2001). If carbon saturation is reached, rangelands and pasturelands have the potential to remove 198 million tons of carbon dioxide from the atmosphere each year for 30 years (Follet et al. 2001). However, rangelands dominated by cheatgrass have much less capacity to store carbon than do rangelands dominated by native perennials, and high-frequency fire in cheatgrass-dominated communities provides a frequent source of carbon to the atmosphere (Rau et al. 2011).

Risk Management and Wildland Fire Decisionmaking

Risk is a part of working with wildland fire. Risk is a two-dimensional measure that includes both the probability and magnitude of potential outcomes (Wildland Fire Leadership Council 2014). In recent years, wildland fire risk evaluations and decisionmaking have focused on determining the values affected positively and negatively by fire, and the probability or likelihood of the event occurring, and then identifying the possible mitigation or suppression actions needed. To meet these challenges, the National Cohesive Strategy Science Panel (Wildland Fire Leadership Council 2014) proposed the use of comparative risk assessment tools as a rigorous basis for analyzing response alternatives. Comparative risk assessment is a long-standing and mature scientific approach to qualifying risk that allows managers and stakeholders to explore the tradeoffs between alternative courses of action (Wildland Fire Leadership Council 2014).

Several datasets and assessment tools are available to assess risk and prioritize management actions. First, data have been generated for the National Cohesive Wildland Fire Management Strategy (Wildland Fire Leadership Council 2014). Second, there is a West-wide wildfire risk assessment (Oregon Department of Forestry 2013). Third, "A Wildfire Risk Assessment Framework for Land and Resource Management" (Scott et al. 2013) guides managers in creating their own risk assessment at the level of detail to match their situation. Finally, the USFS has developed a wildland fire risk potential map for the lower 48 States to highlight areas that have a higher probability of experiencing high-intensity fire (Dillon et al. 2015) (see figure 8.16 for fire risk potential for National Forests in the IAP region).



	Ashley	Boise	Bridger-Teton	Caribou-Targhee	Curlew NG	Dixie	Fishlake	Humboldt-Toiyabe	Manti-La Sal	Payette	Salmon-Challis	Sawtooth	Uinta-Wasatch-Cache
🟩 Very Low	26	3	10	18	15	22	19	8	45	7	2	1	37
🟨 Low	54	31	33	50	53	29	30	43	24	37	36	28	30
🟧 Moderate	15	38	36	21	23	26	28	30	20	37	39	36	19
🟧 High	5	23	18	9	8	18	18	13	10	16	20	26	10
🟥 Very High	1	5	3	2	1	5	6	6	1	2	3	8	4

Figure 8.16—Data on wildland fire risk potential for each national forest in the Intermountain Adaptation Partnership region (data from Dillon et al. 2015). Areas with higher wildland fire risk values have a higher probability of experiencing high-intensity fire. Rounding errors result in totals different from 100 on some national forests.

Changing Socioeconomics of Fire

New residential construction continues to grow outside of communities into areas with higher risk of fire, expanding the wildland-urban interface (WUI). The presence of more homes in the WUI results in increased strain on fire responders and wildland fire management organizations. Fire suppression costs have increased steadily over the past 20 years. The annual cost of suppression reached $1 billion for the first time in 2000 and only barely dropped below that threshold twice in the following 14 years (Jeffrey 2015). The combination of increasing human populations and increasing fire area burned with warming climate is likely to lead to increased fire risk in the WUI and increased fire suppression costs. The path to avoiding the worst possible impacts of wildland fire may be for the public and governments at all levels to become more comfortable with prescribed fire, managed wildfire, and smoke, achieved in part with improved outreach and understanding of the ecological role of fire (USDA and DOI 2014).

Insects

Insect species, in general, have relatively short life cycles, high reproductive capacity, and a high degree of mobility, and thus the physiological responses to warming temperatures can produce large and rapid effects on species population dynamics (Stange and Ayres 2010). Climatic and atmospheric changes can impact biotic disturbances of forests via three general mechanisms: effects on the physiology of insects (direct); effects on tree defenses and tolerance (indirect); and effects on interactions between disturbance agents and their own enemies, competitors, and mutualists (indirect) (Weed et al. 2013). These direct and indirect effects of climate change on biotic disturbances are described next, along with species of insects important in the IAP region: Bark beetles, defoliators, and invasive insects.

Direct Effects of Climate on Insects

Warmer temperatures associated with climate projections will tend to impact (and frequently amplify) insect population dynamics directly through effects on survival, generation time, fecundity, and dispersal. High reproductive potential, rapid evolution, and roles in food webs make insects a good model organism for understanding the effects of a changing climate. Mid- to high-latitudinal insect populations are anticipated to benefit from climate change through more rapid life cycle completion (see the *Expected Effects of Climate Change on Bark Beetle Outbreaks* subsection below) and increased survival. Insect mortality may decrease with warmer winter temperatures, thereby leading to higher-elevation and poleward range expansions (Stange and Ayres 2010).

Indirect Effects of Climate on Host Tree and Insect Interactions

Increased drought severity and frequency are likely to make forests more vulnerable to both direct (reduced growth and mortality) and indirect (insect outbreaks, pathogens, and wildfire) impacts (Dale et al. 2001; Kolb et al. 2016b; Schlesinger et al. 2016; Weed et al. 2013). A forest ecosystem can support an insect outbreak only if the preferred host species is available. Under drought conditions, plants may become more attractive to some insect herbivores, such as defoliators, because of the physiological response that increases concentration of nitrogen compounds and sugars in young plant tissue (McDowell et al. 2016). Most forest insects that cause damage to trees are monophagous (single host). Native insect communities will therefore follow forest communities. Consequently, as forests change (structure, type, and species diversity), so do their associated insect communities.

Bark Beetles

The scolytines (Coleoptera: Curculionidae, Scolytinae), or bark and ambrosia beetles (hereafter bark beetles), represent an ecologically and often economically important group of forest insects. Around 519 species occur north of Mexico in North America (Mercado 2011). Most of these species develop in the inner bark (their name is defined by their feeding niche). The eruptive nature of bark beetles allows populations to build rapidly, causing extensive tree mortality events. Several species, including the mountain pine beetle (*Dendroctonus ponderosae* Hopkins), spruce beetle (*D. rufipennis* Engelm.), and Douglas-fir beetle (*Dendroctonus pseudotsugae*), have caused landscape-scale tree mortality events in the IAP region over the past decades (see following discussion).

The Ecological Role of Native Bark Beetle Disturbances

Both endemic and eruptive bark beetle population levels can affect important ecosystem processes, such as the allocation of water and nutrients within a stand or a watershed, as well as forest structure and composition (Collins et al. 2011; Mikkelson et al. 2013). Typically, endemic populations of bark beetles kill old, suppressed, or otherwise unhealthy host trees suffering some type of stress. Dead trees provide food and a niche to other organisms, such as cavity-nesting birds and detritivores. When dead trees fall, younger or previously suppressed understory trees can respond to an increased availability of resources, including light, water, and nutrients. Nutrients and carbon return to the atmosphere and to the soil, where they are recycled by other plants; over time, there is no significant carbon stock change between bark beetle-disturbed or undisturbed stands (Hansen et al. 2015). Although the short-term effects of bark beetle-caused tree mortality bring change to the age structure of affected forests, the long-term effects can modify tree species composition in a forest (Amman 1977), altering diversity, and potentially resilience, in the face of a changing climate (Peterson et al. 1998). Native bark beetles are an important component of healthy and dynamic forest ecosystems. However, large mortality events are often considered undesirable when they conflict with human resource objectives and ecosystem services.

Population Dynamics of Eruptive Bark Beetles

During any given time, native bark beetles occur at different population levels within the range of their hosts. At low or endemic population levels, these insects usually lack the capacity to overwhelm the defenses of healthy trees; populations survive in susceptible trees experiencing abiotic or biotic stress factors. Stress factors, such as intertree competition (Fettig et al. 2007), pathogens (Goheen and Hansen 1993; Tkacz and Schmitz 1986), drought (Chapman et al. 2012; Hart et al. 2014), and moderate fire damage (Elkin and Reid 2004; Powell et al. 2012), can allow endemic beetle populations to successfully kill trees.

Given suitable stand conditions and susceptible landscapes, endemic populations of eruptive bark beetles can achieve exponential growth, affecting hosts at the landscape level in relatively short periods of time (Lundquist and Reich 2014; Safranyik et al. 2010). Large-scale epidemics can occur following inciting factors such as drought events, when large numbers of trees of suitable size become susceptible (Negrón 1998). Factors fostering epidemic population growth include: (1) an abundance of suitable hosts, (2) a predisposing condition, (3) a potent host attraction signal, (4) a strong intraspecific recruitment signal, (5) reduced competition and depredation during attack and establishment, (6) high nutrient availability, and (7) suitable temperatures for survival and life cycle completion.

Eruptive Bark Beetles in the IAP Region

Climate affects bark beetles directly and indirectly. Many bark beetle life history traits influencing population success are temperature dependent (Bentz and Jönsson 2015), and warming temperatures associated with climate change have directly fostered bark beetle-caused tree mortality in some areas of western North America (Safranyik et al. 2010; Weed et al. 2015a). Specific risk and hazard ratings that incorporate stand- or tree-level metrics are available for several bark beetle species. Risk and hazard rating systems are a critical piece in assessing susceptibility to bark beetle-caused mortality. Indirect effects of climate change include impacts on host tree vigor and susceptibility to bark beetle attack (Chapman et al. 2012; Hart et al. 2014).

Although bark beetle mortality events occur every year in the IAP region, large-scale events for any one agent usually occur infrequently. Bark beetles causing landscape-level tree mortality include species in the genera *Dendroctonus*, *Ips*, *Scolytus*, and *Dryocoetes*. In the IAP region, several species have caused major tree mortality events in the past (table 8.4). The most recent large mortality event associated with mountain pine beetle occurred from 2001 to 2014 across the region, with a peak mortality of 4.5 million trees reported in 2010 (fig. 8.17a). Since the early 1990s, spruce beetle populations have been at outbreak levels at various locations throughout the region, with the greatest tree mortality reported in 2013 (fig. 8.17b). Douglas-fir beetle (fig. 8.17c) attacked Douglas-fir at outbreak levels for more than a decade, from 2000 until 2016, across the region. Two other species that recently have shown population increases in the region are pinyon ips and Jeffrey pine beetle (*Dendroctonus jeffreyi*). Pinyon engraver beetle, also known as pinyon *Ips*, had a spike in population in 2004 (2.9 million trees reportedly killed), when surveys concentrated on the pinyon habitat to document this mortality event (fig. 8.17d).

Expected Effects of Climate Change on Bark Beetle Outbreaks

Indirect Effects on Host Tree Susceptibility and Community Associates

Climate change will have indirect effects on bark beetle population outbreaks within the IAP region. Depending on future carbon dioxide emissions, annual precipitation is predicted to vary greatly across the IAP, ranging from a decrease of about 10 percent to an increase of nearly 30 percent, with a mean projected increase of 5 percent (RCP 4.5) and 8 percent (RCP 8.5) across the region (Chapter 3). With an associated increase in temperature, these precipitation changes suggest a decline in the snow-to-rain ratio for many forested areas in the region, with more precipitation falling as rain than snow (Gillies et al. 2012; Regonda et al. 2005). Interannual changes in snowpack can have significant effects on hydrological processes and ecosystem services (Chapter 13), in addition to effects on trees. Although insects are typically not directly influenced by precipitation, except during adult flight, changes in the timing and type of precipitation will have indirect effects on bark beetles through an influence on the suitability and spatial distribution of host trees. Tree physiological processes can be greatly affected by changes in the type and timing of precipitation.

Carbon-based compounds can be the main defense against bark beetles, and these defenses can be weakened when water availability is altered (Chapman et al. 2012; Gaylord et al. 2013; Hart et al. 2014). Water availability, however, has nonlinear impacts on carbon-based plant compounds (Kolb et al. 2016a). Mild or moderate drought that does not close stomata can increase carbon-based defenses as carbon produced during photosynthesis is shunted away from growth (Herms and Mattson 1992). But intense water stress can cause stomata to close to avoid excessive water loss. This causes a reduction in carbon-based defense compounds (i.e., terpenoids) through carbon starvation and hydraulic failure (McDowell et al. 2011).

Intense drought can also result in an induced production of certain volatile compounds, such as alcohols, that work as olfactory attractants to some bark beetles (Kelsey et al. 2014). Although trees in intense drought conditions may be more attractive and susceptible to bark beetles, low levels of nitrogen, carbohydrates, and phloem moisture could negatively affect developing brood by indirectly affecting the growth of blue-stain fungi (reviewed in Kolb et al. 2016a). Drought intensity and timing will therefore be important factors in predicting effects on bark beetle population success in the future. Moderate tree water stress can reduce bark beetle impact, and more severe water stress can be favorable for bark beetles and result in increased bark beetle-caused tree mortality. Species that are currently considered incapable of attacking live, healthy trees in some areas, including some *Ips* species, could become primary tree killers as their favored habitat increases.

Climate change may influence the frequency and intensity of inciting factors that can trigger bark beetle population outbreaks. An increase in tree fall from wind events could provide a reservoir of favorable habitat of stressed or damaged trees used by some bark beetle species (e.g., spruce beetle), allowing them to surpass the endemic-epidemic threshold (Jenkins et al. 2014). In addition, community associates important to bark beetle population success, including fungi, natural enemies, and competitors, could also be influenced by climatic changes, with both positive and negative indirect effects on bark beetle population outbreaks (Addison et al. 2013; Kalinkat et al. 2015).

Direct Effects on Overwinter Survival

Within the IAP region, projected changes in temperature by the 2040–2060 period range between 2 and 8 °F (Chapter 3). Generally, increasing minimum temperatures will result in increased winter survival for most species, and could result in range expansion, both northward and upward in elevation. All insect species within the IAP region will be affected. For example, *Ips lecontei* populations became more active at higher elevations during the early 2000s, when both winter and summer temperatures increased (Williams et al. 2008). Across mountain pine beetle habitats in the western United States from 1960 to 2011, minimum temperatures increased 6.5 °F. This increase in minimum temperature resulted in a decrease in winter larval mortality and a subsequent increase in beetle-caused tree mortality

Table 8.4—Major bark beetle species affecting trees in the IAP region. Inciting factors associated with climate change effects are listed with supporting literature.

Bark beetle	Subregions affected[a]	Host tree	Inciting factors for outbreaks	Supporting literature
Douglas-fir beetle (*Dendroctonus pseudotsugae*)	All	Douglas-fir	Drought intensity and timing Defoliation events Little known on direct effects of temperature Fire Stand conditions	Cunningham et al. 2005; Furniss 1965; Hadley and Veblen 1993; Hood et al. 2007; McDowell et al. 2011; Negrón et al. 2014
Mountain pine beetle (*D. ponderosae*)	All	Limber pine, ponderosa pine, lodgepole pine, whitebark pine, sugar pine and western white pine	Drought intensity and timing Temperature warming can reduce development to univoltine at highest elevations Stand conditions	Bentz and Powell 2014; Bentz et al. 2010, 2014, 2016; Fettig et al. 2007
Spruce beetle (*D. rufipennis*)	1, 2, 3, 4, 6	Engelmann spruce, blue spruce, lodgepole pine (rarely; recent regional occurrences)	Wind events Temperature warming can reduce development to univoltine at highest elevations	Bentz et al. 2010, 2016; Holsten et al. 1999
Western pine beetle (*D. brevicomis*)	1, 4, 5, 6	Ponderosa pine	Drought intensity and timing Warming temperatures can increase development to multivoltine Fire Stand conditions	Fettig et al. 2008; Furniss and Johnson 2002; Miller and Keen 1960; Miller and Patterson 1927; Negrón et al. 2009
Jeffrey pine beetle (*D. jeffreyi*)	5	Jeffrey pine	Little known on direct effects of temperature Fire Stand conditions	Bradley and Tueller 2001; Maloney et al. 2008
Fir engraver (*Scolytus ventralis*)	All	Grand fir, white fir, subalpine fir (occasionally)	Drought timing and intensity Defoliation events Temperature warming can reduce development to univoltine at highest elevations Fire Stand conditions	Bentz et al. 2010, 2016; Ferrell 1986; Fettig et al. 2008; Maloney et al. 2008; Schwilk et al. 2006
Western balsam bark beetle (*Dryocoetes confusus*)	All	Subalpine fir, grand fir and white fir (occasionally)	Drought intensity and timing Root diseases, fungal pathogens Wind events Temperature warming can reduce development to univoltine at highest elevations Stand conditions	Bentz et al. 2010, 2016; McMillin et al. 2003
Pine engraver beetle (*Ips pini*)	All	Lodgepole pine, ponderosa pine, Jeffrey pine	Drought intensity and timing Wind events Warming temperatures can increase multivoltiism Stand conditions	Kegley et al. 1997; Negrón et al. 2009

Table 8.4—*Continued.*

Bark beetle	Subregions affected[a]	Host tree	Inciting factors for outbreaks	Supporting literature
Spruce engraver beetle (*I. pilifrons*)	All	Spruce	Little known on direct effects of temperature Wind events	Forest Health Protection 2011
Pinyon Ips (*I. confusus*)	3, 4, 5, 6	Singleleaf pinyon pine, two-needle pinyon pine	Drought intensity and timing Dense stands Mistletoe infections	Gaylord et al. 2015; Kleinman et al. 2012; Negrón and Wilson 2003; Shaw et al. 2005
Roundheaded pine beetle (*D. adjunctus*)	4, 5	Ponderosa pine	Little known on direct effects of temperature Drought effects on growth	Negrón et al. 2000

[a] Subregions include: (1) Middle Rockies, (2) Southern Greater Yellowstone, (3) Uintas and Wasatch Front, (4) Plateaus, (5) Great Basin and Semi Desert, (6) Intermountain Semi Desert.

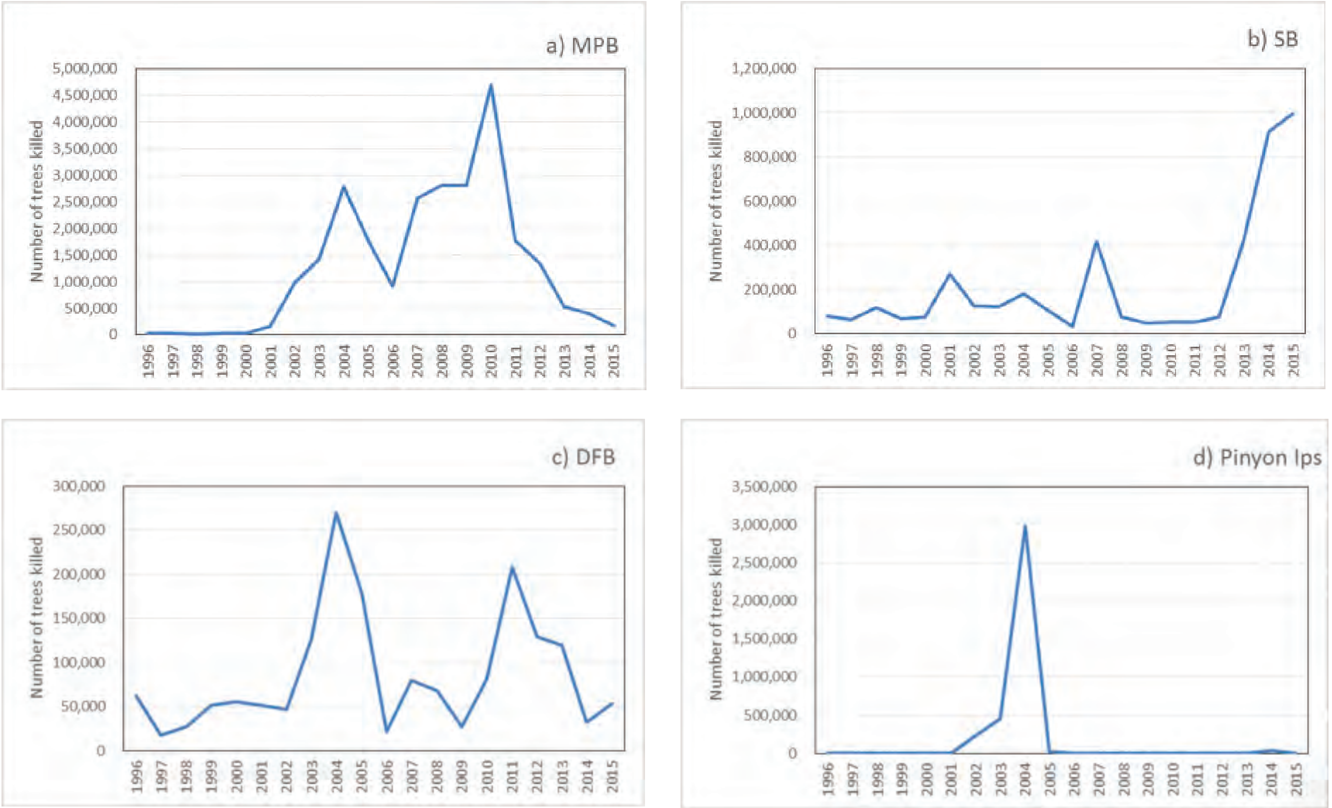


Figure 8.17—Number of trees killed by (a) mountain pine beetle (MPB), (b) spruce beetle (SB), (c) Douglas-fir beetle (DFB), and (d) pinyon ips in the U.S. Forest Service Intermountain Region, 1996–2015. Data are from Aerial Detection Surveys 1996–2015, Intermountain Region, Forest Health Protection.

in some areas. Areas that were historically the coldest showed the greatest increase in tree mortality with warming temperatures (Weed et al. 2015b). Similarly, within the IAP region, winter warming in recent years resulted in increased beetle-caused tree mortality in the subregions that were previously the coldest: the Middle Rockies and Southern Greater Yellowstone subregions (Weed et al. 2015b). Future projections also suggest an increase in mountain pine beetle cold-temperature survival across most IAP subregions, although elevations greater than about 7,800 feet in the Southern Greater Yellowstone subregion remain cold enough for continued low predicted winter survival (Bentz et al. 2010) (fig. 8.18).

Survival will also be complicated by other factors. Bark beetles time their development to reduce cold-caused mortality using several strategies that include developmental

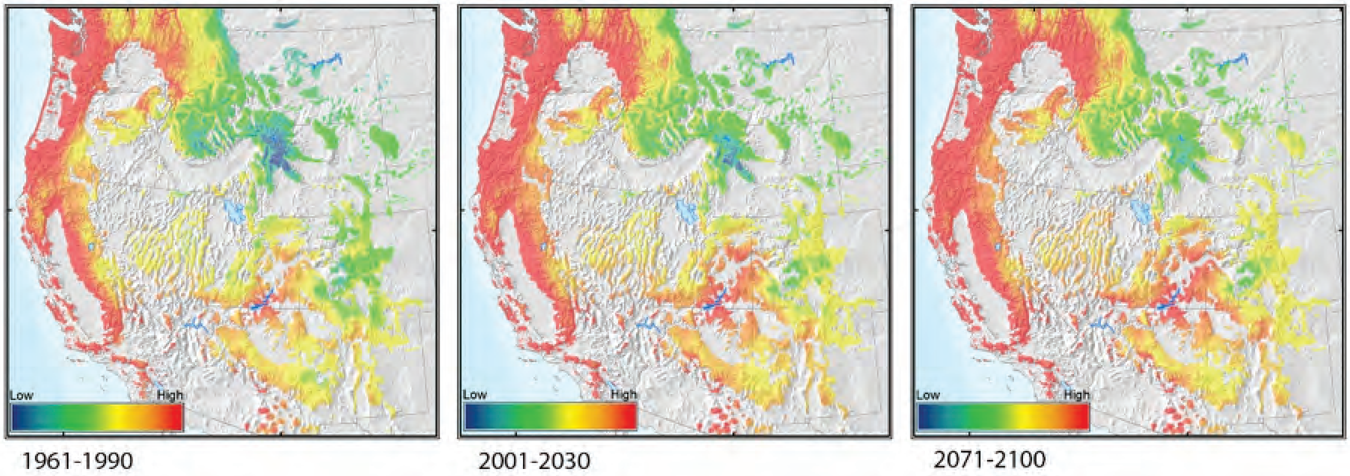


Figure 8.18—Predicted probability of cold survival for mountain pine beetle in pine forests of the western United States during three climate normal periods: 1961–1990, 2001–2030, and 2071–2100. Model results are shown only for areas estimated to be 20th-century spruce habitat (sensu Little [1971]). See Bentz et al. (2010) for a description of the mountain pine beetle model and temperature projections used to drive the model.

thresholds, diapause, and cold hardening (Bentz and Jönsson 2015). Specific thresholds and induction temperatures vary among the species. Therefore, effects of changing temperature will depend on the beetle species, as well as the seasonal timing, amount, and variability of thermal input, as dictated by geographic location.

Although winter warming will generally be beneficial for bark beetles, extreme within-year variability in winter warming could be detrimental to insect survival. Bark beetles metabolize supercooling compounds as temperatures decrease and catabolize compounds as temperatures warm (Bentz and Mullins 1999). Large temperature fluctuations could result in excessive metabolic investment in maintaining appropriate levels of antifreeze compounds, leaving individuals with minimal energy stores at the end of winter. In addition, many bark beetle species overwinter at the base of tree boles, garnering protection from predators and excessive cold temperatures when insulated beneath snow. Reduced snow levels associated with winter warming, and the fact that precipitation will be more likely to fall as rain than snow, could add to increased overwinter mortality.

Direct Effects on Generation Time

In addition to winter warming, projected warming at other times of the year will also directly influence bark beetles within the IAP region. But warming temperatures will not provide a direct and linear response in population increases. Changing temperature regimes can either promote or disrupt bark beetle temperature-dependent life history strategies that drive seasonality and length of a generation. Generally, an increase in the number of generations produced in a year increases tree mortality (Bentz et al. 2010). Voltinism is the number of generations that can be produced in a single year. Within the IAP region, bark beetle species are multivoltine (more than two generations in a year), bivoltine (two generations in a year), univoltine (one generation in a year), or semivoltine (one generation every 2 years), depending on the species, location, and annual thermal input (Bentz et al. 2014; Furniss and Johnson 2002; Hansen et al. 2001; Kegley et al. 1997). As mentioned, generation timing must be appropriately timed with the seasons to avoid excessive winter mortality, in addition to maintaining synchronized adult emergence that facilitates mass attacks on trees (Bentz and Powell 2015). Seasonality strategies, such as developmental thresholds and diapause, are used in this process. Thermal warming in some habitats may allow a reduction in generation time that also maintains seasonality. Other thermal regimes, however, could disrupt diapause and thermal thresholds and hence seasonality (Régnière et al. 2015). Because temperature varies with topography, latitude, and elevation, insect response to warming will also vary across landscapes, with both positive and negative effects on population growth (Bentz et al. 2016).

At the highest elevations within the IAP region, spruce beetle, mountain pine beetle, fir engraver (*Scolytus ventralis*), and western balsam bark beetle (*Dryocoetes confusus*) are generally semivoltine, although in warm years and at lower-elevation sites, populations of these species develop on a univoltine life cycle (Bentz et al. 2014; Hansen 1996; Hansen et al. 2001). Projected warming temperatures through 2100 are predicted to reduce generation time (i.e., from semivoltine to univoltine) at the highest elevations within the IAP region for both mountain pine beetle and spruce beetle (Bentz et al. 2010, 2016) (fig. 8.19). Warming temperatures, however, could also potentially disrupt population success at middle elevations when diapause and development thresholds are disrupted in altered thermal regimes (Bentz et al. 2016; Hansen et al. 2001).

Within the IAP region, western pine beetle (*Dendroctonus brevicomis*) and *Ips* species have developmental thresholds that allow for bivoltinism and multivoltinism (Furniss and Johnson 2002), and warming

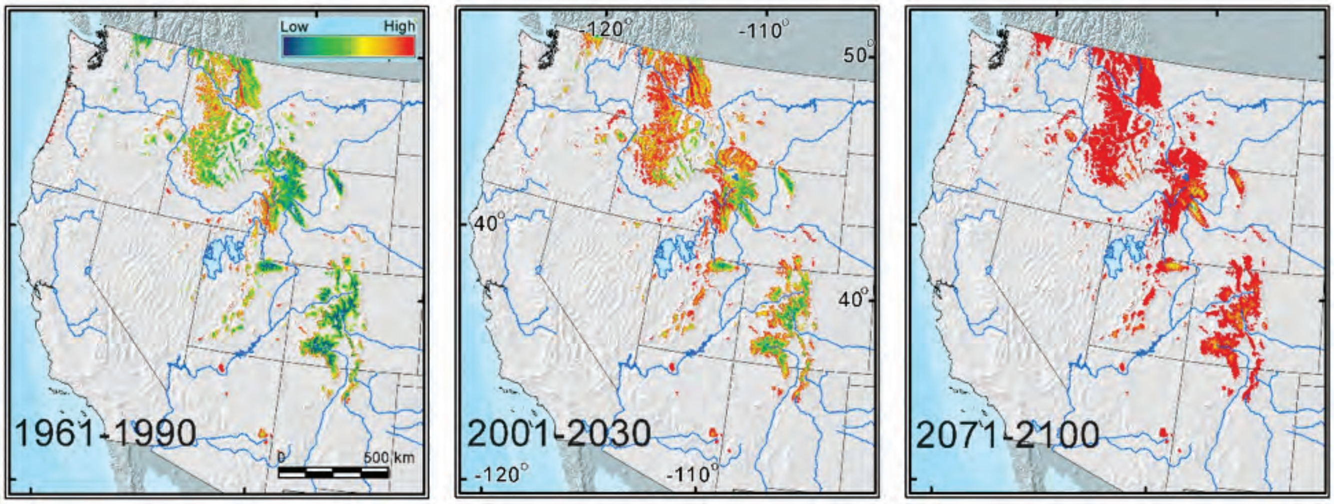


Figure 8.19—Predicted probability of spruce beetle developing in a single year in spruce forests in the western United States during three climate normal periods: 1961–1990, 2001–2030, and 2071–2100. Higher probability of 1-year life cycle duration translates to higher probability of population outbreak and increased levels of tree mortality. Model results are shown only for areas estimated to be 20th-century spruce habitat (sensu Little [1971]). See Bentz et al. (2010) for a description of the spruce beetle model and temperature projections used to drive the model.

temperatures could allow these species to have additional generations in a single year. Bivoltinism of other species that are adapted to cooler temperatures at higher elevations, including mountain pine beetle and spruce beetle, has been limited historically due to diapause and thermal threshold constraints (Bentz and Powell 2014; Hansen et al. 2011; but see Mitton and Ferrenberg 2012). Although temperatures at the lowest elevations (less than 4,000 feet) are projected to warm enough in the next 30 years to produce bivoltine mountain pine beetle populations that are timed appropriately for population success, thermal requirements for bivoltinism will remain generally unmet at locations greater than 4,000 feet (Bentz et al. 2016).

By the end of the century, however, under the warmest emissions scenario (RCP 8.5), portions of the Middle Rockies subregion are predicted to support moderate levels of bivoltine mountain pine beetle populations (Bentz et al. 2016). As temperatures warm in the Plateaus subregion of southern Utah, a complex of bark beetle species (e.g., mountain pine beetle, roundheaded pine beetle [*Dendroctonus adjunctus*], western pine beetle, *Ips* spp.) that infest relatively low-elevation ponderosa pine may also have the potential for a reduction in generation time and an increase in the length of biological activity (i.e., flight initiation and cessation) (Gaylord et al. 2008; Williams et al. 2008).

Douglas-fir beetle, Jeffrey pine beetle, red turpentine beetle (*Dendroctonus valens*), and roundheaded pine beetle are all considered univoltine within current IAP region climates. Although we do not know enough about thermally dependent traits for these species to quantify predictions, warming temperatures could result in outcomes similar to those for mountain pine beetle and spruce beetle. Additional partial generations that could be disruptive to population success could occur. Alternatively, if temperatures warm sufficiently, bivoltine populations that are timed appropriately could enhance population success. Two generations rather than one generation in a single year could result in a doubling of beetle-caused tree mortality in a given year. But some species, such as Douglas-fir beetle and spruce beetle, may not be able to produce two generations in a year due to a required adult winter resting state, or diapause (Bentz and Jönsson 2015). More information is needed on the physiological strategies of these species to better understand the potential for beetle population growth in a changing climate.

Summary

The impact of climate change on bark beetle-caused disturbance patterns will be complex. Temperature-dependent life history strategies that facilitate population success and promote outbreaks have evolved through local adaptation (Bentz et al. 2011). Although bark beetle populations can absorb relatively small changes in temperature and remain successful, as seen in the past decade, changes projected throughout the century for the IAP region may surpass existing phenotypic plasticity in traits. Adaptation to new thermal regimes will be required. Due to local adaptations, population irruptions will be specific for a species and geographic location, although some generalizations can be made. Increasing minimum temperatures are likely to benefit all bark beetle species in cold habitats within the IAP region, probably resulting in increased tree mortality. This effect, however, will be influenced by thermal changes at other times of the year. Warming at other times of the year could reduce generation time and length of adult flight, but also potentially disrupt evolved strategies, resulting in poor population performance and reduced tree mortality. Averaged across the IAP region, precipitation is projected to increase. The timing and type of precipitation (i.e., rain rather than snow), however, will greatly influence tree defense against bark beetle attacks, and the response is likely to be nonlinear. Alterations in water availability that result in moderate water stress can reduce bark beetle performance, whereas more severe water stress can be favorable for bark beetles and result in increased bark beetle-caused tree mortality.

Evaluating future disturbance patterns of native bark beetles in the context of management will benefit from an understanding of changes in future patterns relative to current and historical patterns. Climate change may result in a shift in the severity, location, and particular species of bark beetle responsible for tree mortality. A mechanistic understanding of the influence of temperature on important bark beetle life history traits, as is available for mountain pine beetle, will be required to predict population success in future climates. Moreover, climate has direct effects on both the host tree and the beetle, and models that integrate our understanding of the influence of climate on host trees and beetle populations are needed.

Defoliators

Introduction

Tree folivores are found in many insect orders, with most of the important defoliating insects in western North America occurring in a variety of Lepidoptera families (butterflies and moths); Hymenoptera, particularly Diprionidae (sawflies); and Hemiptera (aphids and scales). The most important native insect defoliators in the IAP region are western spruce budworm (*Choristoneura occidentalis* [Lepidoptera: Tortricidae]), Douglas-fir tussock moth (*Orgyia pseudotsugata* [Lepidoptera: Erebidae]), and pine butterfly (*Neophasia menapia* [Lepidoptera: Pieridae]) (table 8.5). The biology, population dynamics, and outbreak regimes of defoliating insects vary considerably because of this taxonomical diversity.

The Ecological Role of Native Defoliator Disturbances

Western Spruce Budworm

Western spruce budworm defoliation affects cone production, understory regeneration, and tree growth and survival. Effects on stand structure include reducing shade-tolerant host abundance, lowering stand densities, increasing mean tree diameter, and creating more open stands with a greater prevalence of nonhost and more fire-adapted tree species, particularly pine (Carlson et al. 1983; Fellin et al. 1983; Ferguson 1985; Johnson and Denton 1975). Budworm defoliation on large trees increases vulnerability to bark beetles, particularly Douglas-fir beetle, which may increase outbreak likelihood of that insect (Lessard and Schmid 1990; Negrón 1998; Schmid and Mata 1996).

Tree-ring studies indicate that western spruce budworm has coexisted with and developed outbreaks in host forests for centuries (Lynch 2012). Historically, western spruce budworm defoliation and more frequent wildfire resulted in lower stand densities, less susceptibility to western spruce budworm, and greater landscape patchiness. However, fire exclusion favors increased host species abundance and multistoried stands. Fire exclusion has resulted in extensive landscapes of suitable host type throughout the IAP region, and impacts associated with prolonged defoliation on larger landscapes may be more severe (Hadley and Veblen 1993; Johnson and Denton 1975; Swetnam and Lynch 1989, 1993).

Douglas-Fir Tussock Moth

Douglas-fir tussock moth contributes to structuring forest communities and to the stability of forest systems through its effects on tree growth and survival, species composition, forest heterogeneity, and succession (Mason and Wickman 1991; Wickman et al. 1973). After outbreaks, understory vegetation and plant forage biomass increase considerably, and shade-tolerant herbaceous species decline (Klock and Wickman 1978).

Tussock moth outbreaks may cause an increase in bark beetle activity, similar to drought, blowdown, and avalanches. Bark beetle- and tussock moth-related mortality affect different tree size classes, and thus dissimilarly affect post-outbreak stand structure (Negrón et al. 2014). Douglas-fir tussock moth outbreaks can completely defoliate host trees in 1 to 3 years and cause subsequent tree mortality by Douglas-fir beetle and fir engraver attacks. Severe defoliation may significantly suppress tree growth for up to 4 years after an outbreak (Mason et al. 1997). Surviving tree growth and recruitment often increase following an outbreak (Klock and Wickman 1978; Wickman et al. 1973, 1986).

Pine Butterfly

Tree survival is generally high during severe pine butterfly outbreaks (Hopkins 1907; Scott 2012) unless western pine beetle activity increases significantly, killing stressed trees (Evenden 1936, 1940; Helzner and Thier 1993; Hopkins 1907; Scott 2012; Thier 1985). Pine butterfly prefers old foliage and begins feeding at the time of bud break (Evenden 1926, 1936). Although feeding has a severe impact on tree growth (Cole 1966; Dewey et al. 1973; Evenden 1936; Helzner and Thier 1993), production of new foliage usually enables trees to take up nutrients and survive. Pine butterfly may affect wildlife populations. For example, an absence of songbirds and bats has been noted during pine butterfly outbreaks (Scott 2010, 2012; Stretch 1882), although information about explanatory factors and seasonality is lacking.

Population Dynamics of Defoliators

Abundance, condition, and distribution of host foliage in the forest canopy as buds, new foliage, and old foliage of different tree species, as well as complexity of stand structure, influence defoliator regimes. Climate and host

Table 8.5—Major defoliating insect species affecting trees in the IAP region. Inciting factors for outbreaks, including stand susceptibility, are listed with supporting literature.

Defoliator	Subregions affected[a]	Host trees	Factors affecting outbreaks	Supporting literature
Western spruce budworm (*Choristoneura occidentalis*)	All	Douglas-fir, grand fir, subalpine fir, white fir, western larch, Engelmann spruce	Climatic suitability Susceptible host availability Forest structure: multi-storied and high density stands Altered fire regimes (fire intolerant and shade tolerant host species) Parasites and predators	Beckwith and Burnell 1982; Campbell 1993; Carlson et al. 1983; Chen and others 2003; Hadley and Veblen 1993; Johnson and Denton 1975; Fellin and Dewey 1986; Fellin et al. 1983; Maclauchlan and Brooks 2009; Morris and Mott 1963; Mott 1963; Nealis 2008; Shepherd 1992; Volney 1985
Douglas-fir tussock moth (*Orygia pseudotsugata*)	1, 3, 5	Douglas-fir, grand fir, white fir, and subalpine fir	Nuclear polyhedrosis virus (NPV) Other mortality agents Significant variability in triggers Host availability (regional variances) Outbreak control largely unknown Climatic suitability unknown Fire exclusion Forest structure: older (>50 years), multi-storied, dense stands Warm, dry sites Increased susceptibility to bark beetles (see fir engraver beetle and Douglas-fir beetle)	Alfaro et al. 1987; Beckwith 1978; Campbell 1978; Coleman et al. 2014; Dahlsten et al. 1977; Hansen 1996; Huber and Hughes 1984; Ignoffo 1992; Jaques 1985; Killick and Warden 1991; Mason 1976, 1996; Mason and Luck 1978; Mason and Wickman 1991; Mason et al. 1997; Moscardi 1999; Negrón et al. 2014; Shepherd et al. 1988; Stoszek et al. 1981; Thompson and Scott 1979; Thompson et al. 1981; Vezina and Peterman 1985; Weatherby et al. 1992, 1997; Wickman 1963, 1978a,b; Wickman et al. 1973, 1981, 1986; Wright 1978
Pine butterfly (*Neophasia menapia*)	1, 3, 4, 5	Ponderosa pine	Host availability Logging history and fire exclusion Parasitic and predatory controls on pine butterfly populations (i.e., Theronia atalantae) Climatic suitability unknown Abiotic and biotic controls on *T. atalantae* See western pine beetle in table 8.4	Agee 2002; Aldrich 1912; Campbell 1963; Cole 1956; DeMarco 2014; Dewey and Ciesla 1972; Dewey et al. 1973; Di Giovanni et al. 2015; Ehle and Baker 2003; Evenden 1936, 1940; Helzner and Their 1993; Hopkins 1907; Huntzinger 2003; Kerns and Westlind 2013; Lazarus 2012; Orr 1954; Scott 2010, 2012; Stretch 1882; Thier 1985; Weaver 1961; Webb 1906

[a] Subregions include: (1) Middle Rockies, (2) Southern Greater Yellowstone, (3) Uintas and Wasatch Front, (4) Plateaus, (5) Great Basin and Semi Desert, (6) Intermountain Semi Desert

abundance are important factors controlling defoliator regimes. Climate affects host susceptibility (indirect effect) and insect distributions (indirect and direct effects), as well as seasonal and annual variation in insect abundance (indirect and direct effects).

Defoliator Outbreaks in the Intermountain Adaptation Partnership Region

Both western spruce budworm and Douglas-fir tussock moth inhabit Douglas-fir, true fir, and mixed conifer stands in the IAP region. The areas with historical defoliation generally reflect the known distribution of western spruce budworm (Harvey 1985; Lumley and

Sperling 2011) and Douglas-fir tussock moth (Beckwith 1978; Shepherd et al. 1988), although western spruce budworm is known to occur in eastern Nevada (Lumley and Sperling 2011). Ranges and host species preferences for western spruce budworm and Douglas-fir tussock moth populations overlap considerably and are regulated by complex factors that are likely to respond differently to climate change.

Western Spruce Budworm

Extensive western spruce budworm outbreaks occur episodically (Fellin et al. 1983; Lynch 2012), and the IAP region is in the early stages of the third extensive outbreak since the 1920s (Johnson and Denton 1975) (fig. 8.20).

Douglas-Fir Tussock Moth

In the IAP region, Douglas-fir tussock moth outbreaks occur at the landscape scale in the Middle Rockies subregion. They are smaller but more frequent in the Great Basin. The insect has a more restricted range than its hosts (Beckwith 1978; Mason 1996; Mason and Wickman 1991). The early 1990s outbreak in the Middle Rockies was more extensive and severe than previously recorded outbreaks (Weatherby et al. 1997) (fig. 8.21).

Outbreaks occur regularly in many areas, including the Great Basin (fig. 8.21), and are often synchronous across distant portions of western North America (Mason and Luck 1978; Shepherd et al. 1988; Wickman et al. 1981). Outbreaks develop from increasing local populations over a 1- to 3-year period before reaching outbreak status (Daterman et al. 2004; Shepherd et al. 1985). In most areas, outbreaks occur with a 7- to 10-year cycle. Outbreaks usually last 2 to 4 years and collapse abruptly. Between outbreaks, tussock moth populations are often at undetectable levels (Daterman et al. 2004; Mason 1974; Mason and Luck 1978; Shepherd et al. 1988).

Pine Butterfly

Pine butterfly is the most damaging defoliator of ponderosa pine (Furniss and Carolin 1977). Outbreaks vary

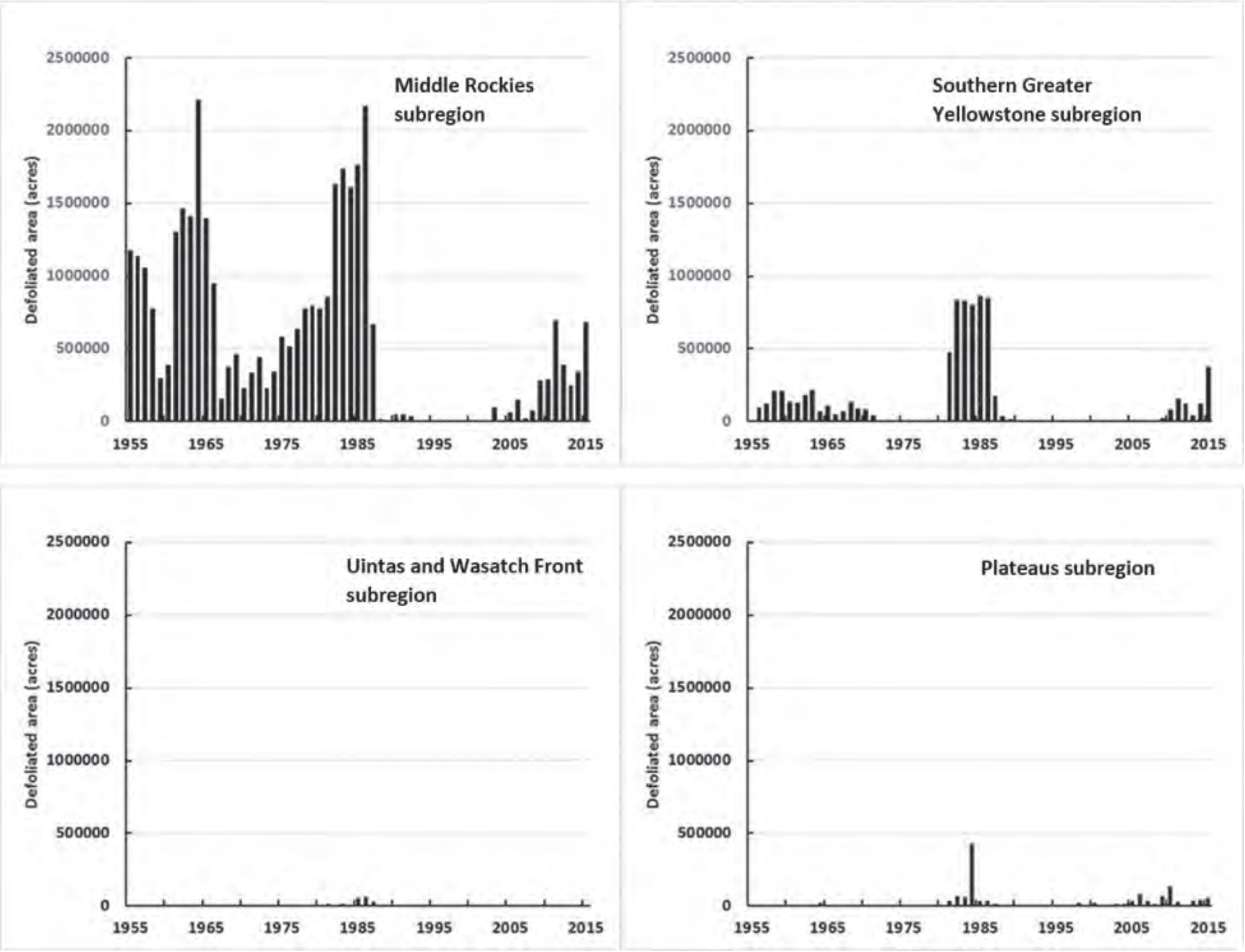


Figure 8.20—Area defoliated by western spruce budworm in four subregions of the Intermountain Adaptation Partnership region, 1955–2015. Johnson and Denton (1975) also documented an extensive but unquantified outbreak in the 1920s in the Greater Yellowstone Area.

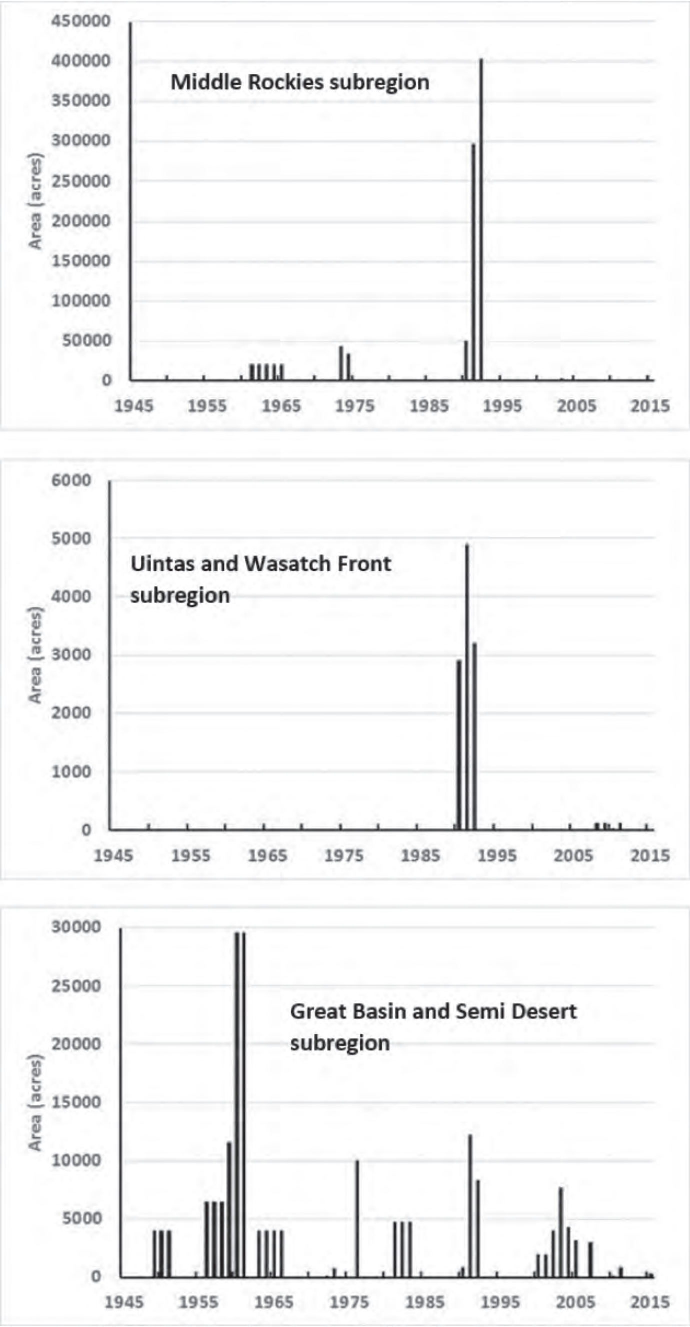


Figure 8.21—Area defoliated by Douglas-fir tussock moth in three subregions of the Intermountain Adaptation Partnership region, 1945–2015. A 500-acre area of Fishlake National Forest in south-central Utah was also defoliated in 1999–2000.

considerably in size and intensity, and can be severe in the Middle Rockies subregion (Cole 1956; Evenden 1940; Orr 1954; Scott 2010, 2012). Though outbreaks have serious ecological consequences, pine butterfly ecology is poorly understood.

Non-outbreak cycles often go unnoticed as the insect prefers the tops of large trees, which are poorly visible from the ground. Light and moderate damage is difficult to detect during aerial surveys because pine butterfly feeds on new foliage only when population densities are high (Helzner and Thier 1993; Orr 1954; Stretch 1882) and is a neat feeder (Evenden 1926; Scott 2012; Stretch 1882). Thus, dead and dying foliage is inconspicuous and damage is obscured by new foliage (Helzner and Thier 1993; Lazarus 2012; Orr 1954; Scott 2012).

Potential Future Effects of Climate Change on Defoliator Outbreaks

Temperature effects on insect biology and population dynamics have not been quantified in natural systems for most defoliating species, though laboratory and field studies provide some information. The seasonality and effects of extreme events are often known to some degree, and general projections can be made for some species about the potential effects of climate change.

Western Spruce Budworm

Climate change will have direct and indirect effects on western spruce budworm outbreaks. Temperature affects budworm developmental rates, dispersion, feeding, fecundity, and survival (Carlson et al. 1983; Kemp et al. 1985; Volney et al. 1983), but these relationships are not well understood. With warming, higher-elevation habitats are likely to support more frequent or severe outbreaks than they have in the past. However, more frequent late-spring frosts or more variability in frost timing would diminish outbreak frequency, extent, and severity by reducing populations. Severe defoliation can trigger Douglas-fir beetle and spruce beetle outbreaks in Douglas-fir and spruce-fir forests, respectively (Johnson and Denton 1975; McGregor et al. 1983; O’Connor et al. 2015). Changing temperature and precipitation regimes will influence the occurrence and spatial distribution of host species, thereby affecting western spruce budworm abundance. Combined effects of climate change and resource management activities, particularly those associated with fire management, are likely to determine forest condition and susceptibility to western spruce budworm.

Weather conditions that negatively affect western spruce budworm population dynamics include warm fall or winter temperatures, which result in (1) overwintering larvae metabolizing at a higher rate and depleting energy reserves (Carlson et al. 1983; Régnière et al. 2012; Thomson 1979; Thomson et al. 1984); (2) frost after budworm emergence from overwintering hibernacula (Carlson et al. 1983; Thomson 1979); (3) rain during larval dispersion or adult flight (Beckwith and Burnell 1982); and (4) unusually cool spring and early summer conditions that slow budworm development (Carlson et al. 1983; Thomson 1979). Factors that slow budworm development increase larval exposure to parasites and predators and may disrupt synchrony between larvae and buds or expanding needles. However, adverse weather events may only temporarily suppress budworm populations if forest stand conditions and subsequent weather still favor budworm dynamics (Fellin and Dewey 1986; Johnson and Denton 1975).

Weather affects budworm and host biological processes that govern budworm population rates of change (Nealis 2008; Volney 1985), such as (1) the degree of synchrony between springtime emergence and host foliage development; (2) energy reserves available for dispersal and establishment at feeding sites after spring emergence; (3) the quality, quantity, and spatial distribution of foliage; (4) long-distance dispersion of adults; and (5) the lack of adverse weather events during dispersal and development. Budworms emerging from overwintering sites may more often encounter host buds and needles in suitable phenological condition in stands composed of several hosts (Volney et al. 1983). The effect of climate change on the complexities of budworm phenology are difficult to predict but will play a significant role in future population dynamics.

Budworm populations are likely to persist during years or decades of less suitable host phenology and then develop outbreaks when host foliage phenology is favorable. Compared to other *Choristoneura* species in western North America, western spruce budworm is associated with relatively warm interior and lower latitude forests (relative to the boreal zone) (Fellin et al. 1983; Harvey 1985; Kemp et al. 1985; Lumley and Sperling 2011; Stehr 1967). It incurs outbreaks as far south as southern New Mexico, and is well adapted to a wide variety of montane situations, including climates warmer than historical climates in the Middle Rockies. Many species of *Choristoneura* in western North America hybridize readily (Harvey 1985; Lumley and Sperling 2011; Nealis 2005; Volney 1989), so new western spruce budworm strains could develop rapidly in new climatic regimes and host species mixtures (Lumley and Sperling 2011; Volney and Fleming 2007).

Several factors make it unlikely that western spruce budworm will be lost from IAP region montane forests, excepting possible retraction at lower elevations and latitudes through the effects of warm winters on larval metabolism and energy reserves. Western spruce budworm outbreaks occur on many conifer species, and the species inhabits forests that vary widely in moisture and temperature regime. Populations encounter a wide range of foliage phenological patterns, so new host species mixtures and altered spring phenological patterns are likely to still be suitable to some extent. Furthermore, at stand and regional levels, western spruce budworm populations can exhibit considerable variation in the heating required for springtime emergence in both single- and multi-species stands (Volney et al. 1983). Although synchrony with bud development may be important for outbreak development, sufficient individuals emerge over a long enough time period to ensure that populations persist when synchrony is poor (Nealis 2012; Reichenbach and Stairs 1984; Volney et al. 1983).

Douglas-Fir Tussock Moth

The influence of climate in regulating Douglas-fir tussock moth populations is unknown and uncertain (Mason 1976, 1996; Mason and Wickman 1991; Shepherd et al. 1988; Vezina and Peterman 1985; Weatherby et al. 1997; Wickman et al. 1973). The role of climate in determining the distribution, frequency, extent, and severity of Douglas-fir tussock moth outbreaks is likely to be indirect. Douglas-fir tussock moth does not attain outbreak status over its entire range and is absent over large portions of host ranges (Beckwith 1978; Daterman et al. 1977; Mason and Luck 1978). Where present, cyclic populations are primarily regulated by nuclear polyhedrosis virus, a viral entomopathogen (Shepherd et al. 1988; Wickman et al. 1973).

The diversity of acceptable and preferred hosts, as well as an evolutionary history of distant races adapting to various host species, indicates that Douglas-fir tussock moth is adaptable to the changes in tree species composition and distribution that are likely to occur with climate change. Outbreaks in mixed-species stands can alter tree species composition, but fire exclusion practices favor increased host species abundance (Wickman et al. 1986). Mortality may be greater with warming temperatures because of the association between Douglas-fir tussock moth outbreaks and warm dry sites (Mason and Wickman 1991), and the combined effects of drought and defoliation on bark beetle activity. Effects of resource management on fire regimes, species composition, stand density, and canopy structure are likely to be stronger determinants of Douglas-fir tussock moth outbreak regimes than climate.

Pine Butterfly

The biology, ecology, and factors regulating populations of pine butterfly are not sufficiently understood to predict its response to a warmer climate. Indications regarding whether there are climatic limitations to pine butterfly outbreak dynamics are meager and contradictory. Outbreaks are more frequent and severe on ponderosa pine in the IAP region (Fletcher 1905; Furniss and Carolin 1977; Hopkins 1907; Ross 1963; Scott 2012). However, outbreaks can occur in relatively cool, mesic climates throughout its range, on a variety of acceptable hosts (virtually all western pine species plus Douglas-fir) that occupy a wide variety of thermal habitats (Hopkins 1907; Stretch 1882). Pine butterfly outbreaks also occur in semiarid pinyon-juniper forests in Colorado (Scott 2010; Young 1986). Thus, pine butterfly is not limited to a narrow thermal zone.

Pine butterfly exhibits some flexibility in its seasonal life history, indicating that a warmer climate may not directly diminish future outbreak frequency or severity. Egg eclosion and adult emergence vary with elevation, aspect, and weather (Evenden 1926, 1936; Scott 2012), and in some cases there may be two emergence periods (Bell 2012; Shellworth 1922). In some places, sympatric allochronic populations produce two broods, where each brood is produced from a univoltine life cycle but they emerge at different times, and interbreeding between the two broods is limited (Bell 2012). It is unknown why pine butterfly outbreaks occur in some portions of the host type but not others. The implications of variability in seasonal life history for population dynamics under a warmer climate are unknown, because of the lack of information about the factors regulating pine butterfly outbreak dynamics. However, pine butterfly outbreaks combined with drought can increase western pine beetle populations on susceptible landscapes. Thus, under a warming climate on susceptible landscapes, more frequent or severe drought periods, combined with tree stress caused by significant or repeated defoliation events, are likely to increase western pine beetle populations and their impacts.

Invasive Insects

Overview

Influences of climate change on invasive insects are likely to depend on host abundance and shifts in hosts. Most nonnative invasive insect species in the Intermountain West have not fully populated their potential range. Additionally, invasive species impacts on ecosystems may differ with changing climates. Examples of invasive insect invasions currently affecting National Forests of the IAP region may provide some insight into ecosystem changes that may occur under climate change and when introductions of other invasive insects occur. Adaptive management will be key as more is learned about introduced species.

Effects of Climate Change on Invasive Insect Species

Warmer temperatures can accelerate the development rates of invasive insects, as for native insect species, and increase or decrease overwintering brood survival (see section below). Increased brood production may hasten range expansion once established. For example, balsam woolly adelgid (*Adelges piceae*), an invasive insect, has been affecting eastern North American fir (*Abies* spp.) since 1900 and western coastal fir since the 1920s. It was discovered in northern Idaho in 1983 (Livingston et al. 2000). During the early 2000s, balsam woolly adelgid expanded its range across the Middle Rockies and into the Southern Greater Yellowstone subregion, and in 2017, it was found in Utah. It is expected to continue to expand its range south and east, causing widespread mortality of true fir (Hrinkevich et al. 2016; Lowrey 2015a).

Winter temperature is likely to be an important factor determining the future distribution of balsam woolly adelgid (Greenbank 1970). Quiring et al. (2008) found that a mean January temperature of 12 °F explained presence or absence of balsam woolly adelgid infestation of balsam fir (*A. balsamea*) in New Brunswick. Surveys suggest a similar threshold in lower latitudes for subalpine fir in the Middle Rockies subregion (Lowrey 2015a). At present, some areas of the IAP region reach the cold threshold affecting balsam woolly adelgid populations, thus reducing impacts and subsequent mortality in those locations (Lowrey 2015a). As mean winter temperatures increase, however, these formerly unsuitable sites may favor balsam woolly adelgid survival and establishment (Lowrey 2015b). As a result of a warming climate, balsam woolly adelgid may invade fir stands at all elevations throughout Utah, Colorado, and Wyoming in the coming decades, potentially affecting species viability and ecosystem function.

Larch casebearer (*Coleophora laricella*) was first reported in mixed conifer forests of the Middle Rockies in 1977 (Valcarce 1978). Host abundance, climate suitability, and lack of natural enemies resulted in successful establishment and range expansion of the larch casebearer into the IAP region. Larch casebearer parasitoids were introduced into southern Idaho in 1978 as a biological control program release (Valcarce 1978). Larch casebearer populations are often kept at tolerable levels with introduced biological control agents (parasitic wasps), native predators and parasitoids, and adverse weather conditions (Miller-Pierce et al. 2015). Changing temperature and precipitation regimes could influence range expansion and impacts, with host shifts and parasitoid synchrony affecting population abundance and effectiveness.

In 2006, invasive poplar scale (*Diaspidiotus gigas*) was found on *Populus* species in Sun Valley, Idaho, and in Colorado (Vail, Aspen) (Progar et al. 2011). Infestations are associated with urban aspen forests, but expansion into forest environments and on other poplar species is probable. Host abundance and quality, conducive weather conditions, and native predators affect population viability (Progar et al. 2014). Recently identified nonnative parasitoid wasps could be used in future suppression programs if populations become damaging to nonurban aspen.

Spruce aphid (*Elatobium abietinum*) is a non-indigenous species that has a high likelihood of incurring outbreak status in the IAP region in a warmer climate. This insect has already altered natural disturbance regimes in southwestern spruce-fir forests (Lynch 2009; O’Connor et al. 2015). Spruce aphid was introduced to Pacific Northwestern coastal forests in the early 1900s, and to Southwestern montane forests in the 1970s (Lynch 2014). Temperature regimes in Intermountain high-elevation forests are comparable to those in areas where spruce aphid and the original host are native (Alexander and Shepperd 1990; Mäkinen et al. 2003; Vygodskaya et al. 1995; Weed et al. 2015b). The primary difference between Southwestern and Intermountain climate regimes at high elevations is in precipitation, not temperature (Alexander and Shepperd 1990). Therefore, ecosystems inhabited by Engelmann and blue spruce (*Picea pungens*) in the IAP region will probably support spruce aphid populations with only modest warming in the coming decades.

Numerous other potentially invasive forest insects are in various phases of introduction, establishment, and integration in the United States (Klepzig et al. 2010). Species in several insect families such as wood-boring beetles (Coleoptera: Cerambycidae and Buprestidae), bark beetles and ambrosia beetles (Coleoptera: Curculionidae), and woodwasps (Hymenoptera: Sircidae) have been identified as potentially invasive to North American forests by the U.S. Department of Agriculture Animal Plant Health Inspection

Service, Plant Protection and Quarantine and State regulatory agencies (Hitchcox 2015).

Early detection rapid response is a tactic employed to identify initial introductions and to assist in developing strategies to address them. In 1989, multiple life stages of European gypsy moth (*Lymantria dispar dispar*) were found in Utah. A successful eradication program was conducted with technical and financial assistance provided by the USFS Intermountain Region, Forest Health Protection program. Currently, an annual interagency trapping program monitors for gypsy moth introductions within the States in the IAP region. Isolated single catches of male moths have occurred occasionally, but established populations have not been found. Unlike the European gypsy moth, Asian gypsy moth (*L. dispar asiatica*, *L. dispar japonica*, *L. albescens*, *L. umbrosa*, and *L. postalba*) females are capable of flight, affecting dispersal and subsequent rate of spread if established (Reineke and Zebitz 1998). The Asian gypsy moths have a much larger host range, exceeding 250 species, that includes crops, shrubs, and trees, both coniferous and deciduous. In 2015, Asian gypsy moth introductions occurred in Washington and Oregon, arriving on ships and cargo from Russia and Japan. Global trade, favorable climate, and a large host range heighten the need to monitor for this invasive insect in the IAP region.

Changing climate regimes have the potential to alter insect vector distributions and associated wildlife diseases, with potentially severe consequences for affected species and ecosystems, but those dynamics are poorly understood for the Intermountain West (Runyon et al. 2012). For example, increased temperatures and altered precipitation patterns can increase the range and abundance of vector species (e.g., mosquitoes and ticks) and thus affect the frequency and severity of vectorborne disease outbreaks. Changes in precipitation are likely to affect migrations, water availability, and congregation patterns of wildlife, increasing exposure to disease by affecting host susceptibility to infection (Lafferty 2009; Rosenthal 2009). However, climate change could limit the spread of some diseases by creating environments that are not conducive to the pathogens or their insect vectors (Runyon et al. 2012).

The potential for new invasions will continue because of global trade. Regulatory measures are in place to reduce the risk of invasive introductions through agency regulations, contract requirements, overseas monitoring, inspection of ships and cargo, and public outreach. Although these strategies reduce risk, they do not eliminate it. Koch et al. (2011) estimated that approximately two nonnative forest insect species will become established in the United States annually, with one identified as a significant forest pest every 5 to 6 years. Determining which introduced insect will become a serious pest can be difficult, and some may not appear to cause significant damage until well after establishing. The added influence of changing temperature and precipitation regimes will affect any introduced species, their potential hosts, and their impacts on agricultural, forest, range, and urban ecosystems.

Diseases of Forest Communities

Overview

Forest diseases are found in all forest ecosystems of the IAP region but the overall impacts of forest diseases on various resources are difficult to quantify. Forest diseases tend to be more cryptic and chronic in their effects than other disturbance agents, and thus estimating their occurrence and abundance is difficult. Native pathogens cause most forest diseases, and as such function as part of their ecosystems.

Climate can affect the impact of forest diseases through impacts on the environment, the disease-causing organisms, and their hosts. This section focuses on the disease-causing agents in the IAP region that are known to have significant effects on ecosystems and ecosystem services, and for which there is some information on their response to climate.

Dwarf Mistletoe

Dwarf mistletoes (*Arceuthobium* spp.) are a group of parasitic seed plants that are widespread across the IAP region (table 8.6). The IAP region covers a broad range of forest ecosystems, and consequently is home to several dwarf mistletoes, including: *A. abietinum* on true firs, *A. americanum* on lodgepole pine; *A. campylopodum* on ponderosa and Jeffrey pine (*Pinus jeffreyi*) in the northern and western parts of the region; *A. cyanocarpum* on limber pine (*Pinus flexilis*); *A. divaricatum* on pinyon pine; *A. douglasii* on Douglas-fir; *A. laricis* on western larch (*Larix laricina*); and *A. vaginatum* ssp. *cryptopodum* on ponderosa pine in the southern part of Utah. Mistletoes can occasionally infest other tree species when they are growing interspersed with infected primary hosts.

Mistletoes primarily cause reduced tree growth and forest structural changes, but in some cases also cause tree mortality. Mortality rates are higher if other stresses are present, such as drought and high tree densities (Schultz and Allison 1982; Schultz and Kliejunas 1982), or insect agents such as the California flathead borer (*Phaenops californica*) (Kliejunas 2011). Mistletoes may play a significant role in tree mortality as trees become stressed by drought and other climate-related stressors (Kliejunas 2011).

The distribution and abundance of dwarf mistletoes are closely related to fire regime in many IAP region forest types (Geils et al. 2002). Frequent, low-intensity fire can maintain low levels of mistletoe infestation in forests. Stand-replacing fires tend to eliminate dwarf mistletoes. Management history also plays an important role, and any management practices that promote interfaces between infected overstory trees and susceptible regeneration promote the spread and intensification of dwarf mistletoes.

Table 8.6—Forest Inventory and Analysis (FIA) plots with dwarf mistletoe present in the USFS Intermountain Region. FIA plot data may not adequately capture the presence of this pathogen where its distribution is clumpy.

Forest type	FIA plots with dwarf mistletoe
	Percent
California mixed conifer	18.0
Douglas-fir	30.8
Engelmann spruce	4.7
Engelmann spruce-subalpine fir	16.2
Limber pine	12.7
Lodgepole pine	33.6
Pinyon-juniper woodland	13.0
Ponderosa pine	15.3
White fir	10.3
Whitebark pine	10.0
Other forest types	1.9
All forest types	15.1

Root Disease

Caused by various species of fungi, root disease is a major cause of tree growth reduction and mortality in the IAP region, although most infections are relatively small (McDonald et al. 1987). Root diseases often occur with bark beetle activity (Tkacz and Schmitz 1986). They typically affect canopy closure by creating small gaps and can be persistent on a site, affecting multiple generations of trees. Mortality from root disease can cause a transition to species more tolerant of root disease, or maintain stands of more susceptible species in early-seral stages (Byler and Hagle 2000). Root disease can alter ecosystem services by degrading landscape aesthetics and limiting accessibility of recreational resources.

The three most significant native root diseases in the region are *Armillaria* root disease (*A. oystoyea*), the tomentosus root disease (*Inonotus tomentosus*), and annosum disease (*Heterobasidium occidentale, H. irregulare*). In the southern portion of the IAP region, *Armillaria* root disease tends to occur on cool-dry to cold-dry fir sites, as well as some high-elevation lodgepole pine-dominated sites with subalpine fir or adjacent to subalpine fir sites (McDonald 1998; Tkacz and Baker 1991). In the rest of the IAP region, the disease occurs on wetter sites, being most common in cool to cold locations.

Tomentosus root disease is locally important in the region, primarily affecting spruce species. The disease can cause growth reduction, butt cull, windthrow, and tree mortality. It can lead to creation of small to large gaps in forest canopies and to regeneration problems in isolated locations (Guyon 1997; Tkacz and Baker 1991).

Annosus root disease can affect forests at broader spatial scales. It is caused by *H. occidentale* on fir and Douglas-fir. This root disease is ubiquitous in fir forests in the IAP region, and plays an important role in the subalpine fir mortality that has occurred over hundreds of thousands of acres over the last two decades.

White Pine Blister Rust

White pine blister rust (*Cronartium ribicola*) is a nonnative fungus that was introduced to western North America from Europe around 1910 (Bingham 1983; Tomback and Achuff 2010). The white pine blister rust fungus infects only five-needle pine species. All nine North American white pine species are susceptible in vitro, but Great Basin bristlecone pine (*Pinus longaeva*) remains uninfected in the field. The life cycle of white pine blister rust requires two hosts, with two spore-producing stages on white pine and three separate spore-producing stages, primarily on *Ribes* species, and rarely on *Pedicularis* and *Castilleja* species (Zambino 2010). Pine infection begins when spores produced on *Ribes* leaves in late summer are wind dispersed to nearby pines. The spores germinate on pine needles, and fungal hyphae grow through the stomata into the cell tissues, needles, and stems (Patton and Johnson 1970).

White pine blister rust-caused tree mortality greatly affects stand structure and species composition, but the most serious impact of white pine blister rust are its long-term effects on white pine regeneration capacity. This may be a critical factor if five-needle pines undergo climatic migration. White pine blister rust causes direct mortality of rust-susceptible seedlings and saplings and the loss of cone and seed production following branch dieback and top kill. This type of impact has been best documented in the IAP region on whitebark pine (*Pinus albicaulis*) (McKinney and Tomback 2007).

White pine blister rust is largely thought to be a disease of cool to cold-moist sites, where sporulation and infection are at their highest levels (Van Arsdel et al. 2006). Relatively warm-dry (lower elevations) or cold-dry (upper elevations) climatic conditions may be the reason that white pine blister rust has not proliferated as widely or been as damaging in the IAP region as other, moister regions (Smith and Hoffman 2000). Another reason may be the relative isolation of the region’s five-needle pine stands; most occur as either scattered components in forest dominated by other tree species or are limited to high elevations (Charlet 1996; Richardson 2000). Many host populations are also typically isolated from other populations of rust-infected pines (Smith and Hoffman 2000).

All native white pine populations show some heritable resistance to white pine blister rust, but the frequency of resistance is low and variable (Zambino and McDonald 2004). Natural and assisted selection can increase resistance, but only if resistant trees are also adapted to other aspects of their environment. Under moderate drought conditions, blister rust-resistant limber pine have greater cold tolerance and lower stomatal conductivity than susceptible trees, indicating that resistant limber pine may be better adapted than susceptible trees to a drier climate (Vogan and Schoettle 2015).

Climate-mediated changes in white pine blister rust host regeneration dynamics could restrict or expand host ranges (Helfer 2014). If mosaics of *Ribes* host populations shift into new higher-elevation areas, driven by drought at lower elevations, white pine blister rust may spread into areas where it has not yet occurred and thus alter white pine blister rust range. It is unlikely that any direct responses of the tree to future climates, such as increased growth, will enhance or degrade the ability of the host to ward off infections. Density of pines and *Ribes* could decrease and sun exposure increase if water limitation becomes severe (Allen et al. 2010). More open stands could decrease spore production on many *Ribes* species, because infections and spore production are typically much lower on *Ribes* plants grown in full sun than plants of the same species grown in shade (Zambino 2010).

Foliar Disease

Needle diseases have historically been of limited significance in the IAP region. Needle casts, rusts, and needle blights in pines, Douglas-fir, and fir usually cause loss of needles in the year following a season favorable for infection. Periodic outbreaks can cause severe damage in local areas (Lockman and Hartless 2008), and several wide-ranging outbreaks have been detected in the IAP and neighboring regions in the last 10 years (Worrall et al. 2008). Severe infection years occur only occasionally, and effects are mostly limited to crown thinning and loss of lower branches, with some mortality of young trees. Needle diseases are favored by long, mild, and damp springs, which may be more common with climate change. Their occurrence at epidemic levels depends on favorable weather conditions and presence of an adequate host population. The significance of recent defoliation events and whether they are increasing in frequency or intensity are yet to be determined.

Abiotic Disease

Most abiotic diseases result from the effects of adverse environmental factors (e.g., drought, freeze injury, wind damage, and nutrient deficiency) on tree physiology or structure. Abiotic diseases can affect trees directly or interact with biotic agents, including pathogens and insects. A number of abiotic and environmental factors can affect foliage, individual branches, or entire trees, tree physiology, and overall tree vigor. The most significant abiotic damage is tree mortality.

Forests in the IAP region periodically suffer damage from weather extremes, such as high temperature and drought. Factors such as air pollutants and nutrient extremes occur infrequently or locally. Drought injury, an abiotic factor that can cause disease through loss of foliage and tree mortality, can initiate a decline syndrome by predisposing trees with stressed crowns and roots and low energy reserves to infection by less aggressive biotic agents, such as canker fungi and secondary beetles.

Canker Disease

Canker disease affects tree branches and boles, where the damage is caused by breakage at the site of the cankers, or by death of branches and boles beyond girdling cankers. Many canker diseases are commonly called facultative parasites (Schoeneweiss 1975), which refers to the tendency of these diseases to be facilitated by environmental stress on the host. Some important canker diseases in the IAP region are the complex of several cankers found on aspen, several cankers found on alder and willows in riparian areas, and a few cankers on conifers, such as Atropellis canker of pines and Valsa cankers on fir and spruce. Cankers in aspen are caused by several fungi, including *Hypoxylon mammatum*, *Encoelia pruinosa*, *Ceratocystis fimbriata*, *Cryptosphaeria populina*, and *Valsa sordia* (anamorph: *Cytospora chrysosperma*). Fungi that cause cankers of alder or willow in riparian areas include *Valsa melanodiscus* (anamorph: *Cytospora umbrina*) on alder, and *V. sordida* on willow.

Declines and Complexes

There are several definitions of forest decline phenomena in the literature. Houston (1981) emphasized that decline can result from stress alone, but that in natural forests, "secondary-action organisms" were necessary to complete the decline, differentiating decline from natural attrition. The most commonly accepted modern definition of a decline was postulated by Manion (1991), and involves a cycle containing predisposing, inciting, and contributing factors involved in a downward spiral of forest and tree health.

Aspen dieback and decline have been detected over the last decade across western North America (Fairweather et al. 2008; Frey et al. 2004; Guyon and Hoffman 2011; Worrall et al. 2008). Anderegg et al. (2012) have posited that the recent aspen mortality is caused by drought stress. Aspen mortality is also occurring under heavy browsing pressure by native and domesticated ungulates (Kay 1997). With aspen already stressed by drought and ungulate pressure, forest insects and diseases can play an important role in aspen dieback and decline; they can have a similar role in the dieback seen in riparian willow and alder (Kaczynski and Cooper 2013; Worrall 2009). While mortality caused by forest insects and diseases is part of fully functioning ecosystems, stands dying due to decline-type phenomena can alter not only the forest canopy structure, but the entire forest community, including understory shrubs and herbaceous plants (Anderegg et al. 2012).

Invasive Plants

Overview

An invasive species is a nonnative species whose introduction does or is likely to cause economic or environmental harm or harm to human health (NISC 2016). Human activity moves species from place to place both accidentally and deliberately and does so at rates that are without precedent in the last tens of millions of years (D'Antonio and Vitousek 1992). Invasive plants do not necessarily have higher growth rates, competitive ability, or fecundity than native plants; rather, the frequent absence of natural enemies in the new environment, and increased resource availability and altered disturbance regimes associated with human activities, increases the performance of invaders over that of natives (Daehler 2003; MacDougall and Turkington 2005; Mack 1989).

A nonnative plant species must pass through a variety of environmental filters to survive in a new habitat (Theoharides and Dukes 2007). First, the nonnative plant species must travel across major geographic barriers to its new location (introduction/transport stage). Once in the new location, the nonnative plant species must survive and tolerate environmental conditions at the arrival site and then acquire critical resources while surviving interactions with the plants, animals, and pathogens already occupying the site (establishment stage). Finally, to become invasive, the nonnative plant species must spread, establishing populations in new sites across the landscape (spread stage). The progression from nonnative to invasive often involves a delay or lag phase, followed by a phase of rapid exponential increase that continues until the invasive species reaches the bounds of its new range and its population growth rate slackens (Cousens and Mortimer 1995; Mack 1985). This lag phase may simply be the result of the normal increase in size and distribution of a population. However, other mechanisms can keep newly introduced species at low levels for decades before they become invasive. These mechanisms include environmental change (both biotic and abiotic) after establishment and genetic changes to the founder populations that enable subsequent spread (Mooney and Cleland 2001). During the lag phase it can be difficult to distinguish nonnative plants that will ultimately not survive in the new range from future invaders (Cousens and Mortimer 1995).

Most invasions over the past several centuries have involved species transported directly or indirectly by humans (McKinney and Lockwood 1999). Invasive plants have attracted much attention because of their economic costs as weeds (Pimentel 2002) and because they may reduce native biodiversity (Daehler and Strong 1994; Wilcove et al. 1998), alter ecosystem functions (D'Antonio and Vitousek 1992; Vitousek 1990), change nutrient pools (Duda et al. 2003; Ehrenfeld 2003), and alter fire regimes (Brooks et al. 2004).

Climate change is expected to alter the distribution and spread of invasive plants, but in largely unknown ways. Climate change can fundamentally alter the behavior and spread of invasive species and the harm they cause, as well as the effectiveness of control methods; likewise, climate change may favor and convert nonnative species considered benign today into invasive plants tomorrow (Runyon et al. 2012). Although some aspects of global change, such as climate change, may be reversed by societal actions, this will not be possible for biotic exchange; the mixing of formerly separated biota and the extinctions these introductions may cause are essentially irreversible (Mooney and Cleland 2001). The Working Group on Invasive Species and Climate Change (WGISCC 2014: 1) summarizes the interaction of invasive species and climate change as follows:

> *Combining the threats of invasive species with those posed by climate change can magnify the intensity associated with both issues. Climate change may reduce the resilience of ecosystems to resist biological invasions, while biological invasions can similarly reduce the resiliency of ecosystems and economies to the impacts of climate change. Beyond that, the interactions among drivers of change become significantly more complex due to the interplay of diverse phenomena like severe climatic events, changing precipitation patterns, and coastal erosion exacerbated by invasive species.*

The History of Plant Invasion in the Intermountain Adaptation Partnership Region

The Intermountain West was intensively settled from 1870 to 1890. European settlers brought with them the cereal, legumes, and forage crops of Western Europe, medicinal and ornamental plants that they valued, and other Western European plants which "hitched a ride" on livestock or as crop seed contaminants. Vast areas in the Intermountain West were converted to crops, and tracts of land unsuitable for crops were rapidly converted to pasture. Livestock destroyed much of the native plant communities in areas not plowed. Nonnative plants became more diverse and conspicuous as settlement increased. Of the many nonnative plants introduced in the West, a small percentage became invasive and began to spread. The speed and extent of regional invasion was facilitated by a railroad system established simultaneously with the wave of human immigrants in the late 19th century. As a result of this convergence of dispersal factors, some invasive plants filled their new ranges in as little as 40 years (Mack 1989).

Where undisturbed, the temperate grasslands of the Intermountain West are dominated solely by bunch (caespitose) grasses, including bluebunch wheatgrass (*Pseudoroegneria spicata*), Idaho fescue (*Festuca idahoensis*), needle-and-thread grass (*Hesperostipa comata*), and Sandberg bluegrass (*Poa secunda*); or these grasses share dominance with drought-tolerant shrubs, principally sagebrush (*Artemisia tridentata*), but also greasewood (*Sarcobatus vermiculatus*), rabbit brush (*Chrysothamnus*

Table 8.7—The number of invasive plant species reported by State in the Intermountain Adaptation Partnership region, according to the Early Detection and Distribution Mapping System (EDDMapS 2016) on February 5, 2016. The EDDMapS is an online database that combines data from other databases, organizations, and volunteer observations to create a national network of invasive species distribution data.

	State			
Invasive plant type	**Nevada**	**Utah**	**Wyoming**	**Idaho**
Grasses/grasslike	81	86	61	71
Forbs/herbs	194	249	198	271
Shrubs/subshrubs	12	35	17	28
Vines	17	17	15	22
Hardwood trees	15	34	16	27
Conifer trees	0	0	0	1
Aquatic	8	8	7	13
Total	327	440	319	433

nauseosus), and saltbrush (*Atriplex confertifolia*). The prominence of shrubs is greater where precipitation is lower. In the spaces between the grasses and shrubs are annual and perennial herbs and cryptobiotic crust (Daubenmire 1969).

With Euro-American settlement, many nonnative species arrived and became naturalized, but probably less than a dozen became community dominants (e.g., wild oats [*Avena fatua*], cheatgrass, bull thistle [*Cirsium vulgare*], medusahead [*Taeniatherum caput-medusae*], hologeton [*Hologeton glomeratus*], Kentucky bluegrass [*Poa pratensis*], Russian thistle [*Salsola tragus*], and tall tumblemustard [*Sisymbrium altissimum*] [Yensen 1981; Young et al. 1972]). The combination of settlement-related disturbance, introduction of invasive plants, and subsequent shifts in native vegetation significantly altered much of the regional vegetation within 50 years (Daubenmire 1970). Current invasive plants in the IAP region are listed in table 8.7.

Invasive Plants in the Intermountain Adaptation Partnership Region

Implications of Increasing Numbers of Invasive Plants

There is little evidence that interference among nonnative species at levels currently observed significantly impedes further invasions. Rather, groups of nonnative species can facilitate one another's invasion in various ways, increasing the likelihood of survival and ecological impact, and possibly the magnitude of impact; the result is an accelerating accumulation of introduced species and effects (Simberloff and Von Holle 1999). The damage of invasive plants to the ecosystems of the IAP region may increase as more nonnative plants establish, and as climate change results in shifts in the environment, giving certain nonnative plants an advantage and allowing them to become invasive.

Invasive plants can alter the evolutionary pathway of native species through competitive exclusion, niche displacement, hybridization, introgression, predation, and ultimately extinction. Invasive species hybridization with native species can cause a loss in fitness in the native species, which may result in extinction of the native plant (Rhymer and Simberloff 1996). There are many examples of the large populations of invading species outcompeting small populations of native species through hybridization (e.g., invasive *Spartina alterniflora* hybridizing with the common native *Spartina foliosa* and the hybrid then invading new marshes [Anttila et al. 1998; Ayres et al. 2008]). In certain cases, small populations of an invader can threaten native species that have much larger populations (Mooney and Cleland 2001).

Invasive Plants in Nonforest Vegetation

Many invasive plant species (both annual grasses and perennial forbs) have degraded the nonforest vegetation types of the IAP region by outcompeting native species and by directly affecting the frequency and intensity of wildfires (see following discussion). Although cheatgrass and medusahead are considered the most problematic of the invasive annual grasses, a number of deep-rooted, creeping invasive perennials, such as Russian knapweed (*Acroptilon repens*), squarrose knapweed (*Centaurea virgata*), Dalmatian toadflax (*Linaria dalmatica*), and Canada thistle (*Cirsium arvense*), are often some of the hardest invasive plants to manage (Ielmini et al. 2015).

Invasive Plants in Forest Vegetation

In general, invasive plants are unable to get the sunlight they require to survive in dense forests (Parendes and Jones 2000). To date, forests in western North America remain relatively unaffected by invasive plants (Oswalt et al. 2015).

However, forest ecosystems remain vulnerable (Dukes and Mooney 2004). Invasive plants are most often encountered in disturbed areas within forest vegetation types (e.g., along roads, streams, or trails, or in areas disturbed by harvesting, windthrow, or fire). The invasive plants encountered in forest vegetation types in the IAP region tend to be the same invasive plants encountered in nonforest vegetation types. When disturbance ceases in forests, however, populations of invasive species tend to decline as forest vegetation recovers.

Invasive Plants in Riparian Zones

Riparian zones in the Intermountain West may be invaded by either annual or perennial invasive plant species, but the most apparent are often perennials. Perennial invasive species with clonal or rhizomatous life forms, or that are capable of root sprouting, are ideally suited to survive in riparian habitats and compete with native vegetation. Perennial invasive species can attain large size, displace native vegetation, and significantly affect the structure of vegetation (Dudley 2009).

Invasive plants currently impacting riparian zones in the IAP region include the perennials saltcedar (*Tamarix* spp.), Russian olive (*Elaeagnus angustifolia*), camelthorn (*Alhagi pseudalhagi*), and perennial pepperweed (*Lepidium latifolium*), and the annual rabbitsfoot grass (*Polypogon monspeliensis*). Upland invasive plants that occur on the periphery of these ecosystems include Russian knapweed, ripgut brome (*Bromus diandrus*), red brome, cheatgrass, and invasive mustards (family Brassicaceae) (Chambers et al. 2013).

Climate Change and Invasive Plants

It is often assumed that climate change will favor nonnative invasive plants over native species (Dukes and Mooney 1999; Thuiller et al. 2008; Vilá et al. 2007; Walther et al. 2009). Although this may be an overgeneralization (Bradley et al. 2009; Ortega et al. 2012), numerous attributes of successful invaders suggest nonnative species could flourish with climatic changes, specifically increased atmospheric carbon dioxide levels, precipitation, and temperatures. For example, many invasive species are fast-growing early-seral species (ruderals) that tend to respond favorably to increased resource availability, including temperature, water, sunlight, and carbon dioxide (Milchunas and Lauenroth 1995; Smith et al. 2000; Walther et al. 2009). Many invasive species respond favorably to disturbance (Zouhar et al. 2008), which can increase resource availability (Davis et al. 2000). Invasive species may exploit postfire conditions better than many native species (Zouhar et al. 2008), despite native plant adaptations to fire. In bunchgrass communities, many invasive plants germinate and become established better than do native species when native vegetation is disturbed, even under equal propagule availability (Maron et al. 2012). Successful invaders also commonly have strong dispersal strategies and shorter generation times, which can allow them to migrate quickly into freshly disturbed sites (Clements and Ditomaso 2011). Collectively, these attributes suggest that many invasive plants would benefit from increased disturbance under changing climate.

Invasive Plants and Climate Change Management Considerations

Climate change may both increase the intensity and duration of drought, and increase the intensity of precipitation events (Trenberth et al. 2003). Intense weather events associated with climate change can create disturbances in ecosystems that may make them more vulnerable to invasion. For example, mudslides, wind damage, and ice storms could damage forest ecosystems by uprooting trees and creating disturbed soil conditions ideal for invasion. Heavy rains, drought, wildfire, unusual movements of air masses, and other extreme climatic events can equally weaken the resilience of ecosystems and expose new areas to invasion (Bhattarai and Cronin 2014; Heller and Zavaleta 2009). Damage from these events, especially where invasive species are present or invade as a result, may affect the ability of these ecosystems to recover from the damage caused by such events. The affects of weather events can be exacerbated where invasive plants dominate the ground cover, yet fail to provide adequate levels of root structure to bind and hold soils. The failure to secure the soil can lead to increased erosion and consequent impacts on stream turbidity and water quality (WGISCC 2014).

Diez et al. (2012) provide examples of how extreme climatic events can affect each stage of the invasion process:

- Introduction/transport: Strong winds and storms can move seeds or propagules of invasive species into previously uninvaded locations;
- Establishment: Extreme climatic events such as drought or severe storms can weaken ecosystems or create significantly disturbed areas (e.g., mudslides, wildfire) that may facilitate successful invasive species establishment;
- Spread: The seeds or propagules of invasive species already within an area can be further spread by winds (e.g., associated with windstorms) and water (e.g., flooding); and
- Impact: Weather events may strengthen or compound the negative impacts of invasive species; for example, extended drought can increase the frequency or severity (amount of fire-caused mortality) of fire in areas invaded by invasive plants, thereby altering historical fire regimes.

Unless desirable plants are present to fill vacated niches, control of existing invasive plants may open niches only for the establishment of other undesirable plants.

The effectiveness of existing invasive species management measures will need to be reevaluated in light of climate change. Control activities may have to be modified in response to climate-induced changes in plant phenology and distribution. Adjustments could include changes in the timing and level of herbicide applications and methods of mechanical control and management for invasive plants (WGISCC 2014). We also highlight the need to better understand how climate change will impact relationships between invasive plants and their biological control agents so managers can predict and advance biocontrol efficacy (Runyon et al. 2012). An integrated pest management strategy for invasive plants which considers all forms of pest control (cultural, mechanical, biological, and chemical) is most likely to be successful through time (DiTomaso 2000; Masters and Sheley 2001). Current context and approach for invasive species management are described in box 8.1, and adaptation strategies for invasive species are described in Chapter 14.

Box 8.1—The Framework for Invasive Species Management

Policy-makers, resource managers, and researchers have generally accepted a hierarchy of actions associated with the management of invasive species: prevention, early detection with a rapid response to eradicate them, or if they gain a foothold and cannot be eradicated, then control and management (WGISCC 2014; Heller and Zavaleta 2009).

Prevention

Prevention is the most effective defense against biological invasions (NISC 2016). Prevention is the only tactic that ensures an invasive species does not become an additional stressor to a vulnerable ecosystem (WGISCC 2014). Unless measures are taken to prevent invasive plant propagules from hitching rides, the ongoing expansion of global commerce is likely to exacerbate the problem of biological invasions (Dukes and Mooney 2004).

Early Detection and Rapid Response

Where prevention fails to stop the arrival of an invasive species to an ecosystem, early detection and a rapid response to eradicate the invasive species can minimize harmful impacts to an ecosystem (Wittenberg and Cock 2001). Early detection of invasive plant populations, followed immediately by decisive management practices to eradicate an incipient population, is critical to preventing a species from becoming invasive. Rapid eradication depends on adequate preparedness, having the necessary methods, legal authorities, and resources to act on the detection before the invasion becomes entrenched. For this reason, eradication efforts should be considered within the broader, proactive conservation planning (WGISCC 2014).

Control and Management

Once an invasive plant has established and spread beyond a point where eradication is feasible, long-term control can still reduce that species' stress on an ecosystem. Reducing the extent or impact of an invasive plant infestation may directly enhance ecological resiliency of the affected resource. Long-term control should improve ecosystem functions of invaded areas while containing further spread of the invasive plant by protecting adjacent uninfested areas (WGISCC 2014).

Most often a single method is not effective to achieve sustainable control of invasive plants. A successful long-term management program should be designed to include combinations of mechanical, cultural, biological, and chemical control techniques as necessary. This is particularly true in revegetation programs in which seeding establishment is the most critical stage and is dependent upon the suppression of competitive species (DiTomaso 2000). The need to integrate control methods to get tolerable levels of invasive plant densities underscores the need for constant monitoring and evaluation of treatments. If a treatment does not result in desired or expected control, land managers need to be prepared to modify their treatments and resource expectations in the future, perhaps incorporating additional control methods or reducing potential resource benefits.

Forest Service Invasive Species Management Policy

The Forest Service Manual addresses invasive species management (FSM 2900) (Forest Service 2011) with five strategic objectives. The first three FSM 2900 strategic objectives mirror the framework outlined above (prevention, early detection and rapid response, control and management), but FSM 2900 adds two additional strategic objectives: restoration and organizational collaboration. The Forest Service seeks to proactively manage aquatic and terrestrial areas of the National Forest System to increase the ability of those areas to be self-sustaining and resistant to the establishment of invasive species. Where necessary, implementation of restoration, rehabilitation, and or revegetation activities following invasive species treatments is desirable to prevent or reduce the likelihood of the reoccurrence or spread of aquatic or terrestrial invasive species (U.S. Forest Service 2011). Cooperation with other Federal agencies, State agencies, local governments, tribes, academic institutions, and the private sector can help to: increase public awareness of the invasive species threat; coordinate invasive species management activities to reduce, minimize, or eliminate the potential for introduction, establishment, spread, and impact of aquatic and terrestrial invasive species; and coordinate and integrate invasive species research and technical assistance activities (U.S. Forest Service 2011).

Geologic Hazards

Background and Mechanistic Models for Hazard Assessment

Geologic hazards related to climate change primarily involve erosional geomorphic processes, such as flooding, mass wasting, periglacial activity, snow avalanches, and aeolian transport. Climate-driven changes in temperature, precipitation, and atmospheric circulation have direct impacts on the physical processes driving erosion (e.g., freeze-thaw, hydrological runoff, and windspeed). Over long periods of time, landscapes evolve to reflect the erosional regime to which they are exposed. Climate change can alter that regime by changing the timing, frequency, magnitude, and style of erosional events, thereby causing a transient geomorphic response that will persist until the system equilibrates with the change in physical regime. This period of transience and the new state toward which the system evolves can alter the potential for geologic hazards. However, climate change may play out differently within and between subregions: geologic hazards may increase in some cases, decrease in others, or show little to no change. Hence, site-specific assessments are frequently required.

The degree of geomorphic response to a given change in climate depends on the physical setting and the associated degrees of freedom for adjusting to the climate perturbation. For example, soil-mantled hillslopes or alluvial rivers will be more responsive to a change in precipitation and runoff because they are composed of loose, mobile material. In contrast, bedrock landscapes are likely to show much less response to the same climatic perturbation. Geomorphic responses and changes in the style and degree of erosion can be quantitatively predicted using regime diagrams (or state diagrams) which relate process and form to the driving physical variables. For example, figure 8.22 shows predicted domains for different types of erosional processes occurring on soil-mantled hillslopes as a function of topographic slope and drainage area (a surrogate for hydrological discharge). Each domain is based on mechanistic predictions for the style of erosion that will result for different combinations of area and slope (Montgomery and Dietrich 1994).

Using mechanistic frameworks, such as figure 8.22, one can map erosional process domains onto the landscape using geographic information systems and digital elevation models, allowing rapid prediction of how geomorphic processes (and hazards) may respond to climate change (in this case, climate-driven changes in precipitation and the runoff associated with a given drainage area). For example, figure 8.23 the predicted spatial distribution of shallow landslides in a mountain basin based on the above framework and given values of hydrology and soil characteristics; the results demonstrate that (all else equal) the risk of landsliding is expected to rise with climate-driven increases in rainfall (figs. 8.23a-d).

Similarly, figure 8.24 shows a state diagram for alluvial rivers, from which one can predict changes in channel characteristics (depth, slope, grain size) or reach-scale morphology (pool-riffle, plane-bed, step-pool, cascade) as a function of climate-related changes in streamflow or sediment supply. Furthermore, alluvial channels can be grouped into process domains (fig. 8.25), from which one can anticipate the physical and ecological conditions (and disturbance regimes) associated with climate-driven shifts in channel morphology.

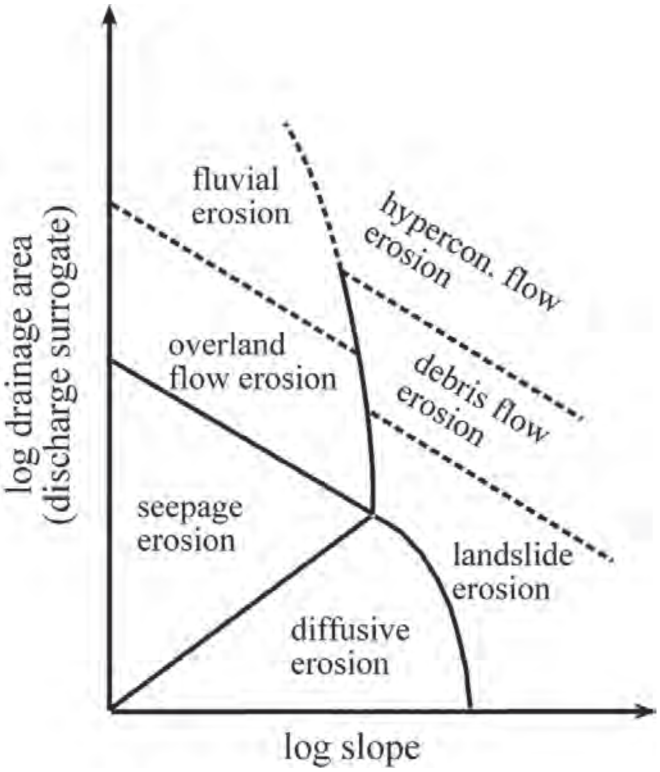


Figure 8.22—Domains for different types of erosional processes on soil-mantled landscapes (hypercon. = hyperconcentrated) (modified from Montgomery and Dietrich [1994]).

An important factor not explicitly included in these state diagrams is vegetation. Grasses, shrubs, and trees alter geomorphic processes by (1) intercepting and shielding the ground from direct impact of precipitation, (2) creating surface roughness that slows erosion from wind and water, and (3) offering root strength that can dramatically increase erosional thresholds. For example, over the long term, vegetated hillslopes may become oversteepened (i.e., achieving steeper slopes than would be possible without the added effects of root strength and surface roughness). Climate-driven changes in forest health, vegetative cover, and species composition (and associated root strength and surface roughness) can cause hillslopes to rapidly unravel, exhibiting accelerated rates of surface erosion and mass wasting. For example, increased frequency and extent of landslides is commonly observed following forest clearing of steep terrain (e.g., Gray and Megahan 1981; Johnson et al. 2000; Montgomery et al.

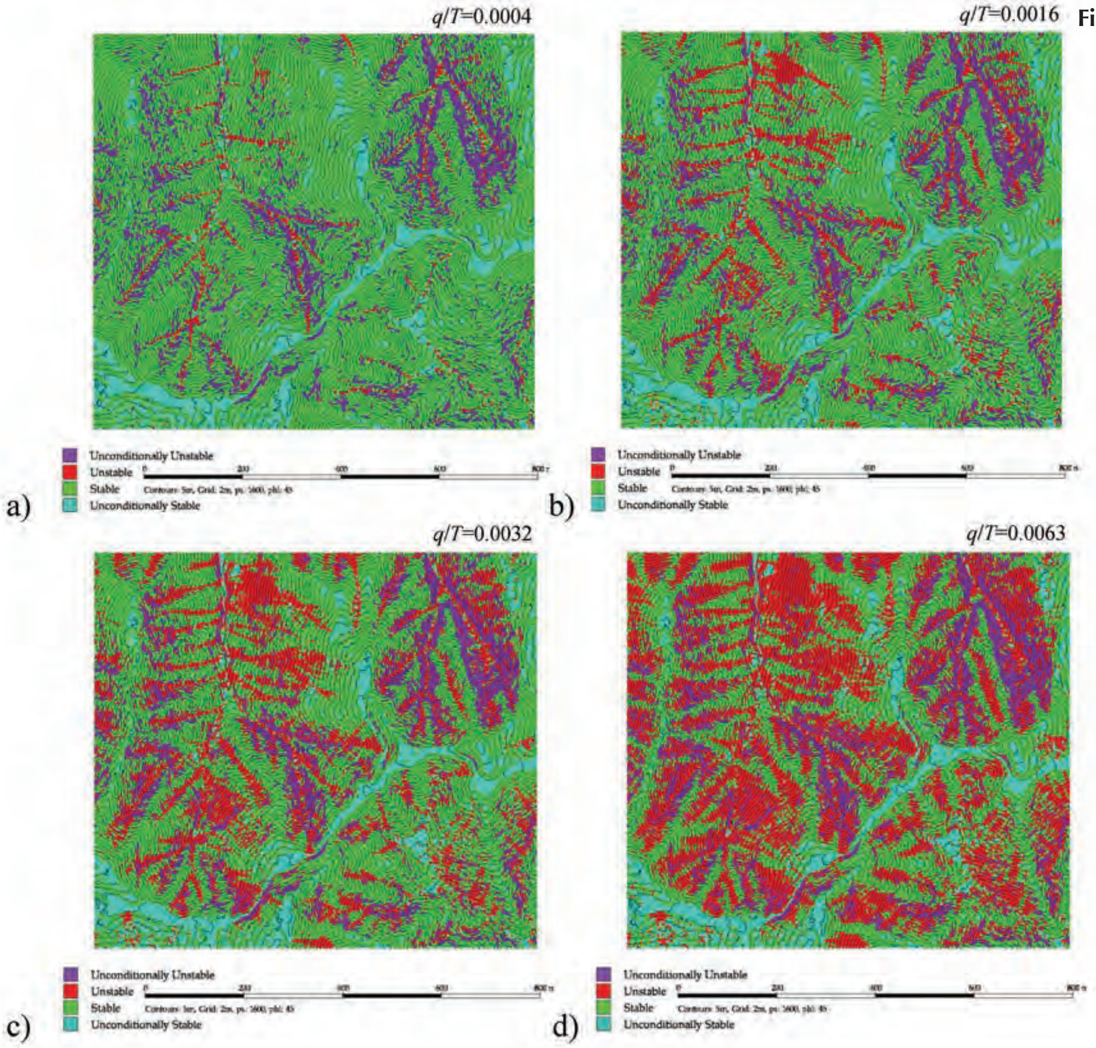


Figure 8.23—Predicted spatial distribution of shallow landsliding at Mettman Ridge, Oregon, for different ratios of effective discharge (q, rainfall minus evapotranspiration) per unit contour width relative to soil transmissivity (T). Results are shown for q/T values of: (a) 0.0004, (b) 0.0016, (c) 0.0032; and (d) 0.0063. The q/T ratio describes the magnitude of the rainfall event relative to the soil's ability to convey water downslope; larger values of q/T indicate greater potential for soil saturation and landsliding. For a given value of T, panels (a)-(d) simulate the effects of climate-related increases in rainfall rate (modified from Dietrich and Matgomery [1998]).

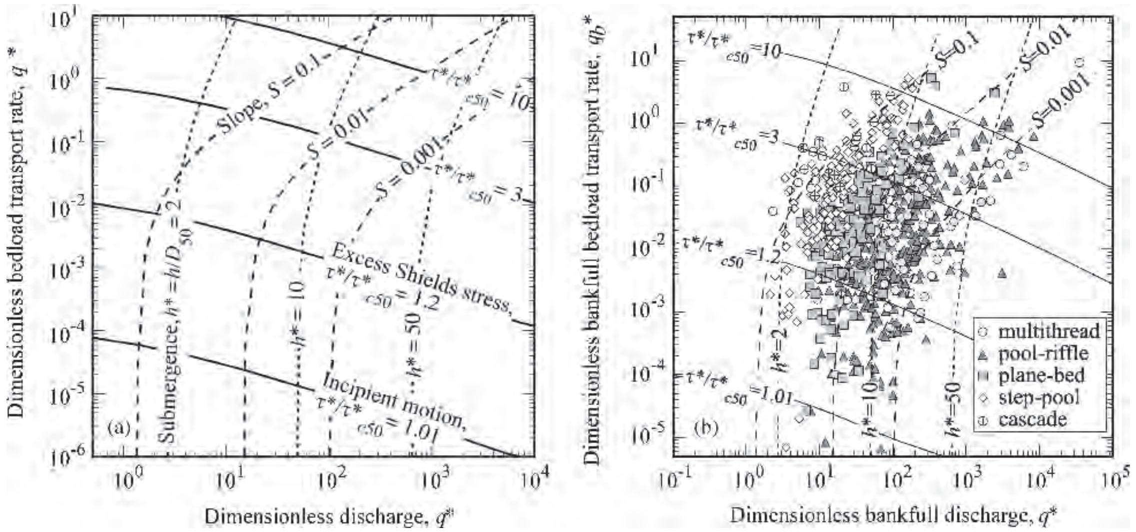


Figure 8.24—State diagram for alluvial rivers showing: (a) contours of equilibrium channel slope (S), relative submergence ($h^* = h/D_{50}$, where h is flow depth and D_{50} is the median surface grain size), and excess Shields stress (τ^*/τ^*_{c50}, where τ^* is the dimensionless shear stress and τ^*_{c50} is the critical value for mobilization of D_{50}) as functions of dimensionless discharge (q^*) and dimensionless equilibrium bedload transport rate (q_b^*, transport rate = sediment supply); and (b) the same figure populated with field data for different reach-scale channel types evaluated at bankfull stage (from Buffington [2012], and Parker [1990]).

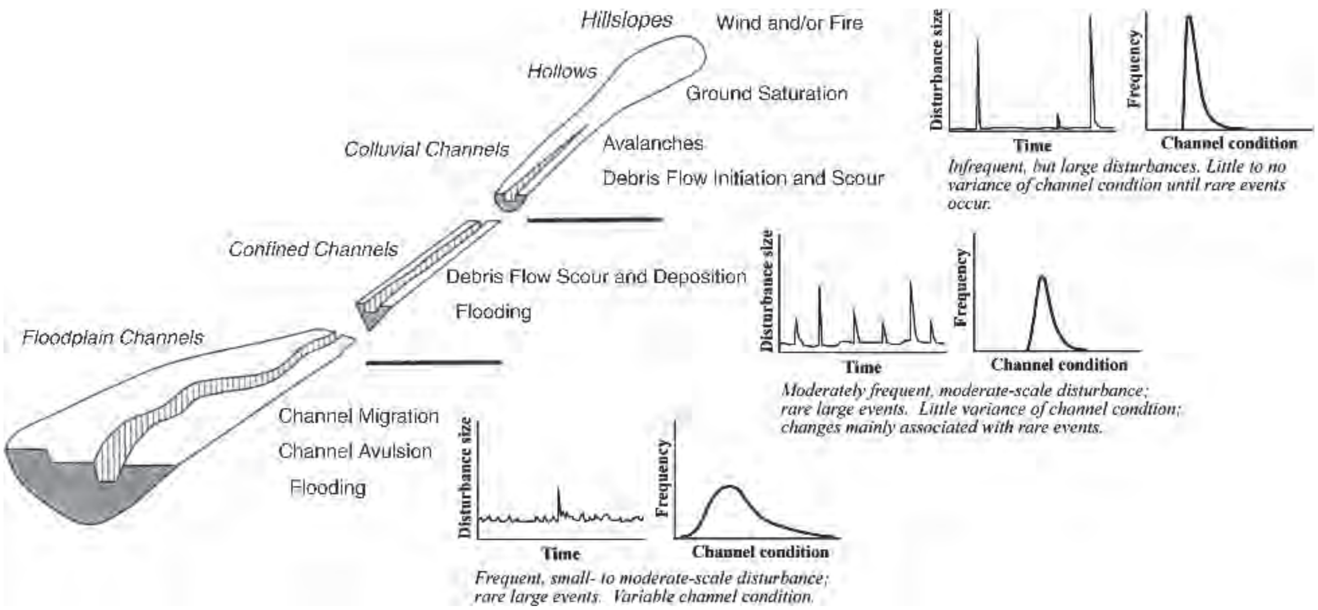


Figure 8.25—Process domains in mountain rivers, showing typical physical conditions and disturbance types (schematic at left). Graphs show disturbance size relative to mean values (first right-hand graph) and variance of channel condition (second right-hand graph) as a function of these disturbances (floods, sediment inputs, changes in vegetation) and degrees of freedom associated with each process domain and channel type (from Buffington [2012]; modified from Montgomery [1999], and after Benda and Dunne [1997a, b], Church [2002], and Wohl [2008]).

2000; Swanston 1970) and may be a useful analog for potential effects of climate change in some settings. In terms of the figure 8.22 framework, climate-driven changes in vegetation alter the area-slope thresholds for different erosional processes, allowing one to mechanistically model the implications for geomorphic hazards. For example, spatially explicit predictions similar to figure 8.23 could be developed for different vegetation scenarios by alerting the effective rainfall rate (rainfall minus interception), surface roughness, and root cohesion in standard erosion laws (Montgomery and Dietrich 1994) to simulate the effects of climate-driven changes in forest health, biomass density, or species composition.

A variety of other process-based models are also available for predicting hazard zones at landscape scales. Examples are the runout path of debris flows (Benda et al. 2007; NetMap 2017), the extent of floodplain inundation (Bates et al. 2010; LISFLOOD-FP 2017), the extent of critical streambed scour for salmonid embryos (Goode et al. 2012), and the extent of aeolian erosion as a function of vegetation type and density (Mayaud et al. 2017) for climate-related changes in physical and biological conditions.

Larger-scale geologic hazards, such as earthquakes and volcanic eruptions, are not directly influenced by climate change. However, the impacts of these events can be modulated by climate. For example, glaciers and ice patches present on Mount St. Helens during its 1980 eruption helped to generate lahars (muddy debris flows) that caused substantial erosion and sediment deposition during the event (Pierson 1985). Similarly, the densely forested landscape around the volcano produced massive loads of

Table 8.8—Relative size of floods in different hydroclimates.[a]

Discharge ratio	Snowmelt (Colorado Front Range)	Frontal rainfall (Klamath Mountains, California)[b]	Thunderstorm (Colorado Front Range)
Q_{ma}/Q_{ma}[c]	1.0	1.0	1.0
Q_5/Q_{ma}	1.3	1.3	1.1
Q_{10}/Q_{ma}	1.4	1.9	1.9
Q_{50}/Q_{ma}	1.8	3.5	4.5
Q_{100}/Q_{ma}	2.0	4.5	8.9

[a] Table from Buffington (2012). Data from Pitlick (1994), based on regional flood frequency curves for mountain basins with roughly comparable ranges of drainage area.

[b] Approximate average value for the three frontal rainfall systems examined by Pitlick (1994).

[c] Q_{ma} = mean annual flood.

wood that were delivered to lakes and rivers within the blast zone; in turn, complex geomorphic responses and shifting habitats ensued as that material was subsequently mobilized or sequestered during hydrological and atmospheric events in the decades after the eruption.

Potential Effects of Climate Change on Fluvial Erosion in the Intermountain Adaptation Partnership Region

In the IAP region, climate-related changes in hydroclimate are likely to be important drivers of increased erosional hazards. As used here, hydroclimate refers to the type of runoff regime (e.g., snowmelt, frontal rainfall, or thunderstorm/monsoonal), which has important implications for fluvial erosion and associated hazards. While rivers and their floodplains are adjusted to the local hydrological regime, each hydroclimate has substantially different physical characteristics. For example, the relative size of a given recurrence-interval flood systematically varies with hydroclimate (table 8.8). The 100-year flood (Q_{100}) is typically 9 times as large as the mean annual flood (Q_{ma}) in thunderstorm systems, 4.5 times as large in frontal rainfall systems, and only twice as large in snowmelt environments. This suggests very different potential for geomorphic work and erosion across hydroclimates. In most cases, global climate models predict subtle changes in the timing and magnitude of precipitation events (e.g., Goode et al. 2013), but where watersheds become transitional from one hydroclimate to another, substantial changes in state (and erosional hazard) may occur due to the flood statistics documented in table 8.8. These hazards may be compounded by concomitant changes in vegetation type and species composition (and thus changes in erosional thresholds as discussed earlier). Identifying regions or subbasins within watersheds where transitional hydroclimates are expected to emerge as a result of climate change may be critically important for planning.

Interactions

Large mortality events in forests are normally associated with the occurrence of several stressors (Allen et al. 2010; McDowell et al. 2016). The interactions among disturbances working over various spatial and temporal scales define the nature of forested landscapes (Jenkins et al. 2008). Changes in drought intensity and frequency, for example, have the potential to alter fire, and populations and impacts of tree-damaging forest insects and pathogens (Ayres and Lombardero 2000; Dale et al. 2001; Weed et al. 2013). In addition, bark beetle-caused tree mortality in conifer forests affects the quantity and quality of forest fuels (Jenkins et al. 2008). Complex interactions make it challenging to predict the effect of multiple stressors and whether threshold-type responses may occur (McDowell et al. 2016). In this section, we explore some potential interactions between several ecological disturbances and discuss the likelihood of climate change effects.

Fire and Bark Beetle Interactions

Introduction

A large reduction in fire as a result of suppression efforts over the last century has substantially altered forest composition, structure, and ultimately vulnerability to insect pests (McCullough et al. 1998), particularly in low-elevation, dry forest types. Changes in stand structure, including increased homogeneity and density, and increased abundance of fire-intolerant, shade-tolerant conifers have increased susceptibility to several bark beetle species (Fettig et al. 2007). Reciprocally, mortality caused by bark beetles can change subsequent fire hazard (Hicke et al. 2012). For example, crown fire potential is increased in lodgepole pine stands immediately (1–4 years) after mountain pine beetle outbreak (red stage) as a result of rapidly desiccating needles still attached to the tree (Jolly et al. 2012). Disturbance interactions like these are a natural component of forests in the IAP region, and understanding their causes and consequences will help managers anticipate possible effects of climate change.

Effects of Bark Beetles on Fuels and Fire Behavior

Effects of bark beetle outbreaks on fire hazard (e.g., probability, severity, and intensity) are of considerable concern in many forest types in the IAP region. It has long been presumed that fire occurrence or intensity, or both, may increase following outbreaks of bark beetles (Hoffman et al. 2013), but studies demonstrating this interaction are few and have contradictory conclusions (Hicke et al. 2012; Parker et al. 2006). A growing body of literature utilizing physics-based models (e.g., Hoffman et al. 2012a, 2015; Linn et al. 2013), historical observations (e.g., Kulakowski and Jarvis 2011), and stand structure and fuels characterizations (e.g., Harvey et al. 2013) addresses the change in both fuels distribution and potential fire behavior after bark beetle outbreaks in many forest types. Outbreak severity, spatiotemporal heterogeneity in tree-level mortality, forest type differences associated with individual species traits, and species composition influence how we interpret the influence of bark beetle outbreaks on fire hazard.

A common approach to evaluate post-outbreak fire hazard is to group impacted stands into three phases that correspond to the bark beetle population stage (endemic, epidemic, and post-epidemic) (Jenkins et al. 2008). These phases can be similarly characterized based on canopy color associated with aerial fuel moisture conditions over time as trees die and deteriorate. Trees in the green phase are usually alive and undergoing a low-level endemic or initial epidemic attack. In this phase, photosynthesis is still occurring, water relations in the tree are close to normal, and there are normal levels of fine canopy fuels. Red phase stands are related to an ending epidemic or to a recent post-epidemic beetle population stage. Here the needles are still on the tree, but in contrast to the previous phase, their moisture is reduced and the composition of the volatile compounds is different, making the canopy fine fuels more flammable (Gray et al. 2015; Jolly et al. 2012). Last, in gray-phase stands, the needles have fallen off the tree, drastically reducing aerial fine fuels, and making a short-term (1–3 years) contribution to the fine surface fuels. A fourth phase, not related to canopy color, is called an old phase. These stands comprise individuals remaining one decade or longer after the beetle epidemic; this is the phase when trees begin to fall and regeneration responds to created openings.

Hicke et al. (2012) conducted the most thorough review of the fire-bark beetle literature to date and noted that, despite varying approaches and research questions, much agreement exists on fire hazard after bark beetle outbreaks. Specifically, during the gray phase, there was strong agreement that surface fire hazard and torching potential increased, but crown fire potential was reduced. Similarly, agreement for reduced fire hazard in old-phase conditions was found. However, most disagreement occurred regarding fire hazard during the red phase, when trees retain their drying needles and changes in foliar chemistry can increase their flammability. Many studies have concluded that during this roughly 1- to 4-year period, fire hazard increases (Hoffman et al. 2012a; Jenkins et al. 2014; Jolly et al. 2012; Klutsch et al. 2011). Fire hazard also increases as the proportion of the stand killed by bark beetles increases, regardless of forest type (DeRose and Long 2009; Hoffman et al. 2012a; Jorgensen and Jenkins 2011; Page and Jenkins 2007). Many, though not all (see Linn et al. 2013), studies suggest as stands transition from red phase into gray phase, fire hazard decreases.

Characterization of bark beetle-caused mortality into phases simplifies the actual spatial and temporal variability associated with the developing insect population on a specific host, and the composition, condition, and arrangement of those hosts at tree, stand, and landscape levels. The rate at which erupting beetle populations build initially is influenced by the amount (proportion) of susceptible host; beetle population movement between stands and across the landscape is influenced by proportion of susceptible host and their arrangement (DeRose and Long 2012b; Hoffman et al. 2015). For example, mountain pine beetle populations can build quickly in homogeneous stands of drought-stressed, suitable lodgepole pines, resulting in relatively rapid mortality of the pine.

The interactions between fire and bark beetles in heterogeneous landscapes need to be discussed across a range of stand conditions and forest types. Forest types should be evaluated separately for fire hazard after bark beetle outbreaks because of varying intensities of bark beetle effects on its host, environmental conditions that characterize a particular forest type (e.g., elevation and aspect), and proclivity of a forest type to promote advance regeneration (e.g., spruce-fir) or not (e.g., persistent lodgepole pine). The amount and arrangement of live fuel in post-outbreak stands are influenced by the presence or absence of advance regeneration, which varies by forest type.

The vast majority of research on beetle outbreak and fire hazard has been conducted in the lodgepole pine forest type (reviewed in Hicke et al. 2012), including study areas in the IAP region (Jenkins et al. 2014; Page and Jenkins 2007). Other forest types that have received notable attention in the IAP region include spruce-fir (DeRose and Long 2009; Jorgensen and Jenkins 2011), Douglas-fir (Guinta 2016; Harvey et al. 2013), and limber pine (Gray et al. 2015). These areas are impacted by the principal eruptive bark beetles in the region, the mountain pine beetle and spruce beetle. Much less research has been conducted in lower-elevation forest types such as ponderosa pine (Hoffman et al. 2012b; but see Hansen et al. 2015), pinyon-juniper types (Linn et al. 2013), and quaking aspen. Increased activity of pinyon ips beetles in some of these forest types merits research on their interactions with fire.

Effects of Fire on Bark Beetles

Fire can directly and indirectly influence bark beetle populations. Fire burning in stands of infested trees can directly kill bark beetles or their developing brood and therefore decrease populations (Martin and Mitchell 1980). However, indirect effects are more common, typically resulting from the effect of fire on host tree suitability and vigor. Trees scorched or wounded by fire are generally thought to be weakened, and as a result, are less resistant to bark beetle attack. But studies investigating the relationship between fire-caused damage to conifers and resin production or flow have reported variable results, ranging from temporary reductions in resin to elevated resin levels for up to 4 years (Davis et al. 2011; Davis et al. 2012; Perrakis and Agee 2006; Wallin et al. 2003). In addition, fire can indirectly increase bark beetle and other beetle attacks by eliciting host tree compounds that may attract bark beetles (Kelsey and Joseph 2003; Wallin et al. 2003).

Susceptibility of fire-damaged trees to bark beetle attacks generally increases with increasing damage level. However, trees must have enough live, suitable phloem for successful attack and brood production to occur (DeNitto et al. 2000; Parker et al. 2006). Populations of bark beetles are not expected to increase in areas of high burn severity where the majority of trees are killed and little to no viable phloem remains, whereas areas of intermediate fire severity are likely to provide the most suitable habitat for bark beetle brood production (Hood and Bentz 2007; Powell et al. 2012).

Besides suitable phloem availability, additional factors affecting fire-driven bark beetle population dynamics include prefire and postfire weather and climatic conditions, prefire bark beetle population levels (e.g., epidemic or incipient populations leading to greater potential for postfire bark beetle effects than endemic levels), and stand structure and composition where extensive tracts of susceptible host within and next to the fire perimeter will promote short-term

Table 8.9—Reciprocal interactions between fire and bark beetles.

Forest type or species	Bark beetle response to fire	Fire (fuels) response to bark beetles
Douglas-fir	Douglas-fir beetle response to fire damage depends on stand conditions: Presence of fire-damaged trees and fire severity Large trees High stand density index (Hood and Bentz 2007) and landscape conditions (Hood et al. 2007) Continuous tracts of susceptible stands, and favorable climate (e.g., drought)	Douglas-fir beetle outbreaks typically cause variable mortality Red-stage surface fuels are relatively unchanged (Harvey et al. 2013), but aerial fuels are more flammable Gray-stage potential fire behavior is likely reduced (Guinta 2016) Post-outbreak snag half-life is 10-20 years
Lodgepole pine	Mountain pine beetle contributes to tree mortality within fire boundary (Amman and Ryan 1991; Geiszler et al. 1984; Jenkins et al. 2014; Lerch 2013; Powell et al. 2012); response to fire depends on: Fire severity Populations prior to fire	Red-stage (1-4 years) potential fire behavior increases (Hicke et al. 2012; but see Simard et al. 2011). Severity of fire is related to severity of mortality (Hoffman et al. 2012a) Gray-stage potential fire behavior is likely reduced (Page and Jenkins 2007) Post-outbreak snag half-life is less than a decade
Ponderosa pine	Complex of bark beetles (western pine beetle, mountain pine beetle, roundheaded pine and pine engraver beetles) contribute to tree mortality within fire boundary and adjacent area following wildland and prescribed fires (Breece et al. 2008; Davis et al. 2012; Fettig et al. 2008, 2010; Fischer 1980; McHugh et al. 2003; Miller and Keen 1960; Miller and Patterson 1927); response to fire depends on: Presence of fire-damaged trees, severe fire effects Favorable climate (e.g., drought) Bark beetle populations prior to fire	Red stage potential fire behavior unknown Gray stage surface fuel increased and crown fuel decreased Post-outbreak snag half-life is less than a decade (Hoffman et al. 2012b)
Whitebark pine, limber pine	Little is known	Post snag half-life is several decades (Perkins and Swetnam 1996)
Jeffrey pine	Jeffrey pine beetle, red turpentine beetle and ips contribute to tree mortality within fire boundary (Bradley and Tueller 2001; Maloney et al. 2008)	Little is known
Pinyon-juniper	Little is known	Thought to increase potential fire behavior (Gaylord et al. 2013), and possibly fire spread in red and gray stage (Linn and others 2013)
Engelmann spruce	Spruce beetle populations may increase in fire-damaged, wind thrown trees (Gibson et al. 1999; Rasmussen et al. 1996)	Red-stage aerial fuels probably increase potential crown fire behavior (1-4 years) (Jorgensen and Jenkins 2011) Gray-stage potential fire behavior low (DeRose and Long 2009) Post-outbreak snag half-life >50 years (Mielke 1950).
Subalpine fir	Western balsam bark beetle response thought to be low, due to direct fire effects and competition with wood borers, but may increase in wind thrown trees (DeNitto et al. 2000)	Little is known
White fir-grand fir	Increased fir engraver activity observed on fire-damaged white fir (Fettig et al. 2008; Maloney et al. 2008; Schwilk et al. 2006)	Little is known
Quaking aspen	Little is known	Little is known

bark beetle outbreaks (Davis et al. 2012; Jenkins et al. 2008). Most bark beetle activity occurs within 1 to 3 years postfire when favorable conditions exist (Davis et al. 2012; Lerch et al. 2016; Tabacaru et al. 2016). One important exception is populations of Douglas-fir beetle, which may take longer to build when prefire populations are low, but populations can be sustained for several years (McMillin and Allen 2003; Rasmussen et al. 1996; Weatherby et al. 2001).

The use of both natural ignition fires and prescribed burns continues to increase in Western forest ecosystems where management goals include fuel reduction, restored functionality, and resilience. Therefore, information on the response of bark beetles to fire is needed to identify where burning can be used appropriately (Jenkins et al. 2014; McCullough et al. 1998; Tabacaru et al. 2016). Predicting tree death following fire is a necessary part of planning prescribed burns, managing stands, and developing salvage-marking guidelines after wildfire (Fowler and Sieg 2004; Hood and Bentz 2007; McCullough et al. 1998). Because bark beetles contribute to postfire tree mortality (reviewed in Jenkins et al. 2008, 2014), models that predict postfire survival are improved if they consider the effects of bark beetle attacks (Breece et al. 2008; Sieg et al. 2006). Conversely, not including bark beetles in predictive models may significantly underestimate delayed tree mortality caused by fire (Hood and Bentz 2007). Mortality levels (less than 10 percent) are typically acceptable in meeting fuels reduction objectives, but may conflict with restoration goals if large-diameter trees are preferentially killed (Perrakis et al. 2011). For example, Douglas-fir beetle shows preference for fire-damaged trees greater than 20 inches diameter (Hood and Bentz 2007).

Fire effects on specific bark beetles are described for host species that occur in the IAP region where there is information on interactions (table 8.9). Information is lacking on fire-bark beetle interactions for whitebark pine, limber pine, pinyon-juniper species, and quaking aspen. The recent ecological interest in whitebark pine and extent of pinyon-juniper forest types in the IAP region warrant further inspection for bark beetles impacting these trees. In addition, behavioral and population dynamics following fire have not been investigated for many bark beetle species, especially for thin-barked trees, where the phloem is easily degraded by direct fire effects.

Climate Change Effects

Assuming there will be an increase in wildland fires and climate-driven host tree stress under a changing climate, there will be corresponding increases in likelihood of bark beetle outbreaks in general (Bentz et al. 2010; Hicke et al. 2012; Weed et al. 2013; Williams et al. 2013) and in the potential for intensified interactions between fire and bark beetles, hastening vegetation changes. Bark beetle population dynamics and wildfire behavior are at least partly driven by drought and warming temperatures (e.g., DeRose and Long 2012a,b; Kolb et al. 2016a; Raffa et al. 2008). Drought predisposes trees to bark beetle attacks (e.g., Gaylord et al. 2013), and dries fuels that contribute to fire initiation and increased fire spread and severity. Both the area burned and area affected by bark beetles has increased (Bentz et al. 2010; Littell et al. 2009). This trend is likely to continue.

As temperatures increase, bark beetle population cycles may shift or intensify, creating an advantage over hosts. This advantage is not without constraints and may be limited by physiological control of beetle population cycles (Bentz and Powell 2014). With warming climate, increased population reproduction and longer growing seasons have the potential to reduce the time it takes to kill all or most suitable host trees in a stand or landscape. This is likely to result in significantly increased fire hazard during the 1 to 4 years of the red phase and possibly the gray phase. If such mortality occurred across the landscape, the potential for large, severe fires would be increased. However, recent work suggested otherwise in an area on the east side of the Cascade Mountains in the Pacific Northwest (Meigs et al. 2016).

Douglas-fir beetles, and to some extent bark beetles in ponderosa pine, have previously shown the strongest response to fire of all bark beetle species in the IAP region. The beetle attacks fire-damaged trees, leading to increased tree mortality both within and outside fire perimeters (Cunningham et al. 2005; Furniss 1965; Hood and Bentz 2007; McMillin and Allen 2003; Rasmussen et al. 1996) (table 8.9). Increased wildfire activity is likely to affect bark beetles most in forests dominated by Douglas-fir or ponderosa pine. There is little evidence that fire triggers sustained or widespread outbreaks of other bark beetle species outside of fire perimeters. Most bark beetle effects are expected to be relatively short-term pulses of increased mortality (1–2 years for pine bark beetles and 2–4 or more years for Douglas-fir beetle and spruce beetle). There may be increased bark beetle response to planned ignition fires (prescribed burns) under a warmer and drier climate, as more trees will be drought stressed, and postburn weather conditions may not be favorable for tree recovery. However, the potential increased beetle response to prescribed burns should be considered a word of caution and not a deterrent to the use of this practice (Fischer 1980; Tabacaru et al. 2016).

Insect Defoliation and Fire

Outbreaks of western spruce budworm are an important driver of forest dynamics in mixed conifer forest and may extend over tens to hundreds of miles and persist for more than a decade. In the last century, changes in land use and fire suppression have led to an increase in the amount and density of spruce budworm host tree species at the landscape level. This has altered the severity and frequency of both fire and western spruce budworm outbreaks. Despite the ecological and economic significance of these disturbances, the interactions among western spruce budworm, fire, and climate are not fully understood.

Figure 8.26—Different scales and types of postfire erosion as one moves downstream in a steep tributary basin, Middle Fork of the Boise River, Idaho: (a) Early stages of post-fire rilling on a hillslope (photo: John Buffington, U.S. Forest Service); (b) postfire debris-flow passage in the tributary basin (the predisturbance channel is obliterated by the debris-flow deposit, with a new channel cut into the deposit during clearwater flooding at the end of the event) (photo: John Buffington, U.S. Forest Service); and (c) debris fan and backwater flooding at the mainstem confluence (note the bulldozer on the right at the end of the flooded road for scale) (photo: U.S. Forest Service).

Defoliating Lepidoptera and other groups can alter the accumulation and distribution of fuels and vegetation. With outbreaks, insolation at the soil surface may increase, affecting moisture levels of fuels such as dead wood, fallen needles or leaves, and other types of litter. Tree mortality or dead treetops resulting from insect attack influence the availability of fuels on the soil surface (e.g., dead wood and vegetation on the ground) and ladder fuels. These factors play a large role in determining the risk of fire ignition, and fire intensity and severity. Insect outbreaks, including those of western spruce budworm, can increase the probability of fire occurrence and forest fire severity because of increased dead fuel loads (Baskerville 1975; Graham 1923; Hummel and Agee 2003; McCullough et al. 1998; Parker et al. 2006; Pohl et al. 2006; Prebble 1950; Ryerson et al. 2003; Schowalter 1986; Stocks 1987; Swaine and Craighead 1924). Historically, many Douglas-fir forests were shaped by a combination of insect outbreaks and mixed-severity fires (Agee 1993; Hessburg et al. 1994, 2007), suggesting the potential for synergistic interactions.

The only studies to explicitly assess the statistical relationship between fire and western spruce budworm outbreak records reported a negative correlation between the disturbance types over a 3- to 6-year period (Lynch and Moorcroft 2008; Preisler et al. 2010). However, these studies examined outbreaks solely during the late 20th century, when fires were being actively suppressed (Lynch and Moorcroft 2008; Preisler et al. 2010). Flower et al. (2014b) found no evidence of a consistent relationship between the timing of fires and western spruce budworm outbreaks among 10 sites along a longitudinal transect running from central Oregon to western Montana. Before 1890, no consistent relationship was apparent in the timing of the two disturbance types. After ca. 1890, fires were largely absent and defoliator outbreaks became longer lasting, more frequent, and more synchronous (Flower et al. 2014a). Other research corroborates findings that the duration and intensity of western spruce budworm outbreaks have increased with the decrease in forest fire frequency in western Montana since 1910, although these authors note that the frequency of budworm outbreaks was not affected (Anderson et al. 1987). Defoliation events thus appear to have no discernible impact on subsequent fire risk (Flower et al. 2014b). Recent studies examining other insect species have found that the observed effect of insect activity on subsequent fire behavior is highly dependent on time since outbreak and weather conditions (Hicke et al. 2012).

Wildland Fire and Erosion Interactions

As mentioned, recent climate warming has increased the frequency, extent, and severity of wildland fire in western North America (Westerling 2006). In terms of erosional processes, wildland fire removes vegetation (loss of interception, surface roughness, and root strength) and creates hydrophobic (water-repellent) soils, both of which increase the potential for surface erosion (fig. 8.26a) and generation of postfire debris flows in steep terrain during high-intensity rainfall or rain-on-snow events. Debris flows that are routed through tributary basins can dramatically alter channel and floodplain habitats through both scour and deposition (fig. 8.26b) and commonly deliver pulses of sediment and wood to mainstem rivers, which are deposited as debris fans at tributary junctions (fig. 8.26c). Fans can temporally dam mainstem rivers, inducing upstream flooding and sediment deposition (fig. 8.26c). Over time the fan erodes and the sediment pulse is routed through the downstream river, causing changes in channel morphology and aquatic habitat that can be either beneficial or detrimental depending on the size and volume of sediment (e.g., Lewicki et al. 2006). Moreover, elevated sediment loads can cause channel aggradation and subsequent flooding that put infrastructure (roads, bridges, campgrounds, dams) at risk.

The window for postfire erosion is typically several years to a decade, depending on the rates of postfire regrowth (Istanbulluoglu et al. 2004), during which time multiple, repeated erosional events may occur. Unlike landslide-related debris flows, which typically take thousands of years to collect enough colluvium to occur again (Dietrich et al. 1982), postfire debris flows in the IAP region are commonly produced by "bulking" events that can be generated each time severe runoff occurs during the window of vulnerability (Cannon et al. 2003, 2010). Bulking debris flows are caused by overland flow and gullying of exposed soil surfaces that contribute high sediment concentrations to the runoff event, causing a downstream change from clearwater flow, to hyperconcentrated flows, and finally to debris flows. The generation of such debris flows can be very rapid, occurring midway along the length of a hillslope or first-order channel. The rapidity of the events and the substantial window for repeated occurrence, makes postfire debris flows particularly hazardous.

Tools are available for predicting postfire erosion at both plot scales (e.g., Robichaud et al. 2007a, b) and basin scales (e.g., USGS 2017). Burned Area Emergency Response activities can reduce plot- and hillslope-scale erosion, but postfire debris flows occur on scales that are not feasibly mitigated.

Sediment yields from postfire debris flows in the IAP region are typically orders of magnitude larger than background sediment loads in rivers (fig. 8.27). Consequently, climate-driven increases in wildland fire are likely to elevate sediment loads above long-term averages, potentially putting downstream reservoirs at risk given that such facilities were designed under conditions of historically lower sediment yields. While massive postfire debris flows and their sediment loads are impractical to mitigate, low-gradient portions of river networks may be able to store substantial amounts of the load, acting as capacitors and thereby offering natural mitigation (Goode et al. 2012). Moreover, despite the dramatic effects and negative connotations of postfire debris flows, they can have important ecological benefits (e.g., providing supplies of wood that promote

Figure 8.27—Sediment yield as a function of basin area for individual erosional events (including postfire gullying and debris flows), short-term averages, and long-term averages in mountain basins of central Idaho (from Goode et al. [2012]).

channel complexity and supplies of gravel needed for salmonid spawning habitat). Many aquatic and terrestrial organisms in western basins have evolved with, and are adapted to, this type of disturbance, but climate-driven changes in fire regime (frequency, extent, severity) could create levels of disturbance that overwhelm species response and population resilience.

Defoliator and Bark Beetle Interactions

Physiological stress to trees caused by needle loss during defoliator outbreaks can predispose them to bark beetle attacks. However, bark beetle attacks do not make trees more susceptible to attack by defoliating insects, because unlike bark beetles, most insect defoliator outbreaks are not driven by host physiological stress (Mattson and Addy 1975; Redak and Cates 1984). The most common defoliator and bark beetle interactions in the IAP region are the western spruce budworm and Douglas-fir tussock moth defoliation events, with subsequent Douglas-fir beetle and fir engraver attacks. Interactions between Douglas-fir tussock moth and Douglas-fir beetle are more common than Douglas-fir tussock moth and fir engraver, because Douglas-fir is the preferred host for Douglas-fir tussock moth in the IAP region. Similarly, much of the mortality and top kill in larger trees during a western spruce budworm outbreak is caused by Douglas-fir beetle in Douglas-fir and fir engraver in true fir (Azuma and Overhulser 2008; Johnson and Denton 1975; Powell 1994). Growth loss, top kill and mortality following western spruce budworm outbreaks are related to the duration of the outbreak, stand conditions, and associated droughts (Alfaro et al. 1982; Ferrell and Scharpe 1982; Fredericks and Jenkins 1988). Mortality predictions for anticipated western spruce budworm outbreaks should include associated bark beetle mortality (Wickman 1978b).

Defoliation severity and duration influence host resistance and subsequent bark beetle attack. In the Douglas-fir tussock moth system, Douglas-fir tussock moth and fir engraver abundance associated with defoliation are regulated by host resistance, directly by resin, or indirectly by limiting the supply of susceptible hosts (Wright et al. 1979). Douglas-fir tussock moth acts as a stress factor to reduce host resistance, allowing Douglas-fir beetle and fir engraver to attack more trees successfully. Douglas-fir beetle and fir engraver activity generally increase after western spruce budworm and Douglas-fir tussock moth defoliation events, though this increase is variable. The increase is influenced by factors such as defoliation intensity, logging activity, drought, presence of root disease, tree-damaging storm events, host tree size and availability (percent of a stand), and stand conditions in the IAP region (Ferrell and Sharpe 1982; Fredericks and Jenkins 1988; Johnson and Denton 1975; Weatherby et al. 1992) and other areas of the West (Azuma and Overhulser 2008; Hadley and Veblen 1993; Klein and Bennett 1995; Lessard and Schmid 1990; Negrón et al. 2014; Wickman 1963, 1978b; Wright et al. 1984).

Bark beetle populations rise and continue killing trees for 2 to 3 years after the short-lived Douglas-fir tussock moth outbreak crashes. Generally, Douglas-fir beetle activity begins increasing during a Douglas-fir tussock moth outbreak when trees are over 80 percent defoliated, and peaks 1 to 2 years following the outbreak (Negrón et al. 2014; Weatherby et al. 1997). Some studies suggest that Douglas-fir trees completely defoliated (or nearly so) may not be the optimal host for beetle brood production because of loss of nutrients, with trees becoming a sink for beetles rather than a source (Fredericks and Jenkins 1988; Weatherby et al. 1997; Wright et al. 1979). Similarly, fir engraver populations increased in trees that were 80 percent defoliated; attacks by Douglas-fir tussock moth lasted 2 years, and 50 percent of attacks occurred on trees defoliated over 90 percent (Wright et al. 1984).

The attack pattern of Douglas-fir beetle and fir engraver following western spruce budworm outbreaks is less clear, perhaps because of the extensive duration and fluctuation of defoliation severity of western spruce budworm outbreaks. Douglas-fir beetle prefers to attack trees heavily defoliated by western spruce budworm (McGregor et al. 1983; Sturdevant et al. 2012). During both Douglas-fir tussock moth and western spruce budworm outbreaks, attacks occur at the tops of trees, making ground observations more difficult (Azuma and Overhulser 2008; Weatherby et al. 1997; Wright et al. 1984).

Site conditions, such as moisture, can influence bark beetle mortality associated with Douglas-fir tussock moth and western spruce budworm outbreak events. After a Douglas-fir tussock moth outbreak in British Columbia, Douglas-fir beetle played only a minor role as a mortality agent (Alfaro et al. 1987). However, a higher percentage of trees were killed by Douglas-fir beetle in eastern Oregon (Wickman 1978b) and central Idaho (Weatherby et al. 1992). Negrón et al. (2014) found no difference in Douglas-fir beetle attack level following light or heavy defoliation of Douglas-fir in Colorado; Douglas-fir beetle activity was attributed to dry site conditions. High host mortality during overlapping western spruce budworm and bark beetle outbreaks suggests that stand susceptibility to western spruce budworm epidemics may be an important precursor to Douglas-fir beetle outbreaks (Hadley and Veblen 1993). Overall, trees with over 90 percent defoliation appear to have a high probability of being killed by bark beetles, and dry sites, even with less defoliation, will be more attractive to bark beetles than wetter sites. In addition, Douglas-fir beetle populations can build in defoliated trees to infest other stressed trees (Wickman 1978b).

Changes in stand composition and structure can be influenced by defoliator events followed by bark beetle mortality. Stand trajectories are differently impacted by mortality caused by successive attacks of western spruce budworm and Douglas-fir beetle (Azuma and Overhulser 2008; Hadley and Veblen 1993). Hadley and Veblen (1993) suggested that stand structure altered by increasing mortality among the climax species would favor seral species such as lodgepole pine in Colorado. However, another study spanning the large western spruce budworm outbreak and associated Douglas-fir beetle and fir engraver mortality of the 1980s found that western spruce budworm host species stocking did not change over a 20-year period in Oregon and Washington (Azuma and Overhulser 2008). Azuma and Overhulser (2008) found that the number of trees severely defoliated was not related to any factors, such as aspect, slope, elevation, or climax tree species, other than the number of host trees available. Negrón et al. (2014) reported that stand trajectories were set back to a seral stage favoring ponderosa pine after Douglas-fir tussock moth and Douglas-fir beetle activity in Douglas-fir of the Colorado Front Range.

Changes in the Defoliator-Bark Beetle Dynamic in Response to Climate Change

Warming temperatures and altered precipitation regimes in the future could affect the incidence and duration of bark beetle attacks on defoliated trees because bark beetles target stressed trees. Warm and dry conditions occurring during defoliator outbreaks are likely to accelerate the loss of trees from bark beetles. Drought-stressed trees are likely to lose needles, and defoliation levels over 90 percent could increase, thereby increasing the potential for bark beetle attack. More frequent and severe wildfires will influence bark beetle response to defoliation events, primarily because bark beetle populations increase after wildfires and could be available to utilize pulses of defoliated hosts.

Bark Beetle and Disease Interactions

Bark beetles have the potential to affect forest pathogens, and vice versa. These interactions may be either direct or indirect (Paine et al. 1997; Parker et al. 2006). Insect vectors, for example, directly aid in the dissemination and introduction of pathogens into new host trees (Cardoza et al. 2008; Klepzig and Six 2004). Feeding insects may benefit nutritionally with pathogen colonization (Bentz and Six 2006). Conversely, fungi and other micro-organisms present in diseased or decaying wood may have antagonistic effects on invading insects (Cardoza et al. 2006; Six and Bentz 2003). Indirect effects on bark beetle and pathogen interaction typically occur through alterations to host trees and habitat (Parker et al. 2006).

Bark Beetle and Dwarf Mistletoe Interactions

Bark beetle-dwarf mistletoe interactions are complex and not completely understood, but they appear to vary with the specific dwarf mistletoe, bark beetle, and host condition. Dwarf mistletoes can increase or decrease the susceptibility of host trees to bark beetles, or have no effect at all (Hawksworth and Wiens 1996). Dwarf mistletoe-caused reductions in tree growth and phloem thickness in the bole may decrease mountain pine beetle performance. However, evidence for dwarf mistletoe infestation decreasing phloem thickness in lodgepole pine remains inconclusive (Agne et al. 2014). Shore et al. (1982) observed higher mountain pine beetle attack rates in lodgepole pines without dwarf mistletoe in British Columbia. In contrast, mountain pine beetle preferentially attacked ponderosa pine infected with dwarf mistletoe in Colorado (Frye and Landis 1975; Johnson et al. 1976; McCambridge et al. 1982). Although no relationships between mountain pine beetle and dwarf mistletoe were observed in areas where mistletoe infestation ratings were low, there was a significant positive trend in beetle attacks in stands with higher infestation ratings (Johnson et al. 1976).

Pine engraver beetles (*Ips* spp.) may preferentially attack ponderosa pine and pinyon pine heavily infested by dwarf mistletoe (Kenaley et al. 2006; Negrón and Wilson 2003). During periods of drought in the Southwest, *Ips* species primarily focused their attacks on suppressed and intermediate size classes of ponderosa pine heavily infected by dwarf mistletoe (Kenaley et al. 2008). Similarly, Douglas-fir beetles concentrated their attacks on heavily dwarf mistletoe-infested Douglas-fir during initial stages of a drought event in the Southwest (McMillin 2005); more than 60 percent of Douglas-fir trees having dwarf mistletoe ratings of 4 or greater (high infection) were killed by Douglas-fir beetles, whereas 30 percent of trees having a rating of 2 or less (low infection) were attacked. Most of the heavily infested trees were attacked just before or at the beginning of the drought, particularly the largest diameter trees; low to moderately infected trees were attacked later. These severely infected, large-diameter trees probably provided a reservoir of beetles during endemic population levels. However, trees of all infestation levels were attacked once populations increased to high levels.

Bark beetle outbreaks can also affect dwarf mistletoe dynamics, affecting tree growth within a stand. The net effect of bark beetle outbreaks on dwarf mistletoe is probably a moderate short-term reduction in stand-level dwarf mistletoe infestation, and a greater availability of resources for dominant and codominant trees, allowing them to release, and potentially become more tolerant of diseases or other stressors. In stands with heavy mistletoe infestation, changes in stand structure following bark beetle outbreaks can also facilitate dwarf mistletoe dissemination if surviving trees are infected by dwarf mistletoe. Increased incidence of dwarf mistletoe in post-outbreak stands can reduce growth and productivity and slow stand recovery over time (Agne et al. 2014; Shore et al. 1982). The magnitude of effects caused by the interactions between bark beetles and dwarf mistletoes is likely to intensify under both warmer/drier and warmer/wetter climates because of increased host tree stress, elevated tree mortality, and potential range expansion of dwarf mistletoes (Kliejunas 2011).

Bark Beetle and Root Disease Interactions

Root diseases have long been associated with endemic-level bark beetle populations and may serve as refugia for these populations (Tkacz and Schmitz 1986). Root disease-infected trees maintain endemic populations of mountain pine beetle and may help to trigger populations during the incipient phase of an outbreak (Geiszler et al. 1980; Goheen and Hansen 1993; Hunt and Morrison 1986). Hinds et al. (1984) showed a significant association between the presence of Armillaria root disease, bark beetle infestation, and ponderosa pine mortality under endemic conditions in the Black Hills of South Dakota; they found 75 percent of mountain pine beetle-infested trees had Armillaria root disease. Endemic populations of fir engraver also regularly attack and accelerate the death of root disease-infected white fir and grand fir trees (Goheen and Hansen 1993). However, other stressors such as drought, high stand density, and severe defoliation, may override this pattern (Guyon 1992). Many bark beetle species, including Douglas-fir beetle and spruce beetle, prefer to infest fresh downed trees with impaired defenses (Franceschi et al. 2005). Significant wind events in and adjacent to root disease centers can consequently result in substantial amounts of suitable host material for bark beetle colonization and brood production (Hebertson and Jenkins 2008). These interactions may become more pronounced under warmer and drier climates, as forests affected by root disease become further stressed by drought, and become more susceptible to bark beetle attack (Allen et al. 2010).

Bark Beetle and White Pine Blister Rust Interactions

The combination of white pine blister rust and mountain pine beetle has already caused major population changes in white pines in the western United States (Keane and Arno 1993; Loehman et al. 2011a). Schwandt and Kegley (2004) found that mountain pine beetles were more likely to attack blister rust-infected whitebark pines when populations were at endemic levels, but this selection pattern was reversed when populations were at epidemic levels. Similarly, Dooley and Six (2015) suggest that preference of mountain pine beetle for blister rust-infected trees is likely to be curvilinear, with beetles initially responding positively to increasing infection severity, then showing a negative response when severity becomes high. However, others have found that mountain pine beetles preferred whitebark pines stressed by white pine blister rust and preference increased as infection increased (Bockino and Tinker 2012; Six and Adams 2007).

Climate change has resulted in an increase in areas thermally favorable to bark beetle reproductive success in whitebark pine ecosystems (Bentz et al. 2016; Bockino and Tinker 2012). Larson (2011) concluded that where blister rust infections were most severe prior to the recent mountain pine epidemic, the effects of both disturbances could be amplified and impacts on whitebark pine increased. During recent severe mortality of whitebark pine and limber pine caused by mountain pine beetle and secondary bark beetles, many potentially blister rust-resistant or -tolerant trees were killed. This could result in decreased whitebark pine regeneration and potentially the accelerated loss of the species. However, in areas where moderate blister rust infections occurred before the mountain pine beetle epidemic, the combined effects of the disturbances may result in increased resistance to blister rust, because beetle attacks may be focused on rust-infected trees. In summary, climate-rust-beetle interactions now and in the future are complex and not uniform (Larson 2011).

Insects as Vectors of Pathogens

In the IAP region, black stain root disease is caused by *Leptographium wageneri* var. *wageneri* on pinyon pines, and *L. wageneri* var. *ponderosum* on Jeffrey and ponderosa pines. The fungus causing this root disease is vectored in part by root-feeding bark beetles and other insects (Bishop and Jacobi 2003; Goheen and Cobb 1980; Harrington et al. 1985). The biology of these beetles is not well known, but they have been shown to attack the roots of drought-weakened pines (Goheen and Hansen 1993). In turn, black stain root disease on ponderosa pine has been demonstrated to predispose trees to attack by other bark beetles (both *Dendroctonus* and *Ips* spp.), either through increased attraction or reduced resistance of weakened, infected trees (Goheen and Hansen 1993). Successful vectoring of the fungus by root-feeding bark beetles may be dependent on moisture conditions, with both beetles and fungi favoring high soil moisture.

Summary

The interactions between bark beetles and disease represent important and complex forest ecosystem dynamics that can have an array of impacts on the structure and function of our forests. Climate change will have demonstrable impacts on the frequency and intensity of bark beetle and disease outbreaks, particularly at the margins of host ranges and in interactions facilitated by stress on host ecosystems (Kliejunas 2011). Although episodic mortality has occurred historically, some ecosystems may already be responding to climate change. Forests may become increasingly vulnerable to higher tree mortality rates and die-off in response to future warming and drought in the presence of forest insects and diseases, even in environments that are not normally considered water limited. This greater vulnerability further suggests risks to ecosystem services, including the loss of sequestered forest carbon and associated atmospheric feedbacks (Allen et al. 2010).

Fire and Nonnative Pathogens

The most important nonnative tree disease in the IAP region is white pine blister rust (Smith and Hoffman 2000). Climate change could indirectly affect white pine blister rust by changing the geographic range of both the pines and the alternate (*Ribes*) host. Both hosts may become exposed to inoculum earlier or later in the year. The physiology of both hosts would be different at these different times of the year, possibly changing susceptibility. Resistance may change during different stages of a host's seasonal growth or under changing temperature regimes (Sniezko et al. 2011) (see also the *White Pine Blister Rust* subsection above).

With warming, fires are currently projected to increase in size, frequency, and intensity (Flannigan et al. 2000; Westerling et al. 2011). These changes in fire may facilitate regeneration of white pines (Loehman et al. 2011a). Conversely, drought conditions may inhibit regeneration (McCaughey and Weaver 1990; Tomback et al. 1993). There is documentation of unsuccessful postfire regeneration in Colorado, even in stands previously dominated by limber pine with suitable conditions and a nearby seed source, and stand-replacing fires could cause extirpation of some limber pine populations (Huckaby 1991; Shankman and Daly 1988).

A study in Colorado illustrates the differences in patterns of reproduction in limber pine as compared to Great Basin bristlecone pine after fire-caused disturbance (Coop and Schoettle 2009). The study concludes that regeneration of bristlecone and limber pine may benefit from increases in natural disturbance, but that beneficial responses may require many decades. Regeneration can occur only if seed source and dispersal are present; survival will occur only if seedlings establish and can survive climatic stresses and the local frequency of fires. In addition, *Ribes* populations may increase after fire through regeneration by seed and sprouting from roots and rhizomes. However, re-burns soon after an initial fire can eliminate regenerating *Ribes* bushes before they can develop a seed bank for the next forest regeneration cycle (Zambino 2010).

White pines exist in multiple forest types and fire regimes, but most exist in infrequent, mixed- and high-severity fire regimes. The implications of changes in fire regimes in forests containing white pines threatened by white pine blister rust have been reviewed extensively for whitebark pine, the species that is currently at the highest risk (Keane and Arno 1993; Loehman et al. 2011b). In whitebark pine stands, fire can reduce shade-tolerant understory species such as fir, reduce rust- and beetle-infested older trees, promote stand conditions that favor whitebark pine seedlings, and provide openings for animals to plant seeds and facilitate plantings of rust-resistant seedlings (Keane and Parsons 2010; Trusty and Cripps 2011). In a modeling study based on Northern Rockies conditions, Loehman et al. (2011) predicted that the rate of canopy gap production could occur at a high enough rate to allow western white pine (*Pinus monticola*) regeneration to survive, despite pressure from white pine blister rust. The few stands of western white pine and sugar pine (*Pinus lambertiana*) in the IAP region may be sufficiently different that the model parameters used for predicting trends are not applicable. Severe fires may reduce mycorrhizal communities and populations to the point that establishing white pine regeneration, either planted or natural, becomes very difficult, but more frequent low-severity fires have not appeared to affect mycorrhizae (Trusty and Cripps 2011). Severe fire that kills rust-resistant pine trees may ensure continued high rust-induced mortality in the future, because it dampens the rate of rust-resistant adaptations (Keane et al. 2012). Alternatively, where rust-resistant five-needle pines survive fire, they may provide the seeds for populating future landscapes that are resilient to both rust infection and fire mortality.

As white pine blister rust slowly kills pine trees, dead foliage and wood added to the fuel bed may increase fire intensity, which may then increase tree mortality (Loehman et al. 2011a). In stands dominated by five-needle pines, white pine blister rust infection often results in the slow, progressive thinning of the shade-intolerant pine overstory, allowing shade-tolerant competitors to occupy the openings. This creates substantially different canopy fuel conditions, such as lower canopy base heights, higher canopy bulk densities, and greater canopy cover, which facilitate more frequent and intense crown fires (Keane et al. 2002; Schwandt et al. 2010).

Conclusions

Ongoing and projected climate change for geographic areas encompassed by the IAP indicates a likelihood of varied shifts and changes to important disturbance regimes. Ecological disturbances are often specific to particular vegetation communities, elevations, and geographic areas. However, we acknowledge there is a lack of information for many of the multifaceted biological systems we have discussed in this chapter. The geographic and ecological diversity of the IAP region adds to the complexity of changes in the timing, magnitude, frequency, and duration of disturbance events, as well as the interactions of disturbances on a landscape**.** Climate-caused variations to ecological disturbances are difficult to describe without fully understanding how the changes will affect vegetation on our landscape (Chapters 6, 7). Although high levels of uncertainty exist, expected increases in disturbances, such as wildland fire, can and often do lead to specific changes in biodiversity and habitat heterogeneity (Grime 1973; McKinney 1998), affecting additional agents of change (i.e., invasive species, insects, and geologic hazards) and their respective interactions.

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Chapter 9: Effects of Climate Change on Terrestrial Animals

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Introduction

Climate Change and Terrestrial Species

The Intermountain Adaptation Partnership (IAP) region encompasses a high diversity of grassland, shrubland, and forest habitats across a broad range of elevational gradients, supporting high biodiversity in the interior western United States. Terrestrial species comprise a wide range of life forms, each expressing varying levels of habitat specialization and life history traits. Species exist within complex communities that have formed over time through a long process of adaptation and coevolution. Over the last century, this balance has been disrupted first by human-induced changes to fire regimes and land conversion, and more recently by climate change.

Currently, the IAP region is facing unprecedented rates of change in climatic conditions that may outpace the natural adaptive capacities of some native species (box 9.1). Climate change is expected to alter the structure and composition of plant and animal communities and destabilize some of the properties and functions of existing ecosystems (box 9.1). The nature of climate change, which includes increased variability and more extreme conditions, will favor species adapted to frequent disturbance and potentially increase the abundance of invasive species. Limited water availability will be exacerbated as higher temperatures increase evaporation rates and human consumption (Chapter 3 and box 9.2). Despite a growing body of science, the magnitude and likelihood of some climate effects remain uncertain. Abrupt changes in conditions are likely to vary across landscapes, and species will vary in their sensitivity to climate. Climate also influences dynamic processes such as wildfire and insect outbreaks, as well as interactions between disturbances.

Climate effects for terrestrial species can be considered in four categories:

- **Habitat loss and fragmentation** are already increasing in animal populations, and the location and condition of suitable habitats will be further altered by changes in temperature and precipitation (Ibanez et al. 2008; McCarty 2001; Sekercioglu et al. 2008).
- **Physiological sensitivities** are typically considered innate characteristics of a species that influence how well it may cope with changing temperature and precipitation conditions.
- **Alterations in the timing of species life cycles** that result from changes in seasonal temperature and precipitation regimes have direct impacts on migration, hibernation, and reproductive success.
- **Indirect effects** on species occur through disruption of predator-prey, competitor, and mutualistic interactions within and across communities.

In the short term, climate-related changes will affect food, cover, and nest site availability. Decreased plant productivity during droughts will reduce food supplies and seed dispersal by small mammals and birds within forest habitats (McKinney et al. 2009; Tomback and Achuff 2010). Habitat changes are expected to reduce roost and nest sites as plant mortality increases because of the interactive effects of drought, wildfire, and insects. Abiotic features of habitat, such as snowpack, are also likely to change, causing negative impacts for snow-dependent species (McKelvey et al. 2011; Murray et al. 2008). Over longer time periods, shifts in habitat are likely to disrupt many communities as the distribution and abundance of species change in response.

Species may respond to habitat changes by moving into more favorable ranges or otherwise adapting, or by going extinct. Shifting habitats can be inaccessible to species with low dispersal ability, and migratory species will be exposed to disparate changes across a large geographic area (Jiguet et al. 2007; Visser 2008). In the absence of adaptation, losing favorable habitat can reduce fitness and abundance, with effects on biodiversity (Settele et al. 2014). Even where species are capable of shifting habitats, there is no certainty that new habitats will effectively fill the roles in current established forests. In the northeastern United States, some bird species in spruce-fir forests have shifted to lower elevations in response to climate change, but these “new” habitats are marginal, so populations may encounter low reproductive success (DeLuca 2012; DeLuca and King 2017).

Physiological requirements and limitations related to temperature and moisture determine critical components of energetics, survival, and reproduction in animal species (Bernardo and Spotila 2006; Helmuth et al. 2005; Sinervo et al. 2010). A species can tolerate the range of new ambient conditions, be more restricted in activity, or be subject to more extreme climate-related events such as fires or storms

Box 9.1—Summary of Effects of Climate Change on Terrestrial Animal Species

Conservation of important natural resource values, including biodiversity, will be increasingly difficult as community compositions begin to shift in response to climatic changes. The ability of terrestrial species to respond successfully to climate change depends on their sensitivity to expected climatic conditions, innate capacity to deal with change, ongoing threats and issues that reduce resilience, and capacity for management to reduce negative impacts.

Climate impacts for terrestrial species can be considered in four categories:

- **Habitat loss and fragmentation**, which are already major driving forces in declining animal populations. The location and condition of suitable habitats will be further altered by changes in temperature and precipitation (Ibanez et al. 2008; McCarty 2001; Sekercioglu et al. 2008).
- **Physiological sensitivities** or areas of resilience. These are typically innate characteristics of a species that influence how well it may cope with changing temperature and precipitation.
- **Alterations in the timing of species life cycles** resulting from changes in seasonal temperature and precipitation regimes. Changes in life-cycle timing have direct impacts on migration, hibernation, and reproductive success.
- **Indirect effects on species** through disruption of predator-prey, competitor, and mutualistic interactions within and across communities. These effects will be profound and the most difficult to predict.

Effects of Habitat Change

- The literature describes a dynamic future resulting from multiple processes both physical (hydrology, soils) and biological over short and long time scales. Warming trends and shifts in seasonal precipitation patterns and temperatures will exert considerable control over soil moisture, plant regeneration, disturbance regimes, and the presence of disease and pest and invasive species.
- Altered tree species distribution and abundance have important implications for availability of cover and food resources for animal species. In the immediate future, reduced cone production and loss of mature, cone-producing trees as a result of drought, wildfire, and insect outbreaks will limit food resources, especially in high-elevation forests. Over longer time periods, shifts in tree species composition will affect nest site availability and predator-prey dynamics in animal communities.
- Climate change will facilitate range shifts within many habitats and in particular, an uphill migration of many tree species. For some animal species, these shifts may represent an expansion of suitable habitat, but for others, shifts will represent significant declines in habitat distribution.
- Abiotic changes in snowpack amount and duration will be an important determinant of species response in most forested habitats. For snow-dependent species such as wolverine and lynx, these changes mean a reduction in winter habitat. For ungulates, lower snowfall increases areas available for winter forage. Reduced snowpack may also limit physiological protection provided by winter and spring snowpack.
- Climates suited to shrublands and grasslands are projected to expand over the next century, although uncertainty exists about which communities will persist in the future. Considerable change in plant species composition and structure are likely because of the combined effects of drought, fire, invasive annuals, and changes in the timing of precipitation events.

Species Assessments

Flammulated owls, wolverines, and greater sage-grouse were the most vulnerable species assessed in this analysis. Utah prairie dogs and American three-toed woodpeckers were the least vulnerable with total scores indicating a relatively neutral response to expected changes. Habitat and physiology scores varied the most among the species assessed, and altered phenology was a common issue for most species. Habitat loss was often an issue for species restricted to high elevation or habitats associated with surface water.

Conclusions

Potential shifts and loss of habitat and habitat features as a result of climate change have both short-term and long-term implications for wildlife species. It is difficult to say with certainty which climate influences will have the greatest effects on habitats and terrestrial species. However, our extensive review of the scientific literature and use of state-of-science vulnerability assessment tools have identified the habitats and wildlife that are most likely to be affected either positively or negatively in a warmer climate.

Box 9.2—Summary of Expected Future Climatic and Hydrological Conditions

- Increased mean annual temperature and warming in all seasons (Diffenbaugh and Giorgi 2012; Romero-Lankao et al. 2014)
- Increased occurrence of extremely hot seasons and warmer summers (Diffenbaugh and Giorgi 2012; Romero-Lankao et al. 2014)
- Decreased snowfall and snowpack, and winter precipitation falling as rain instead of snow (Diffenbaugh and Giorgi 2012)
- Variable precipitation patterns during the year, increased frequency of extreme storms and shift in precipitation events and amounts (Doesken et al. 2003; Worrall et al. 2013)
- Decreased precipitation for some areas, particularly winter precipitation for the American Southwest (Seager and Vecchi 2010; Seager et al. 2007)
- Increased number of hot days, increased drought frequency, and greater frequency of warm, dry summers (Allen et al. 2010; Drake et al. 2005; Gutzler and Robbins 2011; Romero-Lankao et al. 2014; Sheffield and Wood 2008)

(Walsberg 2000). Aestivation, torpor, inactive life stages, and low metabolic rates can improve the adaptive capacity of a species to cope with fluctuating resources (Bronson 2009; Humphries et al. 2002). In addition, more variable and extreme weather can have positive effects on availability of ephemeral water bodies, maintenance of some spawning habitats, and prevention of encroachment of woody plants.

Species whose phenology or timing of activities (e.g., reproduction, migration) is triggered by temperature or moisture cues may be at a disadvantage in a changing climate. When life events become unsynchronized with critical resources or favorable conditions, survival and reproduction decline (Both et al. 2006). Species at the greatest risk of timing mismatch are those that migrate over long distances, obligate hibernators, and species that rely on ephemeral resources. Warmer temperatures are leading to earlier snowmelt, plant green-up, and flowering (Romero-Lankao et al. 2014; Settele et al. 2014), with substantial consequences for terrestrial species. In the IAP region, spring advancement has led to breaks in hibernation (Ozgul et al. 2010), earlier flowering (Hülber et al. 2010; Lambert et al. 2010), earlier arrival dates for migratory birds (Thorup et al. 2007), and decoupling of community phenological behavior (Both et al. 2010; Parmesan 2006; Thackeray et al. 2010).

Earlier spring growth and a longer growing season (Settele et al. 2014) could lead to increased habitat and forage availability and longer breeding seasons for some species. However, ungulates and small mammals are known to be particularly sensitive to the timing and duration of plant phenology (Senft et al. 1987), and it is unclear how current trends will affect them. Earlier snowmelt can also decrease floral resources, thus affecting insect population dynamics and pollinators (Boggs and Inouye 2012; Gilgert and Vaughan 2011). Species with the capacity to engage in irruptive migration or explosive breeding will be least affected by increased resource variability (Visser et al. 2004). Longer, more flexible, and more productive reproductive periods are also beneficial traits for coping with variable and unpredictable conditions, although species with short reproductive periods may be favored during drought (Chessman 2013; Jiguet et al. 2007).

Individual species response to climate change may have ramifications for entire communities by affecting predator-prey relationships, disease, pollination, parasitism, or mutualism. Gradual warming and variable precipitation could reduce resources in favor of diet and habitat generalists; local extinctions and range shifts have been documented in small mammals (Morelli et al. 2012; Moritz et al. 2008; Rowe 2009; Rowe et al. 2011). Generalist species can switch to different prey or host species and thus are not as sensitive to changes as species with more restricted diets (Chessman 2013). These changes in biotic interactions can further alter vulnerability if tied to survival or reproduction (Freed et al. 2005; Gilman et al. 2010; Memmott et al. 2007). In the IAP region, climate-related changes in snowpack and pine cone production will probably affect predator-prey and competitive interactions between snowshoe hares and Canada lynx (Murray et al. 2008), and between boreal owls and martens (Boutin et al. 1995), as well as between keystone species such as red squirrels (fig. 9.1) and Clark's nutcrackers. Ultimately, species composition among habitats may change under new selective pressures. Unless otherwise specified, common and scientific names for all species mentioned in this chapter are given in Appendix 9.

Finally, it is important to note that some climate-related habitat changes will benefit terrestrial species. Elevated carbon dioxide levels and warmer temperatures can enhance the growth of some plants and lengthen the growing season, providing more forage or longer breeding periods (Morgan et al. 2001). Reduced snowpack in quaking aspen and higher elevation habitats could provide increased winter range for ungulate species. Tree damage and mortality caused by drought and insect outbreaks can increase insect food sources and lead to more down woody debris, which provides cover for many species (Hahn et al. 2014). Disturbances

Figure 9.1—Red squirrel. This keystone species depends on pine cones as a food source and provides food for other species by caching cones (photo: U.S. Fish and Wildlife Service)

from climate change or nonclimate stressors that create standing snags and large woody debris can benefit cavity-dwelling animals in the short term. However, these benefits may be short lived because a shift to early-seral forests will ultimately reduce important habitat components for these species (Weed et al. 2013).

Climate Change Assessment for Habitat

In this assessment, we identify critical needs and opportunities for terrestrial species under expected climate change. First, we review the literature to identify the major effects of climate change for wildlife within specific habitats in the IAP region. Second, we use an index-based vulnerability assessment system to quantify vulnerability for 20 species.

Potential shifts and loss of habitat and habitat features as a result of climate change have both immediate and long-term implications for wildlife species. The following discussion considers the many ways in which forests, woodlands, and nonforest habitat are likely to be influenced by climatic changes, and summarizes our knowledge of the consequences of those changes for wildlife within specific vegetation types. It is difficult to say with certainty which climate influences will have the greatest effects on ecosystems and associated terrestrial species. Through reviewing the scientific literature, however, we can begin to identify the ecosystems and wildlife that are most likely to be affected either positively or negatively under warmer conditions.

The literature depicts a dynamic future resulting from multiple biophysical processes over short and long timescales. Warming trends and shifts in temperature and seasonal precipitation patterns will exert considerable control over soil moisture, plant regeneration, disturbance regimes, and the presence of diseases and invasive species. We cannot at this time predict what these effects, which also interact, will mean for future habitat and wildlife nonforest community composition, although these conditions will probably be different from those that have occurred in the past.

Forest Vegetation

We have considered climate-related effects for six forest types as defined by the U.S. Department of Agriculture Forest Service (USFS) Intermountain Region (Chapter 6). The range of potential effects to any one of these types varies, as does the potential effect (positive or negative) for the constituent species within the habitats. To understand potential species response to climate, we must consider both direct effects related to environmental conditions (e.g., heat waves, snowpack) and indirect effects arising from the alteration of forest composition and distribution. Because tree species have varying capacities to adapt to climate change and wildfire, significant changes in the structure, composition, and distribution of forests are likely.

Subalpine Pine Habitat

Subalpine whitebark pine communities provide food, cover, and nesting sites for a diversity of terrestrial species (table 9.1). Pine seeds are a major food source for many birds and mammals, including Clark’s nutcrackers, Steller’s jays, common ravens, mountain chickadees, red-breasted nuthatches, pine grosbeaks, Cassin’s finches, chipmunks, golden-mantled ground squirrels, red squirrels, black bears, and grizzly bears (Tomback and Kendall 2001). Dusky grouse are highly dependent on subalpine pine communities, where they roost in dense crowns of whitebark pine, feed on needles and buds, and obtain shelter from wind and predators (Andrews and Righter 1992).

Altered distribution and abundance of tree species will affect many animal species (box 9.3). Climate change is likely to alter the effects of invasive species, such as cheatgrass, accelerate the migration of twoneedle pinyon and junipers into bristlecone pine areas (Van de Ven 2007), and shift the relative dominance of whitebark pine and bristlecone pine (Briffa et al. 2008; Gibson et al. 2008; Salzer et al. 2009) (Chapter 6). Fire exclusion that accelerates succession and the establishment of other conifer species, such as Douglas-fir, Engelmann spruce, and subalpine fir (Tomback and Achuff 2010), results in loss of food, structural heterogeneity, shelter, cover, and ultimately the biodiversity of subalpine habitats (Smith 1990). Climate-related changes to forest composition will alter competition for nest sites, cavities, and food (Bunnell 2013), as well as other species interactions.

Table 9.1—Terrestrial vertebrates that depend on subalpine whitebark pine habitat for at least part of their life cycle (Lonner and Pac 1990; Tomback 1978; Tomback and Kendall 2001).

Terestrial vertebrate group	Associated species
Raptors	Cooper's hawk, golden eagle, great horned owl, northern goshawk, prairie falcon, red-tailed hawk
Long- and short-distance migratory birds	Allen's hummingbird, common nighthawk, downy woodpecker, hairy woodpecker, mountain bluebird, western tanager, white-throated swift
Mammals	American marten, bighorn sheep, bushy-tailed woodrat, Canada lynx, common porcupine, coyote, elk, mountain lion, mule deer, snowshoe hare, yellow-bellied marmot, wolverine

Loss of trees through these mechanisms will also result in less shade and cover, fewer snowdrifts, and earlier snowmelt (Means 2011). A change in snow cover dynamics may reduce populations of snowshoe hare, a key prey for Canada lynx (Murray et al. 2008; Squires et al. 2010). Climate-related changes to subalpine pine and spruce-fir forests will probably reduce food and nest resources for the boreal owl through several mechanisms (Bunnell 2013) (box 9.3).

Mutualisms may also be disrupted where warm, dry conditions may cause species range shifts in mammals and birds that are important seed dispersal agents (Tomback and Kendall 2001). For example, regeneration of whitebark pines after wildfire is largely from seed caches left by Clark's nutcrackers (Lanner 1996; Lanner and Vander Wall 1980). Whitebark pine depends nearly exclusively on nutcrackers for dispersal, although nutcrackers will feed on and cache seeds from other pines (limber pine, bristlecone pine) that co-occur with whitebark pine. Plasticity in foraging behavior of the nutcracker may enable it to survive range shifts in suitable habitat, but potentially to the detriment of whitebark pine, which could undergo reduced regeneration, dispersal to other areas, and reduced genetic variability

Box 9.3—Potential Effects of Climate-Related Changes on Subalpine Pine and Subalpine Spruce-Fir Habitats for Terrestrial Species

- Declines of forest types at high elevation will result in fewer microhabitats for plants and animals, including blue grouse (Andrews and Righter 1992), and may depress populations of Neotropical migrants such as western tanagers, flycatchers, warblers, and finches (Pyle et al. 1994).
- Altered food supplies and seed dispersal abilities of small mammals and birds will occur with increasing tree damage and mortality and reduced cone production (McKinney et al. 2009; Tomback and Achuff 2010).
- Increased wildfire and insect outbreaks could diminish late-successional dense canopy forests preferred by northern goshawks and American martens (Graham et al. 1999; Kennedy 2003).
- Coarse woody debris left from disturbance may benefit American martens (Buskirk and Ruggiero 1994), although decreased habitat and population connectivity are likely for this species (Wasserman et al. 2011).
- Increased tree mortality and downed wood from wildfire and insect outbreaks may increase nesting sites for species such as American three-toed woodpeckers (Wiggins 2004) and red-breasted nuthatches that use tree snags (Bunnell 2013). Drought-related outbreaks of insects such as wood-boring beetles will also benefit American three-toed woodpeckers (Hansen et al. 2010).
- Boreal owl nest success and survival are tied to prey abundance, so warmer and drier conditions that decrease small mammal populations will negatively affect owl populations (Hayward 1989; Hayward and Verner 1994).
- Snow crusting from repeated freeze-thaw cycles hinders winter hunting of boreal owls, which dive through snow to capture prey (Hayward and Verner 1994).
- Reduced spring snow cover will reduce availability and increase fragmentation of habitat for wolverines, which need snow cover and cool summer temperatures for denning (Copeland et al. 2010; Peacock 2011). Without persistent spring snow cover, wolverine populations may not be able to survive and reproduce successfully (Brodie and Post 2009; McKelvey and Copeland 2011; Peacock 2011).
- Reduced snowpack will reduce suitable nesting habitats and cover for snowshoe hares (Murray et al. 2008).
- Decreased snowpack will reduce habitat quality for Canada lynx and snowshoe hares (Squires et al. 2010, 2013).

(Tomback and Kendall 2001; Tomback and Linhart 1990). Furthermore, reduction in pine seed production means more competition for this resource among birds, squirrels, and other mammals, and a greater chance of species consuming the seeds instead of caching or storing them. Whitebark pine provides an important seed food source for grizzly bears and red squirrels (themselves a prey source for grizzlies), and populations may suffer with increased tree mortality (Mattson and Reinhart 1996). With a reduction in seed availability in the subalpine zone in late summer and fall, grizzly bears will wander farther in search of food, very likely increasing their encounters with people (Mattson et al. 1992; Tomback and Kendall 2001).

Subalpine Spruce-Fir Habitat

Spruce-fir forests provide cover and nesting sites for a diversity of species (table 9.2). Numerous studies point to the importance of structurally diverse stands for supporting biodiverse communities. Standing snags and down woody debris are important habitat features that provide cavities for birds and small mammals (Bunnell 2013; Scott et al. 1978), especially for boreal owls, American three-toed woodpeckers (Klenner and Huggard 1997; Leonard 2001), and red-breasted nuthatches (Bunnell et al. 2002). American three-toed woodpeckers prefer mature, old-growth forests with insect-infested snags and dying trees (Klenner and Huggard 1997; Leonard 2001). Red-breasted nuthatches nest in trees broken off by heart rot and wind (Bunnell et al. 2002). American martens, fishers, and black bears use tree cavities formed by fungi and decay or fire (Bunnell 2013). Dense stands also provide ample shade during summer for ungulates, small mammals, birds, and bears (Blanchard 1980). Dusky grouse overwinter in subalpine spruce-fir and rely on the dense cover to escape predators (Schroeder 1984). Both Canada lynx and snowshoe hares prefer older spruce-fir forests with dense understory canopies for cover, foraging, and denning, especially habitats with ample winter snow cover (Squires et al. 2010, 2013).

These forests provide important browse and forage in addition to nesting and cover sites. Engelmann spruce is browsed when other food resources are scarce (Alexander 1987). Spruce grouse and dusky grouse feed on buds and needles of spruce and fir (Schroeder 1984; Steele et al. 1981), and spruce seeds are consumed by small mammals and birds (Alexander 1987; Youngblood and Mauk 1985). Red squirrels are known to store spruce and fir seeds in middens (Lanner 1983; Uchytil 1991). Subalpine fir is a minor browse for mule deer, elk, bighorn sheep, and snowshoe hares, but a major food source in winter and spring for mountain goats (Saunders 1955) and in winter for moose (Peek 1974). In Yellowstone National Park, grizzly bears are known to strip away bark and eat the cambium of subalpine fir (Blanchard 1980); huckleberries associated with subalpine fir are a critical food for grizzly bears (Contreras and Evans 1986).

Spruce-fir forest distributions and the presence of important habitat features such as snags and downed wood are likely to change given the likelihood for an increase in fire frequency with drought and faster snowmelt. Some vegetation projections show movement of spruce and fir into alpine areas (Decker and Fink 2014). Climate and nonclimate stressors may increase white fir and Douglas-fir regeneration over ponderosa pine at low-elevation sites and increase Engelmann spruce and subalpine fir at high-elevation sites (Battaglia and Shepperd 2007; Fulé et al. 2002; Jenkins et al. 1998). Spruce and fir growth is reduced when snowpack is low (Hu et al. 2010), but a warmer, longer growing season may improve seedling survival, provided there is shade (Moir and Huckaby 1994).

Species-habitat interactions in spruce-fir forests are affected through changes in food and shelter for terrestrial species (box 9.3). Tree damage and mortality can affect food supplies and the seed dispersal abilities of small mammals and birds. Changes in tree mortality may cause declines in suitable nesting habitats for some species such as northern goshawk (Graham et al. 1999; Kennedy 2003), but an increase in nesting sites for others such as the American three-toed woodpecker and red-breasted nuthatch that use tree snags and down woody debris (Bunnell 2013; Wiggins 2004). Climate-related changes in primary cavity nesters will also influence availability and competition for cavity nest sites (Hayward and Hayward 1993).

Spruce-fir forest provides critical microclimates for wolverines and boreal owls, both of which have low temperature thresholds and rely on cooler habitats during the summer (Copeland et al. 2010). Warming will negatively affect both species through this limiting factor, especially at the southern edge of their range (Copeland et al. 2010; Hayward 1997; Hayward and Verner 1994; McKelvey et al. 2011; Peacock 2011). Loss of trees will reduce shade and cover, reduce the number of snowdrifts, and lead to earlier snowmelt with direct effects on species that rely on snow cover (box 9.3).

Table 9.2—Specific resources provided by spruce-fir forest for terrestrial species.

Browse, cover	Nesting, cover, foraging	References
Mule deer, elk, moose, bighorn sheep, mountain goat, woodland caribou (northern Idaho), black bear, grizzly bear, snowshoe hare, northern flying squirrel, red squirrel, porcupine, American marten, fisher, Canada lynx, mice, voles, chipmunks, shrews	Northern goshawk, boreal owl, great horned owl, northern flicker, woodpeckers, flycatchers, kinglets, nuthatches, dark-eyed junco, thrushes, chickadees, crossbills, pine siskin, sapsuckers, brown creeper, dusky grouse, sooty grouse, spruce grouse	Scott et al. 1982; Steele et al. 1981; Uchytil 1991

Creation of open space resulting from tree mortality within spruce-fir forests may encourage other species to move in and may thus disrupt predator-prey relationships and competitive interactions. For example, red-tailed hawks, great horned owls, and long-eared owls can take over northern goshawk nesting sites (Graham et al. 1999). Loss of mature spruce-fir forests and change in snow cover dynamics may reduce populations of snowshoe hare, a key prey species for Canada lynx (Murray et al. 2008; Squires et al. 2010). Red squirrel midden activity declines following drought and wildfire (Mattson and Reinhart 1996), thereby reducing food resources for grizzly bears.

Climate-related changes to spruce-fir habitat will probably reduce food and nest resources for boreal owls through several mechanisms (Bunnell 2013). Boreal owls and American martens prefer mesic over drier spruce-fir forests because of their preferred prey, red-backed voles (Buskirk and Ruggiero 1994; Hayward 1989), which forage on fungal species found in mesic habitats (Rhea et al. 2013). Boreal owl populations are directly related to prey abundance, and warmer and drier conditions that reduce vole numbers may negatively impact nest success and bird survival (Hayward 1989; Hayward and Verner 1994). American marten predation on owls and nests also increases when vole abundance is low (Hayward and Hayward 1993).

Lodgepole Pine Habitat

Lodgepole pine habitat provides cover for mule deer, elk, moose, ruffed grouse, and small mammals and birds (Anderson 2003; Boccard 1980). The value of cover changes throughout the year and by successional stage. Mature, closed-canopy forests provide little forage but excellent cover, whereas open, immature stands support understory growth of grasses, forbs, and shrubs (Ramsey and West 2009). In Utah, lodgepole pine forests are critical summer habitat for mule deer, elk, and Rocky Mountain bighorn sheep, and crucial winter habitat for moose (Baldwin and Banner 2009). Northern goshawks nest in lodgepole pine canopies; lodgepole pine forest communities with mature, large trees are considered high-quality habitat for breeding (Graham et al. 1999). Down woody debris provides cover and drumming sites for ruffed grouse (Boag and Sumanik 1969; Hungerford 1951). Dense lodgepole stands in Washington State with abundant snowshoe hares were the preferred habitat for Canada lynx (Koehler 1990).

Palatability of lodgepole pine is poor, and trees are often browsed only when other food is scarce (Alexander 1986; Kufeld et al. 1973; Ritchie 1978). Snowshoe hares, pocket gophers, voles, squirrels, porcupines, and black bears feed on cambium because the bark is thin and easy to remove (Alexander 1986; Boccard 1980; Sullivan 1985). Foraging on seedlings and saplings by mammals can reduce growth and regeneration and cause significant damage and mortality in lodgepole pine (Barnes 1974; Ferguson 1999; Koch 1996; Sullivan 1985; Sullivan et al. 1993). Mountain pine beetle larvae are a good source of food for woodpeckers (Bull 1983). Pine seeds are an important food for red crossbills, red squirrels, dusky grouse, spruce grouse, and other mammals and birds (Anderson 2003; Benkman 1999; Benkman et al. 2003). Red squirrels are a significant seed predator (Benkman 1999; Lotan and Critchfield 1990).

Vulnerability to climate-related disturbances is likely to be greatest for lodgepole pine at the southern edge of its distribution (western Nevada, northeastern Utah). Typically, lodgepole pine will dominate subalpine spruce-fir after a stand-replacing fire, and will eventually be succeeded by aspen or Engelmann spruce, or both, if a viable seed source is available (Stahelin 1943). Pine beetle outbreaks are likely to increase in a warmer climate, and beetle-related mortality is likely to increase under more arid conditions. Declines in lodgepole pine could reduce food supplies and seed dispersal abilities of small mammals and birds.

Mortality of lodgepole from beetle attacks will reduce critical thermal cover and important winter forage for moose (Ritchie 1978; Wolfe et al. 2010a). Reduced lodgepole pine forage can induce vitamin E or selenium deficiency, leading to lameness, excessive salivation, and death from heart degeneration (Blowey and Weaver 2003; Flueck et al. 2012; Wolfe et al. 2010b). Loss of trees will also affect northern goshawk habitat over time. Goshawk will continue to nest in forests with up to 80-percent beetle-killed trees as long as trees are standing, but as trees start to fall, habitat value for goshawk declines (Graham et al. 1999). Loss of trees and fragmentation of mature forests, especially near riparian areas, will affect American marten habitat (Buskirk and Powell 1994; Zielinski 2014).

Down woody debris from insect outbreaks creates cover for many species (Hahn et al. 2014) including golden-mantled squirrel and northern flying squirrel (Saab et al. 2014). Beetle-killed forests benefit cavity-nesting birds (American three-toed, downy, pileated, and hairy woodpeckers, mountain chickadee, red-breasted nuthatch, house wren) and those nesting in understory shrubs (chipping sparrow, yellow warbler, Swainson’s thrush, flycatchers). Mountain pine beetle outbreaks provide food (beetles and beetle larvae) for bark-drilling woodpeckers, such as American three-toed woodpeckers and black-backed woodpeckers (Saab et al. 2014). Serotiny and dropping of unopened cones triggered by warm, dry conditions after a mountain pine beetle infestation may benefit ground-foraging mammals and red squirrels (Teste et al. 2011). This may explain short-term increases in mammal diversity after beetle disturbances, including elk, mule deer, snowshoe hares, squirrels, voles, and chipmunks (Stone 1995).

Moose that inhabit these forest types may suffer range constraints and contractions from warmer, drier conditions, especially at the southern distribution of their range (e.g., Utah) (Rennecker and Hudson 1986; Wolfe et al. 2010a). In addition, warm spring temperatures coupled with low to absent snow cover may increase winter tick abundance and infestation on moose, leading to mortality (Delgiudice et al. 1997; Wolfe et al. 2010a).

Mixed Conifer Habitat

Mixed conifer communities provide a diverse set of habitats and support a large number of species (table 9.3). Mixed conifer sites with deep snow are important habitat for snowshoe hares and voles, which, in turn, are winter food for American marten (Zielinski et al. 1983). Mature, large-diameter trees of ponderosa pine in dry mixed conifer forest are suitable nesting sites for northern goshawks (Crocker-Bedford and Chaney 1988) and flammulated owls (Hayward and Verner 1994). Pine seeds are important food for Clark's nutcrackers, Cassin's finches, and pine siskins (Hutto et al. 2015). Open, shrubby understory patches created by low-intensity fires provide nesting sites for hummingbirds, lazuli buntings, and MacGillivray's warblers (Hutto 2014).

Shifts in the distribution and abundance of mixed conifer forest will lead to more early-successional stands and will not favor species that prefer mature, diverse forests with large-diameter trees (table 9.4). More high-intensity fires could also eliminate habitat patchiness and suitability for hummingbirds, lazuli buntings, and MacGillivray's warblers (Hutto 2014). Loss of mixed conifer forest or replacement by a less diverse plant community following a stand-replacing fire may reduce diversity of insects (Gilgert and Vaughan 2011), including endemic butterflies (e.g., Mt. Charleston blue butterfly, Morand's checkerspot, Spring Mountains acastus checkerspot, dark blue) (Ostoja et al. 2013). In particular, Mt. Charleston blue butterflies are susceptible to extreme precipitation and drought (Murphy et al. 1990). In addition, climate change effects on host plants (e.g., Torrey's milkvetch) could negatively affect these butterflies (Gilpin and Soulé 1986; Shaffer et al. 2001).

Several species may benefit from increased mortality of trees caused by fire and insect outbreaks (table 9.4). Dead trees provide good nesting and foraging (beetle larvae, ants) for many bird species. Coarse woody debris will also benefit American martens, which occasionally use cool-moist mixed conifer forest (Buskirk and Ruggiero 1994). Seeds released after fire are important food for Clark's nutcrackers, Cassin's finches, and pine siskins (Hutto et al. 2015). Black-backed woodpeckers are a burned-forest specialist known to favor recent high-intensity burns, where it feeds on wood-boring beetle larvae (Bent 1939; Fayt et al. 2005; Hutto 2008).

Extended effects on species interactions are also likely. Snowpack conditions are likely to affect snowshoe hares and voles, which rely on deep snow for foraging and caching; in turn, changes in populations of these species will affect winter food resources for predators such as Canada lynx and American martens (Zielinski et al. 1983). Reduced snowpack could expose martens to life-threatening temperatures in winter.

Aspen Habitat

Quaking aspen forests provide summer shade, hiding places, and thermal cover for many mammals and birds (DeByle 1985b; Shepperd 1986). Deer use forests as fawning grounds (Kovalchik 1987), snowshoe hares use them for hiding and resting in summer (DeByle 1985a,b), and ruffed grouse use accumulated snow in winter for burrowing cover (Perala 1977). Aspen and associated shrubs, forbs, and grasses are also important breeding and foraging resources. Elk, mule deer, white-tailed deer, moose, and livestock

Table 9.3—Some bird and butterfly species that rely on mixed conifer habitat (Hutto et al. 2015; Ostoja et al. 2013; Rhea et al. 2013).

Birds	Endemic butterflies
Black swift, Clark's nutcracker, calliope hummingbird, flammulated owl, Mexican spotted owl, northern goshawk, American three-toed woodpecker, black-backed woodpecker, hairy woodpecker, northern flicker, Lewis's woodpecker, lazuli bunting, Williamson's sapsucker, olive-sided flycatcher, northern hawk owl, great gray owl, mountain bluebird, western bluebird, dark-eyed junco, Townsend's solitaire, MacGillivray's warbler	Mt. Charleston blue butterfly, Morand's checkerspot, Spring Mountains acastus checkerspot, dark blue

Table 9.4—Potential winners and losers under climate change for bird species that inhabit mixed conifer forests (Hutto et al. 2015). Winners include species that will benefit from increased beetle-induced tree mortality; losers include species that rely on mature forests with large-diameter trees.

Winners	Losers
Black-backed woodpecker, hairy woodpecker, northern flicker, Lewis's woodpecker, Williamson's sapsucker, olive-sided flycatcher, northern hawk owl, great gray owl, bluebirds, flammulated owl, dark-eyed junco, Townsend's solitaire, red crossbill, house wren	Flammulated owl, northern goshawk, Mexican spotted owl

(sheep and cattle) browse on aspen year-round (DeByle 1985a,b; Ritchie 1978). Grizzly bears and black bears eat understory forbs and berries (DeByle 1985b). Rabbits, snowshoe hares, and American pikas feed on aspen buds, twigs, and bark (Stubbendieck et al. 1997). Aspen is an important food source and dam-building material for American beavers and many other rodents, including porcupines, which feed on aspen bark, leaves, buds, and twigs (DeByle 1985a,b). Common gray foxes, red foxes, mountain lions, and bobcats also use aspen forests (Banner et al. 2009).

Aspen communities support a wealth of feeding and nesting resources for songbirds, owls, and raptors, and many insects that are food for woodpeckers and sapsuckers (DeByle 1985b). The high biotic diversity of aspen forests is associated with structurally diverse stands. Mature aspen stands are used by dusky grouse, yellow-rumped warblers, warbling vireos, dark-eyed juncos, house wrens, and hermit thrushes in Utah. Young stands are used by chipping sparrows, song sparrows, and lazuli buntings. Community edges provide resources for mountain bluebirds, tree swallows, pine siskins, red-naped sapsuckers, and blue grosbeaks (DeByle 1981, 1985a,b). Ruffed grouse rely on communities with at least three size classes for foraging, courting, breeding, and nesting (Brinkman and Roe 1975; Gullion and Svovoda 1972).

Increased wildfire activity is likely to increase aspen regeneration, although a transition from aspen to conifers is possible where conditions become much warmer and drier (Morelli and Carr 2011). In the Dixie National Forest, many of the aspen forests have late-successional classes and vegetation on a conversion pathway to conifer establishment and growth. Replacement of aspen by conifers results in a loss of cover, hiding spaces, and roosting spots for wildlife. Some evidence points to more deer being killed by mountain lions in conifer and pinyon-juniper habitats than in nearby aspen and mountain mahogany habitats (Altendorf et al. 2001; Laundre and Hernandez 2003). Transitions have also been associated with decreased songbird abundance, especially for American robins and Lincoln's sparrows, and increased nest predation of species that prefer deciduous forests for nesting (LaManna et al. 2015). There may also be an increase in conifer-dependent nest predators, such as red squirrels (Goheen and Swihart 2005).

Site conditions will play an important role in whether aspen stands respond to changes in climate (Morelli and Carr 2011). On sites that are dry and have shallow soils, aspen are more susceptible to damage by disease, insects, herbivores, and drought (Rehfeldt et al. 2009). Drought-induced aspen decline and mortality could also reduce snowpack and snow depth (Kovalchik 1987), with consequences for many terrestrial species. Earlier snowmelt can decrease floral resources, thus affecting insect population dynamics (Boggs and Inouye 2012). Increased temperature may reduce the time interval between egg hatch of forest tent caterpillars and bud break in aspen (Schwartzberg et al. 2014).

Response of aspen-associated animal species to climate change will largely depend on their ability to adapt or move and the persistence of mature aspen forests. Generalists and opportunists may adjust to changes, but more specialized animals (e.g., ruffed grouse, beaver, cavity nesters, some herbivores) may be at a disadvantage. Northern goshawk is a habitat generalist at large scales, using a variety of forest types but with a preference for mature forests with large trees, closed canopies, and open understories during the breeding season (Barrett 1998; Kennedy 2003). Therefore, any disturbance that affects these habitat characteristics on a large scale (e.g., wildfire, insect outbreaks), and particularly within aspen (Graham et al. 1999), will negatively affect nestling success (Kennedy 2003) and juvenile survival (Wiens et al. 2006). Purple martins and ruffed grouse may face a decline in the availability and quality of nesting and foraging habitat if aspen forests shift or disappear. Reduced water in aspen ecosystems also threatens purple martins, although this species may be able to move to new sites even in urban areas, as long as it can find suitable cavities and foraging sites over open water (Rhea et al. 2013). Ruffed grouse may be less adaptable to changes in aspen because grouse rely on mixed forest age classes throughout the year. Young stands are important for brood-rearing habitat, 10- to 25-year-old stands are important for overwintering and breeding, and older stands are used for foraging (Brinkman and Roe 1975; Gullion and Svovoda 1972).

Birds and rodents nest in the canopy, on the ground, in understory vegetation, and in cavities, so aspen mortality would reduce suitable nesting habitats for a number of species (LaManna et al. 2015), especially primary and secondary cavity nesters (e.g., Lewis's woodpecker, red-naped sapsucker, northern flicker, mountain chickadee, flammulated owl, several bat species) (Bunnell 2013; Marti 1997). Even without increased mortality of aspen, warming and drought may lead to declines in cavity sites by reducing fungal activity important in the formation of cavities (Bunnell 2013; Morelli and Carr 2011). Lower canopy closure can increase solar radiation, causing heat stress and death in some species, as has been observed in northern goshawk fledglings (Barrett 1998; Rhea et al. 2013).

Reduced snow cover in aspen forest can limit year-round habitat for deer (Kovalchik 1987), ruffed grouse (Perala 1977), snowshoe hares (Murray et al. 2008), northern goshawks (Graham et al. 1999), and owls (DeByle 1985a,b). On the other hand, reduced snowfall can allow elk to overwinter longer in aspen stands, increasing the likelihood that elk will cause damage to trees and understory vegetation (Brodie et al. 2012; Howard 1996; Martin 2007; Martin and Maron 2012; Romme et al. 1995). Furthermore, rabbits, hares, pikas, and rodents can girdle aspen sprouts and mature trees, even below snowpack (DeByle 1985b; Howard 1996). Because new growth is palatable to wildlife and livestock, heavy utilization can be detrimental to aspen stands (Brodie et al. 2012; Greenway 1990; Rogers and Mittanck 2014). In turn, this overutilization of understory vegetation can lead to decreased bird abundance (e.g., house wren) in aspen stands (Martin 2015).

Ponderosa Pine Habitat

Many terrestrial species are associated with ponderosa pine habitats (table 9.5). There is potential for an accelerated rate of change in species composition in this habitat as animals respond to shifts in plant community composition. Drought is associated with diminished seed supply, which will adversely affect consumers and dispersers. For example, Clark's nutcrackers eat and cache seeds and are important dispersers of ponderosa pine seeds after wildfire (Hutto et al. 2015). Species that rely on ponderosa pine for nesting, food, and cover (e.g. Lewis's woodpecker, flammulated owl, Abert's squirrel, several songbirds) may be able to tolerate expected changes in these forests. It is unknown whether loss of suitable habitat will exacerbate competitive interactions among species (e.g., for cavities and prey), as is expected for higher elevations. As ponderosa pine forest structure and composition change, primary excavator populations (woodpeckers, sapsuckers) may transition to more favorable habitat, reducing the number of cavities available to secondary-cavity nesters (e.g., flammulated owl, mountain bluebird, western bluebird, nuthatches, squirrels) in remaining forest patches (Bunnell 2013; Casey et al. n.d.).

The direct effects of loss of ponderosa pine at the lower elevation end of its distribution include reduced habitat for flammulated owls (Hayward and Verner 1994) and northern saw-whet owls (Scholer et al. 2014), and loss of cavity-nesting sites for flammulated owls, mountain bluebirds, pygmy nuthatches, and Williamson's sapsuckers (Casey et al. n.d.). Losses of mature ponderosa pine (e.g., to beetles) may reduce roosting sites for fringed myotis (Keinath 2004). Simplification of plant communities may also lead to reduced insect diversity (Gilgert and Vaughan 2011) with downstream effects on pollinator and trophic systems. Early-successional stages of ponderosa pine communities are unsuitable for flammulated owls (Hayward and Verner 1994), northern goshawks (Graham et al. 1999), and Abert's squirrels (Bosworth 2003). However, beetle outbreaks can provide short-term benefits to insectivores and cavity nesters, such as Lewis's woodpeckers (Saab et al. 2014).

Spring advancement is likely to lead to earlier flowering, longer growing seasons, and mismatched phenological behavior (e.g., arrival and abundance of insects and small mammals used as prey for larger mammals) (Both et al. 2010; Parmesan 2006; Steenhof et al. 2006; Thackeray et al. 2010). For example, changes in moth and insect populations resulting from variable temperature and precipitation patterns may affect flammulated owl migration patterns (Linkhart et al. 2016), Lewis's woodpecker breeding patterns (Abele et al. 2004), and fringed myotis (Keinath 2004).

Woodland Vegetation

Pinyon-Juniper Habitat

Pinyon-juniper woodlands provide valuable cover, food, and nesting sites for many species, including bats and reptiles (table 9.6). Mountain lions use this habitat to hunt deer, especially in winter (Laing 1988; Laundre and Hernandez 2003). Pine nuts and juniper berries are important food for small mammals, birds, bears, and bats. Ungulates that find forage and cover in these woodlands include elk, mule deer, bighorn sheep, and pronghorn (Anderson 2002; Zouhar 2001). Pinyon-juniper woodlands are wintering sites for

Table 9.5—Species associated with ponderosa pine habitats; additional species noted in text (Bunnell 2013; Oliver and Tuhy 2010; Pilliod and Wind 2008; Ramsey and West 2009; Rhea et al. 2013).

Birds	White-breasted nuthatch, Steller's jay, Clark's nutcracker, northern flicker, black-backed woodpecker, pileated woodpecker, flammulated owl, Mexican spotted owl, pygmy nuthatch, Merriam's turkey, northern goshawk, northern saw-whet owl, peregrine falcon, Lewis's woodpecker
Large mammals and predators	Mule deer, elk, bighorn sheep, mountain lion, coyote
Small mammals	Kaibab squirrel, red squirrel, porcupine, spotted bat, fringed myotis, Allen's big-eared bat, Mexican vole
Amphibians and reptiles	Long-toed salamander, tiger salamander, rubber boa, many-lined skink, western skink, milksnake, southern alligator lizard, rattlesnake

Table 9.6—Reptile and bat species for which pinyon-juniper is preferred habitat; see text for discussion of pinyon obligate species (Bosworth 2003; Corkran and Wind 2008; Oliver 2000; Oliver and Tuhy 2010; Rhea et al. 2013; Valdez and Cryan 2009).

Reptiles	Speckled rattlesnake, western rattlesnake, plateau striped whiptail, tiger whiptail, western skink, pygmy short-horned lizard, sagebrush lizard, western fence lizard, common side-blotched lizard, gopher snake, nightsnake, striped whipsnake
Bats	Allen's big-eared bat, long-eared myotis, little brown bat, Yuma myotis, fringed myotis, hoary bat, silver-haired bat, western pipistrelle, spotted bat

Box 9.4—Potential Effects of Climate-related Declines in Pinyon-Juniper Habitats

- Loss of trees for stalking cover and deer-kill sites for mountain lions, especially in the winter (Laing 1988; Laundre and Hernandez 2003).
- Loss of wintering sites for Clark's nutcracker (Vander Wall et al. 1981) and mule deer (Evans 1988); loss of cover and food for elk, mule deer, bighorn sheep, pronghorn, upland game birds, coyotes, and small mammals (Anderson 2002; Zouhar 2001).
- Reduced reptile habitat. Many lizards and snakes find food and shelter on and in trees and down woody debris in pinyon-juniper. These sites are a preferred habitat for speckled and western rattlesnakes, plateau striped whiptails, tiger whiptails, western skinks, pygmy short-horned lizards, sagebrush lizards, western fence lizards, common side-blotched lizards, gopher snakes, nightsnakes, and striped whipsnakes (Bosworth 2003; Corkran and Wind 2008; Oliver and Tuhy 2010).
- Impairment of bat foraging and roosting sites, especially in pinyon-juniper near cliffs, caves, and riparian areas. Allen's big-eared bat, long-eared myotis, little brown bat, Yuma myotis, fringed myotis (tree rooster), hoary bat, silver-haired bat (tree rooster), western pipistrelle, and spotted bat may be affected (Bosworth 2003; Oliver 2000; Rhea et al. 2013). However, increased insect outbreaks may benefit some insect-eating species, such as fringed myotis (Keinath 2004).
- Prevention of cones of twoneedle pinyon from opening. These cones do not open during wet springs, making seeds more difficult to reach by birds and small mammals and reducing seed dispersal during wetter years (Floyd and Hanna 1990).
- Potential loss of resources for insects, such as pinyon pitch, which bees use for building nests (Lanner 1981).

Clark's nutcrackers (Vander Wall et al. 1981) and mule deer (Evans 1988). Many lizards and snakes find food and shelter on and in trees, and in down woody debris. Woodlands located near cliffs, caves, and riparian areas provide habitat for peregrine falcons (Craig and Enderson 2004) and several bat species.

Reduced densities of pinyon-juniper could have short-term benefits for browsers where sufficient understory vegetation is present. However, loss of trees or conversion to grass-shrub caused by drought and fire will reduce food, cover, and nest site availability for pinyon-juniper obligate species (box 9.4). For example, loss of food (juniper berries, pine seeds) and sites for breeding and nesting would affect small mammals (chipmunks, jackrabbits, squirrels, woodrats) (Anderson 2002; Zlatnik 1999; Zouhar 2001), ferruginous hawks (Holechek 1981; Bosworth 2003), pinyon jays (fig. 9.2), scrub jays, gray vireos, and gray flycatchers, many of which are already showing population declines (Sauer et al. 2008).

Commensal relationships between twoneedle pinyon and seed eaters are likely to accelerate declines in pinyon because caches by scrub jay, pinyon jay, Steller's jay, and Clark's nutcracker are important for tree regeneration (Evans 1988; Hall and Balda 1988; Ronco 1990; Zouhar 2001). Declines in pinyon-juniper would also be detrimental to obligate species (e.g., pinyon mouse, Stephen's woodrat, pinyon jay, gray flycatcher, western screech-owl, scrub jay, juniper titmouse, gray vireo) (Balda and Masters 1980; Bosworth 2003; Meeuwig et al. 1990; Morrison and Hall 1999; Short and McCulloch 1977), some of which are important prey populations for large mammals and raptors (Zouhar 2001).

Figure 9.2—Pinyon jay. This species, which engages in irruptive movements, is an example of a species that may be able to adjust to local changes in available resources, but would be negatively affected where reduced vigor, reduced cone production, or mortality affects pinyon pines across large landscapes (photo: National Park Service).

Under conditions that would encourage expansion of pinyon-juniper into shrub and grasslands, obligate species may benefit, provided there are no barriers to dispersal, and pinyon-juniper remains present in large enough quantities to support the diverse assemblage of species. Higher temperatures may improve growth and development of young hoary bats that inhabit these areas (Cryan 2003). The pinyon mouse has shown the capacity to follow the downslope migration of pinyon-juniper woodlands, although other small mammals (Great Basin pocket mouse, least chipmunk) are showing range contraction as pinyon-juniper transitions into sagebrush-steppe (Rowe et al. 2010). Expansion and increase in tree density caused by potential increases in precipitation may negatively affect desert bighorn sheep by limiting escape routes from mountain lion predation and could degrade habitat quality for pinyon jays (Ostoja et al. 2013).

Finally, phenological changes would affect species whether pinyon-juniper expands or recedes. Altered arrival of migratory birds, which are prey for peregrine falcons, could have negative impacts for falcon populations that breed near high cliffs (Craig and Enderson 2004). Migration of hoary bats, which forage in pinyon-juniper and are associated with moth abundance (Valdez and Cryan 2009), may also be affected by altered temperature and precipitation. Any change in the availability of water resources near pinyon-juniper woodlands would negatively impact Great Basin spadefoots, tiger salamanders, many-lined skinks, ornate tree lizards, ring-necked snakes, common kingsnakes, and terrestrial gartersnakes (Pilliod and Wind 2008).

Curl-Leaf Mountain Mahogany Habitat

Mountain mahogany woodlands provide food and cover for many species, including browse for deer, bighorn sheep, elk, and livestock (Davis and Brotherson 1991; Olson 1992). Young plants are highly palatable, and old-growth mahogany, often out of reach for browsing, provides shelter during winter and summer extremes (Davis and Brotherson 1991). In an Idaho study, curl-leaf mountain mahogany and antelope bitterbrush were major browse species for nonmigratory bighorn sheep during summer and winter, especially when grassland sites were covered with snow. Mountain mahogany is important browse and shelter for mule deer, especially during winter (Mauk and Henderson 1984; Olson 1992), and provides browse and refuge from predators during summer (Wagner and Peek 2006). Small mammals, such as deer mice and woodrats, consume seeds (Everett et al. 1978; Plummer et al. 1968), leaves, and fruits (Mehringer and Wigand 1987). Woodlands are also important nesting sites for dusky grouse, ruffed grouse, dusky flycatchers, rock wrens, and American kestrels (provided there are cavities) (Steele et al. 1981). Among the many insects that feed on mountain mahogany is the mountain-mahogany looper in Utah, where dense stands exist with bitterbrush (Furniss 1971). Mountain mahogany relies on native bees for pollination (Gilgert and Vaughn 2011).

If the range of mountain mahogany increases, winter browse for ungulates and other associated species will increase. Any loss of mountain mahogany would lead to reduced winter browse and nesting sites (Gucker 2006a,b). This could happen if more frequent wildfires kill mountain mahogany and reduce regeneration (Gruell et al. 1985). Invasive plant species can influence fire regimes and thereby affect plant composition and forage resources for ungulates (Wagner and Peek 2006). Replacement of mountain mahogany by conifer species would reduce cover, hiding spaces, and roosting spots for wildlife. Although Douglas-fir/curl-leaf mountain mahogany habitat types in central Idaho are important breeding and hunting grounds for mountain lions (Steele et al. 1981) and coyotes (Gese et al. 1988), deer kills by mountain lion are higher in conifer and pinyon-juniper habitats than nearby in aspen and mountain-mahogany habitats (Altendorf et al. 2001; Laundre and Hernandez 2003). Ungulates are also sensitive to potential changes in the timing and duration of plant phenology (Senft et al. 1987). In southern Idaho, 45 percent of variation in overwinter mule deer fawn survival was explained by early winter precipitation (negative relationship), and spring and autumn plant phenology. Late summer and fall nutrition (brought on by summer and early-fall precipitation) may positively influence mule deer populations over winter more than spring nutrition (Hurley et al. 2014).

Maple-Oak Habitat

Maple-oak woodlands provide habitat for quail, ring-necked pheasants, scrub jays, black-billed magpies, black-capped chickadees, and spotted towhees (Marti 1977) and support many other species (table 9.7). Acorns are a primary food source for many species, and maple seeds are used by squirrels and chipmunks (Martin et al. 1951). Maple-oak woodlands are also good browse and cover for deer and elk (Mower and Smith 1989) and winter food and cover for porcupines (Stricklan et al. 1995). Ponderosa pine-oak woodlands are important habitat for Mexican

Table 9.7—Habitat components for species that inhabit maple-oak woodlands (Bosworth 2003; Keinath 2004; Martin et al. 1951; Mower and Smith 1989; Patton 1975; Patton and Green 1970; Pederson et al. 1987; Platt 1976; Ramsey and West 2009; Rhea et al. 2013; Simonin 2000; Stauffer and Peterson 1985; Stricklan et al. 1999).

Shelter, cover, nesting	California quail, Merriam's wild turkey, band-tailed pigeon, dusky grouse, ruffed grouse, sharp-shinned hawk, bald eagle, deer, elk, moose, dwarf shrew (riparian woodlands), fringed myotis, Lewis's woodpecker, canyon tree frog, Abert's squirrel, porcupine
Food	Band-tailed pigeon, Merriam's wild turkey, Abert's squirrel

spotted owls (Ganey et al. 1999) and northern pygmy-owls (Woyda and Kessler 1982) and provide nonbreeding habitat for Lewis's woodpecker (Abele et al. 2004), cavity nests for Abert's squirrels (Patton 1975; Patton and Green 1970) and nesting sites for sharp-shinned hawks (Platt 1976).

Oak woodlands generally increase after stand-replacing fires, and maple-oak woodlands have wide ecological amplitude, with a capacity to quickly recover from disturbance. Response of wildlife in these habitats will mirror expected habitat changes, with expansion likely to benefit species that already reside in these areas, such as Lewis's woodpeckers and fringed myotis (Abele et al. 2004; Keinath 2004; Rhea et al. 2013). However, reduced water availabilty in these habitats would negatively affect canyon tree frog populations (Rhea et al. 2013).

Nonforest Vegetation

Sagebrush Habitat

Sagebrush shrublands support many terrestrial species that use sagebrush habitat for part or all of their life cycle. Some of these semi-obligate and obligate and species include greater sage-grouse and Gunnison sage-grouse (the latter is on the ESA threatened list), Columbia sharp-tailed grouse, sagebrush voles, pygmy rabbits, and sage sparrows. Sagebrush provides essential browse and cover for pronghorn, mule deer, elk, and bighorn sheep, especially during the winter. Coyotes and mountain lions also use sagebrush shrublands. Other primary animal associates include migratory birds (e.g., burrowing owl, short-eared owl, Brewer's sparrow, sage thrasher). Sagebrush-associated insects, songbirds, and small mammals are important prey for Swainson's hawks, ferruginous hawks, burrowing owls, and kit foxes (Bosworth 2003; Hayward et al. 1976; Walters and Sorensen 1983).

Any expansion of sagebrush will benefit sagebrush obligate species, provided that regeneration and adaptation of key shrubs and herbaceous plants occur. Alternatively, a decline in sagebrush habitat will reduce browse for ungulates (pronghorn, mule deer) and pygmy rabbits (Gahr 1993; Green and Flinders 1980), resulting in loss of nesting sites for birds (Ramsey and West 2009). Some terrestrial species, such as prairie falcons, northern harriers, rough-legged hawks, golden eagles, and many small mammals, may be able to shift to other habitats or adjust to current changes (conversion to invasive grasses and forbs), (Marzluff et al. 1997; Moritz et al. 2008; Paprocki et al. 2015; Steenhof and Kochert 1988). However, drought, wildfire, and conversion to nonnative grasses will reduce food (insects, forbs, browse, berries) for many species (Miller and Freeman 2001), including forbs and insects that are especially important for sage-grouse chick survival and growth (Connelly et al. 2004; GSRSC 2005) (fig. 9.3).

Warmer winters may allow expansion of invasive fire ant populations, which can reduce survival of burrowing mammals, ground-nesting birds, and native ant species (Ostoja et al. 2013). Mild winters may also disrupt predator-prey relationships and increase nest predation (Yanishevsky and Petring-Rupp 1998). Severe spring and summer storms may impact songbird nesting and brood success, effectively reducing prey species for loggerhead shrikes (Wiggins 2005). Winter precipitation, which is expected to decrease, is positively associated with reproductive success for songbirds in these habitats (Rotenberry and Wiens 1989).

Compositional changes in the distribution of sagebrush subspecies such as Wyoming big sagebrush could mean loss of critical habitat for pygmy rabbit and greater sage-grouse (Still and Richardson 2015). For songbirds, predicted conversion to annual grassland will favor species that require grassland habitat (e.g., horned lark) and deter those needing shrub structure (e.g., Brewer's sparrow, sage sparrow, sage-grouse, sage thrasher, loggerhead shrike) (Paige and Ritter 1999; Williams et al. 2011). Fragmentation of sagebrush breeding habitats may favor songbird nest predation by common ravens, black-billed magpies, and small mammals, and nest parisitism by brown-headed cowbirds (Connelly et al. 2004; Holmes and Johnson 2005; Rotenberry et al. 1999). Many amphibian and reptile species favor the habitat heterogeneity provided by shrub-steppe that includes open, barren spaces between shrubs (Jenkins et al. 2008). Adverse effects are expected for amphibians and reptiles that use shrublands and grasslands, including Great Plains toads, Great Basin spadefoots, tiger salamanders, long-toed salamanders, many-lined skinks, ornate tree lizards, ring-necked snakes, milksnakes, and smooth greensnakes (Jenkins et al. 2008; UDNR 2015). Amphibians that need water for all or part of their life cycle are particularly at risk under more variable weather conditions.

Mountain Shrubland Habitat

Mountain shrublands provide breeding habitat for many bird species, including Columbian sharp-tailed grouse, greater and Gunnison sage-grouse, gray flycatchers, green-tailed towhees, chipping sparrows, gray vireos, eastern kingbirds, and white-crowned sparrows. Mammals associated with this habitat include deer, elk, bighorn sheep, lagomorphs, Merriam's shrews, sagebrush voles, and Yuma myotis. Common reptiles include short-horned lizards, gopher snakes, and terrestrial garter snakes. Mountain snails are also found within mountain shrublands.

The greatest threats facing species that depend on mountain shrublands relate to potential changes in availability and productivity of forbs and insect food sources caused by drought, fire, and conversion to nonnative grasses (Miller and Freeman 2001). For example, insect diversity is expected to decline because of changes in plant composition from climate and nonclimate stressors (Gilgert and Vaughan 2011), with multiple consequences for trophic and pollinator interactions. Reduction in food would have particularly negative impacts for sage-grouse and Columbian sharp-tailed grouse chick survival and population growth (Connelly et al. 2004; GSRSC 2005; Hoffman and Thomas 2007; Miller and Freeman 2001).

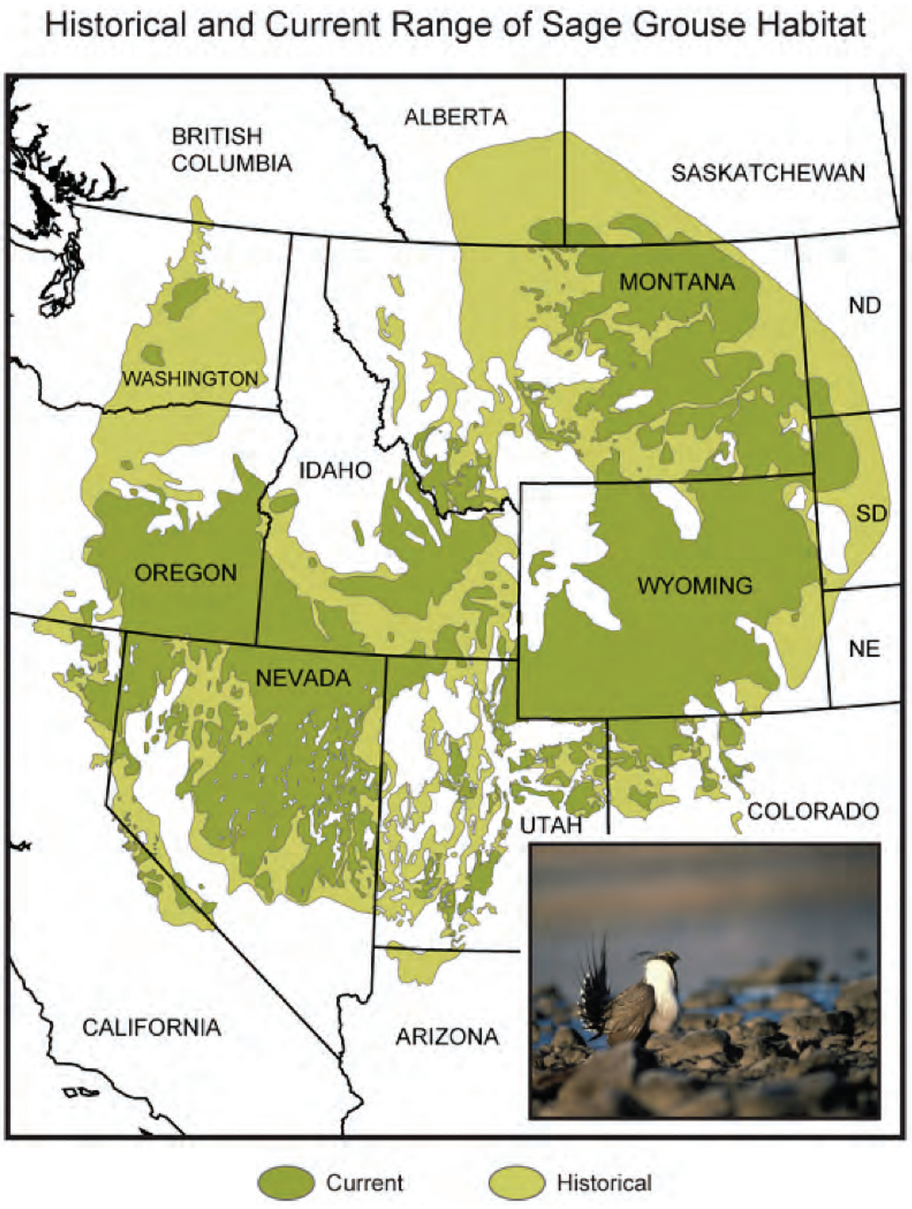

Figure 9.3—Current sagebrush habitat in western North America, which is about 50 percent of its historical extent, as a result of agriculture, livestock grazing, energy development, and other land use practices. Loss of sagebrush across large spatial scales constrains the amount of habitat available for sagebrush-obligate species such as greater sage-grouse (shown in inset) (from Melillo et al. [2014]).

Climate-related effects may also be manifested through changes in habitat features. For many songbirds, climate-related changes in plant species assemblages and productivity will alter breeding habitat, such that a conversion to annual grasses will favor species associated with grassland (e.g., horned lark) and deter those needing shrub structure (e.g., Columbian sharp-tailed grouse) (Hoffman and Thomas 2007; Paige and Ritter 1999). In addition, fragmentation of mountain shrublands may increase songbird nest predation by common ravens, black-billed magpies, and small mammals, and nest parasitism by brown-headed cowbirds (Connelly et al. 2004; Holmes and Johnson 2005; Rotenberry et al. 1999). On drier sites, climate change will probably reduce habitat favored by Columbian sharp-tailed grouse. Reduced snow cover and changes to snow structure caused by warming can alter roosting and cover dynamics for Columbian sharp-tailed grouse in the winter (Hoffman and Thomas 2007). Reduced snowfall may allow browsers to overwinter longer in mountain shrublands, which will increase the likelihood of overgrazing and alter plant community composition (Martin 2007; Martin and Maron 2012). Mild winters may disrupt predator-prey relationships by increasing nest predation (Yanishevsky and Petring-Rupp 1998). Finally, reduction in water sources could have negative consequences for amphibians and reptiles in shrublands and grasslands, including Great Plains toads, Great Basin spadefoots, tiger salamanders, long-toed salamanders, many-lined skinks, ornate tree lizards, ring-necked snakes, milksnakes, and smooth greensnakes (Jenkins et al. 2008; UDNR 2015).

Mountain Grassland/Montane Meadow Habitat

Primary animals in this habitat type include elk, deer, pronghorn, moose, and bighorn sheep, as well as multiple small mammal, reptile, amphibian, and songbird species. In particular, mountain grasslands are critical habitat for northern Idaho ground squirrels (Haak et al. 2003) and Gunnison's prairie dogs (Oliver and Tuhy 2010). Grasslands and wet meadows with year-round water are important foraging and breeding habitats for amphibians and reptiles (e.g., Woodhouse's toad, northern leopard frog, tiger salamander, smooth greensnake) (Oliver and Tuhy 2010; Pilliod and Wind 2008; Smith and Keinath 2007). Spotted bats and fringed myotis forage in mountain grasslands (Bosworth 2003; Oliver 2000). Mountain grassland also provides critical summer and fall food and cover for greater sage-grouse and Gunnison sage-grouse (Connelly et al. 2004; GSRSC 2005; Schroeder et al. 1999).

Mountain grassland may be affected by earlier snowmelt, changes in timing and amount of streamflow, snowpack duration, and thaw dates for soil and snow (Romero-Lankao et al. 2014). In turn, these are likely to lead to earlier greening and flowering and a longer growing season (Settele et al. 2014), with implications for insect pollinators and food sources. Spring advancement can decouple community phenological behavior by affecting emergence from hibernation, insect hatches, predator-prey relationships (Both et al. 2010; Inouye et al. 2000; Parmesan 2006; Thackeray et al. 2010), arrival dates for migratory birds (Inouye et al. 2000; Thorup et al. 2007), and migration and breeding for amphibians (Beebee 1995; Reading 2007). However, earlier snowmelt dates may increase grass production in meadows (Ostler et al. 1982) to the benefit of grazing species.

Mortality of peripherally located trees could lead to expansion of meadows and grasslands (Munroe 2012) and benefit many obligate species. However, drought and warmer temperatures can also favor invasion by drought-tolerant trees, shrubs, and nonnative species, with negative impacts for species that use these habitats (Coop and Givnish 2007) (box 9.5). Increased bare ground may also occur over time from drought-induced loss of plant cover (Debinski et al. 2010).

Salt Desert Shrubland Habitat

Salt desert shrubland habitat is used by wild and domestic ungulates, small mammals, and insects (Blaisdell and Holmgren 1984; Ramsey and West 2009; West 1983). Predators include coyotes, bobcats, kit foxes, badgers, great horned owls, bald eagles, golden eagles, Swainson's hawks, and red-tailed hawks (Fautin 1946; Hancock 1966). Short-eared owls (Walters and Sorensen 1983) and Preble's shrews (Bosworth 2003) have been found in saltbush shrublands in Utah. Winterfat, fourwing saltbush, and budsage are valued forage during winter and drought conditions for mule deer, elk, pronghorn, bighorn sheep, livestock, cottontails, black-tailed jackrabbit, and desert tortoise (Carey 1995; Howard 2003; McArthur et al. 1994). In central Idaho, golden eagles selected sagebrush and salt desert shrublands and avoided grasslands and farmland; the shrublands probably contained their principal prey, black-tailed jackrabbits (Marzluff et al. 1997). Several songbird species, such as black-throated sparrows, horned larks, Brewer's sparrows, loggerhead shrikes, vesper sparrows, lark sparrows, and western meadowlarks, breed and forage in saltbush communities (Bradford et al. 1998; Medin 1986, 1990; Williams et al. 2011). Notable reptiles include prairie rattlesnakes, striped racers, gophersnakes, long-nosed snakes, common side-blotched lizards, desert horned lizards, tiger whiptails, western skinks, long-nosed leopard lizards, and sagebrush lizards (Fautin 1946; Jenkins et al. 2008).

Many animal inhabitants of salt desert shrublands need burrows for nesting, hunting, predator avoidance, and thermoregulation (Kitchen and Jorgensen 1999). Burrowing in shallow soils with a calcareous horizon restricts animals to "shrub islands." Pocket gophers, kangaroo rats, and deer mice are the most common on these islands; other species include badgers, ground squirrels, kit foxes, burrowing owls, reptiles, and arthropods (Blaisdell and Holmgren 1984).

Because natural regeneration and restoration of salt desert shrublands are challenging and confounded by wildfire, urbanization, recreation, and invasive species, there is some risk that these habitats will decline despite projected increases in climate suitability (Ostoja et al. 2013; Rehfeldt et al. 2012) (fig. 9.4). In addition, climates suited to salt

Box 9.5—Potential Effects of Conifer Encroachment into Mountain Grasslands for Terrestrial Animals

- Loss of habitat critical for northern Idaho ground squirrels (Haak et al. 2003) and Gunnison prairie dogs (Oliver and Tuhy 2010).
- Loss of foraging and shelter sites for amphibians and reptiles, especially those that need wet conditions or water features and suitable grasslands and meadows nearby (e.g., Woodhouse's toad, northern leopard frog, tiger salamander, smooth greensnake) (Oliver and Tuhy 2010; Smith and Keinath 2007; Wind 2008).
- Loss of Rocky Mountain bighorn sheep habitat (Beecham et al. 2007) and important elk foraging habitats (Munroe 2012).
- Loss of foraging sites for bats including spotted bat and fringed bat (Bosworth 2003; Oliver 2000).
- Potential loss of summer and fall food and cover (i.e., grasses and forbs in riparian meadows and mountain grass-forb areas) for greater sage-grouse and Gunnison sage-grouse (Connelly et al. 2004; GSRSC 2005; Schroeder et al. 1999).
- Diminished reproductive success of smooth greensnakes if spring temperatures increase (Stille 1954).

Figure 9.4—Oil well pads in the Uinta Basin in southeastern Utah. Energy development fragments salt desert shrubland and other vegetation types at fine spatial scales, greatly reducing the quality of these areas as habitat for many animal species (photo: M. Collier, http://michaelcollierphoto.com).

desert shrublands are also suitable for cheatgrass and other annual plants that facilitate wildfire (Bradley et al. 2016). More frequent fires will kill salt desert shrubs and reduce browse for ungulates and nesting sites for birds (Ramsey and West 2009). Loss of shrub structure from die-off events will reduce reptile habitat (Jenkins et al. 2008), shrub-steppe bird habitat (Paige and Ritter 1999), and cover for many other wildlife species (West 1983). Some terrestrial species, such as prairie falcon, northern harrier, rough-legged hawk, golden eagle, and small mammals, will be able to shift to alternative habitats or adjust to current changes where salt desert declines (Marzluff et al. 1997; Moritz et al. 2008; Paprocki et al. 2015; Steenhof and Kochert 1988). However, models indicate that elk and ground squirrel distributions may shrink, and these species may not be able to relocate to new areas (Johnston and Schmitz 1997).

Invasive plant species can also modify plant composition and recruitment, and thus forage and cover for ungulates, pollinators, and small mammals (Kitchen and Jorgensen 1999). Replacement of salt desert shrubs with nonnative annual species reduces browse and cover for many wildlife species (West 1983), such as badgers (Eldridge 2004) and ground squirrels (Steenhof et al. 2006; Yensen et al. 1992). Desert tortoise habitat has declined where shrubs have been replaced by invasive annual grasses and forbs, which, in combination with habitat degradation, poor nutrition, and drought, are linked to upper respiratory tract disease in the tortoise (Jacobson et al. 1991; USFWS 2011).

Conversion of shrubland to invasive grassland may cause some species to use alternative habitats. Golden eagles will use other habitat types and feed on secondary prey, whereas prairie falcons and rough-legged hawks may increase in sites dominated by invasive annuals and primary prey (small mammals, horned lark, western meadowlark) (Marzluff et al. 1997; Paprocki et al. 2015; Steenhof and Kochert 1988). Drought and warm temperatures lead to lower Piute ground squirrel abundance in grass-dominated habitats than in shrub-dominated habitats, and conversion of shrubland to grassland contributes to fluctuation in ground squirrel populations (Van Horne et al. 1997; Yensen et al. 1992) and to reduced body mass (Steenhof et al. 2006). Conversion from shrubs to grass will also reduce habitat for reptile species that favor the habitat heterogeneity provided by shrub-steppe (Jenkins et al. 2008). Changes in the structure and composition of vegetation will affect songbird breeding habitat, such that a conversion to annual grassland will favor species associated with grassland (e.g., horned lark) and deter those needing shrub structure (Brewer's sparrow, black-throated sparrow) (Bradford et al. 1998; Paige and Ritter 1999; Williams et al. 2011).

Altered species interactions in salt desert habitats are more likely in a warmer climate. Predation by common ravens on tortoises can be high during drought years (Esque et al. 2010). Fluctuations in prey populations will affect birds of prey, including golden eagles, ferruginous hawks, and prairie falcons (Kindschy 1986; Marzluff et al. 1997; Nydegger and Smith 1986; Ogden and Hornocker 1977; Yensen et al. 1992) and prey relationships for kit foxes (Bosworth 2003). There may also be an increase in less desirable species such as fire ants, which reduces survival of burrowing mammals, ground-nesting birds, and native ant species (Ostoja et al. 2013). Early plant senescence caused by drought may trigger immergence for Piute ground squirrels, meaning less food for prairie falcons and other raptors; drought may also cause low abundance of ground squirrels the year following drought (Steenhof et al. 2006).

Alpine Habitat

Year-long residents of alpine habitat include shrews, snowshoe hares, yellow-bellied marmots, pocket gophers, deer mice, voles, weasels, American pikas, wolverines, and white-tailed ptarmigans (Aho et al. 1998; Pilliod and Wind 2008; Ramsey and West 2009; Rawley et al. 1996; Rhea et al. 2013). Relatively cold temperatures during summer provide safe haven for boreal owls, wolverines, and American pikas, which cannot tolerate warm temperatures (Copeland et al. 2010; Hayward and Verner 1994; Smith 1974). Snow cover amount, depth, and duration are important habitat features for snowshoe hares, which, in turn, are important prey for Canada lynx (Murray et al. 2008) and wolverines (Brodie and Post 2009; Copeland et al. 2010; McKelvey et al. 2011; Peacock 2011). Elk and bighorn sheep browse alpine vegetation (Beecham et al. 2007; Zeigenfuss et al. 2011). Alpine forbs are also important for bees and other pollinators (Elliott 2009).

Species reliant on adequate snow cover and specific phenological characteristics are at particular risk of population declines (box 9.6). Risk of hyperthermia and death increases in American pikas with increasing temperatures and snow loss (MacArthur and Wang 1973, 1974; Ray et al. 2016; Smith 1974). Without persistent spring snow cover and denning habitat, wolverine populations may not be able to survive and reproduce successfully (Brodie and Post 2009; Copeland et al. 2010; McKelvey et al. 2011; Peacock 2011). Reduction in spring snow cover effectively fragments and reduces wolverine habitat (Banci 1994; Copeland et al. 2010). In addition, wolverines rely on cool summer temperatures (<72 °F), especially at the southern edge of their range (Copeland et al. 2010; McKelvey et al. 2011; Peacock 2011). The black rosy finch may be adversely affected if warming accelerates melting of snow and glaciers.

Changes in plant phenology, including spring advancement, will affect immergence and emergence of hibernators (Both et al. 2010; Parmesan 2006; Thackeray et al. 2010). In Colorado, early emergence was documented for yellow-bellied marmots in response to early snowmelt (Ozgul et al. 2010). Late-season snowstorms can also delay emergence from hibernation and reduce population growth rates in some species (Lane et al. 2012; Morelli et al. 2012). Warming may cause differences in snow cover patterns and affect the timing of nesting for white-tailed ptarmigans, which nest in snow-free areas (Hoffman 2006). Changes in snow cover patterns may also increase risk of mismatch in pelage change for snowshoe hares (Mills et al. 2013). Phenological mismatches between alpine forbs and pollinators (e.g., bees) may occur (Elliott 2009), and pollinator generalists may be favored over alpine specialists (Inouye 2008). These changes may benefit American pipits, which have experienced earlier onset of egg laying and increased clutch size with earlier snowmelt (Hendricks 2003).

Riparian Forests and Aquatic Habitats

Riparian systems provide essential habitat for many terrestrial species including American beavers, river otters, songbirds, and insects. Riparian vegetation provides nesting and foraging habitat for yellow-billed cuckoos, southwestern willow flycatchers (Hanberg 2000; Johnson et al. 2008; Paxton et al. 2007; Oliver and Tuhy 2010), Lewis's woodpeckers (Abele et al. 2004), and Columbian sharp-tailed grouse (Hoffman and Thomas 2007). Riparian systems provide critical habitat for water-dependent species including frogs (Columbia spotted frog, yellow-legged

Box 9.6—Potential Effects of Reduced Alpine Habitat Caused by Conversion to Subalpine Forests and Uphill Movement of Treeline

- Loss of critical habitat for white-tailed ptarmigans (alpine obligate), which forage on willow buds during winter, use treeline for breeding, and forage on forbs, willows, and insects in spring and summer (Rawley et al. 1996). White-tailed ptarmigans need willow during winter to survive; willow is an important part of their breeding and nonbreeding habitat (Hoffman 2006). It is unclear how willow will respond to climate change at higher elevations.
- Loss of open areas and foraging sites for bighorn sheep (Beecham et al. 2007); opening of habitat suitable for elk and other ungulate browsers, which may exert increased browsing pressure on alpine willows and other plants (Zeigenfuss et al. 2011).
- Loss of habitat and population connectivity for American pikas (Beever et al. 2010, 2011). In addition, declines in alpine plant species will adversely affect American pika populations, which cache alpine vegetation (Aho et al. 1998). Pika declines could also affect plant community composition (Aho et al. 1998).

frog, relict leopard frog [extirpated in Utah]), salamanders, toads (boreal [western] toad, Arizona toad), lizards (many-lined skink, ornate tree lizard, eastern fence lizard), snakes (smooth greensnake, ring-necked snake, milksnake), and turtles (painted turtle) (Olson 2008; Pilliod and Wind 2008). Bald eagles have a strong connection with tall trees (e.g., cottonwoods) in riparian zones and use them for nesting; they also rely on fish year-round (Buehler 2000). Bats (spotted bat, hoary bat, Yuma myotis, western red bat, fringed myotis; see vulnerability assessment, next section) use riparian habitats for foraging and nesting (Luce and Keinath 2007; Oliver 2000; UDNR 2015). Riparian corridors are important to species during migrations, especially for olive-sided flycatchers (Altman and Sallabanks 2000), hoary bats (Valdez and Cryan 2009), and ungulates (pronghorn, elk).

Riparian habitats are expected to decline with warming, drought, and lower streamflows, with the largest declines at lower elevations (Lucas et al. 2014). Changes in riparian plant species composition, structure, and function are expected to affect cottonwood, willow, boxelder, alder, currant, serviceberry, and oak (Glenn and Nagler 2005; Perry et al. 2012) (Chapter 6). Climate-related effects on native species may favor invasion and expansion of saltcedar and Russian olive along riparian corridors, with consequences for water tables, soil salinity, and plant diversity (Bradley et al. 2009; DeLoach et al. 2000; Masters and Sheley 2001; Nagler et al. 2011). Increased wildfire is also likely to disrupt riparian vegetation and water quality, including water temperature, sediment load, pH, and shade (Dwire and Kauffman 2003; Isaak et al. 2010; Miller et al. 2003) (Chapter 6). Riparian habitats will be directly affected by changes in hydrological regimes (Chapter 4), and a change in plant dispersal and regeneration of species dependent on periodic floods is likely (Hupp and Osterkamp 1996; Nilsson and Svedmark 2002) (box 9.7).

Expected changes in quality and more variable availability of water in riparian habitats have many implications. Arizona toads are more sensitive to changes in water availability than to plant community (Degenhardt et al. 1999), and permanent water sources are important to relict leopard frog populations (Jennings et al. 1995). Fires and postfire flooding, which increase sediments in rivers, have direct and indirect effects on fish and their reproduction, thereby affecting species that feed on fish (e.g., osprey, bald eagle, river otter). Water availability affects many species that forage over open-water bodies, including spotted bats and Yuma myotis (Luce and Keinath 2007; Oliver 2000). Mild winters may mean more open water for foraging, but warming and reduced precipitation could lead to a net decline in open water during summer.

Wetlands (Meadows, Emergent Marsh, Seeps/Springs)

Wetlands provide essential habitat for many species including Columbian spotted frogs (Ross et al. 1994; McMenamin et al. 2008), relict leopard frogs (Jennings 1988), blotched tiger salamanders, boreal chorus frogs (McMenamin et al. 2008), boreal toads (Kiesecker et al. 2001; Muths et al. 2003) and smooth greensnakes. Several

Box 9.7—Potential Effects of Loss of Native Riparian Forests for Terrestrial Species

- Loss of tall trees, which will negatively affect bald eagle populations (Buehler 2000).
- Reduced winter habitat for Columbian sharp-tailed grouse, which forages on shrub protruding from snow and roosts under snow for warmth and predator avoidance (Hoffman and Thomas 2007).
- Loss of foraging and nesting sites (cottonwood) for hoary bats, Yuma myotis, western red bats, fringed myotis (Oliver 2000; UDNR 2015), and Lewis's woodpeckers (Abele et al. 2004).
- Loss of forage and dam materials for American beavers.
- Reduced availability of riparian and mesic sites important for Gunnison sage-grouse and greater sage-grouse brood rearing (Connelly et al. 2004; GSRSC 2005).
- Negative impacts for species that use riparian corridors during migration, such as olive-sided flycatcher (Altman and Sallabanks 2000) and hoary bats (Valdez and Cryan 2009).
- Reduced water sources and warmer temperatures, which may affect species with high metabolic rates, such as spotted bats whose reproductive success has been linked to availability of open water (Luce and Keinath 2007).
- Altered growth and reproduction of many animals in response to changes in water regimes (hydrological and fluvial processes) (Catford et al. 2012; Perry et al. 2012).
- Degradation of riparian habitats from livestock grazing and climate change, which has been associated with an increase in nest parasitism of native songbirds by brown-headed cowbirds (Finch et al. 2002).
- Possible exacerbation of interspecific competition and hybridization between Arizona toads (UDNR 2015) and Woodhouse's toads in southern Utah (Oliver and Tuhy 2010) because of disturbances to riparian habitat.
- Possible mismatches in predator-prey relationships due to warming (Parmesan 2006). For example, hoary bat migrations are timed to coincide with moth abundance (Valdez and Cryan 2009), and a warmer climate could alter moth abundance (Singer and Parmesan 2010).

species of mollusks rely on seeps and springs for their entire life cycle (e.g., Utah physa, desert springsnail, fat-whorled pondsnail, Kanab ambersnail) (Oliver and Tuhy 2010). Long-billed curlews and Preble's shrews also depend on wetland habitats (UDNR 2015). Other animal associates include American beavers, songbirds, amphibians, reptiles, insects, elk, moose, deer, and bats. Wetlands provide nesting and foraging habitat for southwestern willow flycatchers (Hanberg 2000; Johnson et al. 2008; Oliver and Tuhy 2010; Paxton et al. 2007) and Lewis's woodpeckers (Abele et al. 2004). Multiple bat and raptor species use wetlands for foraging and nesting (Hayward et al. 1976; Luce and Keinath 2007; Oliver 2000; UDNR 2015). Wetlands are important for Gunnison and greater sage-grouse brood rearing (Connelly et al. 2004; GSRSC 2005). Lowland saline wetlands are important habitat for Preble's shrews (Cornely et al. 1992; Larrison and Johnson 1981).

Changes in precipitation timing and amount (especially monsoons) will alter wetland size and distribution (Matthews 2008). Under wetter conditions, some wetlands will expand (Gitay et al. 2001). However, declines in the long-term persistence of wetlands and other aquatic bodies fed by precipitation, runoff, and groundwater are likely with warmer summers, decreased snowpack and depth, and changes in snowmelt timing (Diffenbaugh and Giorgi 2012; Doeskin et al. 2003; Romero-Lankao et al. 2014). In addition, there may be contraction of groundwater-fed wetlands (Poff et al. 2002; Winter 2000) and an increase in the number of dry ponds (McMenamin et al. 2008). Lower water tables from warming and drought will influence wetland plant communities (Chimner and Cooper 2002, 2003a,b) and associated availability of food and cover for terrestrial species.

Reduction of habitat will negatively affect amphibian and bird species that rely on wetlands for some or all of their life requirements (Jennings 1988; Kiesecker et al. 2001; McMenamin et al. 2008; Muths et al. 2003; Ross et al. 1994) (box 9.8). Direct effects on water quality and temperature will also be important, especially for amphibians for which increased temperatures increase stress and susceptibility to disease and infection (Muths et al. 2008; Pounds et al. 2006). Mild winters may mean more open and available water for foraging species. However, where warming and reduced precipitation lead to less open water, populations of species such as spotted bats and Yuma myotis (Luce and Keinath 2007; Oliver 2000) may be greatly reduced. Possible increases in invasion of native and nonnative plants (e.g., cattail, sawgrass, bulrush, saltcedar, phragmites) could also decrease access to open water (Oliver and Tuhy 2010).

Species Vulnerability Assessment

We conducted an index-based vulnerability assessment of 20 vertebrate species to understand how they may respond to climate change and how this information could be used in conservation efforts (table 9.8). We calculated vulnerability index values with the System for Assessing Vulnerability of Species to climate change (SAVS) to examine and compare vulnerability of individual species (Bagne et al. 2011). SAVS is based on species traits associated with sensitivity and adaptive capacity with respect to projected levels of exposure specific to the region of interest (box 9.9). We generated scenarios of exposure (e.g., habitat loss) based on future climate and habitat projections in the IAP region. Given the large area encompassed, exposure can be highly variable; thus, vulnerability can also vary for widely distributed species. We noted differences within the region, and in one case (bighorn sheep) provided two sets of scores corresponding to different subspecies.

Box 9.8—Potential Effects of Wetland Loss for Terrestrial Species

- Negative impacts for American beavers caused by loss of forage and dam materials (willows, aspen, cottonwood) either from climate factors, fire, or overgrazing by ungulates (elk, cattle, moose) (Bilyeu et al. 2008; Smith and Tyers 2008; Wolf et al. 2007).
- Loss of foraging sites for peregrine falcons (Hayward et al. 1976).
- Loss of wetland sites important for Gunnison sage-grouse and greater sage-grouse brood rearing (Connelly et al. 2004; GSRSC 2005).
- Loss of lowland saline wetlands, which are important habitat for Preble's shrews (Cornely et al. 1992; Larrison and Johnson 1981; UDNR 2015).
- Reduced water sources and warmer temperatures, which may affect species with high metabolic rates; reproductive success of spotted bat is linked to availability of open water (Luce and Keinath 2007).
- Altered growth and reproduction of species in response to changes in hydrological and fluvial processes (Catford et al. 2012; Perry et al. 2012). For example, increased desiccation of breeding habitats for amphibians prevents spawning and causes population declines (Daszak et al. 2005; McMenamin et al. 2008; Winter 2000).
- Reduced cover and connectivity among ponds, which reduces amount and quality of amphibian habitat (Pounds et al. 2006; Whitfield et al. 2007).

Table 9.8—Total score and uncertainty[a] based on projected species vulnerability and resilience from System for Assessing Vulnerability of Species to climate change.

Species (score, uncertainty)	Critical vulnerabilities	Areas of resilience
Birds		
American three-toed woodpecker (0.33, 41%)	Reduced forest area, drier forests, altered timing of beetle development	High mobility, increased tree stress and food resources, irruptive movements
Black rosy finch (5.3, 36%)	Reliance on alpine habitat, association with snow patches, limited breeding window	Ability to travel large distances to track food
Flammulated owl (8.2, 27%)	Loss of dense forests, sensitive to high temperature, relies on environmental cues, migrates	Predators and disease not a big source of mortality, cold limited and potential for expansion northward and up in elevation
Greater sage-grouse (6.1, 32%)	Reduced plant cover (sagebrush, herbaceous), more frequent fires, migration (some populations), increased West Nile virus	Extended breeding season, high mobility
White-headed woodpecker (2.6, 36%)	Winter survival tied to fluctuations in pine seeds, limited breeding	High mobility
Mammals		
American pika (4.3, 32%)	Loss of high-elevation habitat, increasing barriers to dispersal, heat sensitive, cold sensitive, change in growing season	Extended breeding season, food storage, mobility where habitats remain connected
Desert bighorn sheep (5.1, 36%)	Dehydration, drought mortality, loss of water sources, reduced activity in high temperatures, timing of high nutrient availability, reduced plant growth, higher disease risk	High mobility, extended reproductive period
Sierra Nevada and Rocky Mountain bighorn sheep (2.2, 41%)	Dehydration, drought mortality, reduced activity under high temperatures, timing of high nutrient availability, reduced plant growth, higher disease risk	Potential for habitat expansion because of less snow, high mobility, reduced competition on winter range
Canada lynx (4.4, 41%)	Loss of mature forest, reduced snowpack, mismatched timing with snowshoe hare cycles, more variable prey, greater predation risk for kits, increased competition	High mobility
Fisher (5.2, 50%)	Loss of forests, loss of denning and resting sites, increased predation with more open habitats	High mobility, improvement of hunting success with less snow
Fringed myotis (3.4, 45%)	Reliance on temperature cues, one reproductive event per year, loss of open water foraging areas	Potentially increased period of seasonal activity
Northern Idaho ground squirrel (3.2, 32%)	Less snow insulation during hibernation, cold spring weather, altered hibernation and growing season timing, increased plague risk, short breeding season	Expansion of dry meadows, high mobility
Sierra Nevada red fox (5.3, 23%)	Restricted range, increased predation and competition as new species immigrate	Generalist diet, ability to move long distances
Townsend's big-eared bat (3.3, 36%)	Reduced surface water, timing of hibernation, timing of prey peaks	Increased winter foraging
Utah prairie dog (0.33, 36%)	Fewer moist swales, altered hibernation timing, change in growing season, short breeding season	Expansion of shrub-steppe and grassland, facultative torpor, cooperative behavior, high mobility
Wolverine (7.0, 36%)	Loss of alpine and high-elevation forest, reduced annual snow, altered timing and depth of spring snow, reduced caching longevity, increased competition for food	High mobility, higher ungulate populations

Table 9.8—*Continued.*

Species (score, uncertainty)	Critical vulnerabilities	Areas of resilience
Amphibians and reptiles		
Boreal toad (5.0, 27%)	Loss of wetlands, stream and pond drying, loss of protective vegetation, desiccation risk in terrestrial habitats, altered breeding timing, change in risk of chytridiomycosis	Low metabolic rate, explosive breeding, change in risk of chytridiomycosis
Columbian spotted frog (5.9, 41%)	Loss of wetlands, stream and pond drying, use of distinct breeding and winter habitats (some populations), altered breeding timing, increased risk of ranaviruses	Low metabolic rate, improved survival with warmer winter, reduced fish predation, explosive breeding
Great Basin spadefoot (2.2, 41%)	Loss of wetlands, reduced activity, altered breeding timing, increased competition for breeding habitats, desiccation risk, altered hibernation timing	Low metabolic rate, retention and absorption of water, explosive breeding, reduced fish predation
Prairie rattlesnake (4.3, 36%)	Loss of cover for refugia, heat sensitive, changes in active periods, altered hibernation timing, loss of conspecifics for denning, low reproductive rates	Low metabolic rate, higher small mammal populations

[a] Positive scores indicate higher vulnerability, negative scores indicate potentially positive effects, and zero defines a neutral response. Uncertainty is the percentage of questions with no published information or for which information implied opposing or complex predictions.

Box 9.9—System for Assessing Vulnerability of Species to Climate Change

The System for Assessing Vulnerability of Species to climate change (SAVS) divides predictive traits into four categories: habitat, physiology, phenology, and biotic interactions.

- Vulnerability predictors for habitat relate to the degree to which associated breeding and nonbreeding habitat changes, the change in availability of habitat components and habitat quality, reliance on stopover habitat (migrants), and ability to disperse to new habitats.
- Vulnerability predictors for physiology relate to the range of physiological tolerances, susceptibility to or benefits from extreme weather events, temperature-dependent sex ratios, metabolic rate, and adaptations for dealing with resource shortages (e.g., caching, torpor).
- Vulnerability predictors for phenology relate to the likelihood a species will have an increased risk of timing mismatch between important life events (e.g., hatching, arousal from hibernation) and critical resources (e.g., food sources, ponds). Four indicators are important: (1) reliance on temperature or precipitation cues (e.g., spadefoot toad emergence), (2) reliance on resources that are tightly tied to temperature or precipitation (e.g., breeding ponds, deep snow), (3) large spatial or temporal distance between a cue and a critical life event (e.g., migration of songbirds to breeding grounds), and (4) annual duration or number of reproductive opportunities.
- Vulnerability caused by biotic interactions with other species is considered for food resources, predators, symbionts, competitors, and diseases and parasites. To be considered for scoring, the interaction must have a demonstrable effect on populations of the assessed species (e.g., nestling survival correlated to predator abundance).

Future population trends are inferred through the response of a species as measured by the SAVS. Vulnerability scores are estimated given the balance of factors (e.g., more traits predicting lower versus higher survival and reproduction), relative importance of individual effects (e.g., exceeding physiological tolerance or effects of a vegetation shift), and local conditions that alter exposure (e.g., slope or recent fire, which can alter flood risk). Vulnerability scores identify critical issues for individual species, including migration and biotic interactions, providing a consistent method to compare species flexibility for including new information and local knowledge (Small-Lorenz et al. 2013; Sutherst et al. 2007).

Vulnerability was assessed for a group of species that are of management concern for USFS Intermountain Region resource managers over the next 50 years (table 9.8). Species represent a variety of taxonomic groups with diverse traits responsive to climate change effects. Species already at risk of extirpation and extinction may be particularly vulnerable, and opportunities for early intervention could be missed if climate stressors are not recognized (Moyle et al. 2013).

Species Vulnerability

Summary

Flammulated owl, wolverine, and greater sage-grouse were the most vulnerable to population declines as a result of climate change (table 9.8, fig. 9.5). Utah prairie dog and American three-toed woodpecker were the least vulnerable with total scores indicting a relatively neutral response rather than population increase. Most species exhibited some sensitivity to changes in phenology, but habitat and physiology scores were variable among the species assessed. Habitat loss was often an issue for species restricted to high elevation or habitats associated with surface water (table 9.1, Appendix 9).

To interpret vulnerability scores, it is important to consider not just the total scores, but the relative balance of individual traits that represent specific vulnerabilities or adaptive capacity. For example, Townsend's big-eared bat and northern Idaho ground squirrel have a similar overall score of around 3, but the score for the ground squirrel includes both areas of resiliencies and sensitivities, whereas the bat was more consistently sensitive across all criteria (Appendix 9). This suggests that response of the ground squirrel is more uncertain because it depends on the strength and interplay of many factors.

Interpretation of assessment results must consider uncertainty and how it may influence the final scores. A score of 0 is given where information or future response is unknown for a particular trait. Therefore, some species scores may be lower than expected where information was unavailable. As part of the assessment process, we generated uncertainty scores that represent availability of information for each score. As seen in table 9.8, uncertainty is invariably high for these species because their life histories are poorly understood. In particular, information was consistently insufficient for factors related to interactions including disease, competition, and food resources.

American Three-Toed Woodpecker (Picoides dorsalis)

Three-toed woodpeckers are attracted to various forest disturbances in relatively large numbers, leading to conspicuous irruptions of an otherwise poorly known species (Leonard 2001; Virkkala 1991). Their diet consists primarily of bark beetles, coinciding with the birds' high mobility and attraction to tree mortality associated with bark beetle outbreaks, fires, pollution, and windthrow (Leonard 2001). Bark beetle populations in most of the region are not expected to increase from direct effects of warming because, in contrast to Canada, current conditions already favor rapid development and low winter mortality (Bentz et al. 2010).

However, indirect effects of climate change on tree vigor and mortality caused by increased heat and drought are likely to increase beetle populations (Chapter 7) and thereby an important food source for the woodpecker. In addition,

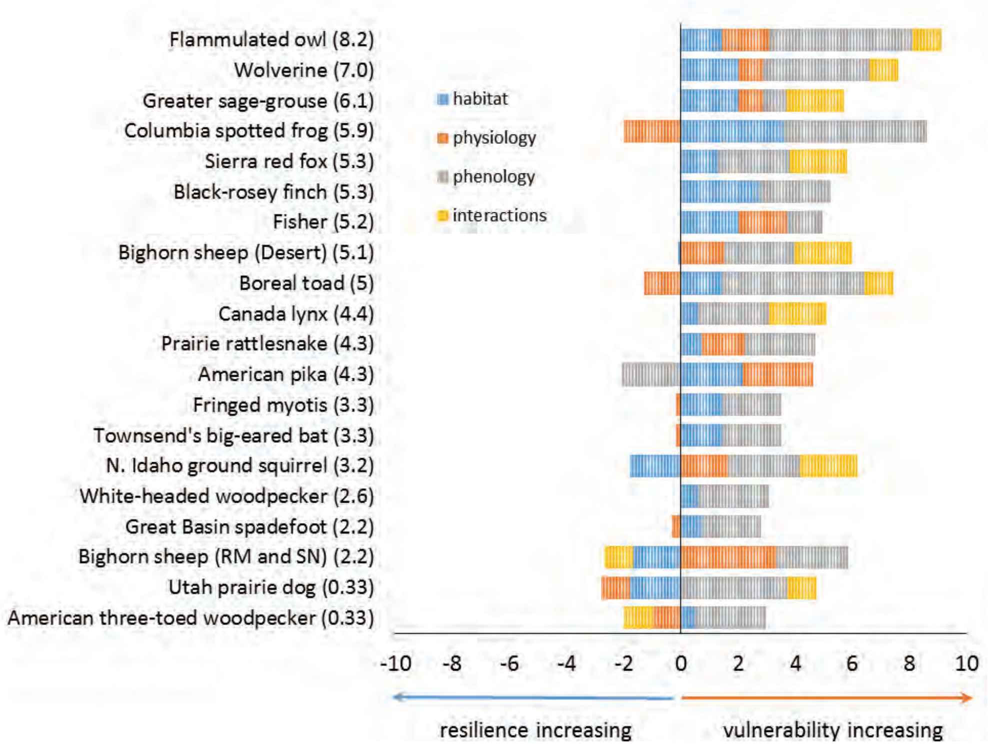

Figure 9.5—Vulnerability scores (value in parentheses) for 20 terrestrial animal species. Positive scores indicate higher vulnerability, negative scores indicate higher resilience, and zero defines a neutral response. Color of bars represents the relative contribution of habitat, physiology, phenology, and biotic interactions to overall vulnerability.

outbreaks are expected to be more severe and cover larger areas (Seidl et al. 2009). Woodpecker populations, in turn, affect beetle populations because during outbreaks, woodpeckers eat large numbers of beetles; thus, these birds can reduce the overall impact of an outbreak (Fayt et al. 2005).

Favorable landscapes for three-toed woodpeckers will be dynamic, varying with disturbance events at small and large scales and over time as snags fall, fuel structure changes, and forests regenerate or are replaced by other vegetation types. It is unknown whether climate-induced shifts in the distribution of different tree species and bark beetle species will negatively or positively affect these birds. However, some projections show declines in the preferred forest habitat for this woodpecker over time.

Black Rosy Finch (Leucosticte atrata)

The black rosy finch is an alpine specialist, associated with areas with at least patchy snow cover. This finch breeds above treeline in cracks or holes in cliffs or rock slides and forages for food around snowfields and on nearby tundra (French 1959; Johnson 2002). During winter storms and periods of deep snow cover, they descend to open or semi-open habitats at lower elevations such as open valleys, mountain parks, and high deserts. The most significant climate effects for this species result from potential loss of alpine habitat, snowfields, and glaciers. Warming conditions are likely to reduce the size and duration of snowfields and glaciers. Some alpine habitats are expected to decline very slowly where trees encroach on alpine habitat.

Other sensitivities include a potential reliance on insects, which may undergo population shifts with spring advancement. Seed food sources may also change with changing plant composition and growing seasons. Breeding cues are unknown, but may be related to when snow cover is reduced to the point where sufficient food is available. If that is the case, altered snowmelt could affect reproductive success. Currently, this species breeds only once per season (laying 3–6 eggs) during short summers at high elevation (French 1959; Johnson 2002), and it is unlikely that this species would be able to take advantage of longer growing seasons by increasing nest opportunities.

The black rosy finch exhibits traits that would allow it to adapt to changing conditions as long as its preferred habitat remains. The finch does not migrate over long distances but is quite mobile and known to wander widely to take advantage of food sources during nonbreeding seasons (French 1959; Johnson 2002). This mobility may lend it some capacity to adapt to local conditions. This species also does not seem to be overly affected by predators or competitors. As one of only a few bird species that breed in alpine habitat, it is unlikely to see any significant changes in competitors during the breeding season. This could change if species from lower elevations move upslope and into black rosy finch habitat in response to warming conditions. However, birds in the nonbreeding season in human-altered habitats may be negatively affected by competition with house sparrows and European starlings for roost sites. The specialized habitat requirements of the black rosy finch will require careful measures to reduce disturbances in areas that are likely to remain suitable for this species. Ultimately, this species will probably disappear from some areas where snowfields and glaciers are lost.

Flammulated Owl (Psiloscops flammeolus)

The flammulated owl has the highest vulnerability score in this assessment because of sensitivities identified in all SAVS vulnerability categories. Wildfire, insects, and changes in climate suitability will probably increase early-seral forest structure over time, conditions detrimental for this species, which prefers mature, open ponderosa pine and other semiarid forests with brushy understories (Linkhart 2001). Reduced availability of critical nesting trees may occur over time, and abundance of arthropod prey needed as food for chicks may be altered (Linkhart and McCallum 2013; Linkhart and Reynolds 2004). Although owls are highly mobile and can disperse long distances (Arsenault et al. 2005), breeding site fidelity is very high among males, which typically occupy the same territory their entire lives (Arsenault et al. 2005; Linkhart et al. 2016). The lower elevational range for owls is determined by maximum daytime temperature or high humidity, and the upper elevational range is limited by minimum night temperatures or high humidity, or both (McCallum 1994). Thus, owls may need to move up in elevation or to the north under warmer temperatures. Like other insectivorous birds, they are vulnerable to late-spring storms, a potential issue with climate change.

Flammulated owls are sensitive to phenological changes. Onset of incubation appears to be correlated with temperature, and owls may already be nesting earlier in response to warmer spring temperatures. High densities of arthropod prey are required for feeding and successfully raising young, so altered insect emergence could decouple with critical times in hatchling development. As with all long-distance migrants, this species is at risk of mismatch between summer and winter habitats (Bagne et al. 2011). Finally, this owl breeds rather late and only once per year (Arsenault et al. 2005; Linkhart and McCallum 2013; Linkhart and Reynold 2004), making it susceptible to reproductive failure in years with unfavorable conditions.

Flammulated owls are a secondary nester, so their well-being is associated with species such as woodpeckers that create cavities (Linkart and McCallum 2013; McCallum 1994). In the short term, primary cavity nesters are likely to benefit under climate change if tree mortality increases. In the long term, snags and large trees may become less common, with a lag between tree loss and establishment after fire and in response to shifting climate. Competition for nesting cavities can be high with other cavity nesters, although it is difficult to predict whether it will increase or decrease for owls. Where habitat declines, flammulated owls may face increased competition for nesting cavities among conspecifics, other owls, woodpeckers, and squirrels. However, this species persists where primary cavity species remain stable and under situations where arthropod abundance increases. Increasing nighttime temperatures coinciding with appropriate humidity levels will also allow flammulated owl to move into new, potentially suitable habitats.

Greater Sage-Grouse (Centrocercus urophasianus)

Vulnerability of greater sage-grouse is linked with the future of sagebrush. Invasion by cheatgrass and tree species (e.g., junipers) degrades sagebrush habitat, resulting in habitat loss (Boyd et al. 2014). Lower elevations are particularly prone to invasion by nonnative grasses, which can fuel frequent wildfires, kill mature sagebrush, and promote a transition from shrubland to grassland (Bradley 2010; Knick et al. 2013). The Great Basin is expected to experience a substantial increase in the probability of large wildfires, which will threaten isolated sage-grouse populations (Brown et al. 2004). Higher elevation sagebrush habitats are prone to conifer encroachment, particularly in northern parts of the region (Knick et al. 2013). Under warmer and drier conditions, sagebrush is expected to decline throughout much of Nevada and Utah (Bradley 2010; Schlaepfer et al. 2012). In addition to habitat loss, drought is expected to reduce forb cover and arthropod abundance (Miller and Eddleman 2000) and increase the likelihood of heat stress (Blomberg et al. 2012), particularly for chicks and juveniles (Miller and Eddleman 2000).

West Nile virus is an emerging infectious disease that is virulent in sage-grouse (Walker and Naugle 2011). Because mosquitoes transmit the virus, transmission of the virus and its prevalence are related to local temperature and precipitation (Walker and Naugle 2011). Warmer summer temperatures increase infection rates by favoring mosquito vectors and accelerating virus replication. Lower annual precipitation and increased drought can increase transmission of the virus by increasing contact between individuals who congregate in remaining mesic habitats and by creating more ephemeral water sources that cannot support mosquito predators (Harrigan et al. 2014; Naugle et al. 2004). Increased presence of West Nile virus is predicted for California, as well as northern Nevada and Idaho, where stronghold sage-grouse populations currently occur (Harrigan et al. 2014). Probability of West Nile virus presence in Utah may decrease (Harrigan et al. 2014). Artificial bodies of water, such as stock tanks and ponds associated with coal-bed natural gas extraction, further enhance West Nile virus transmission and sage-grouse vulnerability (Walker and Naugle 2011).

White-Headed Woodpecker (Picoides albolarvatus)

The white-headed woodpecker breeds in mature coniferous woodlands dominated by pines, most commonly ponderosa pine (Garrett et al. 1996). Preferred habitat is in areas with high numbers of more than one pine species and mature trees with an abundance of large cones with seeds (Hollenbeck et al. 2011; Mellen-McLean et al. 2013) perhaps as a buffer to variation in seed production among species. In the short term, increased beetle activity and increased tree mortality and drought could improve habitat quality, but reliance on pine seeds during winter provides less advantage than for species such as the American three-toed woodpecker. Loss of preferred habitat (e.g., through logging or fires) is the primary threat to this species (Environment Canada 2014) and will be exacerbated by increased wildfire activity. Woodpeckers can thrive in moderately burned areas if suitable habitat remains (Garrett et al. 1996; Latif et al. 2014), although loss of nest sites and food resources over long time periods could lead to population decline. White-headed woodpeckers may also be sensitive to phenological changes in food resources; they appear to breed later in the season than other woodpeckers (Kozma 2009), presumably to coincide with peak abundance of favored prey. This species produces a single clutch per year, which increases susceptibility to reproductive losses caused by fluctuations in food resources and spring storms (Hollenbeck et al. 2011).

White-headed woodpeckers have several sources of resilience. They can move long distances but are rarely found away from breeding areas, so they are not prone to the risks of migrating species. As a resident species, it is well adapted to a wide variety of weather conditions. In addition, warmer temperatures are positively correlated with nesting success associated with increased availability of insects (Hollenbeck et al. 2011). Woodpeckers are known to move short distances (less than 10 miles) to take advantage of exceptional food resources, such as spruce budworm outbreaks. Ultimately, the persistence of this species will be tied to the availability of appropriate forest habitats that can provide adequate food sources.

American Pika (Ochotona princeps)

Some consider the American pika highly vulnerable to a warming climate as its cool mountain habitats shift upward and occupy less area (Beever et. al 2011; Parmesan 2006). Bioclimatic data suggest that if greenhouse gas emissions continue to increase unabated, populations will become increasingly isolated and pikas may be extirpated in some portions of their range including the Great Basin (Galbreath et al. 2009). Pikas are sensitive to both temperature and precipitation changes and are likely to respond to both direct and indirect climate change effects. Physiologically, pikas are not tolerant of very high or very low temperatures, and higher summer temperatures may limit periods when they can actively forage (Beever et al. 2010; Jeffress et al. 2013; MacArthur and Wang 1973). Precipitation, particularly during the growing season, has been positively linked to pika population trends probably through effects on forage availability (Beever et al. 2003, 2013; Erb et al. 2011).

Annual net primary productivity on a broad scale, as a measure of forage quantity, may be enhanced by carbon dioxide fertilization in more northerly regions, and changes in precipitation may reduce annual productivity in southern regions (Reeves et al. 2014). Projected expansion of cheatgrass at low-elevation sites in northern parts of the IAP region may increase vulnerability of resident pika populations, but effects of cheatgrass have not been studied (Beever et al. 2008; Bradley 2010). Pikas are considered to be dispersal limited, with movements restricted to short distances or along continuous elevational gradients where lowlands do not need to be crossed. Thus, pikas in some locations will have difficulty tracking a geographic shift in habitat. Movement may be facilitated by favorable weather conditions, such as years of high precipitation (Castillo et al. 2014; Franken and Hik 2004; Jeffress et al. 2013; Smith 1974), although the frequency of such conditions in the future is unknown.

Several areas of potential resilience to climate change have been noted for pikas, although the nature of this resilience varies according to landscape context. Although not tolerant of high heat, pikas have recently been found to occur at lower elevations than previously thought, suggesting a broader range of temperature tolerance (Beever et al. 2008; Collins and Bauman 2012; Millar and Westfall 2010). In warm climates, pikas may seek sites with favorable microclimates where temperature is buffered locally (e.g., lava tubes, talus interstices) (Jeffress et al. 2013; Millar and Westfall 2010). In addition, pikas are active year round and can produce more than one litter per year, which may help this species take advantage of longer growing seasons (Bagne et al. 2011). At lower elevation sites, pikas may not have the same requirements for snow cover, which provides insulation against cold winter temperatures at higher elevation sites (Simpson 2009). Thus, lower elevation populations may be less vulnerable to reduced snowpack, but may still suffer physiological stress from high temperature.

Pikas will be the most vulnerable on isolated mountaintops, at lower elevations where they may already be near their physiological tolerance, and where primary productivity is expected to decline. Accordingly, populations in the southern Great Basin are probably the most vulnerable in the IAP region. Across the species range, resilient populations are likely to occur in locations that support loosely arranged rocks (rock-ice features, lava tubes) and deep rock features, and that are close to wetlands or other high-quality forage (Millar and Westfall 2010; Ray and Beever 2007).

Bighorn Sheep (Ovis canadensis)

We calculated vulnerability for the desert (*Ovis canadensis nelsoni*) and Sierra Nevada/Rocky Mountain (*O. c. sierra/O. c. canadensis*) bighorn sheep subspecies. Different parts of the IAP region, and thus different bighorn subspecies, will be subject to differential changes in climate linked to bighorn sheep population dynamics. A warmer climate will facilitate establishment of more arid vegetation types and reduce primary productivity within the southern portions of the region occupied by the desert subspecies (Reeves et al. 2014). Desert bighorn sheep will also be more vulnerable to increasing drought and high temperatures that reduce forage and standing water. Populations in the most arid, low-elevation areas and without access to dependable springs are most vulnerable (Epps et al. 2005).

Fluctuations in precipitation that affect spring forage availability and timing may have significant impacts on bighorn sheep (Portier et al. 1998). In general, areas with more topographic relief and fewer natural or anthropogenic barriers may be more resilient to negative impacts on year-round forage availability. Expected reductions in snowpack could increase winter range for Sierra Nevada and Rocky Mountain subspecies (Maloney et al. 2014). Forage quality may decline in mountainous habitats where warmer springs encourage faster green-up (Pettorelli et al. 2007; Wagner and Peek 2006). Changes in snowpack, in conjunction with nitrogen deposition, can also reduce selenium content of forage, resulting in deficiency that can lead to population declines (Flueck et al. 2012; Williams et al. 2002).

Bighorn sheep regularly undergo large mortality events that counter recovery efforts to reverse declining population trends. Endemic and introduced diseases are important drivers, but interactions with livestock, habitat quality, weather, predation, and infectious agents make it difficult to identify a single cause of these die-offs (Miller et al. 2012). Parasites that cause scabies and lungworm may expand with warmer temperatures as suitable habitats expand and parasite and host populations develop more rapidly (Hoberg et al. 2008). Potential climate-related changes in the prevalence of scabies and predation within winter ranges are of particular concern for bighorn sheep populations in the Sierra Nevada (USFWS 2007). Drought, severe weather, and vegetation changes can increase contact with infected individuals and facilitate transmission of pathogens such as those that cause brucellosis (Hoberg et al. 2008; Wolfe et al. 2010b).

Predation affects how bighorn sheep use habitats (Festa-Bianchet 1988). Mountain lions have been implicated in declines of sheep in the Sierra Nevada (USFWS 2007), but it is unclear whether predation pressure will increase under climate change. A longer growing season in mountainous areas may benefit bighorn sheep by allowing it to maintain proximity to escape terrain at higher elevations for a greater proportion of the year. Shifts in winter range could also potentially reduce contact with domestic livestock and competing ungulates. How the benefits of longer growing seasons and enhanced access to escape terrain will balance potential loss of forage quality and more frequent drought is unclear. Because several agents of disease may be enhanced under warmer temperatures, and because many bighorn populations in the region are small, factors related to high rates of infection and morbidity will affect efforts to increase populations.

Canada Lynx (Lynx canadensis)

Canada lynx is a specialist predator expected to be vulnerable to climate change through a variety of mechanisms. Projecting change to lynx habitat in the IAP region is difficult because of the complexity of interactions among climate, wildfire, and insect outbreaks across a diverse landscape. Drought-related mortality may affect some tree species and late-seral forests used by lynx for breeding (Bigler et al. 2007; McDowell and Allen 2015). Nonbreeding habitats, which typically contain a variety of seral stages and well-developed understory, may increase in areas with mixed-severity fires but decline in drier areas where more extensive wildfires favor homogeneity (McKenzie et al. 2004).

Canada lynx depends on snowshoe hares as a primary food source, although a variety of prey species are taken, particularly in summer (Interagency Lynx Biology Team 2013; Squires and Ruggiero 2007). Lynx and snowshoe hare populations are linked and fluctuate with climate; thus, the magnitude and timing of climatic events are noteworthy. Lynx will be vulnerable to projected reductions in snowpack (Maloney et al. 2014), which will reduce its competitive advantage over other predators in winter (Interagency Lynx Biology Team 2013; Ruggiero 1999). Alternate prey species such as grouse or tree squirrels are smaller and may not compensate for reduced snowshoe hare populations (Ruggiero et al. 1994). Conversely, lynx may experience increased hunting success where white-coated snowshoe hares are unable to match molting cycles to more rapid and earlier snowmelt (Mills et al. 2013) (fig. 9.6). This short-term advantage is unlikely to compensate for the negative impacts of increasingly variable hare populations. Habitat fragmentation and lynx hybridization with bobcats are also threats (Interagency Lynx Biology Team 2013) that could increase as habitat quality declines and changing conditions induce dispersal. Lynx are expected to be more resilient where dense understory vegetation and large forest patches are maintained, whereas more vulnerable populations will be found where forests are drying and at high risk for wildfire or insect outbreaks.

Figure 9.6—Snowshoe hare. If pelage change for snowshoe hares does not keep pace with early snowmelt in a warmer climate, they will be susceptible to increased predation by Canada lynx and other species (photo: U.S. Fish and Wildlife Service).

Fisher (Pekania pennanti)

The fisher relies on the physical structure of forest habitat rather than a specific forest type. A modeling analysis suggests that probability of fisher occurrence is highest for mesic forest types with tall trees, high annual precipitation, and mid-range winter temperatures (Olson et al. 2014). Given the expected effects of an altered fire regime on the extent and pattern of late-seral forests (Littell et al. 2009, 2010; McKenzie et al. 2011), the extent, quality, and connectivity of fisher habitat in the IAP region will probably decrease in response to climate change. Habitat change will be driven largely by increasing area burned, which will reduce late-seral forest habitats.

Fishers are probably not dispersal limited, so they can move from unfavorable to favorable habitat as needed. They are opportunistic predators, primarily of snowshoe hare, squirrels (*Tamiasciurus, Sciurus, Glaucomys,* and *Tamias* spp.), mice (*Microtus, Clethrionomys,* and *Peromyscus* spp.), and birds (numerous species) (Powell 1993). They also consume carrion and plant material (e.g., berries). No clear trends are projected for the effects of climate change on availability of prey species.

Fringed Myotis (Myotis thysanodes)

Although the fringed myotis is relatively rare, it can be abundant in local populations and inhabits most of the western United States (Hester and Grenier 2005; Keinath 2004). The fringed myotis frequents a fairly broad range of habitats (Keinath 2003), but is typically associated with oak, pinyon, and juniper woodlands or ponderosa pine forests at mid-elevations (Keinath 2003). Caves, abandoned mines, and buildings can be used for maternity colonies, hibernacula, and solitary day and night roosts. Fringed myotis appears to exhibit high breeding site fidelity, returning to the same geographic areas year after year (Keinath 2004). Although this species regularly roosts underneath bark and inside hollows of tree snags, roosts in relatively permanent structures (e.g., caves, buildings, rock crevices) seem to elicit high fidelity, whereas roosts in trees do not (Keinath 2003). Winter range is poorly known for this species (Hester and Grenier 2005; IDFG 2005; Oliver 2000; USDA FS 2014).

Like other bats, fringed myotis inhabits environments where persistent sources of water are readily available (Hester and Grenier 2005; Keinath 2004). Roost sites are usually located close to stream channels. In addition, most bats need open, still bodies of water to drink, and lactating females have additional water requirements (Keinath 2004). Bats are small and have a high ratio of surface area to volume, making them prone to losing large amounts of water through evaporative loss. A long-term study demonstrated that water availability was crucial to the reproductive effort of insectivorous bats (Adams 2010). Several species (including fringed myotis) showed a threshold-type response to decreased streamflow rates, with reproductive output decreasing rapidly as stream discharge declined. The number of nonreproductive females captured increased as mean high temperatures increased. Instead of abandoning traditional roost sites impacted by detrimental environmental conditions, fringed myotis responded by reducing their reproductive output. Slower ontogeny may jeopardize survival of both young and adult females by shortening the window needed for increasing body mass for hibernation or migration (Adams 2010).

Fringed myotis exhibits some traits that increase resilience to climate-related changes. Because it is agile in flight, very small watering holes may be sufficient for water supplies (Keinath 2004). It is also somewhat opportunistic, feeding on diverse insect species when they are abundant, although beetles are normally a large portion of their diet. Finally, migration events are relatively fast, synchronous, and closely tied to breeding and seasonal weather patterns, so fringed myotis can respond quickly to changing conditions. Resilience will be highest in areas where water sources continue to be associated with roost sites.

Northern Idaho Ground Squirrel (Urocitellus brunneus brunneus)

Recent declines in the northern Idaho ground squirrel have been partly attributed to livestock grazing and encroachment of young trees facilitated through fire exclusion (Sherman and Runge 2002). Higher frequencies of wildfire projected for the IAP region (Peterson and Littell 2012) could increase the quantity of suitable habitat and availability of dispersal corridors. This ground squirrel has a long hibernation period, requiring accumulation of fat stores and hibernacula insulated by snowpack. The species can suffer winter mortality when snow is not deep enough to provide insulation (Sherman and Runge 2002; USFWS 2003). Assuming that snowpack will decrease (Maloney et al. 2014), overwinter mortality may increase, particularly for juveniles.

Primary productivity is expected to increase across the current range of northern Idaho ground squirrels (Reeves et al. 2014), potentially increasing seed production but perhaps at the cost of plant species diversity (Suttle et al. 2007), which could reduce the availability and timing of preferred forage species. Earlier snowmelt, longer growing seasons, nonnative plant species, increasing fires, and altered pollinator populations all affect plant species composition and seed set (Alward et al. 1999; Inouye and McGuire 1991; Sherman and Runge 2002). Timing and availability of fat-laden seeds are likely to affect ground squirrel response, but it is difficult to project how food sources will change in the future.

Ground squirrel populations in the IAP region are small, isolated, and vulnerable to additional stress related to climate and other factors. Individual squirrels are capable of dispersing to new areas in pace with habitat change (Sherman and Runge 2002), but small populations and human-caused barriers constrain movement (USFWS 2003). Plague is a potential threat but has not been recorded in these populations, although climate is expected to become more favorable for plague transmission in Idaho (Nakazawa et al. 2007). Improved habitat through increased productivity may benefit northern Idaho ground squirrel, but short-term drought, cold spring weather, and disease, as well as nonclimatic factors (overgrazing, recreational shooting, land development) may be significant stressors.

Sierra Nevada Red Fox (Vulpes vulpes necator)

The Sierra Nevada red fox is adapted to snowy, high-elevation habitats (Buskirk and Zielinski 2003; USFWS 2015), and altered snowpack is the biggest threat to fox persistence through its effects on species interactions. This fox subspecies appears to have habitat and distribution limitations and is not as common as other subspecies (Perrine et al. 2010). Even in favorable habitat, red fox has been reported in small numbers, and several studies have noted population declines (Buskirk and Zielinski 2003; SNRFIWG 2010). It is a USFS sensitive species in California and a candidate for listing with the U.S. Fish and Wildlife Service in California and Nevada (USFWS 2015). Many populations are small and isolated and at risk of inbreeding depression and stochastically driven local extinctions (USFWS 2015).

Climate change may alter forest habitat through increased wildfires, drought stress, and insect outbreaks (USFWS 2015). In addition, low snowpack in the Sonora Pass area may be increasing competition and predation from coyotes (Perrine 2005; Perrine et al. 2010). Red foxes tend to avoid areas frequented by coyotes, which may be an important factor in restricting it to higher elevations. Hybridization between the two species is occurring at the Sonora Pass area (USFWS 2015) and could increase if climate facilitates range shifts. This fox is susceptible to several communal diseases (elokomin fluke fever, sarcopic mange, canine distemper, rabies), but it is unclear whether climate-related changes in habitat and behavior would affect transmission among individuals. Where red foxes are negatively affected, recovery tends to be slow because they have only one breeding season per year. Low reproductive capacity also makes it susceptible to climate-related fluctuations in prey species.

Living in remote mountain habitats, red foxes are sensitive to the presence of humans (Buskirk and Zielinski 2003; SNRFIWG 2010), although they can move long distances and could migrate into new habitats if available. Habitat management that improves prey availability and reduces coyote pressure can improve resilience of Sierra Nevada red fox populations.

Townsend's Big-Eared Bat (Corynorhinus townsendii)

Two subspecies of Townsend's big-eared bat (ssp. *townsendii* and *pallescens*) may occur in the IAP region (Pierson et al. 1999), and shifts in distributions of subspecies may occur under climate change. Use of a variety of forest, shrub, and woodland habitats by big-eared bats confers some resilience to habitat change. Although many shrub habitats are expected to remain or expand (Chapters 6, 7), increasing wildfires and proliferation of nonnative grasses could degrade habitats and reduce prey availability (Pierson et al. 1999) (Chapter 8). Northern portions of Nevada may be especially prone to cheatgrass invasion (Bradley 2010).

This insectivorous bat species needs access to surface water, especially during lactation (Adams 2003; Neuweiler 2000), and expected changes in snowpack and higher evaporation rates will probably reduce water availability in summer (Maloney et al. 2014). Although little is known about how the quality of various habitats relates to bat survival and reproduction, changes in proximity of suitable roost sites to foraging grounds will probably make big-eared bats vulnerable. Spread of white-nose fungus into the IAP region is expected by the 2020s, with earlier arrival in the north than south (Maher et al. 2012). Warmer weather and torpor characteristics are associated with frequent arousal, which may mitigate effects of fungal infection (Bernard et al. 2015; Johnson et al. 2012).

Although big-eared bats feed heavily on moths that are sensitive to climate, there is no evidence that generalist and specialist moth populations would decline synchronously across all species (Wilson and MacLean 2011). Rising temperatures will affect phenology related to foraging, breeding, torpor, and movement in bats while also affecting moth life cycles and distributions, which could lead to a mismatch in prey availability and bat energy requirements (Both et al. 2006). Because of a relatively sedentary nature and cave-roosting habits, this bat species is less likely than others to be vulnerable to wind turbine collisions (Johnson 2005). Disturbance at roost sites is an important stressor (Humphrey and Kunz 1976; Pierson et al. 1999) and is pertinent to climate change adaptation strategies that include roost monitoring. Managers will also need to consider the effect of phenological shifts on the timing of seasonal cave closures. Bats may be more resilient in landscapes where more roosts are available, surface water is available year round, and risk of cheatgrass invasion is low.

Utah Prairie Dog (*Cynomys parvidens*)

Little information is available on the potential effects of climate change on the Utah prairie dog. Increasing wildfires and invasive grasses may play a role in local habitat change, although the ultimate outcome for prairie dogs is unclear. Plague transmission in Utah is not expected to change based on past climate relationships (Nakazawa et al. 2007), but future climate relationships are unclear for the complex dynamics of outbreaks, such as climate effects on short-term disease reservoirs and flea species (Salkeld et al. 2010; Webb et al. 2006).

Prairie dogs will be vulnerable to changes in resource timing, such as availability of forage during lactation and before onset of hibernation. Drought is of particular concern because it has been implicated in past population declines through limitations related to food availability and water balance (Collier and Spillet 1975). Specialized traits pertaining to colonial living, such as communal nursing (Hoogland 2009), predator evasion (Hoogland 1981), and habitat manipulation (Bangert and Slobodchikoff 2006), may offer some resilience to changing conditions. More resilient populations will be those that are near persistent, moist swales and with few barriers to dispersal. Response of Utah prairie dogs to climate change is important because their presence on the landscape has implications for a diversity of mammal, bird, and reptile species (Kotliar et al. 1999).

Wolverine (*Gulo gulo*)

Climate-induced changes that reduce suitable habitat, especially snowpack, will have negative impacts on wolverine populations in the IAP region, although response to these changes is uncertain because of limited information (Ruggiero et al. 1994; Curtis et al. 2014). Wolverines depend on high-elevation forests and alpine habitats, which are likely to contract gradually in the future. Wolverine range is closely tied to areas with high snow levels (Schwartz et al. 2009), where the animals' large feet allow them to travel more easily than many other species (Ruggerio et al. 1994). Reduced snowpack, which is projected for most lower elevations in western North America, may be less severe in the Sierra Nevada than in other locations (Curtis et al. 2014; Maloney et al. 2014), although little is known about wolverine populations there (Moriarty et al. 2009). More precipitation falling as rain rather than snow and earlier spring snowmelt will restrict wolverine movement across the landscape (Aubry et al. 2007), fragment its habitat (McKelvey et al. 2011), increase competition with other predators, and reduce availability of cold food-caching and denning sites (Inman et al. 2012).

Wolverines have low reproductive rates that may decline further with loss of spring snow associated with preferred den sites. Loss of snow cover may also expose kits to increased predation (Ruggerio et al. 1994). Strong avoidance of human disturbance, including roads, may also limit the ability of this species to respond to change, particularly in its southern range, where habitats are more restricted (Fisher et al. 2013; McKelvey et al. 2011). This makes protection of narrow corridors for dispersal in Wyoming and Utah a priority (Schwartz et al. 2009).

Wolverines may be fairly resilient to food resource fluctuations because of their relatively broad diet and food caching behavior (Inman et al. 2012), but only within areas that otherwise remain suitable under future climate. Ungulates are an important scavenging item; thus, ungulate populations and hunting success of predators will affect food availability (Ruggerio et al. 1994). Reduced depth and duration of snow cover may benefit certain ungulate species, and hence may increase prey, but could also increase competition with other predators and scavengers. Despite a few resilient traits, wolverines will probably decline because of low populations (Schwartz et al. 2009) and the number of anticipated negative impacts from climate change.

Boreal Toad (Anaxyrus boreas boreas)

The boreal toad contains considerable genetic diversity, with eastern populations in Utah and southeastern Idaho considered distinct from western populations in Nevada and California (Center for Biological Diversity 2011; Federal Register 2012, 77 FR 21920) (fig. 9.7). Recent population declines have occurred throughout its range, including within unaltered habitats (Drost and Fellers 1996; Wente et al. 2005), coinciding with the introduction of chytrid fungus, although chytridiomycosis may be just one of many drivers of decline (Hof et al. 2011; Pilliod et al. 2010). Warmer temperatures are associated with spread of the fungus in cool, high-elevation habitats, but precipitation and humidity are also important, with limited infections in warm, dry areas (Berger et al. 2016; Puschendorf et al. 2009). Seasonality of prevalence and intensity of infection are affected by temperature, with high severity in summer for temperate climates (Berger et al. 2016). Warmer and drier climates have been associated with a lower occurrence of chytrid fungus in Australia and Costa Rica, but die-offs of Arizona lowland leopard frogs illustrate that chytrid can impact amphibians in dry climates as well (Berger et al. 2016). Some seasonal drying of habitats within levels that toad species can tolerate may benefit toad populations (Bielby et al. 2008) by discouraging the establishment of chytrid fungus and the fish and bullfrogs that are predators and carry the fungus (Berger et al. 2016; Puschendorf et al. 2009).

Although the mechanism is unclear, boreal toads appear to respond positively to wildfire, at least in the short term, and may benefit from climate-driven increases in fire frequency (Hossack and Pilliod 2011). Like all amphibians, boreal toads are sensitive to water balance as affected by rainfall, high temperatures, and drought (Bagne et al. 2011; Friggens et al. 2013). These factors affect when and where the toads can be active. A study in Idaho projected significant reductions in activity periods and growth under warmer conditions, especially in more open habitats where desiccation risk is higher (Bartelt et al. 2010). Toads generally select refuge within landscapes with favorable microclimates and relatively high humidity (Long and Prepas 2012).

Figure 9.7—Boreal toad. This amphibian species will probably have less wetland habitat in a warmer climate, although the manner in which climate affects chytrid fungus, and in turn vigor and mortality of toad populations, may determine future abundance and distribution (photo: U.S. Forest Service).

Juvenile toads are more diurnal (Lillywhite et al. 1973) and may be at an increased risk of reduced growth due to decreased activity under warmer conditions. Warmer temperatures may increase the rate of metamorphosis but can reduce pond longevity, causing tadpole mortality. Warmer temperatures also lead to increased livestock activity at water bodies, increasing the risk of trampling and loss of vegetative cover in breeding habitats (Bartelt 1998; DelCurto et al. 2005). Timing and duration of water availability, plus sufficient refuge from predation, cold, and desiccation, will help identify locally vulnerable or resilient habitats.

Columbia Spotted Frog (Rana luteiventris)

Climate change may exacerbate the major cause of historical declines in the Columbia spotted frog through alteration and fragmentation of aquatic habitats. Drought, warmer temperatures, altered precipitation regimes, and reduced snowpack will alter the timing of peakflows in streams, transform some permanent reaches to ephemeral, and reduce duration of temporary waters for breeding (Maloney et al. 2014; Seager et al. 2007). Warmer temperatures may increase suitability of some oviposition sites (Pearl et al. 2007), but greater evaporation can increase reproductive failure, which occurs when ponds become desiccated before metamorphosis is complete (McMenamin et al. 2008). Although spotted frogs can disperse relatively long distances, previous habitat changes have left some populations isolated (Bull and Hayes 2001; Funk et al. 2005; Pilliod et al. 2002). Fragmentation of habitat may be intensified by drier conditions, particularly in southern portions of the IAP region.

Chytridiomycosis has not been clearly linked to population declines (Russell et al. 2010), and there is no clear evidence that infection rates and pathology would increase in this species with climate change (Pearl et al. 2009; Wilson et al. 2005). Columbia spotted frogs appear susceptible to malformations caused by larval trematodes transmitted by birds, fish, and snails (*Planorbella* spp.). Host snail populations are known to increase with shrinking water sources and eutrophication, and are often associated with artificial water sources (e.g., stock tanks), which may become more common under drier conditions (Blaustein et al. 2005; Johnson et al. 2002).

Because stressors such as pollution, ultraviolet-B radiation, and habitat change can interact with pathogens, disease outbreaks can cause rapid widespread mortality

(Blaustein and Kiesecker 2002). Disease-climate interactions are poorly known for this species, and monitoring to detect early signs of outbreaks would be prudent. Livestock grazing, which was also implicated in recent declines (DelCurto et al. 2005; but see Adams et al. [2009]), may have an increased impact on this species as drier conditions concentrate livestock at water sources (DelCurto et al. 2005; Reaser 2000). One source of resilience is the expansion of potential habitat as high-elevation areas become more viable in warmer winters (McCaffery and Maxell 2010). Overall, Columbian spotted frogs will be more resilient where water sources are reliable, dispersal corridors are intact, and they coexist with few fish and Planorbella snails.

Great Basin Spadefoot (Spea intermontana)

The Great Basin spadefoot occurs in a wide variety of vegetation types, which provides some resilience to climate change, but its reliance on temporary and permanent ponds for breeding makes this species vulnerable to changes in precipitation and increased evaporation rates. Long-distance dispersal by spadefoots is irregular and limited by presence of ponds and habitat fragmentation (Semlitsch 2000). Movement in response to climate-induced habitat shifts will be further limited by occurrence of friable soils and burrows. Cheatgrass, which is projected to expand (Bradley 2010), grows best on the same sandy soils used by burrowing spadefoot and may degrade habitats. Fibrous roots of cheatgrass remove soil moisture, reduce permanency of water sources, and restrict burrowing activity (Buseck et al. 2005).

Breeding spadefoots will be most vulnerable to longevity of pools and ponds. Summer and monsoon precipitation are expected to decrease (Maloney et al. 2014). The collective impact of reduced summer precipitation, more variable precipitation patterns, and higher temperatures may reduce the number and duration of ephemeral ponds typically used for breeding. However, high breeding capacity, rapid tadpole development, and flexible breeding seasons improve the likelihood that this species will be able to successfully respond to changes in pond availability (O'Regan et al. 2014). Spadefoot is more resilient during nonbreeding periods because of its generalist diet and ability to aestivate in burrows for long periods. Biotic interactions with other species are poorly known. Competitive interactions with other amphibians may increase where pond availability is reduced, but an accompanying shift to ephemeral water sources could decrease predation by fish. Great Basin spadefoot populations are likely to be more vulnerable in areas where they rely more on ephemeral than permanent pools (Morey 1994), and in the southern portion of the species range where more frequent drought will have a major impact on breeding ponds (Maloney et al. 2014).

Prairie Rattlesnake (Crotalus viridis)

Rattlesnakes in eastern Idaho were recently grouped as part of the eastern clade along with Hopi rattlesnake, which occurs in southeastern Utah and may itself be a distinct subspecies (Douglas et al. 2002; Goldenberg 2013). For this assessment, we focus on projected changes for the prairie rattlesnake in Idaho, which probably includes more than one subspecies. This species may be vulnerable to climate change because it has low fecundity, long generation times, and low dispersal ability (Gibbons et al. 2000). Sensitivity to human predation and roads (Clark et al. 2010) further reduces adaptive capacity. Although modeling suggests that suitable climate for prairie rattlesnakes will shrink (but will persist in Idaho to 2100) (Lawing and Polly 2011), this projection does not include the potentially significant effects of fire or biotic interactions. Extreme events such as flooding can reduce prey and damage habitats (Seigel et al. 1998). Refugia under down woody debris and shrubs provide favorable microclimates (Harvey and Weatherhead 2006) and would be reduced by frequent fires, which pose a moderate to high risk in central Idaho.

Warmer temperatures could reduce time spent in hibernacula, thereby decreasing time needed to build fat stores, could shorten digestion time, and could positively influence reproductive success (Beck 1996; Gannon and Secoy 1985; Graves and Duvall 1993). Several important activities, including hibernation, breeding, basking, and foraging, are closely timed with temperature conditions (Gannon and Secoy 1985; King and Duvall 1990), and mismatched timing of those activities could create considerable stress (Bagne et al. 2011). Projections of increased primary productivity in Idaho (Reeves et al. 2014) may increase rodent populations, depending on habitat, which would benefit snakes in the area. Prairie rattlesnakes may be more resilient where microclimate refugia (e.g., low fire risk, rocky terrain) remain and habitats are not fragmented.

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Appendix 3—List of Common and Scientific Names for Species in Chapter 9

Amphibians

Arizona lowland leopard frog (*Lithobates yavapaiensis*)
Arizona toad (*Anaxyrus microscaphus*)
blotched tiger salamander (*Ambystoma tigrinum melanostictum)*
boreal chorus frog (*Pseudacris maculata*)
boreal toad (*Anaxyrus boreas boreas*)
canyon tree frog (*Hyla arenicolor*)
Columbia spotted frog (*Rana luteiventris*)
Great Basin spadefoot (*Spea intermontana*)
Great Plains toad (*Anaxyrus cognatus*)
long-toed salamander (*Ambystoma macrodactylum*)
northern leopard frog (*Lithobates pipiens*)
relict leopard frog (*Lithobates onca*)
tiger salamander (*Ambystoma tigrinum*)
Woodhouse's toad (*Anaxyrus woodhousii*)
yellow-legged frog (*Rana muscosa & R. sierrae)*

Birds

Allen's hummingbird (*Selasphorus sasin*)
American kestrel (*Falco sparverius*)
American robin (*Turdus migratorius*)
American pipit (*Anthus rubescens*)
American three-toed woodpecker (*Picoides dorsalis*)
bald eagle (*Haliaeetus leucocephalus*)
band-tailed pigeon (*Patagioenas fasciata*)
Bewick's wren (*Thryomanes bewickii*)
black rosy finch (*Leucosticte atrata*)
black swift (*Cypseloides niger*)
black-backed woodpecker (*Picoides articus*)
black-billed magpie (*Pica hudsonia*)
black-capped chickadee (*Poecile atricapillus*)
black-throated sparrow (*Amphispiza bilineata*)
blue grosbeak (*Passerina caerulea*)
bluebird species (*Sialia* spp.)
boreal owl (*Aegolius funereus*)
Brewer's sparrow (*Spizella breweri*)
brown creeper (*Certhia americana*)
brown-headed cowbird (*Molothrus ater*)
burrowing owl (*Athene cunicularia*)
California quail (*Callipepla californica*)
calliope hummingbird (*Selasphorus calliope*)
Cassin's finch (*Haemorhous cassinii*)
chickadee species (*Poecile* spp.)
chipping sparrow (*Spizella passerina*)
chukar (*Alectoris chukar*)
Clark's nutcracker (*Nucifraga columbiana*)
Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*)
common nighthawk (*Chordeilis minor*)
common raven (*Corvus corax*)
Cooper's hawk (*Accipiter cooperii*)
crossbill species (*Loxia* spp.)
dark-eyed junco (*Junco hyemalis*)
downy woodpecker (*Picoides pubescens*)
dusky flycatcher (*Empidonax oberholseri*)
dusky grouse (*Dendragapus obscurus*)
eastern kingbird (*Tyrannus tyrannus*)
ferruginous hawk (*Buteo regalis*)
flammulated owl (*Psiloscops flammeolus*)
flycatcher spp. (*Tyrannidae* spp.)
golden eagle (*Aquila chrysaetos*)
gray flycatcher (*Empidonax wrightii*)
gray vireo (*Vireo vicinior*)
great gray owl (*Strix nebulosi*)
great horned owl (*Bubo virginianus*)
greater sage-grouse (*Centrocercus urophasianus*)
green-tailed towhee (*Pipilo chlorurus*)
Gunnison sage-grouse (*Centrocercus minimus*)
hairy woodpecker (*Picoides villosus)*
hermit thrush (*Catharus guttatus*)
horned lark (*Eremophila alpestris*)
house wren (*Troglodytes aedon*)
hummingbird species (*Trochilidae* spp.)
juniper titmouse (*Baeolophus ridgwayi)*
kinglet species (*Regulus* spp.)
lark sparrow (*Chondestes grammacus*)
lazuli bunting (*Passerina amoena*)
Lewis's woodpecker (*Melanerpes lewis*)
Lincoln's sparrow (*Melospiza lincolnii*)
loggerhead shrike (*Lanius ludovicianus*)
long-eared owl (*Asio otus*)
MacGillivray's warbler (*Geothlypis tolmiei*)
Merriam's wild turkey (*Meleagris gallopavo merriami*)
Mexican spotted owl (*Strix occidentalis lucida*)
mountain bluebird (*Sialia currucoides*)
mountain chickadee (*Poecile gambeli*)
northern flicker (*Colaptes auratus*)

northern goshawk (*Accipiter gentilis*)
northern harrier (*Circus cyaneus*)
northern hawk owl (*Surnia ulula*)
northern pygmy-owl (*Glaucidium gnoma*)
northern saw-whet owl (*Aegolius acadicus*)
nuthatch species (*Sitta* spp.)
olive-sided flycatcher (*Contopus cooperi*)
osprey (*Pandion haliaetus*)
owl species (*Strigiformes* spp.)
Pacific wren (*Troglodytes pacificus*)
peregrine falcon (*Falco peregrinus*)
pileated woodpecker (*Dryocopus pileatus*)
pine grosbeak (*Pinicola enucleator*)
pine siskin (*Spinus pinus*)
pinyon jay (*Gymnorhinus cyanocephalus*)
prairie falcon (*Falco mexicanus*)
purple martin (*Progne subis*)
pygmy nuthatch (*Sitta pygmaea*)
red crossbill (*Loxia curvirostra*)
red-breasted nuthatch (*Sitta canadensis*)
red-naped sapsucker (*Sphyrapicus nuchalis*)
red-tailed hawk (*Buteo jamaicensis*)
ring-necked pheasant (*Phasianus colchicus*)
rock wren (*Salpinctes obsoletus*)
rosy finch species (*Leucosticte* spp.)
rough-legged hawk (*Buteo lagopus*)
ruffed grouse (*Bonasa umbellus*)
sage sparrow—now split to sagebrush sparrow (*Artemisiospiza nevadensis*) and Bell's sparrow (*Artemisiospiza belli*)
sage thrasher (*Oreoscoptes montanus*)
sapsucker species (*Sphyrapicus* spp.)
scrub jay—now split to Woodhouse's scrub-jay (*Aphelocoma woodhouseii*) and California scrub-jay (*Aphelocoma californica)*
sharp-shinned hawk (*Accipiter striatus*)
short-eared owl (*Asio flammeus*)
song sparrow (*Melospiza melodia*)
southwestern willow flycatcher *Empidonax traillii extimus*)
spotted towhee (*Pipilo maculatus*)
spruce grouse (*Falcipennis canadensis*)
Steller's jay (*Cyanocitta stelleri*)
Swainson's hawk (*Buteo swainsoni*)
Swainson's thrush (*Catharus ustulatus***)**
thrush (*Turdidae* spp.)
Townsend's solitaire (*Myadestes townsendii*)
tree swallow (*Tachycineta bicolor*)
vesper sparrow (*Pooecetes gramineus*)
warbling vireo (*Vireo gilvus*)
western bluebird (*Sialia mexicana*)
western meadowlark (*Sturnella neglecta*)
western screech-owl (*Megascops kennicottii*)
western tanager (*Piranga ludoviciana*)
white-crowned sparrow (*Zonotrichia leucophrys*)
white-headed woodpecker (*Picoides albolarvatus)*
white-tailed ptarmigan (*Lagopus leucura*)
white-throated swift (*Aeronautes saxatalis*)
Williamson's sapsucker (*Sphyrapicus thyroideus*)
woodpecker species (*Picidae* spp.)
yellow warbler (*Setophaga petechia*)
yellow-billed cuckoo (*Coccyzus americanus*)
yellow-rumped warbler (*Dendroica coronata*)

Insects

fire ant (*Solenopsis invicta*)
forest tent caterpillar (*Malacosoma disstria*)
Morand's checkerspot (*Euphydryas anicia morandi*)
mountain pine beetle (*Dendroctonus ponderosae*)
mountain-mahogany looper (*Iridopsis clivinaria*)
Mt. Charleston blue butterfly (*Icaricia shasta charlestonensis*)
Spring Mountains acastus checkerspot (*Chlosyne acastus robusta*)

Mollusks

desert springsnail (*Pyrgulopsis deserta*)
fat-whorled pondsnail (*Stagnicola bonnevillensis*)
Kanab ambersnail (*Oxyloma haydeni kanabense* or *Oxyloma kanabense*)
Utah physa (*Physella utahensis*)

Mammals

Abert's squirrel (*Sciurus aberti*)
Allen's big-eared bat *(Idionycteris phyllotis*)
American beaver (*Castor canadensis*)
American marten (*Martes americana*)
badger (*Taxidea taxus*)
bat species (*Chiroptera* spp.)
bighorn sheep (*Ovis canadensis*)
black bear (*Ursus americanus*)
black-tailed jackrabbit (*Lepus californicus*)
bobcat (*Lynx rufus*)
bushy-tailed woodrat (*Neotoma cinerea*)
Canada lynx (*Lynx canadensis*)
chipmunk species (*Tamias* spp.)
common gray fox (*Urocyon cinereoargenteus*)
cottontail species (*Sylvilagus* spp.)
coyote (*Canis latrans*)
deer mouse (*Peromyscus* spp.)

dwarf shrew (*Sorex nanus*)
elk (*Cervus canadensis*)
fisher (*Martes pennant*)
fringed myotis (*Myotis thysanodes*)
golden-mantled ground squirrel (*Spermophilus lateralis*)
Great Basin pocket mouse (*Perognathus parvus*)
grizzly bear (*Ursus arctos*)
ground squirrel species (*Scuiridae* spp.)
Gunnison's prairie dog (*Cynomys gunnisoni*)
hoary bat *(Lasiurus cinereus*)
kangaroo rat (*Dipodomys* spp.)
kit fox (*Vulpes macrotis*)
least chipmunk (*Tamias minimus*)
little brown bat (*Myotis lucifugus*)
long-eared myotis (*Myotis evotis*)
Merriam's shrew (*Sorex merriami*)
moose (*Alces alces*)
mountain goat (*Oreamnos americanus*)
mountain lion (*Felis concolor*)
mouse species (*Muridae* spp.)
mule deer (*Odocoileus hemionus*)
northern flying squirrel (*Glaucomys sabrinus*)
northern Idaho ground squirrel (*Urocitellus brunneus brunneus*)
pika (*Ochotona princeps*)
pinyon mouse (*Peromyscus truei*)
Piute ground squirrel (*Urocitellus mollis*)
pocket gopher species (*Geomyidae* spp.)
porcupine (*Erethizon dorsatum*)
Preble's shrew (*Sorex preblei*)
pronghorn (*Antilocapra americana*)
pygmy rabbit (*Brachylagus idahoensis*)
rabbit species (*Leporidae* spp.)
red fox (*Vulpes vulpes*)
red squirrel (*Tamiasciurus hudsonicus*)
red-backed vole (*Myodes gapperi*)
river otter (*Lontra canadensis*)
rodent (*Rodentia* spp.)
sagebrush vole (*Lemmiscus curtatus*)
shrew (*Soricidae* spp.)
Sierra Nevada red fox *(Vulpes vulpes necator)*
silver-haired bat (*Lasionycteris noctivagans*)
snowshoe hare (*Lepus americanus*)
spotted bat (*Euderma maculatum*)
squirrel (*Sciurus* spp.)
Stephens' woodrat (*Neotoma stephensi*)
Townsend's big-eared bat (*Corynorhinus townsendii*)
Utah prairie dog (*Cynomys parvidens*)
vole (*Cricetidae* spp.)
weasel (*Mustela* spp.)
western pipistrelle (*Parastrellus hesperus*)
western red bat (*Lasiurus blossevillii*)
white-tailed deer (*Odocoileus virginianus*)
wolverine (*Gulo gulo*)
woodland caribou (*Rangifer tarandus caribou*)
woodrat (*Neotoma* spp.)
Yuma myotis (*Myotis yumaensis*)
yellow-bellied marmot (*Marmota flaviventris*)

Reptiles

common kingsnake (*Lampropeltis getula*)
common side-blotched lizard (*Uta stansburiana*)
desert horned lizard (*Phrynosoma platyrhinos*)
desert tortoise (*Gopherus agassizii*)
eastern fence lizard (*Sceloporus undulatus*)
gopher snake (*Pituophis catenifer*)
greater short-horned lizard (*Phrynosoma hernandesi*)
Hopi rattlesnake (*Crotalus viridis nuntius*)
long-nosed leopard lizard (*Gambelia wislizenii*)
long-nosed snake (*Rhinocheilus lecontei*)
many-lined skink (*Plestiodon multivirgatus*)
milksnake (*Lampropeltis triangulum*)
nightsnake (*Hypsiglena torquata*)
ornate tree lizard (*Urosaurus ornatus*)
painted turtle (*Chrysemys picta*)
plateau striped whiptail (*Aspedoscelis velox*)
prairie rattlesnake (*Crotalus viridis*)
pygmy short-horned lizard (*Phrynosoma douglasii*)
rattlesnake (*Crotalus* spp.)
ring-necked snake (*Diadophis punctatus*)
sagebrush lizard (*Sceloporus graciosus*)
smooth greensnake (*Opheodrys vernalis*)
southern alligator lizard (*Elgaria multicarinata*)
speckled rattlesnake (*Crotalus mitchellii*)
striped racer (*Masticophis lateralis*)
striped whipsnake (*Masticophis taeniatus*)
terrestrial garter snake (*Thamnophis elegans*)
tiger whiptail (*Aspidoscelis tigris*)
western fence lizard (*Sceloporus occidentalis*)
western rattlesnake (*Crotalus oreganus*)
western skink (*Plestiodon skiltonianus*)

Plants

alder (*Alnus* spp.)
antelope bitterbrush (*Purshia tridentata*)
aspen (*Populus tremuloides*)
bitterbrush (*Purshia* spp.)
boxelder (*Acer negundo*)

bristlecone pine (*Pinus longaeva*, *P. aristata*)
budsage (*Picrothamnus desertorum*)
bulrush (*Cyperaceae* spp.)
cattail (*Typha* spp.)
cheatgrass (*Bromus tectorum*)
chokecherry *(Prunus virginiana*)
cottonwood (*Populus* spp.)
curl-leaf mountain mahogany (*Cercocarpus ledifolius*)
currant (*Ribes* spp.)
Douglas-fir (*Pseudostuga menziesii*)
Engelmann spruce (*Picea engelmannii*)
fourwing saltbush (*Atriplex canescens*)
huckleberry species (*Vaccinium* spp.)
juniper species (*Juniperus* spp.)
lodgepole pine (*Pinus contorta*)
maple (*Acer* spp.)
mountain big sagebrush (*Artemisia tridentata vaseyana*)
oak (*Quercus* spp.)
phragmites (*Phragmites* spp.)
ponderosa pine (*Pinus ponderosa*)
Russian olive (*Elaeagnus angustifolia*)
saltcedar (*Tamarix* spp.)
sawgrass (*Cladium* spp.)
serviceberry (*Amelanchier alnifolia*)
skunkbush sumac (*Rhus trilobata*)
snowberry (*Symphoricarpos albus*)
subalpine fir (*Abies lasiocarpa*)
Torrey’s milkvetch (*Astragalus calycosus*)
twoneedle pinyon (*Pinus edulis*)
whitebark pine (*Pinus albicaulis*)
willow (*Salix* spp.)
winterfat (*Krascheninnikovia lanata*)
Wood’s rose (*Rosa woodsii*)
Wyoming big sagebrush (*Artemisia tridentata wyomingensis*)

Other

chytrid fungus (*Batrachochytrium dendrobatidis*)
plague (*Yersinia pestis*)
trematode (*Ribeiroia ondatrae*)
West Nile virus (*Flavivirus*)
white-nose fungus (*Pseudogymnoascus destructans*)

Appendix 4—Summary of System for Assessing Vulnerability of Species to Climate Change Scores for Selected Species in the Intermountain Adaptation Partnership Region

The following table summarizes scores from the System for Assessing Vulnerability of Species to climate change (SAVS) for 20 terrestrial animal, bird, and amphibian and reptile species in the Intermountain Adaptation Partnership region. Positive scores indicate higher vulnerability, whereas negative scores indicate potentially positive effects; zero defines a neutral response. Uncertainty about the SAVS scores for each species is also indicated. See Bagne et al. (2011) for full scoring system.

Species		H1	H2	H3	H4	H5	H6	H7	PS1	PS2	PS3	PS4	PS5	PS6	PH1	PH2	PH3	PH4	I1	I2	I3	I4	I5
	Uncertainty (%)	Breeding habitat	Nonbreeding habitat	Breeding Habitat component	Nonbreeding habitat components	Habitat quality	Dispersal ability	Additional habitat (migrant)	Thresholds	Sex ratio	Disturbances	Activity periods	Resource fluctuations	Metabolic rate	Cues	Critical events	Proximity	Breeding	Food	Predators	Symbionts	Disease	Competitors
American pika	32	1	1	0	0	0	1	0	1	0	0	1	1	0	0	1	-1	-1	0	0	0	0	0
Bighorn sheep (desert)	36	0	0	0	1	0	-1	0	1	0	1	1	-1	0	0	1	0	1	1	0	0	1	0
Bighorn Sheep (Rocky Mountain, Sierra Nevada)	41	0	-1	0	0	0	-1	0	1	0	1	1	1	0	0	1	0	1	-1	0	0	1	-1
Canada lynx	41	1	0	0	1	0	-1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	1
Fisher	50	1	1	1	1	0	-1	0	1	0	0	0	1	0	0	0	0	1	-1	1	0	0	0
Fringed myotis	45	0	0	1	0	1	0	0	0	0	0	-1	1	0	1	1	-1	1	0	0	0	0	0
N. Idaho ground squirrel	32	-1	-1	0	1	0	-1	0	0	0	1	0	1	0	1	0	0	1	1	0	0	1	0
Sierra red fox	23	1	1	0	0	1	-1	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	1
Townsend's big-eared bat	36	0	0	1	1	0	0	0	0	0	0	-1	1	0	1	1	-1	1	0	0	0	0	0
Utah prairie dog	36	-1	-1	0	0	1	-1	0	0	0	0	0	-1	0	1	1	0	1	1	0	0	0	0
Wolverine	36	1	1	1	1	0	-1	0	0	0	0	0	1	0	0	1	1	1	-1	1	0	0	1
American three-toed woodpecker	41	1	1	0	1	-1	-1	0	0	0	0	0	-1	0	0	1	0	1	-1	0	0	0	0
Black rosy finch	36	1	1	1	1	1	-1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
Flammulated owl	27	0	0	1	0	0	0	1	1	0	1	0	0	0	1	1	1	1	0	0	0	0	1
Greater sage-grouse	32	1	1	1	0	0	-1	1	0	0	1	0	0	0	1	1	0	-1	1	0	0	1	0
White-headed woodpecker	36	0	0	1	1	0	-1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
Boreal toad	27	0	0	1	0	1	0	0	1	0	-1	1	-1	-1	1	1	1	1	0	0	0	1	0
Columbia spotted frog	41	1	1	1	1	0	0	1	-1	0	0	0	0	-1	1	1	1	1	0	-1	0	1	0
Great Basin spadefoot	41	0	0	1	0	0	0	0	1	0	0	1	-1	-1	1	1	-1	1	0	-1	0	0	1
Prairie rattlesnake	36	0	0	0	1	0	0	0	1	0	0	1	1	-1	1	0	0	1	-1	0	1	0	0

Chapter 10: Effects of Climate Change on Outdoor Recreation

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Introduction

Federal agencies and other public land management agencies in Utah, Nevada, and southern Idaho provide and manage for numerous outdoor recreation opportunities. National forests in the U.S. Department of Agriculture Forest Service (USFS) Intermountain Region have nearly 19 million visits per year (table 10.1); adjacent National Park System units account for an additional 24 million visits per year (table 10.2). The popularity of publicly managed outdoor recreation opportunities is not surprising, given the numerous psychological, physiological, and social benefits derived from outdoor recreation (Bowker et al. 2012; Thompson Coon et al. 2011).

In addition to individual benefits, publicly managed outdoor recreation opportunities contribute substantially to the economic well-being of communities throughout the region (box 10.1). Nearly $1 billion is spent annually on visits to recreation destinations managed by the USFS (USDA FS n.d.), translating into economic benefits for the private sector in local communities.

Recreation opportunities offered on public lands throughout the Intermountain Adaptation Partnership (IAP) region are as diverse as the ecosystems on which they depend (table 10.3). From the dry deserts of southern Utah to the high-altitude Rocky Mountains of northwestern Wyoming, these ecosystems are highly variable. As climate change alters the conditions of these ecological systems, it also directly affects the ability of public land management agencies to consistently provide high-quality outdoor recreation opportunities to the public (Loomis and Richardson 2006; Richardson and Loomis 2004).

Changing climatic conditions will alter the supply of and demand for outdoor recreation opportunities, affecting visitor use patterns and the ability of outdoor recreationists to obtain desired benefits derived from publicly managed lands in the future (Bark et al. 2010; Matzarakis and de Freitas 2001; Morris and Walls 2009). Benefits provided by outdoor recreation opportunities are expected to increase for some recreationists as the climate warms (Loomis and Crespi 2004; Mendelsohn and Markowski 2004), but will probably vary considerably by geographic region and activity.

Although broad trends in recreation participation under climate change may emerge at the regional scale, little is known about how specific outdoor recreation activities, opportunities, or settings in the IAP region will be affected. This chapter describes the broad categories of outdoor recreation activities believed to be sensitive to climate change, and assesses the likely effects of projected climatic changes on both visitor use patterns and the ability of outdoor recreationists to obtain desired experiences and benefits.

Relationships Between Climate Change and Outdoor Recreation

The supply of and demand for outdoor recreation opportunities are sensitive to climate through an indirect effect of climate on the characteristics and ecological condition of recreation settings, and a direct effect of changes in temperature and precipitation on recreationist decisions about whether to visit a site (Loomis and Crespi 2004; Mendelsohn and Markowski 2004; Shaw and Loomis 2008) (fig. 10.1). For example, warming temperatures in the winter will reduce snowpack levels at ski resorts, diminishing the supply of outdoor recreation opportunities dependent upon skiing. This indirect pathway connects climatic conditions to the conditions of an outdoor recreation setting to the ability of that setting to provide outdoor recreation opportunities. In the same example, warming winter temperatures affect individual recreationist decisions to visit, or not to visit, a site. Whether that effect is positive or negative will depend on a variety of factors specific to individual recreationists.

Indirect effects tend to be important for recreation activities and opportunities that depend on additional ecosystem inputs, such as wildlife, vegetation, and surface water. The quality of cold-water fishing is expected to decline in the future because climate effects on temperature and streamflow will degrade cold-water fish species habitat (Jones et al. 2013) (Chapter 5). Surface water area and streamflow are also important for water-based recreation (e.g., boating). Recreation visits to sites with highly valued natural characteristics, such as glaciers or popular wildlife species (chapters 4, 9), may be reduced under some future climate scenarios if the quality of those characteristics is threatened (Scott et al. 2007). The indirect effects of climate on disturbances, and wildfire in particular (chapters 7, 8), may also play a role in recreationist behavior, although the effects may be diverse and variable over time (Englin et al. 2001; Loomis and Crespi 2004).

Table 10.1—Participation in different recreational activities in national forests in the U.S. Forest Service Intermountain Region.

Activity	National forest visitors for whom this was their primary activity[a]		Relationship to climate and environmental conditions
	Percent	*Number*	
Warm-weather activities	46.2	8,683,390	Participation typically occurs during warm weather; dependent on the availability of snow- and ice-free sites, dry weather with moderate daytime temperatures, and the availability of sites where air quality is not impaired by smoke from wildfires.
Hiking/walking	17.1	3,211,475	
Viewing natural features	16.2	3,050,410	
Developed camping	3.5	652,192	
Bicycling	3.0	559,385	
Picnicking	2.2	422,613	
Other nonmotorized	1.3	247,131	
Horseback riding	1.2	229,879	
Primitive camping	1.2	220,311	
Backpacking	0.5	89,995	
Winter activities	20.6	3,869,580	Participation depends on the timing and amount of precipitation as snow and cold temperatures to support consistent snow coverage. Inherently sensitive to climate variability and interannual weather patterns.
Downhill skiing	16.1	3,021,644	
Snowmobiling	2.5	461,262	
Cross-country skiing	2.1	386,673	
Wildlife activities	10.2	1,910,240	Wildlife is a significant input for these activities. Temperature and precipitation are related to habitat suitability through effects on vegetation, productivity of food sources, species interactions, and water quantity and temperature (for aquatic species). Disturbances (wildland fire, invasive species, insect and disease outbreaks) may affect amount, distribution, and spatial heterogeneity of suitable habitat.
Hunting	5.3	1,002,604	
Fishing	3.8	712,832	
Viewing wildlife	1.0	194,804	
Gathering forest products	0.8	141,395	Depends on availability and abundance of target species (e.g., berries, mushrooms), which are related to patterns of temperature, precipitation, and snowpack. Disturbances may alter availability and productivity of target species in current locations and affect opportunities for species dispersal.
Water-based activities, not including fishing	1.7	320,023	Participation requires sufficient water flows (in streams and rivers) or levels (in lakes and reservoirs). Typically considered a warm-weather activity, and depends on moderate temperatures and snow- and ice-free sites. Some participants may seek water-based activities as a refuge from heat during periods of extreme heat.
Nonmotorized	1.0	192,878	
Motorized	0.7	127,145	

[a] Data are from USDA FS (n.d.), collected for national forests between 2012 and 2015.

Table 10.2—Recreation visits to National Park Service units.

National Park Service unit	Number of visitors[a]	Number of overnight visitors	Three consecutive months with the most visitors
IDAHO			
City of Rocks NRES[b]	105,289	0	May–June–July
Craters of the Moon NM	246,826	17,957	June–July–August
Hagerman Fossil Beds NM	24,695	0	June–July–August
Minidoka NHS	N/A	0	N/A
NEVADA			
Death Valley NP	1,154,843	214,430	March–April–May
Great Basin NP	116,123	40,703	July–August–September
Lake Mead NRA	7,298,465	611,055	June–July–August
Tule Springs Fossil Bed NM	N/A	0	N/A
UTAH			
Arches NP	1,399,247	50,933	May–June–July
Bryce Canyon NP	1,745,804	150,488	June–July–August
Canyonlands NP	634,607	97,734	April–May–June
Capitol Reef NP	941,029	43,522	July–August–September
Cedar Breaks NM	793,601	1,337	July–August–September
Dinosaur NM	291,799	62,581	June–July–August
Glen Canyon NRA	2,495,093	1,446,023	June–July–August
Golden Spike NHS	59,147	0	June–July–August
Natural Bridges NM	94,797	7,502	April–May–June
Rainbow Bridge NM	77,270	0	June–July–August
Timpanogos Cave NM	104,023	0	June–July–August
Zion NP	3,648,846	333,781	June–July–August
WYOMING			
Fossil Butte NM	19,293	0	June–July–August
Grand Teton NP	3,149,921	631,240	June–July–August
Total	24,400,718	3,709,286	

[a] Source: NPS (2014).
[b] NHS = National Historic Site, NM = National Monument, NP = National Park, NRA = National Recreation Area, NRES = National Reserve, N/A = not available.

The direct effects of altered temperature and precipitation patterns are likely to affect most outdoor recreation activities in some way. Direct effects are important for skiing and other snow-based winter activities that depend on seasonal temperatures and the amount, timing, and phase of precipitation (Englin and Moeltner 2004; Irland et al. 2001; Klos et al. 2014; Smith et al. 2016; Stratus Consulting 2009; Wobus et al. 2017). Increases in minimum temperatures have been associated with increased national park visits in Canada, particularly during nonpeak "shoulder" seasons (spring and fall) (Scott et al. 2007). The number of projected warm-weather days is positively associated with expected visitation for U.S. national parks (Fisichelli et al. 2015), including specific regions such as Alaska (Albano et al. 2013) and the southeastern United States (Bowker et al. 2013), although visitation is expected to be lower under extreme-heat

Box 10.1—Economic Effects of National Park Visitation for Local Communities

A recent National Park Service report (Cui et al. 2013) shows that the 3,376,000 visitors to Zion National Park, Cedar Breaks National Monument, and Pipe Spring National Monument spent $159,975,000 in communities surrounding the parks, supporting 2,614 jobs in the local area.

"Zion is a world-renowned destination that offers opportunities for a range of recreational and educational experiences including passive activities and high adventure excursions," Zion Superintendent Jock Whitworth said. "The millions of visitors that come here also spend time and money enjoying the services provided by our neighboring communities."

Cedar Breaks Superintendent Paul Roelandt noted, "Cedar Breaks alone is responsible for bringing the local economy about $18 million… Cedar Breaks sees itself as an important part of the regional economy. Our location offers opportunities for visitors to experience a high-elevation scenic drive, colorful geology, and pristine night skies."

John Hiscock, Superintendent of Pipe Spring, added, "Pipe Spring may be comparatively small in size, but the rich history told here is unmatched. Visitation to the park supported an estimated 42 jobs in the local communities, including Fredonia, Arizona, Kanab and Hurricane, Utah, and on the Kaibab Paiute Indian Reservation. The National Park Service is proud to have been entrusted with the care of America's most treasured places, and delighted visitors generate significant contributions to the local economy."

The information on the three parks is part of a nationwide analysis of national park visitors' spending across the country, which documented $13 billion of direct spending by 279 million park visitors in communities within 60 miles of a national park (Cui et al. 2013). Visitor expenditures had a $30 billion impact on the U.S. economy and supported 252,000 jobs nationwide. That spending contributes to jobs in lodging, food, and beverage services (63 percent of jobs supported), recreation and entertainment (17 percent), other retail (11 percent), transportation and fuel (7 percent), and wholesale and manufacturing (2 percent).

Table 10.3—Categories of recreation activities by season. Note that these may differ somewhat from the official categories in the National Visitor Use Monitoring data (table 10.1).

Recreation activity	Winter	Spring	Summer	Fall
Boating		X	X	X
Camping, picnicking		X	X	X
Cycling (mountain biking, road biking)		X	X	X
Hunting	X	X	X	X
Fishing		X	X	X
Hiking, backpacking (incl. long-distance hiking)		X	X	X
Horseback riding		X	X	X
Motorized recreation (snowmobiles)	X			
Motorized recreation (off-road vehicles)		X	X	X
Nonmotorized winter recreation (downhill skiing, cross-country skiing, fat-tire bikes, dog sledding, sledding and tubing, general snow play, mountaineering)	X			
Recreation residences	X	X	X	X
River rafting		X	X	
Scenic driving (nature viewing)	X	X	X	X
Special forest products (e.g., mushrooms, cones)		X	X	X
Swimming			X	
Other forest uses (Christmas tree harvest, firewood cutting)	X	X	X	X

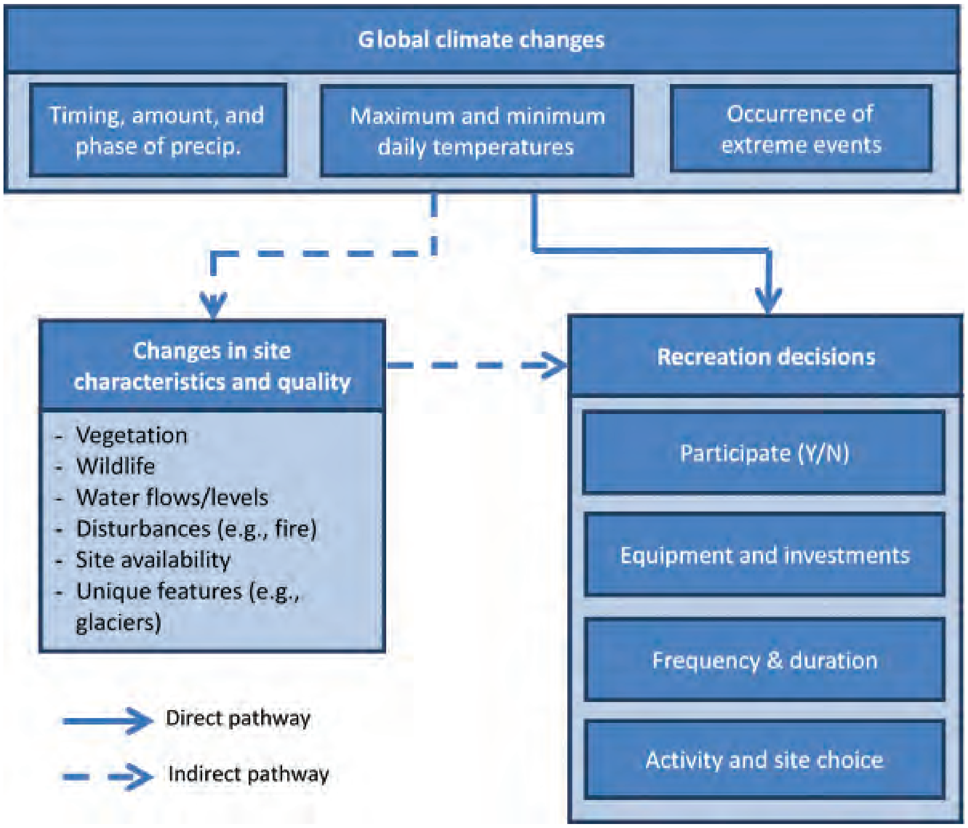

Figure 10.1—Conceptual model of the effects of climate change on recreation, showing direct and indirect pathways of effects.

scenarios (Richardson and Loomis 2004). Temperature and precipitation directly affect the comfort and enjoyment that participants derive from engaging in an activity on a given day (Mendelsohn and Markowski 2004).

The recent update to the USFS 2010 Resources Planning Act (RPA) assessment modeled the effects of climate change on different recreation activities (USDA FS 2016). Model results indicate that projected changes in recreation are expected to vary considerably (both positively and negatively) by geographic location and activity (table 10.4). For the IAP region, the number of participants in warm-weather activities in 2060 is projected to increase significantly (mostly as a result of population increase), but with minimal effects of climate change, except for primitive area use. Significant climate change effects (negative) are projected for hunting, fishing, and undeveloped skiing.

Recreation Participation and Economic Value

Recreation is an important component of public land management in the IAP region, and recreation managers aim to provide diverse recreation opportunities that span the Recreation Opportunity Spectrum, from modern and developed to primitive and undeveloped (Clark and Stankey 1979) (box 10.2). For lands managed by the USFS, sustainable recreation serves as a guiding principle for planning and management purposes (USDA FS 2010, 2012b). In the USFS, sustainable recreation seeks to “sustain and expand benefits to America that quality recreation opportunities provide” (USDA FS 2010). The National Park Service (NPS) emphasizes visitor enjoyment of the parks while recognizing that it is necessary to preserve natural and cultural resources and values for the enjoyment, education, and inspiration of present and future generations (NPS 2006). Recreational resources are managed to connect people with natural resources and cultural heritage, and to adapt to changing social needs and environmental conditions.

The USFS Intermountain Region classifies recreation sites in 31 categories. Of the 2,335 sites across 12 national forests, trailheads (691), campgrounds (628), interpretive sites (126), boating sites (102), and picnic sites (104) account for 70 percent of the total. The Uinta-Wasatch-Cache National Forest has the most sites (451), followed by Bridger-Teton National Forest (234) and Boise National Forest (233); Dixie National Forest has the fewest sites (106).

People participate in a wide variety of outdoor recreation activities in the IAP region. The USFS National Visitor Use Monitoring (NVUM) program surveys recreation visitation and activity on national forests, and monitors 27 recreation activities in which visitors participate. These include a variety of activities and ways that people enjoy and use national forests and other public lands. Current recreation visitation (tables 10.1, 10.2, 10.5, 10.6), activities (table 10.3), and expenditures (table 10.7) illustrate the importance and diversity of recreation in this region.

Table 10.4—Modeled projections of the effects of climate change on recreation in the Intermountain Adaptation Partnership region[a] for 2060. Model output is based on an average of results under the A2, A1B, and B2 emissions scenarios.

Recreation activity	Number of participants in 2060	Projected change without climate change[b]	Projected change with climate change	Net effects of climate change[c]
	Millions	*Percent*		
Visiting developed sites	17	94	94	0
Visiting interpretive sites	15	108	107	-1
Birding	7	104	103	-1
Nature viewing	18	97	96	-1
Day hiking	10	110	110	0
Primitive area use	12	89	73	-16
Motorized off-roading	6	83	83	0
Motorized snow activities	1	30	21	-9
Hunting	3	32	15	-17
Fishing	7	76	48	-28
Developed skiing	3	135	136	+1
Undeveloped skiing	1	86	74	-12
Floating	3	71	71	0

[a] Data are from the "RPA Rocky Mountain Region" (USDA FS 2016), which includes the U.S. Forest Service Intermountain Region.

[b] Percentage changes for total number of participants are compared to 2008.

[c] Net effects of climate change equal "with climate change" minus "without climate change."

The activities listed in table 10.3 account for the primary recreation activities for 79 percent of visits to national forests in the IAP region. Warm-weather activities are the most popular, and include hiking/walking, viewing natural features, developed and primitive camping, bicycling, backpacking, horseback riding, picnicking, and other nonmotorized uses. These were the main activity for 46.2 percent of national forest visitors (8.7 million visits per year) (table 10.1). Of these, hiking/walking was the most popular, and is the primary reason for a visit for 17.1 percent of visitors (3.2 million visits). Snow-based winter activities (primarily downhill skiing, snowmobiling, and cross-country skiing) were the primary activities for 20.6 percent of visitors (3.9 million visits). Wildlife-related activities (primarily hunting, fishing, and viewing wildlife) were the primary activity for 10.2 percent of visits (1.9 million visits). Gathering forest products (e.g., berries and mushrooms) was the primary activity for 0.8 percent of visitors (141,000 visits). Motorized and nonmotorized water activities (other than fishing) drew 1.7 percent of visits (320,000 visits).

Nonlocal visitors (those who report a home ZIP code that is more than 30 miles from the national forest boundary) spend $686 million (in 2014 dollars) per year within 50 miles of the forest boundaries (table 10.7). We focus on spending by nonlocal visitors because these individuals spend money in local communities that would not have occurred otherwise, and in this case account for 70 percent of spending. Lodging expenses make up nearly 30 percent of total expenditures, followed by gas and oil (18 percent), restaurant (17 percent), and groceries (13 percent). The remaining expenditure categories of other transportation, activities, admissions and fees, and souvenirs account for 23 percent of all spending.

Outdoor recreation opportunities supported by Federal lands are complemented by additional recreation opportunities offered on State lands (table 10.6). For example, the Idaho State park system, which includes 32 units such as State parks and State recreation areas (Statewide, not just in the IAP region), had over 5 million day-use visitors in 2014 (ISPAR 2013; Leung et al. 2015). Off-highway visitors accounted for 1 million visits and $434 million in expenditures (Anderson and Taylor 2014). In 2011, 246,000 hunters accounted for 3.2 million hunting days and $478 million in expenditures; 447,000 anglers accounted for 5.5 million angling days and $422 million in expenditures; and 558,000 wildlife watchers accounted for 3.8 participant days and $432 million in expenditures (USFWS 2013).

Recreation on public lands is very important to State economies. For example, in Utah, $7.4 billion was spent on travel, tourism, and recreation in 2012 (75 percent in the Wasatch Front), with $5.3 billion spent by out-of-State visitors (Leaver 2014). This economic activity supports 129,000

Box 10.2—The Recreation Opportunity Spectrum

The Recreation Opportunity Spectrum (ROS) is a classification tool used by Federal resource managers since the 1970s to provide visitors with varying challenges and outdoor experiences (Clark and Stankey 1979; USDA FS 1990). The ROS classifies lands into six management class categories defined by setting and the probable recreation experiences and activities it affords: modern developed, rural, roaded natural, semi-primitive motorized, semi-primitive nonmotorized, and primitive.

Following are the setting characteristics that define the ROS.

- Physical: type of access, remoteness, size of the area
- Social: number of people encountered
- Managerial: visitor management, level of development, naturalness (evidence of visitor impacts and management activities)

The ROS is helpful for determining the types of recreation opportunities that can be provided. After a decision has been made about the opportunity desirable in an area, the ROS provides guidance about appropriate planning approaches and standards by which each factor should be managed. Decisionmaking criteria include: (1) relative availability of different opportunities, (2) their reproducibility, and (3) their spatial distribution. The ROS Primer and Field Guide (USDA FS 1990) specifically addresses access, remoteness, naturalness, facilities and site management, social encounters, and visitor impacts. The ROS can be used to:

- Inventory existing opportunities,
- Analyze the effects of other resource activities,
- Estimate the consequences of management decisions on planned opportunities,
- Link user desires with recreation opportunities,
- Identify complementary roles of all recreation suppliers,
- Develop standards and guidelines for planned settings and monitoring activities, and
- Help design integrated project scenarios for implementing resource management plans.

In summary, the ROS approach provides a framework for Federal land managers to classify recreational sites and opportunities, and to allocate improvements and maintenance within the broader task of sustainable management of large landscapes.

Table 10.5—National Forest visits by activity category for five of the six Intermountain Adaptation Partnership subregions.

Activity category	Middle Rockies[a]	Southern Greater Yellowstone	Uintas and Wasatch Front	Plateaus	Great Basin and Semi Desert
	------------------*Percentage of annual visitors reporting main activity*[b]----------------				
Warm-weather activities[c]	19.6	29.9	38.4	34.2	16.1
Snow-based winter activities	40.3	32.5	20.0	9.9	1.2
Wildlife activities	10.6	13.5	10.8	21.2	1.9
Forest product gathering	2.1	1.6	0.2	1.6	0.1
Water-based activities, not including fishing	3.4	1.8	2.1	0.2	0.0

[a] To estimate activity participation, subregions are defined by groups of national forests as shown in table 2.1.
[b] Data are from USDA FS (n.d.), collected for national forests between 2012 and 2015.
[c] Percentages do not sum to 100 because not all visitors report activities, and not all activities are included in climate-sensitive categories (e.g., nature center activities, visiting historic sites).

Table 10.6—Outdoor recreation settings managed by State park systems in States that are totally or partially within the Intermountain Adaptation Partnership region.

State	State park units[a]	Area	Trails		Improved campsites	Primitive campsites	Visitation
		Acres	*Number*	*Miles*			
Idaho[b]	32	58,922	3	108	1,762	172	5,008,136
Wyoming	41	119,559	286	129	109	1,418	3,917,507
Utah	50	150,758	105	302	1,416	574	3,536,704
Nevada	25	146,225	114	290	401	960	3,217,125

[a] Includes parks, recreation areas, natural areas, historic areas, environmental education areas, scientific areas, forests, and fish and wildlife areas.

[b] Source: Leung et al. (2015).

Table 10.7—Total annual expenditures by visitors to national forests in the U.S. Forest Service Intermountain Region, by spending category.

	Non-local spending[a,b]		Local spending[b]	
Spending category	Total annual expenditures[c]	Spending for each category	Total annual expenditures[c]	Spending for each category
	Thousands of $ (2014)	*Percent*	*Thousands of $ (2014)*	*Percent*
Lodging	205,286	30	18,575	6
Restaurant	116,559	17	40,713	14
Groceries	91,260	13	47,998	17
Gasoline, oil	120,165	18	87,975	31
Other transportation	3,639	1	723	0
Activities	43,799	6	28,300	10
Admissions, fees	53,735	8	33,923	12
Souvenirs	51,655	8	29,206	10
Total	686,093		287,409	

[a] Non-local refers to trips by visitors who reported a ZIP code greater than 30 miles from a national forest boundary.

[b] Data are from USDA FS (n.d.), collected for national forests between 2012 and 2015.

[c] Expenditures within 50 miles of a national forest (USDA FS n.d.).

jobs (directly and indirectly). Public lands play a big role in the Utah economy; during the past 30 years, national park visits have increased from 2 million to 7.2 million, and skier days have increased from 2 million to 4 million (Gardner Policy Institute 2016).

Climate Change Vulnerability Assessment

Managing recreation on public lands is a complex enterprise that varies from year to year and season to season. It includes (1) maintaining standard opportunities and facilities (e.g., hiking trails, primitive campgrounds), (2) providing access for harvesting animals and plants, (3) regulating access for motorized vehicle use (e.g., off-highway vehicles, snowmobiles), and (4) coordinating with concessionaires who operate large ski resorts with thousands of visitors putting millions of dollars in circulation in the local economy.

Providing high-quality opportunities, adequate facilities, and satisfying experiences for a diverse population of recreationists is a significant challenge, and responding to the effects of a warmer climate will require monitoring of changing opportunities and demands for recreation. Because the majority of recreation occurs during warm weather, Federal agencies add large numbers of staff for the summer season to assist with all aspects of recreation. In recent years, declining budgets have made it difficult to employ a

Box 10.3—Summary of Climate Change Effects on Recreation

All categories of recreation considered to be potentially sensitive to the effects of climate change in the IAP region were aggregated into five activity categories. Positive (+) and negative (-) signs indicate expected direction of effect on overall benefits derived from recreation activity; (+/-) indicates that both positive and negative effects may occur.

Warm-weather activities (e.g., hiking, camping, sightseeing)

- Magnitude of climate effect: Moderate (+)
- Likelihood of climate effect: High
- Direct effects: Warmer temperature (+), higher likelihood of extreme temperatures (-)
- Indirect effects: Increased incidence, area, and severity of wildfire (+/-); increased smoke from wildfire (-)

Snow-based winter activities (e.g., downhill skiing, cross-country skiing, snowmobiling)

- Magnitude of climate effect: High (-)
- Likelihood of climate effect: High
- Direct effects: Warmer temperature (-), reduced precipitation as snow (-)
- Indirect effects: Increased incidence, area, and severity of wildfire (+/-); increased smoke from wildfire (-)

Wildlife activities

- Magnitude of climate effect: Terrestrial wildlife: low (+); fishing: moderate (-)
- Likelihood of climate effect: Moderate
- Direct effects: Warmer temperature (+); higher incidence of low streamflow (fishing: -); reduced snowpack (hunting: -)
- Indirect effects: Increased incidence, area, and severity of wildfire (terrestrial wildlife: +/-); increased smoke from wildfire (-); reduced cold-water habitat, incursion of warm-water tolerant species (fishing: -)

Gathering forest products

- Magnitude of climate effect: Low (+/-)
- Likelihood of climate effect: Moderate
- Direct effects: Warmer temperature (+)
- Indirect effects: More frequent wildfires (+/-), higher severity wildfires (-)

Water-based activities (not including fishing)

- Magnitude of climate effect: Moderate (+)
- Likelihood of climate effect: Moderate
- Direct effects: Warmer temperature (+), higher likelihood of extreme temperatures (-)
- Indirect effects: Lower streamflows and reservoir levels (-), increase in algal blooms (-)

sufficient seasonal workforce to accommodate recreation demands, especially during the shoulder seasons (late spring, early fall). The scope and complexity of management vary considerably across the IAP region, as do the projected effects of climate change (box 10.3) and how climate change is perceived by resource managers (box 10.4).

Current climatic and environmental conditions within the region are characterized by large intra-annual and interannual (within and between years) variability. These highly variable climatic and environmental conditions include: temperature and precipitation (Chapter 3), water flows and levels (Chapter 4), wildlife distributions (Chapter 9), vegetative conditions (chapters 6, 7), and wildfire activity (Chapter 8). Recreationists are probably already accustomed to making decisions with a significant degree of uncertainty about conditions at the time of participation.

Recreation in the IAP region is affected by several existing challenges and stressors. Increased population, particularly near public lands, can strain visitor services and facilities because of increased use; projected population increases in the future may exacerbate these effects. Increased use can reduce site quality because of crowding (Yen and Adamowicz 1994).

The physical condition of recreation sites and natural resources is constantly changing due to human and natural forces. Recreation sites and physical assets need maintenance, and deferred or neglected maintenance may increase congestion at other sites that are less affected or increase hazards for visitors who continue to use degraded sites.

Box 10.4—How Do Recreation Managers View Climate Change?

We asked recreation managers throughout the USFS Intermountain Region to provide their perspectives on current conditions for recreation opportunities and facilities and on the potential effects of climate change. The following narratives indicate that recreation managers are aware of current stressors on the recreation enterprise, anticipate significant changes in a warmer climate, and have ideas for how to adapt.

Trish Callaghan (Salmon-Challis National Forest)

> "Staffing is inadequate for a longer shoulder season—an earlier summer would be the biggest issue. We do staff into the fall, mostly to accommodate hunters and fall steelhead anglers. Our largest spring use is also anglers, but for the spring steelhead run in March.
>
> "I think some of our water systems are actually getting less reliable due to the extended summer heat season and shorter winters. When we have to turn off systems because they don't flow correctly, or because they fail the required monthly tests, then we will lose visitation. Our warm-weather users will have reduced water flow for river-related activities, and some of our natural lakes will lose water earlier in the season, becoming less attractive for visitors.
>
> "Our 'make your own winter trail' type of skiing, snow shoeing, and snowmobiling has tapered off pretty slowly over the past several years. Recreationists are very reactive to actual day-to-day snowfall information and weather conditions."

Jane Cropp (Payette National Forest)

> "We don't have the staffing to open our campgrounds earlier, but would find some way to manage if our seasons were longer due to earlier snowmelt. We don't have concessionaires here, so we would need to rely on our temporary workforce. Hopefully we could collect more funds in the campgrounds to help us pay for a longer working season. Mountain biking would probably increase if summers were longer, because trails would open up earlier in the year.
>
> "Our winter season is as busy as our summer season. Shorter winters would affect cross-country skiing opportunities; in fact, they have already been affected over the last several years, with shorter seasons. Our two downhill ski areas would be affected by shorter winters. The biggest impact would be to snowmobile users, because the Payette National Forest is a very popular snowmobiling destination. A shorter winter season, with fewer snowmobilers coming into the area, would have negative economic effects to the towns of McCall and Donnelly."

Nell Highfill (Boise National Forest)

> "With longer shoulder seasons, funding would not be available to keep campgrounds open, especially in the spring. Most of the ranger districts lock the restrooms in the winter until the site is open. Because there are no staff to patrol, and visitors are accessing the developed recreation sites while they are closed, they have had a human waste issue in the campgrounds in the spring. Some sites are not gated, and those were especially heavily used in early shoulder seasons, but did not have the staff for operating the site, cleaning, etc. Concessionaires have not wanted to open early or stay later because although there is use, it is not profitable.
>
> "Most roads in the Boise National Forest are not gated and are available year round. Some are groomed for snowmobile use. Longer wet periods that are free from snow will result in increased maintenance needs to repair damage. Also, more year-round use on roads will result in longer periods of wildlife disturbance, especially during spring nesting, calving, etc.
>
> "Bogus Basin Ski Area is a lower elevation ski resort. They are already adding more summer recreation activities to supplement shorter ski seasons. They have an active snowmobile grooming program in some areas, and grooming is being reduced to 2–3 months a year. Many of the small mountain towns depend on snowmobile use economically, and have been doing studies to determine economic loss. Fewer people are buying snowmobiles and are using ATVs that can have tracks attached for winter use. Boise has a popular yurt system operated by the State for cross-country skiing. Most use is in winter, but it is also available in summer. Milder winters and more warm weather could change use patterns or make their operation less viable.
>
> "When it is warmer in populated valleys, people will seek to go higher and travel farther to get out of the heat. We also anticipate an increase in water-based recreation. It may be necessary to build or expand facilities near water amenities if use increases. Whitewater rafting is important in Idaho. If the rafting season gets shorter as expected, it will have a negative effect on outfitter guides."

Box 10.4 (*continued*)—How Do Recreation Managers View Climate Change?

Carol Majeske (Uinta-Wasatch-Cache National Forest)

> "Our concessionaire mobilized to open some sites early last season when it was warm, and likewise kept some sites open longer as a test on the Spanish Fork Ranger District. In some cases, it's difficult to keep people out of sites when it's warm, although technically they're closed. I'm not sure the longer shoulder seasons were economically viable for the concessionaire, because there were additional expenses (e.g., trash removal), although having recreation sites available did please some of the public.
>
> "It's not always possible to open water systems early or keep them open in fall when spring sources and infrastructure may be under snow or there's a freeze threat. We can advertise that no water is available, but some sites have flush toilets. It might be possible to rent porta-potties, although they're not allowed in some locations and would incur additional costs.
>
> "For recreation sites operated by national forests, limitations on seasonal staff appointments (1039 hours) may limit staffing for longer seasons unless it's done by permanent employees. For both the Forest Service and concessionaires, it's difficult to hire and train employees concurrent with opening sites (water system requirements, hazard inspections, hazard tree removal, etc.). Likewise in the fall, it can be difficult to retain personnel who return to school or are ready to move on to other jobs. In a warmer climate, our dispersed sites would be accessible for a longer period and used more heavily (trails, rock climbing, etc.). Repair and maintenance of trails and infrastructure could become more challenging and costly."

Dan Morris (Humboldt-Toiyabe National Forest)

> "Currently there is no staff to operate longer shoulder seasons. Memorial to Labor Day is the common recreation season, and that would probably change. I don't really think climate change would increase summer use, but perhaps demand in spring and fall.
>
> "For the Sierra Nevada, winter recreation is pretty big. Many of our winter staging areas are at an elevation where slightly warmer seasons could make them useless for winter. It could be necessary to construct new snow parks at higher elevations. Snowmobilers would be most affected because they are restricted to open areas, although backcountry skiing could also be affected."

Jamie Fields (Humboldt-Toiyabe National Forest)

> "I echo what Dan [Morris] says that the expanded season of activities associated with summer (biking, hiking, off-highway vehicles, etc.) is probably the biggest management challenge. We don't have staff or funding to open trailhead or camping facilities earlier or to close them later. I would expect human waste issues and people being grumpy that they cannot use the facilities. Also, trail crews will not have been out in early season to open trails that have a lot of down trees, so I would expect complaints about that and resource impacts from people trying to go around blockages on uncleared trails. This would cause more trail and rehab work to be accomplished by trail crews when they arrive during the 'normal' season. I think the main impacts we would see from extreme heat events is more people going uphill into national forest land to recreate and escape the heat in the valleys.
>
> "The impact on winter recreation is obviously substantial. We may occasionally have some issues with people just wanting to get out snowmobiling when there's not enough snow to protect the vegetation underneath, but the greatest challenge is just that people cannot get out to recreate when there's no snow. Or they will go higher and become more concentrated in places that might not have the capacity to handle more people cramming into shrinking snow areas. It might cause conflicts between uses and safety issues in some locations. There could be a potential increase in snowmobile incursions into wilderness if people are losing motorized snow opportunities at low elevation. We don't have capacity to prevent or enforce snowmobile wilderness incursion.
>
> "Increased fuel loads from fire suppression plus the drought and invasives that come with climate change mean more intense fire seasons that could close recreation opportunities temporarily or permanently. Hazard trees may become a greater concern from forests stressed by beetles and drought, as well as a possible increase in extreme weather events.
>
> "I would expect that more animal species will be threatened/endangered when they are unable to adapt to changes in habitat. Besides hunting, recreational uses could stress those animals—I know there are lots of studies about trail use impacts on birds and ungulates, including impacts of climbing on nesting raptors. If some animals are already stressed from climate change, and if they're listed, there may be closures or new restrictions on recreational opportunities. That's a far-out, if-then situation that is hard to quantify, but I do think it's coming."

Unmanaged recreation can create hazards and contribute to natural resource degradation (USDA FS 2010). This stressor may interact with others, such as population growth and maintenance needs, if degraded site quality or congestion encourages users to engage in recreation that is not supported or appropriate at certain sites or at certain times of the year. Natural hazards and disturbances may create challenges for the provision of recreation opportunities. For example, wildfire affects recreation demand (as a function of site quality and characteristics), but may also damage physical assets or exacerbate other natural hazards such as erosion (chapters 4, 8, 12).

The biggest effect of climate change on recreation activity is likely to differ between warm-weather activities (increase in participation) and snow-based activities (decrease in participation). In general, warmer temperatures and increased season length appropriate for warm-weather activities will increase the duration and quality of weather for activities such as hiking, camping, and mountain biking, whereas reduced snowpack will decrease the duration and quality of conditions for downhill skiing, cross-country skiing, and snowmobiling. However, these general findings mask potential variation in the effects of climate on recreation between types of activities and geographic locations.

To assess how recreation patterns may change in the IAP region, categories of outdoor recreation activities are identified that may be sensitive to climatic changes (fig. 10.2). For the purposes of the recreation assessment, an outdoor recreation activity is sensitive to climate change if changes in environmental conditions that depend on climate would result in a significant change in the demand for or supply of that outdoor recreation activity. The recreation activities identified in the NVUM survey are grouped into five climate-sensitive categories of activities, plus an "other" category of activities that are judged to be less sensitive to climatic changes. (Note that although participation in many of the activities in the "other" category is probably linked to climate in some way, other factors are likely to be more important determinants of participation, such as maintenance of infrastructure for visiting interpretive sites.) Each category includes activities that are likely to be affected by changes to climate and environmental conditions in similar ways (fig. 10.2).

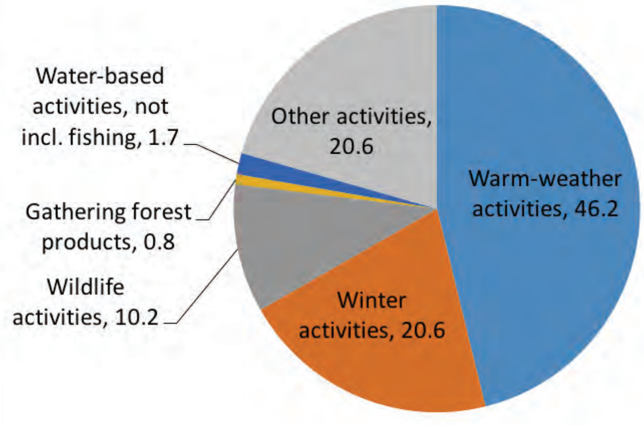

Figure 10.2—Percentage of total visits to national forests in the U.S. Forest Service Intermountain Region, by climate-sensitive primary activity (USDA FS n.d.).

This section provides an assessment of the likely effects of climate on major climate-sensitive recreation activities in the IAP region. Two sources of information are used to develop assessments for each category of recreation activity. First, reviews of existing studies of climate change effects on outdoor recreation and studies of how recreationist behavior responds to climate-sensitive ecological characteristics are used to draw inferences about likely changes for each activity category. Second, projections of ecological changes specific to the IAP region, as detailed in the other chapters in this volume, are paired with the recreation literature to link expected responses of recreation behavior to specific expected climate effects.

Warm-Weather Activities

Warm-weather activities are the most common recreation activities in national forests and national parks in the IAP region. Warm-weather recreation is sensitive to the availability of snow- and ice-free trails and sites, and the timing and number of days with temperatures within minimum and maximum comfortable range (which may vary with activity type and site). The number of warm-weather days (Richardson and Loomis 2004) and minimum temperature are positively correlated with visitation (Albano et al. 2013; Fisichelli et al. 2015; Scott et al. 2007).

Participants are also sensitive to site quality and characteristics, such as the presence and abundance of wildflowers, condition of trails, vegetation, and shade. The condition of unique features that are sensitive to climate change, such as glaciers and snowfields, may affect the desirability of certain sites (Scott et al. 2007). Forested areas are positively associated with warm-weather activities, such as camping, backpacking, hiking, and picnicking (Loomis and Crespi 2004), and are sensitive to future climatic changes (USDA FS 2012a).

Wildfire can also affect participation in warm-weather activities through changes to site quality and characteristics (fig. 10.3). Wildfires may have a diverse and temporally nonlinear effect on recreation (Englin et al. 2001). The presence of recent wildfires has differential effects on the value of hiking trips (positive) and mountain biking (negative), although recent wildfire activity tends to decrease the number of visits (Hesseln et al. 2003, 2004; Loomis et al. 2001). The severity of fire may also matter; high-severity fires are associated with decreased recreation visitation, whereas low-severity fires are associated with slight increases in visitation (Starbuck et al. 2006). Recent fires are associated with initial losses of benefits for camping (Rausch et al. 2010) and backcountry recreation activities (Englin et al. 1996), but these losses are attenuated over time. Research in Yellowstone National Park showed that visitation tends to be lower during and immediately after high wildfire activity,

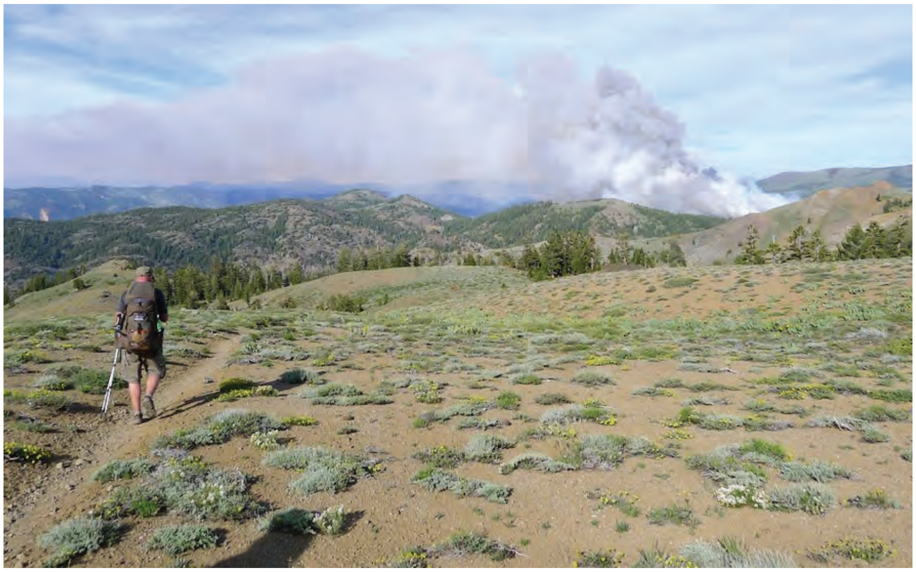

Figure 10.3—Increased occurrence of wildfires in the future may cause safety concerns, reduce access, and impair air quality and vistas for hikers (photo courtesy of K. Schwartz).

although there is no discernible effect of previous-year fires (Duffield et al. 2013).

Overall demand for warm-weather activities is expected to increase because of the direct effect of climate change on season length. Temperatures are expected to increase 5 to 12 °F across the region by the year 2100 (Chapter 3), which is expected to result in earlier availability of snow- and ice-free sites and an increase in the number of warm-weather days in spring and autumn (Albano et al. 2013; Fisichelli et al. 2015). For example, higher minimum temperatures are associated with an increased number of hiking days (Bowker et al. 2012). Higher maximum summer temperatures are associated with reduced participation in warm-weather activities (Bowker et al. 2012), so extreme heat scenarios for climate change are expected to reduce visitation in some cases (Richardson and Loomis 2004). Extreme heat may shift demand to cooler weeks at the beginning or end of the warm-weather season, or shift demand to alternative sites that are less exposed to extreme temperatures (e.g., at higher elevations, near lakes and rivers).

Adaptive capacity among recreationists is high because of the large number of potential alternative sites, ability to alter the timing of visits, and ability to alter capital investments (e.g., appropriate gear). However, benefits derived from recreation can vary whether or not substitute activities or sites are available. For example, some alternative sites may involve higher costs of access (because of remoteness or difficulty of terrain). In addition, limits on ability to alter seasonality of visits may exist (e.g., the timing of scheduled academic breaks). Although recreationists commonly shift to substitute sites and activities, how people substitute across time periods or between large geographic regions (e.g., choosing a site in the IAP region instead of in the Southwest) is poorly quantified (Shaw and Loomis 2008).

Summary

Projected climatic changes are expected to result in a moderate increase in warm-weather recreation activity and benefits derived from these activities. Longer warm-weather seasons will increase the number of days when warm-weather activities are viable and increase the number of sites available during shoulder seasons. The effects of a longer season may be offset somewhat by negative effects on warm-weather activities during extreme heat and increased wildfire activity. The likelihood of effects on warm-weather recreation is high because the primary driver of climate-related changes to warm-weather recreation is through direct effects of temperature changes on the demand for warm-weather recreation. The climate scenarios outlined in Chapter 3 differ in their projection of the magnitude of warming, but overall they project rising temperatures. Indirect effects on recreation, primarily through wildfire effects, may be harder to project with certainty and precision (particularly at small spatial scales).

Cold-Weather Activities

The IAP region contains many winter recreation sites that in total exhibit a wide range of site characteristics and attract local, national, and international visitors. Twenty-one developed sites support downhill skiing and snowboarding operated by special permit on lands administered by the USFS (table 10.8). Sites for cross-country skiing, snowshoeing, and snowmobiling tend to be maintained directly by the USFS, although national parks also provide access for these activities.

Snow-based recreation is highly sensitive to variations in temperature and the amount and timing of precipitation as snow. Seasonal patterns of temperature and snowfall determine the likelihood of a given site having a viable season (Scott et al. 2008). Lower temperatures and the presence of new snow are associated with increased demand for skiing and snowboarding (Englin and Moeltner 2004).

Climate change is expected to have a generally negative effect on snow-based winter activities (Wobus et al. 2017), although a wide range of effects at local scales is possible

Table 10.8—Location of developed downhill ski areas on national forest lands in the U.S. Forest Service Intermountain Region.

National forest	Ski area
Boise	Bogus Basin
Bridger-Teton	Jackson Hole
	Snowking
	White Pine
Caribou-Targhee	Kelly Canyon
	Pebble Creek
	Grand Targhee
Dixie	Brian Head
Humboldt-Toiyabe	Las Vegas Ski and Snowboarding Resort
	Mount Rose
Payette	Brundage
	Payette Lakes
Sawtooth	Magic Mountain
	Pomerell
	Soldier Mountain
	Sun Valley
Uinta-Wasatch-Cache	Alta
	Brighton
	Snowbasin
	Snowbird
	Solitude

because of variations across the region in site location and elevation. Warmer projected winter temperatures for the region are expected to reduce the proportion of precipitation as snow, even if the total amount of precipitation does not deviate significantly from historical norms (Chapter 4). The rain-snow transition zone (i.e., where precipitation is more likely to be snow rather than rain for a given time of year) is expected to move to higher elevations, particularly in late fall and early spring (Klos et al. 2014). This effect places lower elevation sites at risk of shorter or nonexistent winter recreation seasons (fig. 10.4), although the highest elevation areas in the region remain snow-dominated for a longer portion of the season in future climate scenarios. In some cases, climate-related disturbance (e.g., insect outbreaks) can reduce the quality of downhill skiing (box 10.5, fig. 10.5).

Studies of the ski industry in North America uniformly project negative effects of climate change (Scott and McBoyle 2007). Overall warming is expected to reduce expected season length and the likelihood of reliable winter recreation seasons. Climatological projections for the IAP region (Chapter 3) are consistent with studies of ski area vulnerability to climate change in other regions, in which projected effects of climate change on skiing, snowboarding, and other snow-based recreation activities is negative (Dawson et al. 2009; Hamlet 2000; Mote et al. 2008; Scott et al. 2008; Stratus Consulting 2009; Wobus et al. 2017).

Snow-based recreationists have moderate capacity to adapt to changing conditions given the relatively large number of winter recreation sites in the region. For undeveloped or minimally developed site activities (e.g., cross-country skiing, backcountry skiing, snowmobiling, snowshoeing), recreationists may seek higher elevation sites with higher likelihoods of viable seasons (Hand and Lawson 2018). Although developed downhill skiing sites are fixed improvements, potential adaptations include snowmaking, and new run development at higher elevation (Scott and McBoyle 2007). Warmer temperatures and increased precipitation as rain may increase availability of water for snowmaking in the near term during winter, but warmer temperatures may also reduce the number of days per season when snowmaking is viable. Large ski resorts owned and operated by corporations will probably be more resilient and have more options for maintaining viable skiing opportunities than smaller, locally owned businesses.

Although far fewer people participate in snowmobiling than in skiing (table 10.1), snowmobiling is locally important as a recreation activity and an economic driver in small communities. In the IAP region, snowmobiling is prominent in the Boise, Caribou-Targhee, Dixie (Cedar City Ranger District), and Uinta-Wasatch-Cache (Logan and Ogden Ranger Districts) National Forests. At least one study suggests that snowmobiling may be more vulnerable than downhill skiing to reduced snowpack in a warmer

Figure 10.4—Low snowpacks, which are expected to be more common in a warmer climate, can reduce the amount, quality, and safety of skiing in some locations (photo: J. Cronan, U.S. Forest Service).

climate (Scott et al. 2008), which is consistent with projections in the RPA assessment (USDA FS 2016).

Changes in snow conditions in the IAP region relative to other regions may also be important. If other regions experience relatively large effects of climate on snow-based recreation, recreationists may view sites in the IAP region as a substitute for sites in other regions (e.g., the Southwest) (Hand and Lawson 2018). However, interregional substitution patterns for recreation activities are poorly understood (Shaw and Loomis 2008), and limits exist on distances people are willing to travel to recreate at alternative sites. In the mountainous IAP region, it may not be possible to simply go to higher elevations to find adequate snow, especially if wilderness restricts certain uses (e.g., snowmobiling).

Summary

The magnitude of negative climate-related effects on snow-based winter activities is expected to be high. Warmer temperatures are likely to shorten winter recreation seasons and reduce the likelihood of viable seasons at lower elevation sites. Developed sites may have limited ability to adapt to these changes unless additional areas are available and feasible for expanded development. In comparison to other regions, winter recreation sites at high elevation in the IAP region may see fewer effects from climate change; interregional substitution could mitigate losses in some years if participants from other regions visit IAP region sites. The likelihood of negative effects is expected to be high for snow-based recreation, although variation across sites is possible because of differences in location and elevation. Climate models generally project warming temperatures and a higher-elevation rain-snow transition zone, which would leave additional sites exposed to the risk of shorter seasons.

Box 10.5—How Do Insects Affect Skiing?

Interactions among biophysical and social factors make it challenging to project the effects of climate change on natural resources. Brian Head Ski Resort on the Dixie National Forest in southern Utah provides a case in point.

A spruce beetle population grew to epidemic levels on the Cedar City Ranger District in the early 1990s. By 2003, the beetle outbreak had spread across the Markagunt Plateau, killing all mature and intermediate-age Engelmann spruce trees over thousands of acres. The spruce-dominated landscape is regenerating in quaking aspen that will dominate forest structure for many decades to come.

Photos of Brian Head Ski Resort before and after the beetle outbreak (fig. 10.5) show a stark difference in forest cover over a period of 6 years. Previously sheltered ski runs are now open to high wind and sun exposure, negatively affecting the experience of downhill skiers. Ski lifts are subject to frequent stoppage (wind holds) during windy conditions. Snow is scoured from ridge tops and on the most exposed slope locations, creating variable snow depth and quality at relatively fine spatial scales—challenging conditions for most skiers. In addition, because most of the ski runs are on south or southwest aspects, the sun reaches more of the snow cover for longer periods of time in the absence of forest cover. This increases snowmelt and induces a continual freeze-thaw cycle that can create icy snow.

The future of ski resorts like Brian Head is uncertain. Downhill skiing may continue for decades, although a shortened ski season caused by reduced snowpack, combined with undesirable snow conditions, may reduce the quality of the recreation experience and the economic viability of ski operations.

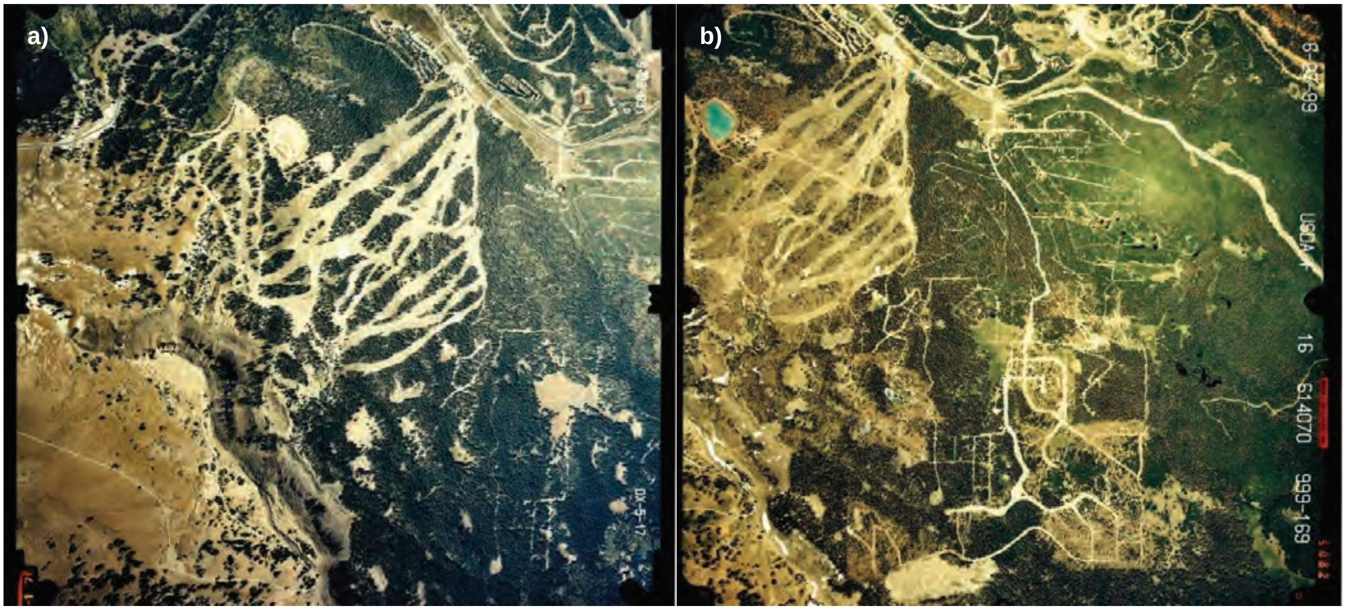

Figure 10.5—Aerial photos of Brian Head Ski Resort (Dixie National Forest) in 1993 (a) and 1999 (b), showing extensive mortality of Engelmann spruce caused by spruce beetle (photos: Dixie National Forest).

Wildlife-Dependent Activities

Wildlife-dependent recreation activities involve terrestrial or aquatic animals as a primary component of the recreation experience. Wildlife recreation can involve consumptive (e.g., hunting) or nonconsumptive (e.g., wildlife viewing, bird watching, catch-and-release fishing) activities. Distinct from other types of recreation, wildlife activities depend on the distribution, abundance, and population health of desired target species. These factors influence activity "catch rates," that is, the likelihood of harvesting or seeing an individual of the target species. Sites with higher catch rates can reduce the costs associated with a wildlife-dependent activity (e.g., time and effort tracking targets) and enhance overall enjoyment of a recreation day for that activity (e.g., greater number of views of highly valued species).

Participation in wildlife-dependent activities is sensitive primarily to climate-related changes that affect expected catch rates. Catch rates are important determinants of site selection and trip frequency for hunting (Loomis 1995; Miller and Hay 1981), substitution among hunting sites (Yen and Adamowicz 1994), participation and site selection for fishing (Morey et al. 2002), and participation in nonconsumptive wildlife recreation (Hay and McConnell 1979). Altered habitat, food sources, or streamflows and water temperature (for aquatic species) may alter wildlife abundance and distribution, which, in turn, influence expected catch rates and wildlife recreation behavior.

Wildlife-dependent activities may also be sensitive to other direct and indirect climate change effects. The availability of highly valued target species (e.g., cutthroat trout [*Oncorhynchus clarkii*] for cold-water anglers) affects anglers' ability to obtain desired benefits from fishing (Pitts et al. 2012) (box 10.6). Similarly, the diversity of game species present can affect hunt satisfaction (Milon and Clemmons 1991) and enjoyment of nonconsumptive wildlife-dependent activities such as birdwatching (Hay and McConnell 1979). Temperature and precipitation are related to general trends in participation for multiple wildlife activities (Bowker et al.

Box 10.6—Drought, Rivers, Fish, and Recreation

Climate change is expected to cause longer periods of drought in the IAP region, leading to lower streamflows in summer, warmer stream temperatures, and reduced populations of cold-water fish species (chapters 3, 4, 5). Extremely low snowpacks in the Sierra Nevada and adjacent areas in the winter of 2014–2015, following three previous drought years, resulted in natural resource effects that may become more common in the future. The following article explores the connection among drought, streams, fish, and recreation for the Truckee River, a portion of which flows through Humboldt-Toiyabe National Forest in Nevada.

Trout Drought: Anglers Ready for Long, Dry Summer (By Benjamin Spillman)

(Reprinted from the Reno-Gazette Journal, June 11, 2015)

Tucked away in a bucolic, residential neighborhood on Reno's west side, Ambrose Park looks like little more than a parking lot and a patch of grass and trees.

Box 10.6 (*continued*)—Drought, Rivers, Fish, and Recreation

But it's also an ideal access point to, "classic trout territory," on the Truckee River according to Jason Edwards and other anglers.

That's because the boulders form breaks and seams in the water and the tree-lined banks make shade and help bugs and other critters thrive, a combination that makes for great habitat for rainbow and brown trout.

> "People travel all over the world to try and get a 30-inch brown trout and they are pretty much all through this river," said Edwards, 26, during a recent fly fishing session. "We are pretty lucky to have this right in our backyard."

But the snowpack that feeds the Truckee River via Lake Tahoe, not to mention streams throughout the Sierra Nevada, was nearly non-existent last winter. And several consecutive years of drought have sapped reservoirs that serve as storage for lean years.

It means trout and people who fish for them are likely to be left high and dry this summer. Edwards and other anglers can only hope there's enough water to keep the fish alive until more rain and snow replenishes the system.

> "This is just a killer little section of river but soon enough it is going to be dried out," he said. "Those fish are going to have to move down and condense in one pool and that is when things start to get really scary."

For anglers the reality of the drought is nothing new. They've been watching Sierra Nevada streams and reservoirs shrink for several years.

What's new this season is that the problem is worse than ever.

On June 6, the flow rate in Reno was about 100 cubic feet per second (cfs). On this date in 2014 and 2013, the river was flowing around 500 cfs or more. Last year, it did not dip to around 100 cfs until about mid-July. The year before it hovered around 300 cfs from July through November.

> "We're four years into it and we have been able to get along the last few years based on the reservoir storage," said Kim Tisdale, Nevada Department of Wildlife supervising biologist for western Nevada. "It has kind of cushioned the blow from the drought. Last fall we ran out of that cushion. The reservoirs are depleted so now we are really seeing the impacts of the drought we are in."

The multi-year drought in the Sierra Nevada is taking a toll on the Truckee River. The problem extends throughout Nevada.

Wildlife officials haven't stocked trout Wild Horse Reservoir, a popular northeastern Nevada fishing spot, in two years, said Joe Doucette, regional outdoor education coordinator for NDOW. He said the reservoir came out of winter at 20 percent capacity and is likely to get lower before relief arrives in the form of significant snow or rain. "It will probably continue to be fairly severe," Doucette said. "I suspect Wild Horse will get down below 10 percent of capacity before summer is over, if not even lower."

There's nothing anglers can do to bring more snow to the Sierra Nevada. But they can still improve the odds that Truckee River trout will survive to see another season.

One of the main ways they can help is to avoid fishing during extremely low flows, especially in the afternoon when the water is warm. That's because low water levels force fish to congregate in pools instead of spreading throughout the river.

The concentration of too many fish in small pools combined with low oxygen levels in the warm water make it difficult for the trout to survive. Fishing them out of the water only adds to their misery and increases the likelihood they won't survive the summer.

> "As humans we can be sensitive to the conditions for the fish," said Reno Fly Shop owner Jim Litchfield. "We can voluntarily give them a break from angling pressure when the water temperature gets above 70 degrees."

Anglers can also fish places where there's still sufficient water to maintain the fishery at a healthy level. Litchfield mentioned reservoirs such as Frenchman, Davis and Eagle Lake. He also said streams in Feather, Yuba and American systems could be good spots. "We're going to focus on some of those this summer and lay off the Truckee River," he said.

Guide Mike Sexton, who works at Reno Fly Shop, said it's difficult for anglers to watch the river they love dwindle to a trickle. Sexton, a former member of Fly Fishing Team USA, said the Truckee is among the best rivers he's fished. The rushing waters, boulders and alpine surroundings give it the feel of a classic western trout stream. It's location in the center of a mid-size city adds to the allure. Those factors also make it more difficult for anglers forced to stand by when it's imperiled.

> "It is a special place to fish," Sexton said. "I try not to think about it much because it is kind of depressing."

2012; Mendelsohn and Markowski 2004), although the precise relationship may be specific to the activity or species. Some activities (e.g., big game hunting) may be enhanced by cold temperatures and snowfall at particular times to aid in field dressing, packing out harvested animals, and tracking. Other activities may be sensitive to climate change effects similar to warm-weather activities, in which moderate temperatures and snow- and ice-free sites are desirable.

Warming temperatures projected for the IAP region are expected to increase participation in terrestrial wildlife activities because of an increased number of days that are desirable for wildlife-dependent outdoor recreation. In general, warmer temperatures are associated with higher participation in and number of days spent hunting, bird watching, and viewing wildlife (Bowker et al. 2012). However, hunting that occurs during discrete seasons (e.g., elk and deer hunts managed by State agencies) may depend on weather conditions during a short period of time. The desirability of hunting during established seasons may vary if warmer weather later into fall and early winter alters harvest rates (positively or negatively). This issue is also relevant for outfitters who operate under legal hunting and fishing seasons and may also operate under special-use permits with specific dates and areas. These regulatory constraints could become less aligned with "catch rate" based on climatic conditions.

The effects of changes in habitat for target species are likely to be ambiguous because of complex relationships among species dynamics, vegetation, climate, and disturbances (primarily wildfire and invasive species) (Chapter 8). Overall vegetative productivity may decrease in the future, although this is likely to have a neutral effect on game species populations, depending on the size, composition, and spatial heterogeneity of forage opportunities in the future (chapters 6, 7, 9). Similarly, the effects of disturbances on harvest rates of target species are ambiguous because it is unknown exactly how habitat composition will change in the future.

An interesting context for the future of hunting is an ongoing decrease in hunting participation. For example, in Utah, the number of mule deer permits issued annually has declined from around 100,000 to 80,000 between 1995 and 2015, while elk permits remained relatively constant (Bernales et al. n.d.). Deer and elk populations both increased by about 50 percent over this time. Effects of climate change on both animal populations (Chapter 8) and demand for harvesting animals will shape the overall effects on wildlife-dependent recreation.

Higher temperatures are expected to decrease populations of native cold-water fish species as climate refugia retreat to higher elevations (Chapter 5). This change favors increased populations of fish species that can tolerate warmer temperatures. However, it is unclear whether shifting populations of species (e.g., substituting other fish species for cutthroat trout) will affect catch rates, because relative abundance of fish may not necessarily change.

Increased interannual variability in precipitation and reduced snowpack could cause higher peakflows in winter and lower low flows in summer (Chapter 4), creating stress for fish populations during different portions of their life history (Chapter 5). The largest patches of habitat for cold-water species will be at higher risk of shrinking and fragmentation. Mountain lakes currently used for ice fishing will have a decreased period of time available for this activity. Increased incidence and severity of wildfire may increase the likelihood of secondary erosion events that degrade streams and riparian habitat (Chapter 8). These effects could degrade the quality of individual sites in a given year or decrease the desirability of angling as a recreation activity relative to other activities.

Summary

The magnitude of climate-related effects on activities involving wildlife is expected to be low overall for terrestrial wildlife activities and moderate to severe for fishing, depending on location and fish species. Ambiguous effects of vegetative change on terrestrial wildlife populations and distribution suggest that conditions may improve in some areas and deteriorate in others. Overall warming tends to increase participation, but may create timing conflicts for activities with defined regulated seasons (e.g., big game hunting). Anglers may experience moderate negative effects of climate change on benefits derived from fishing. Opportunities for cold-water species fishing are likely to be reduced as cold-water refugia contract and move to higher elevations and are eliminated in some areas. Cold-water species tend to be high-value targets, suggesting that this habitat change will decrease benefits enjoyed by anglers. Warm-water tolerant species may increasingly provide targets for anglers, mitigating reduced benefits from fewer cold-water species. Warmer temperatures and longer seasons encourage additional participation, but indirect effects of climate on streamflows and reservoir levels could reduce opportunities in certain years. The likelihood of climate-related effects on wildlife activities is expected to be moderate for both terrestrial and aquatic wildlife activities. Uncertainties exist about the magnitude and direction of indirect effects of climate on terrestrial habitat and the degree to which changes in available target species affect participation.

Forest Product Gathering

Forest product gathering accounts for a small portion of primary visit activities in the IAP region, although it is relatively more common as a secondary activity. A small but avid population of enthusiasts for certain types of products supports a small but steady demand for gathering as a recreation activity. Small-scale commercial gathering probably competes with recreationists for popular and high-value products such as huckleberries (*Vaccinium* spp.), although resource constraints may not be binding at current participation levels. In addition, traditional foods (often called first foods) have high cultural value for Native Americans and rural residents. For example, pinyon nuts (seeds within cones) from single-leaf pinyon (*Pinus monophylla*) and twoneedle pinyon (*P. edulis*) are collected in many areas of the IAP region. In recent years, seeds collected from native plants are increasingly used for restoration of native vegetation where nonnative species have become prevalent.

Forest product gathering is sensitive primarily to climatic and vegetative conditions that support the distribution and abundance of target species. Participation in forest product gathering is also akin to warm-weather recreation activities, depending on moderate temperatures and the accessibility of sites where products are typically found. Vegetative change due to warming temperatures and increased interannual variation in precipitation may alter the geographic distribution and productivity of target species (chapters 6, 7). Increased incidence and severity of wildland fires may eliminate sources of forest products immediately after fire, but encourage medium-term productivity for other products (e.g., mushrooms, huckleberries). Long-term changes in vegetation that reduce forest cover may reduce viability of forest product gathering in areas that have a high probability of vegetative transition to less productive vegetation types.

Outdoor recreationists engaged in forest product gathering may be able to select different gathering sites as the distribution and abundance of target species change, although these sites may increase the costs of gathering. Those who engage in gathering as an ancillary activity may choose alternate activities to complement primary activities. Commercial products serve as a market alternative for some forest products such as Christmas trees.

Summary

The magnitude of climate effects on forest product gathering is expected to be low. This activity is among the less common primary recreation activities in the region, although it may be more often engaged in as a secondary activity. Longer warm-weather seasons may expand opportunities for gathering in some locations, although these seasonal changes may not correspond with greater availability of target species. The likelihood of effects on forest product gathering is expected to be moderate, although significant uncertainty exists regarding direct and indirect effects. Vegetative changes caused by climatic changes and disturbances may alter abundance and distribution of target species, but the magnitude and direction of these effects is unclear.

Water-Based Activities (Not Including Fishing)

Apart from angling, water-based activities account for a small portion of primary recreation activity participation on Federal lands. Upper reaches of streams and rivers are generally not desirable for boating and floating. Lakes and reservoirs provide opportunities for both motorized and nonmotorized boating and swimming, although boating may commonly be paired with fishing. Existing stressors include the occurrence of drought conditions that reduce water levels and site desirability in some years, and disturbances that can alter water quality (e.g., erosion events following wildfires).

The availability of suitable sites for non-angling, water-based recreation is sensitive to reductions in water levels caused by warming temperatures, increased variability in precipitation, and decreased precipitation as snow. Reductions in surface-water area are associated with decreases in participation in boating and swimming activities (Bowker et al. 2012; Loomis and Crespi 2004; Mendelsohn and Markowski 2004), and streamflow is positively associated with number of days spent rafting, canoeing, and kayaking (Loomis and Crespi 2004; Smith and Moore 2013). Demand for water-based recreation is also sensitive to temperature. Warmer temperatures are generally associated with higher participation in water-based activities (Loomis and Crespi 2004; Mendelsohn and Markowski 2004), although extreme heat may dampen participation for some activities (Bowker et al. 2012).

River recreation, in particular commercial and private rafting, is vulnerable to the effects of climate change on drought (e.g., low streamflow) (chapters 3, 4) and wildfire (e.g., degraded scenery, reduced access). River rafters prefer mid-season, intermediate water levels and warm weather over turbulent, cold spring runoff or late-season low water (Yoder et al. 2014). A warmer climate will shorten the period of time when desirable conditions are available. High-quality whitewater rafting requires different conditions than floating the river. For example, on the Boise River, the longer period of high flows through town during spring to prevent flooding delays floating season. On rivers such as the Middle Fork of the Salmon, low flows late in the season limit the number of days for whitewater rafting (fig. 10.6). This can be a dilemma in locations where whitewater and family float trips are both popular activities, and outfitters depend on appropriate streamflows for a positive experience (Associated Press 2012). These issues are compounded when threatened and endangered fish species are present, potentially reducing rafting seasons for commercial river outfitters because low streamflow puts salmon redds at risk, in addition to reducing the quality of rafting conditions.

Increasing temperatures, reduced storage of water as snowpack, and increased variability of precipitation are expected to increase the likelihood of reduced water levels and greater variation in water levels in lakes and reservoirs on Federal lands (Chapter 4), both of which are associated with reduced site quality and suitability for certain activities. Increased demand for surface water by downstream users may exacerbate reduced water levels in drought years. Warmer temperatures are expected to increase the demand for water-based recreation as the viable season lengthens, but can also increase undesirable algal blooms (e.g., Hand and Lawson 2018), which are already a problem in Utah streams, lakes, and reservoirs (Penrod 2015). Extreme heat encourages some people to seek water-based activities as a refuge from climatic conditions, although extreme heat also

Figure 10.6—Low water level in the Middle Fork of the Salmon River in Idaho. Low water levels in streams can reduce the quality of whitewater rafting, but can be suitable for floating (photo courtesy of Northwest Rafting Company).

discourages participation in outdoor recreation in general (Bowker et al. 2012). Overall, projections of water-based activities in response to climate change tend to be small compared to the effects of broad population and economic shifts on these activities (Bowker et al. 2012).

Summary

Climate change is expected to have a moderate effect on water-based activities. Increasing temperatures and longer warm-weather seasons are likely to increase demand, although the incidence of extreme temperatures may dampen this effect in certain years. A higher likelihood of lower streamflows and reservoir levels may also offset increased demand to some extent. Climate change effects are expected to occur with moderate likelihood. Climate model projections tend to agree on a range of warming temperatures and longer seasons, although changes in precipitation are uncertain. Changes in the timing of snowmelt may increase the likelihood of negative effects to water-based activities (through lower summer flows and reservoir levels) that offset increased participation levels due to warmer temperatures.

Conclusions

Several recreation activities are considered highly sensitive to changes in climatic and environmental conditions (box 10.3). However, recreation in the IAP region is diverse, and the effects of climate are likely to vary widely between different categories of activities and across geographic areas within the region. Overall, participation in climate-sensitive recreation activities is expected to increase in the region because longer warm-weather seasons will make more recreation sites available for longer periods of time; participation is also expected to increase due to a gradual growth in population. Increased participation in warm-weather activities is likely to be offset somewhat by decreased snow-based winter activities. Receding snow-dominated areas and shorter seasons in the future are likely to reduce the opportunities (in terms of available days and sites) for winter recreation.

Beyond these general conclusions, the details of changes to recreation patterns in response to climatic changes are complex. Recreation demand is governed by several economic decisions with multiple interacting dependencies on climate. For example, decisions about whether to engage in winter recreation, which activity to participate in (e.g., downhill or cross-country skiing), where to ski, how often to participate, and how long to stay for each trip depend to some degree on climatic and environmental characteristics. On the supply side, site availability and quality depend on climate, but the effect may differ greatly from one location to another. Thus, climate effects on recreation depend on spatial and temporal relationships among sites, environmental conditions, and human decisions.

Uncertainty derives from unknown effects of climate on site quality and characteristics that are important for some recreation decisions (e.g., indirect effects of climate on vegetation, wildlife habitat, and species abundance and distribution). The exact effects of climate on target species or other quality characteristics are difficult to predict and are likely to be diverse across the region, yet these characteristics play a large role in recreation decisions for some activities. Another source of uncertainty is how people will adapt to changes when making recreation decisions. Substitution behavior between regions and over time is not yet well understood (Shaw and Loomis 2008; Smith et al. 2016). This may be important for the IAP region if in the future some sites experience relatively little effect from climate change compared with sites in other regions. For example, winter recreation sites in the region may experience shorter or lower quality seasons in the future, but experience increased demand if the quality of sites in other regions becomes relatively worse during the same time period.

Substitution will be an important adaptation mechanism for recreationists. Some popular activities may have several alternate sites, and the timing of visits may be altered to respond to climatic changes. However, spatial and temporal substitution may represent a loss in benefits derived from recreation even if it appears that participation changes little (Loomis and Crespi 2004); the new substitute site may be more costly to reach or lower quality than the preferred visit prior to climate change, although the converse could also be true. This demonstrates the complexity of accounting for benefits to the person engaging in recreation.

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Chapter 11: Effects of Climate Change on Infrastructure

Michael J. Furniss, Natalie J. Little, and David L. Peterson

Introduction

Climatic conditions, particularly extreme rainfall, snowmelt, and flooding, pose substantial risks to infrastructure in and near public lands in the Intermountain Adaptation Partnership (IAP) region (box 11.1). Minor floods happen frequently in the region, and large floods happen occasionally. These events can damage or destroy roads and other infrastructure and affect resource values and ecosystem services (Murray and Ebi 2012) (fig. 11.1). Drought (extended periods of heat and low precipitation) can also affect resource values, especially as it influences fuel moisture and wildfire, soil moisture, drying road conditions, low streamflow, exposed streambanks and facilities, and interactions among drought, fire, and flooding.

These are familiar problems and risks because infrastructure has always been vulnerable to climatic stresses (Gucinski et al. 2001). Climate warming is very likely to increase the magnitude and frequency of these climate stressors, thereby increasing hazards and risk to infrastructure, people, and ecosystems of the region. Anticipating changes in risk and consequences can enable managers to respond by helping to set priorities and implement projects that increase resilience (Peterson et al. 2011; Vose et al. 2012).

Human population growth and demand for water and other natural resources have resulted in cumulative effects to forest resources, particularly near populated areas. Climate change adds to these effects, and in some cases exacerbates the risks (e.g., washouts, landslides, culvert failure, local

Box 11.1—Summary of Climate Change Effects on Roads and Infrastructure in the Intermountain Adaptation Partnership Region

Broad-scale climate change effect: Increase in magnitude of winter and spring peak streamflows.

Resource entity affected: Infrastructure and roads near perennial streams, which are valued for public access.

Current condition, existing stressors: Many roads with high value for public access and resource management are located near streams. A large backlog of deferred maintenance exists because of decreasing budget and maintenance capacity. Many roads are in vulnerable locations subject to high flows.

Sensitivity to climatic variability and change: Roads in near-stream environments are periodically exposed to high flows. Increased magnitude of peakflows increases susceptibility to effects ranging from minor erosion to complete loss of the road prism. These effects influence public safety, access for resource management, water quality, and aquatic habitat.

Expected effects of climate change: Projections for increased magnitude of peakflows indicate that more miles of road and more facilities will be exposed to higher flow events and greater impacts.

Adaptive capacity: Knowing the extent and location of potentially vulnerable road segments will help with prioritizing scarce funding, treatments to reduce storm damage risk, and communicating potential hazard and risk to the public.

Risk assessment:

<u>Potential magnitude of climate change effects</u>

- For those watersheds determined to be sensitive
  - Moderate magnitude by 2040
  - High magnitude by 2080

<u>Likelihood of climate change effects</u>

- For those watersheds determined to be sensitive
  - Moderate likelihood by 2040
  - High likelihood by 2080

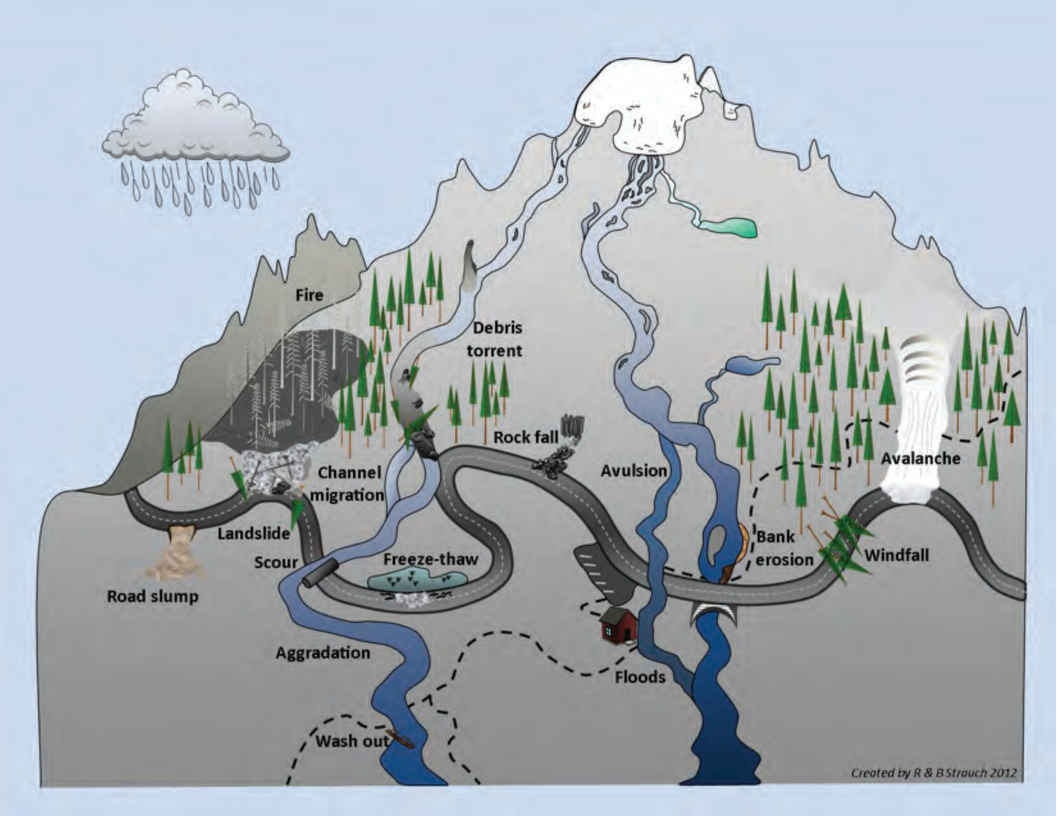


Figure 11.1—Schematic depicting the many geomorphic, hydrological, and weather-related disturbances that can damage roads and other infrastructure (from Strauch et al. 2014).

flooding, road closures) (Furniss et al. 2013; Strauch et al. 2014). The importance of particular infrastructure, and probability of damage, may vary. By anticipating changes that a rapidly warming climate may bring, resource managers can be proactive in making infrastructure more resilient, safe, and reliable on Federal lands, thus reducing negative consequences for public land, water, and ecosystem services.

This chapter is a review of vulnerable infrastructure, namely roads, trails, structures, developed recreation facilities, and dams. The focus is primarily within the boundaries of national forests and grasslands in the U.S. Department of Agriculture Forest Service (USFS) Intermountain Region, although the methods and inferences can be applied to infrastructure systems throughout the IAP region and other geographic areas.

Assessment Approach

The following three-level assessment approach can be used to systematically analyze the vulnerability of infrastructure to climate change. Assessment Level 1 (the top level) simply documents the type and quantity of infrastructure. Assessment Level 2 examines infrastructure investments at the regional level. Assessment Level 3 considers infrastructure at local or smaller scales.

Assessment Level 1—Inventory

The presence of an infrastructure feature is a first approximation of vulnerability. Although exposures and risks differ greatly from place to place, all infrastructure is vulnerable, so an inventory of the amount and spatial distribution of infrastructure is also a first approximation of vulnerability. A description of infrastructure by quantity, type, and feature within Federal lands shows the investments that are potentially affected by climatic forces. Assessment units, such as national forests, ranger districts, or subwatersheds, with higher infrastructure density or higher levels of infrastructure investment, can be considered more vulnerable than those with little or no infrastructure (fig. 11.2).

Assessment Level 2—Regional Scales

Two indicators of vulnerability can be discerned at the regional scale via simple geographic information system (GIS) queries: (1) proximity of infrastructure to streams, and (2) trail and road-stream crossings. Together, these two indicators depict components associated with moving water that may be vulnerable to extreme climatic events (fig. 11.3). Although some errors may exist in spatial resolution and mapping, the indicators reliably capture hydrological connectivity and vulnerability to fluvial processes, which are of greatest concern and potential consequence. Slope steepness and soil type may also be indicators of vulnerability discerned at broad spatial scales, but the relationships to vulnerability can be more context dependent and require local knowledge about potential effects of hydrological events. The ecological disturbance of wildfire can also be a significant impact to infrastructure.

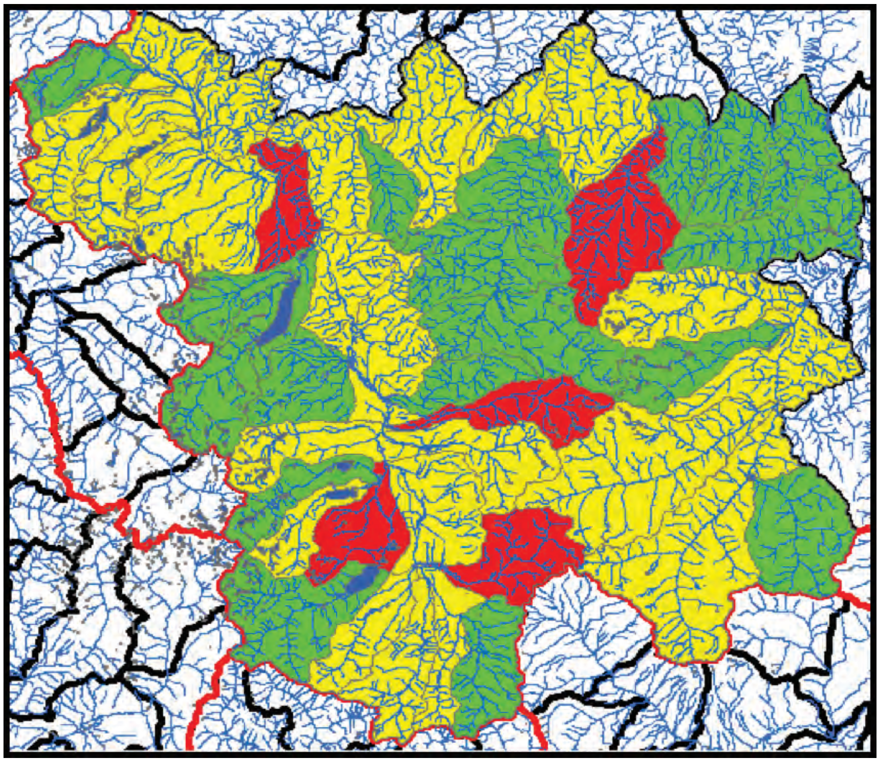


Figure 11.2—An example of using the presence of infrastructure as an indicator of vulnerability. This map shows the amount of infrastructure in Sawtooth National Recreation Area in Idaho by subwatersheds (Hydrologic Unit Code 6). Red-shaded subwatersheds have high amounts of infrastructure; yellow, moderate amounts; and green, low amounts (from Furniss et al. [2013]).

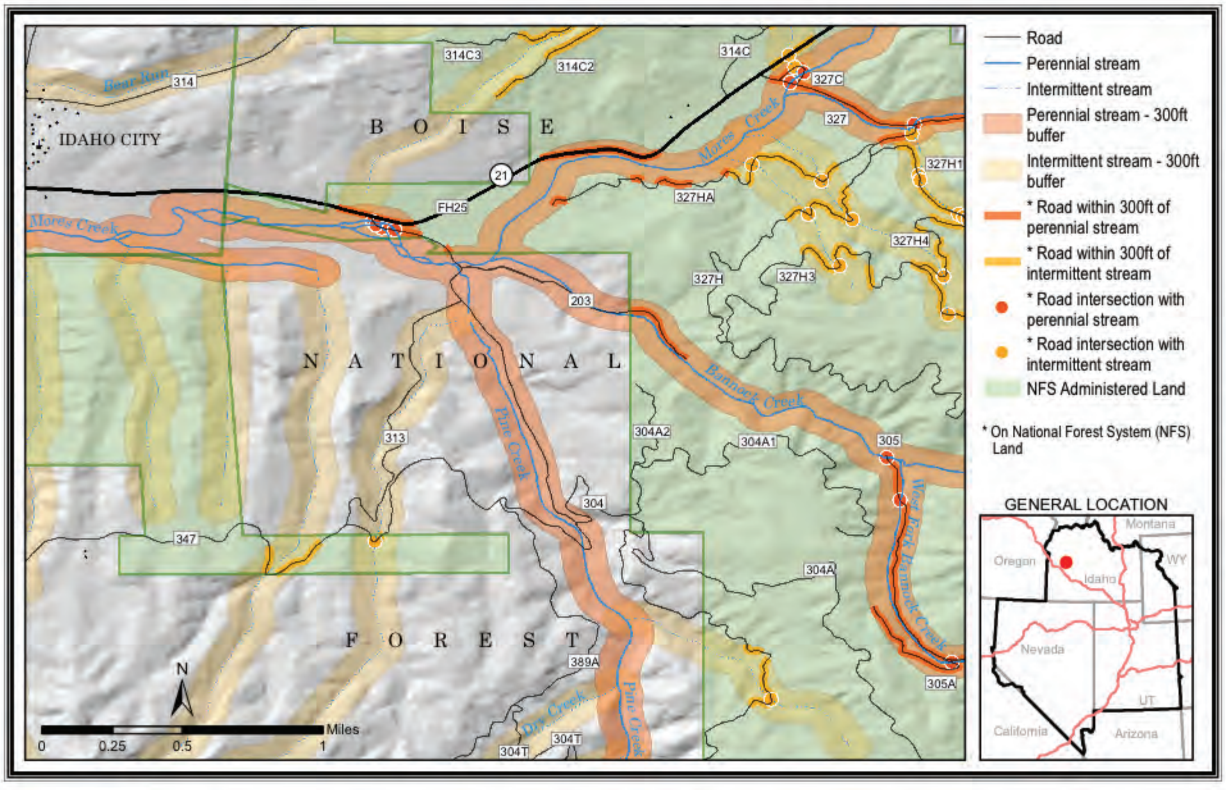


Figure 11.3—Map of an area from Upper Morse Creek and adjacent watersheds in Boise National Forest, Idaho, depicting 300-foot buffers around streams (map created by Teresa Rhoades, U.S. Forest Service). Mapping buffers around streams can be used to identify current roads that are potentially at risk from flooding, and to preclude the placement of new roads in vulnerable locations. Mapping the intersection of streams with roads can be used to identify road sections and culverts that are potentially vulnerable to flooding. These are locations that can be prioritized for infrastructure improvement.

Assessment Level 3—Local Scales

Many vulnerability indicators are best derived at smaller scales—national forests and parks, ranger districts, subbasins, watersheds, subwatersheds—where specific data about context and conditions are usually available. These indicators are not included in this assessment but can be incorporated into smaller-scale assessments and forest planning efforts. These indicators may include:

- Presence of vulnerable communities that rely on Federal roads for access;
- Local population density and land development patterns;
- Infrastructure value information, such as alternate road routes for community access, investment levels, and historical maintenance costs;
- Road assessments, such as Geomorphic Road Analysis and Inventory Package (GRAIP) surveys and flood damage surveys;
- Landslides and landslide-prone terrain;
- Steep terrain that can lead to rockfall, debris slides, and drainage failures;
- Stream channels with high probability of avulsion (sudden cutting off of land by flood, currents, or change in course of water);
- Areas of high wildfire risk and postfire flood risk;
- Presence of sensitive aquatic systems, terrestrial systems, and cultural resources that may be affected by damage, failure, or destruction of infrastructure; and
- Past Emergency Relief of Federally Owned Roads projects (box 11.2); these roads are sometimes called "repeat offenders."

Infrastructure that is costly to maintain and has high usage is generally considered more vulnerable. For example, roads and road drainage structures are major investments, facilitate many valued uses, and can be costly to repair if damaged by storms. In contrast, trailheads are often easily repaired if damaged by wind, water, or heat, and may be of little consequence to resource management if they are out of service for a short time.

Box 11.2—Emergency Relief for Federally Owned Roads

The **Emergency Relief for Federally Owned Roads program** (ERFO) was established to assist Federal agencies with the repair or reconstruction of tribal transportation facilities, Federal lands transportation facilities, and other Federally owned roads that are open to public travel and are found to have suffered serious damage by a natural disaster over a wide area or by a catastrophic failure (FHWA n.d.). The intent of the ERFO is to pay the unusually heavy expenses for the repair and reconstruction of eligible facilities.

The Emergency Relief for Federally Owned Roads program is not intended to cover all repair costs but to supplement repair programs of Federal land management agencies. Repairs are classified as either emergency or permanent. Emergency repairs are those repairs undertaken during or immediately after a disaster to restore essential traffic, to minimize the extent of damage, or to protect the remaining facilities. Prior approval is not required, although all other eligibility requirements of the program still apply. Permanent repairs are undertaken after the occurrence of the disaster to restore facilities to their pre-disaster conditions. Prior approval is required.

The Emergency Relief for Federally Owned Roads program provides assistance to Federal agencies whose roads meet the definition of "open to public travel." The Federal share payable for the repair of tribal transportation facilities, Federal lands transportation facilities, and other Federally owned roads is 100 percent. Funds for the ERFO are provided from the Highway Trust Fund and the General Fund through the Emergency Relief Program for Federal-aid Highways. The ERFO funds are not to duplicate assistance under another Federal program or compensation from insurance, cost share, or any other source.

The Office of Federal Lands Highway is responsible for efficient and effective management of public funds entrusted by Congress and for ensuring that the ERFO is administered consistent with laws, regulations, and policies. Applicants are expected to prioritize the repair of the ERFO projects that are in the public's best interest, based on available funds. Federal agencies and local government entities have the responsibility to perform emergency repairs, shift project and program priorities, give emergency relief work prompt attention and priority over nonemergency work, and assist the Office of Federal Lands Highway in its stewardship and oversight responsibilities.

Current ERFO regulations require that roads be "replaced in kind" in most circumstances, that is, with a similar type of road in the same location. This is not a climate-smart practice if the road is at risk to climate-induced changes in hydrological regimes, including extreme events (e.g., floods, landslides). This is especially true for roads already in high-risk locations, such as floodplains. Resolving this issue between the Federal Highway Administration and Federal agencies will improve climate resilience, ensure good investments, and promote a sustainable transportation system on Federal lands.

Risk Assessment

Infrastructure risk can be proactively addressed by identifying assets that have a high likelihood of being affected by future climatic conditions and significant consequences if changes do occur. The connection between likelihood and consequences can be addressed through a formal or informal risk assessment that can assist land managers with anticipating and responding to future conditions (Ojima et al. 2014). For example, a two-dimensional matrix can be used to determine an integrated risk factor (Keller and Ketcheson 2015) (fig. 11.4) for infrastructure or other resources.

Knowing that storm events will occur, a storm damage risk reduction (SDRR) approach can help minimize effects from natural disasters. Infrastructure system management should be comprehensive and address basic questions such as: (1) Is the infrastructure needed? (2) Should it be decommissioned? (3) Should it be relocated? and (4) Can it be adapted to future climatic conditions? Storm damage risk reduction methods incorporate design to minimize road damage and associated environmental impacts from storm events. The principles can be transferred to other types of infrastructure. Key SDRR storm-proofing principles (Keller and Ketcheson 2015) include:

- Identify areas of documented or potential vulnerability;
- Avoid local problematic and high-risk areas;
- Use appropriate minimum design standards;
- Employ self-maintaining concepts in the selection and implementation of treatments; incorporate relevant, cost-effective technology;
- Perform scheduled maintenance;
- Use simple, positive, frequent roadway surface drainage measures and use restrictions;

Likelihood of damage or loss	**Magnitude of consequences**		
	RISK		
	Major	**Moderate**	**Minor**
Very likely	Very high	Very high	Low
Likely	Very high	High	Low
Possible	High	Intermediate	Low
Unlikely	Intermediate	Low	Very low

Likelihood of damage or loss

Very likely: Nearly certain occurrence (>90%)

Likely: Likely occurrence (50-90%)

Possible: Possible occurrence (10-50%)

Unlikely: Unlikely occurrence (<10%)

Magnitude of consequences

Major: Loss of life or injury to humans, major road damage, irreversible damage to critical natural or cultural resources

Moderate: Possible injury to humans, likely long-term but temporary road closure and lost use of major road or road systems, degradation of critical natural or cultural resources, resulting in considerable or long-term effects

Minor: Road damage minor, little effect on natural or cultural resources, resulting in minimal, recoverable, or localized effects

Figure 11.4—Example of a risk rating matrix that can be used to evaluate the likelihood and consequences of climate change effects for infrastructure or other resources. The location of conditions within the matrix can vary over time, allowing for an ongoing assessment of risk and development of potential responses for reducing the risk of storm damage (from Keller and Ketcheson 2015).

- Properly size, install, and maintain culverts to pass water as well as debris and sediment;
- Design culverts based on stream simulations;
- Use simple fords or vented low-water crossings;
- Stabilize cut slopes and fill slopes;
- Use deep-rooted vegetation to "anchor" soils;
- Design high-risk bridges and culverts with armored overflows;
- Eliminate diversion potential at culverts;
- Use scour prevention measures for structures on questionable foundation material; and
- Consider channel morphology and stream channel changes near a bridge, culvert, ford, or road along a stream.

Risk assessment can also focus on storm damage as a factor by assessing (1) probability of a climatic event and subsequent infrastructure failure, and (2) expected consequences, which can include safety, loss of life, cost of infrastructure damage, and environmental damage (Keller and Ketcheson 2015) (fig. 11.4). Ideally, roads and other infrastructure determined to be at high risk would be improved, closed, or relocated.

Other Assessment and Resilience Efforts

This assessment is informed by other assessments and activities that have been conducted for Federal lands (Peterson et al. 2014; Vose et al. 2012, 2016). Much of the work done on transportation systems can aid in the development of assessment of other infrastructure types. National forests can efficiently complete more localized analyses by building on this existing work.

Watershed Condition Assessment

In 2010, every national forest and grassland in the United States completed a Watershed Condition Assessment (WCA) at the subwatershed scale (Hydrologic Unit Code 6, 10,000–40,000 acres). This was conducted by using a national Watershed Condition Framework (WCF) model that rated various factors that influence watershed condition. This model is based on 12 watershed condition indicators, each composed of various attributes (Potyondy and Geier 2011). Each attribute was rated as good, fair, or poor for each subwatershed based on standard quantitative and qualitative criteria. The attribute ratings were then integrated into a combined rating for each ecological process domain and then into an overall watershed condition score. In the watershed condition classification for the Intermountain Region, road density, condition, and proximity to streams contributed significantly to the ratings.

Transportation Analysis Process

Planning for transportation and access in national forests is included in national forest land management plans. The 2001 Road Management Rule (36 CFR 212, 261, 295) requires national forests to use science-based analysis to identify a minimum road system that is ecologically and fiscally sustainable. National forests in the Intermountain Region are currently identifying a sustainable road network in accordance with the rule. The goals of transportation analyses are to assess the condition of existing roads, identify options for removing damaged or unnecessary roads, and maintain and improve necessary roads without compromising environmental quality. Transportation analysis has several benefits, including: (1) road improvement and decommissioning, (2) establishing a framework to set annual maintenance costs, and (3) identifying and improving the ability to meet agreement and Best Management Practice (BMP) requirements with regulatory agencies. Consideration of climate change is not currently a formal part of the analysis.

The objective of the USFS Transportation Analysis Process (TAP) is to reduce environmental effects and road mileage to levels that can be supported by available financial and human resources. Most infrastructure imposes some costs on the environment. Costs and transportation requirements need to be balanced to arrive at a sustainable and suitable transportation system. This climate change vulnerability assessment is best integrated with the TAP reports and updates as appropriate, including analyses identified in the USFS Travel Planning Handbook (Forest Service Handbook 7709.55). Analysis includes:

- Map of the recommended minimum road system;
- List of unneeded roads;
- List of key issues;
- Prioritized list of risks and benefits associated with changing the part of the forest transportation system under analysis;
- Prioritized list of opportunities for addressing those risks and benefits;
- Prioritized list of actions or projects that would implement the minimum road system; and
- List of proposed changes to current travel management designations, including proposed additions to or deletions from the forest transportation system.

This vulnerability assessment can be used to help set priorities for improving roads to increase their resilience and reduce their environmental effects. The TAP should be interactive with the WCF process and vice versa. Every national forest in the Intermountain Region has completed a Travel Analysis Report that differentiates roads likely to be needed from those that are likely to be unneeded and recommended for decommissioning.

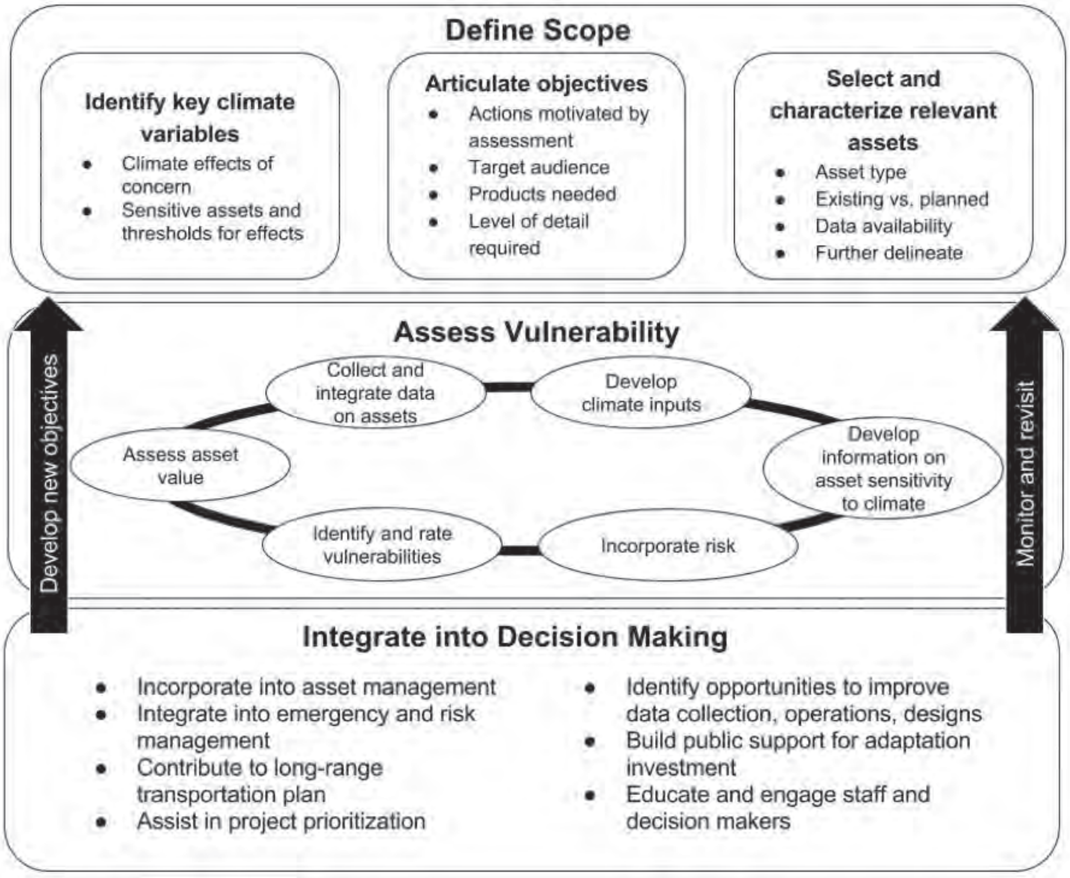
Best Management Practices

Implementing, monitoring, and improving practices for management of water quality and watershed health are central to adapting to climate change. The publication "National Best Management Practices for Water Quality Management on National Forest System lands, Volume 1: National Core BMP Technical Guide" (USDA FS 2012) provides a set of BMPs for most aspects of forest management, including roads, trails, and recreation. Volume 2: National Core BMP Monitoring Technical Guide" (USDA FS, in press) provides guidance on monitoring the effectiveness of BMP implementation. These technical guides, which also contain national directives and data management structures, should be used in new planning efforts, National Environmental Policy Act (NEPA) analysis, design, implementation, maintenance, and evaluation of proposed activities, particularly if projects affect water resources.

Federal Highway Administration

The Federal Highway Administration vulnerability assessment framework consists of three primary components: (1) defining objectives and scope, (2) assessing vulnerability, and (3) integrating vulnerability into decisionmaking (FHWA 2012). This approach is important in all aspects of infrastructure management in order to efficiently and effectively utilize funding. A comprehensive approach helps to determine relevant objectives, identify and categorize assets, and identify appropriate climatic factors to track. Developing a clear approach minimizes data collection and analyses, streamlines the evaluation process for complex climate change issues, and saves land managers and engineers time and money (fig. 11.5).

For transportation and other infrastructure systems, the kinds of climatic changes that can cause the most significant damage or be the most disruptive to operations are often extreme events of relatively short duration, as opposed to annual or seasonal averages. Heat waves, drought, and flooding affect infrastructure over short timescales (days to months), whereas climate-related changes in the freeze-thaw cycle, construction season length, and snowmelt hydrology affect infrastructure over longer time periods (years to decades).



Define Scope

Identify key climate variables
- Climate effects of concern
- Sensitive assets and thresholds for effects

Articulate objectives
- Actions motivated by assessment
- Target audience
- Products needed
- Level of detail required

Select and characterize relevant assets
- Asset type
- Existing vs. planned
- Data availability
- Further delineate

Assess Vulnerability

Integrate into Decision Making

- Incorporate into asset management
- Integrate into emergency and risk management
- Contribute to long-range transportation plan
- Assist in project prioritization
- Identify opportunities to improve data collection, operations, designs
- Build public support for adaptation investment
- Educate and engage staff and decision makers

Figure 11.5—A framework for assessing the effects of climate change and extreme weather vulnerability on infrastructure. This framework can be used for both high-level planning and on-the-ground project implementation. This structured approach ensures thoroughness and consistency in designing and maintaining infrastructure in a changing climate (modified from Federal Highway Administration [FHWA] 2012).

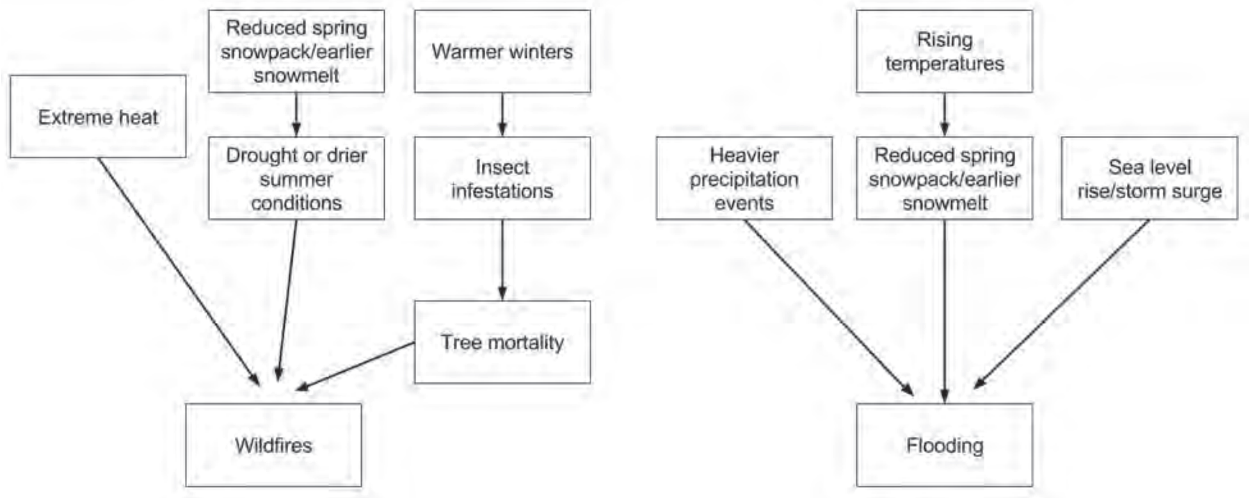


Figure 11.6—Conceptual framework of changes in climate- and weather-related stressors to flooding, wildfires, and tree mortality (modified from USDA FS n.d.).

Other Considerations

Although experienced engineers and maintenance personnel may be knowledgeable about historical and current storm system patterns, future climatic conditions may be underestimated. To build risk awareness, a Washington State Department of Transportation assessment asked staff, “What keeps you up at night?” and then used this information to help identify system vulnerabilities that may be exacerbated by future climatic changes. Local knowledge from specialists who have historical information about sites and trends can be particularly useful.

Similar to natural resource categories (e.g., vegetation, wildlife), infrastructure can be analyzed in a structured, detailed manner based on the vulnerability components: exposure, sensitivity, and adaptive capacity (IPCC 2007). Exposure is the potential for infrastructure to be adversely affected by a climate stressor, such as flooding and wildfires. Sensitivity is the degree to which infrastructure would be affected by exposure to climate stressors. Adaptive capacity is the ability of infrastructure to adjust to potential effects from a climate stressor.

In order to complete a detailed assessment, an interdisciplinary team can be identified to determine key assets. Then, climate stressors are identified (fig. 11.6), and information is collected for key assets. For climate stressors, indicators or thresholds can be identified to categorize vulnerabilities. Ranking assets by defined values and risks will help prioritize planning, funding, replacement, and maintenance activities. For example, roads and recreation sites that are heavily used and are likely to be exposed to multiple stressors (e.g., wildfire, flooding) are key assets that may require significant investment to ensure resilience in a warmer climate.

Assessing the Effects of Climate Change

Roads, trails, bridges, and other infrastructure were developed in the IAP region over more than a century to provide access for mineral prospectors, loggers, hunters, ranchers, and recreationists. National forests, national parks, and other Federal lands were created to protect water supply, timber and range resources, and wildlife, and to provide multiple uses and enjoyment for the public. Transportation infrastructure provides access that is largely determined by where these activities historically occurred in relation to land management objectives. Today, reliable and strategic access is critical for people to recreate, extract resources, monitor and manage resources, and respond to emergencies. Access to public lands promotes use, stewardship, and appreciation of their value as a resource contributing to quality of life (Louter 2006).

The 12 national forests in the Intermountain Region contain 45,769 miles of roads (table 11.1) and 31,074 miles of trails (tables 11.2, 11.3). Of the existing roads, only 2,007 miles are paved. Road density is typically higher at low elevations or adjacent to mountain passes near major highways. Roads and trails cross many streams and rivers because of rugged mountain topography. Most known road-stream crossings are culverts or bridges that were installed decades ago. Some crossings have been replaced, but many culverts have not been inventoried and conditions are unknown. In many landscapes, historical road locations are more likely to be adjacent to streams, greatly increasing risk of road damage and degraded aquatic resources.

There are 862 USFS-owned bridges in the Intermountain Region that are regularly inspected per Federal Highway Administration criteria, which include waterway

Table 11.1—Road length for different maintenance levels in national forests in the U.S. Forest Service Intermountain Region (INFRA USFS n.d.).

National forest	Basic custodial care (closed)[a]	High-clearance vehicles[b]	Suitable for passenger cars[c]	Moderate degree of user comfort[d]	High degree of user comfort[e]	Total
	Operational maintenance level					
	Miles					
Ashley	34	1,159	364	221	248	2,027
Boise	1,685	3,107	1,121	126	457	6,496
Bridger-Teton	617	995	407	248	358	2,624
Caribou-Targhee	1,554	1,538	593	199	23	3,908
Dixie	1,050	2,118	483	64	539	4,254
Fishlake	308	2,094	195	30	42	2,669
Humboldt-Toiyabe	826	5,837	1,338	118	47	8,165
Manti-La Sal	346	1,914	454	133	1	2,848
Payette	968	1,888	444	36	11	3,347
Salmon-Challis	1,241	2,316	388	41	2	3,987
Sawtooth	320	1,519	404	46	53	2,342
Uinta-Wasatch-Cache	234	1,979	491	171	226	3,102
Total	9,182	26,465	6,682	1,433	2,007	45,769

[a] Roads placed in storage (more than 1 year) between intermittent uses, basic custodial maintenance is performed, and road is closed to vehicles.

[b] Open for use by high-clearance vehicles.

[c] Open for and maintained for travel by a prudent driver in a standard passenger car.

[d] Moderate degree of user comfort and convenience at moderate travel speeds.

[e] High degree of user comfort and convenience.

capacity and stream channel characteristics and condition. Approximately 70 percent of them are constructed of timber, and the remaining are constructed of concrete and steel. Many timber bridges, which were constructed during the 1960s when timber sales were common, are too short, resulting in scour near bridge abutments. Most timber bridges are nearing the end of their intended lifespan, whereas most concrete and steel bridges were designed adequately for flows and are in good condition. The Regional Bridge Engineer may determine whether a specific bridge is particularly vulnerable to climatic events. New USFS bridges and bridge replacements are designed in accordance with the agency's aquatic organism passage stream simulation guide (Stream Simulation Working Group 2008), making bridges significantly more resilient to climate change.

Determining the effects of construction, maintenance, operations, decommissioning, or abandoning roads and trails is crucial, because each of these actions affects the environment in many ways (Gucinski et al. 2001). Geotechnical evaluation of proposed road locations, which is essential for stable roads, was not done in the early years of road construction. Roads constructed several decades ago often have culverts and bridges (table 11.4) that are at

Table 11.2—Summary of trail distance and trail bridges in national forests in the U.S. Forest Service Intermountain Region (INFRA USFS n.d.).

National forest	Distance	Trail bridges
	Miles	*Number*
Ashley	1,219	41
Boise	2,251	67
Bridger-Teton	3,500	47
Caribou-Targhee	4,016	52
Dixie	2,004	23
Fishlake	2,559	3
Humboldt-Toiyabe	3,647	9
Manti-La Sal	1,035	5
Payette	1,885	103
Salmon-Challis	3,448	53
Sawtooth	2,574	84
Uinta-Wasatch-Cache	2,936	95
Total	31,074	542

Table 11.3—Summary of Watershed Condition Framework criteria used to classify road and trail function in the U.S. Forest Service Intermountain Region.

Attribute	Good: functioning properly[a]	Fair: functioning at risk[b]	Poor: impaired function[c]
Open road density	Road/trail density is <1 mile per square mile or a locally determined threshold for good conditions supported by forest plans or analysis and data.	Road/trail density is 1–2.4 miles per square mile, or a locally determined threshold for fair conditions supported by forest plans or analysis and data.	Road/trail density is >2.4 miles per square mile, or a locally determined threshold for poor conditions supported by forest plans or analysis and data.
Road and trail maintenance	Best Management Practices (BMPs) for maintenance of designed drainage features are applied to >75% of roads, trails, and water crossings.	BMPs for maintenance of designed drainage features are applied to 50–75% of roads, trails, and water crossings.	BMPs for maintenance of designed drainage features are applied to <50% of roads, trails, and water crossings.
Proximity to water	<10% of road/trail length is located within 300 feet of streams and water bodies or hydrologically connected to them.	10–25% of road/trail length is located within 300 feet of streams and water bodies or hydrologically connected to them.	>25% of road/trail length is located within 300 feet of streams and water bodies or hydrologically connected to them.
Mass wasting	Very few roads are on unstable landforms or rock types subject to mass wasting with little evidence of active movement or road damage. No danger of large quantities of debris being delivered to the stream channel.	A few roads are on unstable landforms or rock types subject to mass wasting with moderate evidence of active movement or road damage. Some danger of large quantities of debris being delivered to the stream channel, although this is not a primary concern.	Most roads are on unstable landforms or rock types subject to mass wasting with extensive evidence of active movement or road damage. Mass wasting that could deliver large quantities of debris to the stream channel is a primary concern.

[a] Density and distribution of roads and linear features indicate that the hydrological regime (timing, magnitude, duration, and spatial distribution of runoff flows) is substantially intact and unaltered.

[b] Density and distribution of roads and linear features indicate that there is a moderate probability that the hydrological regime is substantially altered.

[c] Density and distribution of roads and linear features indicate that there is a higher probability that the hydrological regime is substantially altered.

the end of their design life, making them more susceptible to damage by extreme hydrological events. Many stream crossings with culverts were designed to accommodate 25-year peakflows, whereas current standards typically require sizing for 100-year flows. Many older culverts have reached or passed their design life and are failing. Until recently, culvert sizing was generally expected to last 25 years, representing a surprisingly high probability of failure. For example, the probability of exceedance is 56 percent over a 20-year design life, and 87 percent over 50 years (Gucinski et al. 2001). Although engineering knowledge is greater now than when most roads and other infrastructure were built, geotechnical skills are still in short supply at many locations in the USFS and other land management agencies.

The relationship between vulnerability and the current value of roads and other infrastructure may not be clear in some cases. For example, some roads constructed for timber purposes are now used for public recreation and access to small rural communities. Therefore, road standards and risk of the loss of continuity are not consistent with the value of the access or consequences of loss. Many administrative and recreation sites are vulnerable because they are located near streams and geomorphically unstable areas (table 11.5). Although exposures and risks differ from place to place, many roads and trails are vulnerable, and as noted earlier, documentation of the amount and spatial distribution of infrastructure is a first approximation of vulnerability (figs. 11.2, 11.5). In general, units of analysis (e.g., subwatersheds) that have extensive infrastructure are more vulnerable than those that have little or no infrastructure.

Road Management and Maintenance

The condition of roads and trails differs widely across the IAP region (tables 11.1, 11.3), as do the effects of roads on watersheds and aquatic ecosystems. Road construction has declined since the 1990s, with few new roads being added. Road maintenance is primarily the responsibility of Federal agencies, but County road maintenance crews maintain some roads. The Federal Highway Administration is also involved with the management, design, and funding of highways within national forests and national parks, as well as the State highway system.

Roads vary in level of environmental impact. They tend to accelerate runoff rates, decrease late season flows, increase peakflows, and increase erosion rates and sediment

Table 11.4—Summary of bridge conditions in national forests in the U.S. Forest Service Intermountain Region (INFRA USFS n.d.).

National forest	Adequate	Structurally deficient	Total
	---------------------*Number*-------------------		
Ashley	30	7	37
Boise	90	9	99
Bridger-Teton	85	31	116
Caribou-Targhee	58	19	77
Dixie	38	13	51
Fishlake	15	0	15
Humboldt-Toiyabe	60	5	65
Manti-La Sal	26	4	30
Payette	60	2	62
Salmon-Challis	101	20	121
Sawtooth	95	12	107
Uinta-Wasatch-Cache	68	14	82
Total	726	136	862

delivery to stream systems (Furniss et al. 2000; Guckinski et al. 2001). These impacts are generally greater from roads near rivers and streams, although roads in uplands also affect surface flows, shallow groundwater flows, and erosion processes (Trombulak and Frissell 2000). The effects of stream proximity and terrain slope on road failures can be discerned from data on road damage and failures, although these data are uncommon in most areas.

Each national forest develops a road maintenance plan for the fiscal year, primarily based on priorities by operational maintenance level, then by category and priority. Roads for passenger cars are subject to National Traffic and Motor Vehicle Safety Act standards (23 USC chapter 4, section 402), receiving priority for appropriated capital maintenance, road maintenance, and improvement funds over roads maintained for high-clearance vehicles. Activities that are critical to health and safety receive priority for repair and maintenance, but are balanced with demands for access and protection of aquatic habitat.

Given current and projected funding levels, national forest staff are examining tradeoffs associated with providing access, and maintaining and operating a sustainable transportation system that is safe, affordable, and responsive to public needs while causing minimal environmental impact. Management actions being implemented to meet these objectives include reducing road maintenance levels, stormproofing roads, upgrading drainage structures and stream crossings, reconstructing and upgrading roads, decommissioning roads, converting roads to alternative modes of transportation, and developing more comprehensive access and travel management plans. Unfortunately, current levels of funding for maintenance are generally insufficient to reduce the risk of climate-related damage to roads.

Major transportation projects in national forests, such as reconstruction of roads and trails or decommissioning, must comply with NEPA, which often requires an environmental assessment and public involvement. Decommissioning or obliteration of roads is a process of restoring roads to a more natural state by reestablishing drainage patterns, stabilizing slopes, restoring vegetation, blocking road entrances, installing water bars, removing culverts, removing unstable fills, pulling back road shoulders, scattering slash on roadbeds, or completely eliminating roadbeds (36 CFR 212.5; Road System Management; 23 USC 101) (Luce et al. 2001).

Spatial and terrain analysis tools developed to assess road risks, such as the Water and Erosion Predictive model (Flanagan and Nearing 1995), GRAIP (Black et al. 2012; Cissel et al. 2012), and NetMap (Benda et al. 2007), are often used to identify hydrological effects and guide management on projects. For example, a recent analysis on the Payette National Forest determined that 8 percent of the road system contributes 90 percent of the sediment; analysis results help to prioritize treatment plans by identifying the most critical sites (Nelson et al. 2014). Similar findings have been observed with GRAIP modeling on other national forests in the Intermountain Region.

Climate Change Effects on Transportation Systems

Most effects of high temperatures on roads and associated infrastructure are indirect, through the influence of altered snowpack dynamics, wildfire, and extreme events. However, some direct effects of high temperature exist, including softening and buckling of pavement, thermal expansion of bridge-expansion joints, rail-track deformities related to heating, limitations on periods of construction activity due to health and safety concerns, lengthening of the construction season in cold areas, and vehicle overheating (resulting in roadway incidents and safety issues) (INFRA n.d.).

Climate change is expected to significantly alter hydrological regimes, especially in the latter half of the 21st century (Chapter 4) (fig. 11.7). Specifically, climate and hydrology may affect the transportation system in the IAP region through reduced snowpack and earlier snowmelt and runoff, resulting in a longer season of road use, higher peakflows and flood risk, and increased landslide risk on steep slopes associated with more intense precipitation and elevated soil moisture in winter (Strauch et al. 2014). Increased drought and wildfire disturbance (chapters 6, 7), in combination with higher peakflows, may also lead to increased erosion and landslide frequency. Proximity of roads and other infrastructure to streams provides an approximation of hydrological connectivity (Furniss et al. 2000), indicating the hazard of sedimentation, pollutants, and peakflow changes. Changes in climate and hydrology

Table 11.5—Developed recreation sites in national forests in the U.S. Forest Service Intermountain Region (INFRA USFS n.d.).

National forest	Boating site	Campground	Camping area	Group campground	Interpretive site	Interpretive visitor	Lookout/ cabin	Picnic site	Trailhead
Ashley	15	60	8	12	26	1	9	6	11
Boise	20	68	7	8	4	0	18	5	88
Bridger-Teton	18	40	3	4	15	3	11	12	110
Caribou-Targhee	14	47	6	5	2	2	14	3	31
Dixie	5	23	6	3	0	2	4	2	45
Fishlake	3	27	14	4	8	0	8	2	52
Humboldt-Toiyabe	2	60	7	6	4	1	5	11	49
Manti-La Sal	4	34	3	9	17	1	8	1	51
Payette	1	36	23	0	29	0	3	1	31
Salmon-Challis	2	50	24	2	5	0	2	7	30
Sawtooth	10	74	1	5	9	2	0	12	35
Uinta-Wasatch-Cache	8	109	11	7	7	4	10	42	158
Total	102	628	113	65	126	16	92	104	691

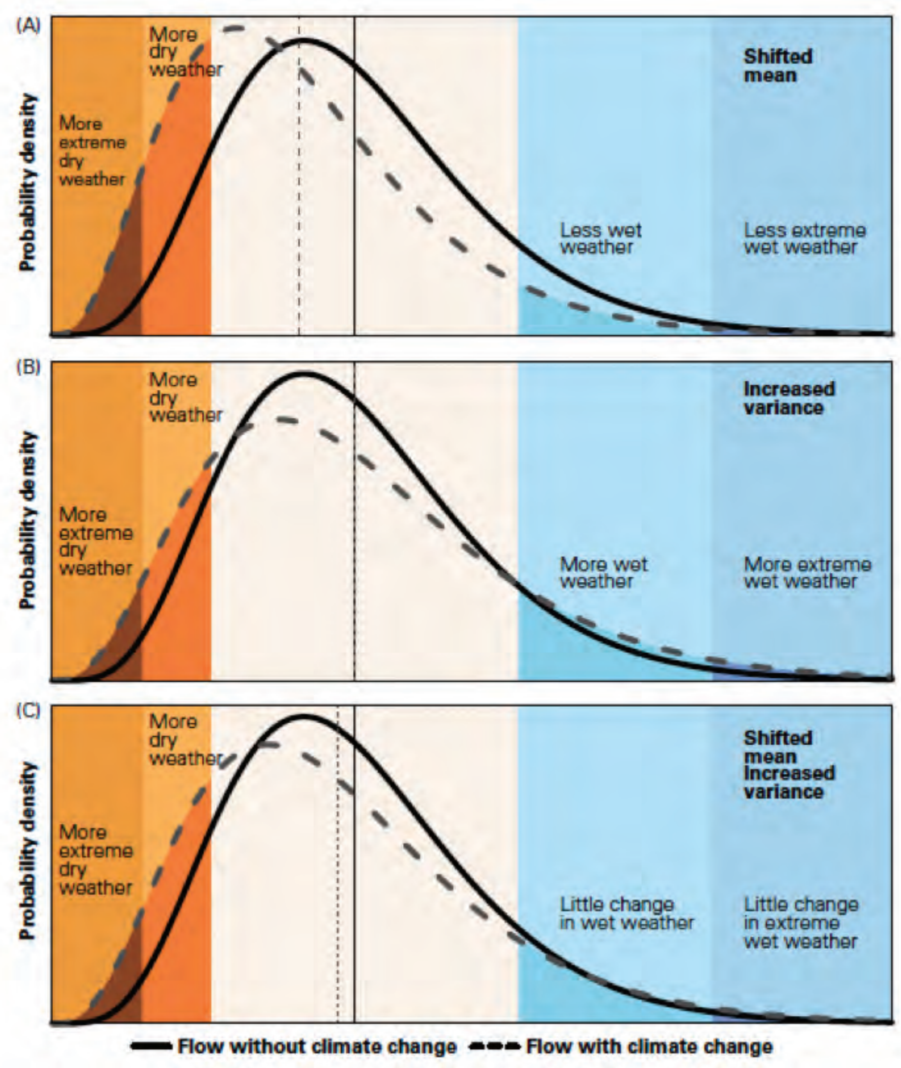


Figure 11.7—Conceptual diagram of how hydrological flow can be affected by both a change in the mean and change in the variance of climate and weather. Climate change is expected to increase the frequency and magnitude of peakflows and flooding in winter (from Field et al. 2012).

can have direct and indirect effects on infrastructure and access, and damage can be chronic or sudden (Bisson et al. 1999; Goode et al. 2012). Direct effects are those that physically alter the operation or integrity of transportation facilities (figs. 11.8–11.10). These include effects related to floods, snow, landslides, extreme temperatures, and wind. Indirect effects include secondary influences of climate change on access that can increase threats to public safety and change visitor use patterns. For hydrological extremes such as flooding, the effect on access may be related more to weather events (e.g., the effects of a single storm) than to climate trends (Keller and Ketcheson 2015). But the expansion of future extremes outside the historical range of frequency or intensity is likely to have the greatest impacts, for example by exceeding current design standards for infrastructure.

Projected changes in soil moisture and form of precipitation with climate change may locally accelerate mass wasting. Shallow, rapid debris slides may become more frequent, impacting infrastructure and access. Climate projections indicate that the conditions that trigger landslides will increase because more precipitation will fall as rain rather than snow, and more winter precipitation will occur in intense storms (Goode et al. 2012; Salathé et al. 2014). These effects will probably differ with elevation because higher elevation areas typically have steeper slopes and more precipitation during storms. Flooding can also be exacerbated by increased basin size during rain events because elevation at which snow falls is projected to move higher (Hamlet et al. 2013). Furthermore, reduced snowpack is expected to increase antecedent soil moisture in winter (Clifton et al. 2017; Goode et al. 2012; Luce 2018).

Elevated soil moisture and rapid changes in soil moisture can affect slope stability and are responsible for triggering more landslides than any other factor (Crozier 1986). Antecedent moisture, geology, soil conditions, land cover, and land use also affect landslides (Kim et al. 1991; Strauch et al. 2014), and areas with projected increases in antecedent soil moisture (coupled with more intense winter storms) will have increased landslide risk (box 11.3). Although the Variable Infiltration Capacity (VIC) model (Chapter 4) does not directly simulate slope stability failures or landslides, VIC model projections of December 1 total column soil moisture can be used as an indicator of landslide risk.

Figure 11.8—Damage caused by a small stream. Proximity to streams affects the vulnerability of roads and associated infrastructure to high streamflows. Even small streams can cause road damage and failure during large storms and where slopes are unstable (photo: S. Hines, U.S. Forest Service).

Figure 11.9—Erosion next to a forest road. Extreme rainfall and flooding can cause severe gully erosion adjacent to forest roads (photo from Keller and Ketcheson 2015, used with permission).

Figure 11.10—Washout of a road in a floodplain as a result of channel widening during high river flow (photo from Keller and Ketcheson 2015, used with permission).

Box 11.3—Factors Related to Vulnerability of Infrastructure to Climate Change

Transportation system (general)

- Aging and deteriorating infrastructure increases sensitivity to climate impacts, and existing infrastructure is not necessarily designed for future conditions (e.g., culverts are not designed for larger peak flows).
- Roads and trails built on steep topography are more sensitive to landslides and washouts.
- A substantial portion of the transportation system is at high elevation, which increases exposure to weather extremes and increases the costs of repairs and maintenance.
- Roads built across or adjacent to waterways are sensitive to high streamflows, stream migration, and sediment movement.
- Funding constraints or insufficient funds, or both, limit the ability of agencies to repair damaged infrastructure or take preemptive actions to create a more robust system.
- Design standards or operational objectives that are unsustainable in a new climate regime may increase the frequency of infrastructure failure in the future.

Roads and trails

- Are located near streams and rivers
- Cross streams and rivers
- Are built on steep, unstable slopes
- Are built in steep, wet areas
- Have crossings located in depositional areas
- Have diversion potential (drainage failure will result in stream capture)
- Have the potential for “cascading failure” (a failure will probably cause failures down-road)
- Have unstable fills and side cast
- Are subject to diverted drainage from other roads and facilities
- Are built in geologic materials that are unstable, have abundant interflow (shallow drainage), or are difficult to compact
- Have infrequent cross-drainage
- Are beyond their design life
- Have designs that are maintenance dependent
- Have little or no regular maintenance
- Have high use without commensurate maintenance
- Are wide and intercept abundant hillslope drainage

Campgrounds and developed recreational facilities

- Are located near streams and rivers
- Have facilities that attract public use in areas subject to flooding or landslides, or both
- Are reached by roads or trails that are vulnerable
- Are in locations where changes in snow affect use
- Have little or no shade to provide respite from extremes of hot weather
- Have high fuel loading and wildfire vulnerability

Buildings

- Are reached by roads or trails that are vulnerable
- Are located near streams or rivers and subject to flooding
- Are in areas subject to landslide hazards
- Have high risk of damage or destruction by wildfire
- Are poorly insulated
- Have inadequate ventilation
- Have substandard plumbing or plumbing not protected from the weather
- Are in locations that are subject to loss or changes due to climatic extremes

Box 11.3 (*continued*)—Factors Related to Vulnerability of Infrastructure to Climate Change

Dams

- Have inadequate safety provisions
- Have inadequate safety inspection frequency
- Have inadequate spillways for extreme storms
- Have inadequate structural integrity against aging and extreme events
- Are subject to cracking or failure caused by earthquakes, extreme flooding, or landslides
- Are subject to new hydrological regimes in areas where snowfall and snowpack are declining

Ecosystems associated with streams that are subject to impacts from infrastructure

- Have rare species that are sensitive to changes in sediment or flow
- Have species or communities that are sensitive to sediment
- Infrastructure is located in or near key habitat locations (e.g., fish spawning areas)
- Infrastructure provides or encourages public access to sensitive sites
- Improper maintenance activities (e.g., side casting) periodically disturb habitats
- Multiple crossings or road or trail segments in near-stream locations remove shade and may reduce large-wood recruitment
- Other factors are stressing communities and habitats
- Have lotic habitats that are fragmented by road-stream crossings or other barriers that restrict migration and movement (connectivity) of aquatic organisms

Projections from the VIC model indicate that December 1 soil moisture will be higher as the climate warms, and thus there will be higher landslide risk in winter on unstable land types at higher elevations (Goode et al. 2012).

Vulnerability of roads to hydrological change (Chapter 4) varies based on topography, geology, slope stability, design, location, and use. To assess vulnerability of the transportation system and infrastructure in the IAP region, we identified traits of the transportation system most sensitive to projected climatic changes (box 11.3) in order to inform transportation management and long-range planning (Flanagan and Furniss 1997; Flanagan et al. 1998).

Roads and trails built decades ago have increased sensitivity because of age and declining condition. Many infrastructure components are at or near the end of their design lifespan. Culverts were typically designed to last 25 to 75 years, depending on structure and material. Culverts remaining in place beyond their design life are less resilient to high flows and bed load movement and have a higher likelihood of structural failure. Underdrains can clog with time and retaining structure components can corrode, degrade, and weaken. As roads and trails age, their surface and subsurface structure deteriorates, and less intense storms can cause more damage than storms of high intensity would have caused when the infrastructure was new.

Advanced material design, alignment, drainage, and subgrade that are required standards today were generally not available or were not required when much of the travel network was developed. Consequently, newer or replaced infrastructure will generally have higher resilience to climate change, especially if climate change is considered in the design. New culverts and bridges are often wider than the original structures to meet agency regulations and current design standards. In the past 15 years, many culverts have been replaced to improve fish passage and stream function, using open-bottomed arch structures that are less constricted during high flows and accommodate aquatic organism passage at a range of flows. Natural channel design techniques that mimic natural stream channel condition upstream and downstream of the crossing are being used effectively at these crossings (Gillespie et al. 2014). In addition, culverts on nonfish-bearing streams are being upgraded as funding and opportunities become available.

The location of roads and trails can increase vulnerability to climate change. Many roads and trails were built on steep slopes because of the rugged topography of the region, and cut slopes and side-cast material have created landslide hazards. Past timber harvesting and its associated road network in national forests have contributed to the sensitivity of existing infrastructure by increasing storm runoff and peakflows, which can affect road crossing structures (Croke and Hairsine 2006; Schmidt et al. 2001; Swanston 1971). Many roads and trails were also constructed in valley bottoms near streams to take advantage of gentle grades, but proximity to streams increases sensitivity to flooding, channel migration, bank erosion, and shifts in alluvial fans and debris cones. Most road-stream crossings use culverts rather than bridges, and culverts are generally more sensitive to increased flood peaks and associated debris.

Roads currently in the rain-on-snow zone, typically in mid-elevation basins, may be increasingly sensitive to warmer temperatures because this is where significant snowpack accumulation is subject to warm storms. Increased peakflow magnitudes can be modeled with some accuracy for changes in snowpack and effects on rain-on-snow runoff mechanisms (Safeeq et al. 2014). Although temperature-induced changes in snowpack dynamics will be manifested in the Pacific Northwest sooner than in most of the Intermountain Region, some areas of the western IAP region are considered vulnerable to increased peakflows. In addition, if total precipitation and intensity increase, peakflows in subalpine watersheds may increase significantly (Muzik 2002). Management of roads and trails (planning, funding, maintenance, and response) affects sensitivity of the transportation system, and the condition of one road or trail segment can affect the function of connected segments. Major highways within the IAP region, built to higher design standards and maintained more frequently, will be less sensitive to climate change than unpaved roads in national forests that were built with lower design standards. Lack of funding can limit options for repairing infrastructure, as well as result in less maintenance, which can affect the short- and long-term vulnerability of the transportation system. For example, replacing a damaged culvert with an “in kind” culvert that was undersized for the current streamflow conditions leads to continued sensitivity to both current flow regime and projected higher flows.

Climate Change Effects on Trails

Land managers can follow a similar assessment process for trail systems as for roads. The IAP region has an extensive trail system in a variety of ecosystems managed and maintained in collaboration with various partners (table 11.2) (Chapter 10). To respond to expected changes in hydrological regimes (Chapter 4), trails will need to be increasingly resilient to higher peakflows and flood frequency, so design changes may need to accommodate projected peakflows rather than historical peakflows (Strauch et al. 2014). With declining agency budgets, increasing the resilience of trail systems will require creative approaches. Partnerships are helping national forests in the Intermountain Region to maintain parts of the trail system.

Climate Change Effects on Developed Recreation Sites

Although trails make up a significant proportion of the recreation system, developed recreation sites are also common assets that are often vulnerable to climate-related stresses (table 11.6). Damaged recreation sites reduce access and services for visitors (Chapter 10) and may incur considerable economic loss. Camping is one of the most popular warm-weather activities in the IAP region (Chapter 10). Many campgrounds are located near streams, often in floodplains, locations that are particularly vulnerable because climate change will increase the frequency and magnitude of flooding (Chapter 4), potentially damaging infrastructure and creating safety problems. Similar issues may affect boating sites along streams, and some lakeshore sites may become less accessible if water levels decrease during droughts. Additional drought-related impacts include erosion and soil compaction of shorelines, decreased water quality from algal blooms, and exposure to invasive species. Dump sites can also be affected by water-related disturbance.

Recreation infrastructure in upland areas will be vulnerable to wildfire damage. Interpretive sites and visitor centers are high-value facilities that are often constructed of wood and would be costly to repair or replace. Hotels, lodges, and cabins located in or near Federal lands are often wood structures adjacent to vegetation with high fuel loadings, and access for fire suppression may be difficult. Downhill ski areas, and, to a lesser extent, cross-county ski areas and snowparks, typically have dense clusters of recreational infrastructure and lodging, with the potential for large economic losses.

Climate Change Effects on Facilities

The Intermountain Region has 2,195 fire, administrative, and other facilities that encompass a structural footprint of over 2 million square feet (table 11.7). The facilities serve many purposes, ranging from administrative offices in urban areas to backcountry cabins. In 2017, the total current replacement value for these facilities was $440 million.

Since 2004, every national forest in the Intermountain Region has had a facility master plan (FMP), and some forests have done updates. Following a standard template, an FMP documents four main management options: (1) retain, (2) decommission, (3) convert to alternate use, or (4) acquire. Each existing building has a management option listed. Owned and leased buildings are included, and proposed future acquisitions are discussed. The FMPs are considered to be valid for 10 years, at which time they need to be updated. Future revisions of FMPs can incorporate components of climate change assessment and adaptation.

The USFS has a Capital Improvement Program (CIP), which is a national-level funding mechanism that funds top-ranked CIP projects. This is typically the only funding source for new facilities. Most maintenance and decommission projects are managed by national forests or the regional office. To date, emphasis has been on developing energy-efficient facilities for which national funding is available for selected projects striving for “net zero” emissions (Meyer et al. 2013). Energy savings performance contracts (ESPCs), which seek to reduce energy requirements, have been implemented. These utilize third-party financers and contractors to develop large-scale (>$1 million) energy efficiency measures. The Intermountain Region is currently paying on a 25-year ESPC that funded small projects such as light and sink fixture replacement.

Increased use of wood in building projects links USFS facilities with healthy forests. Wood products in building systems tend to have lower environmental burdens than functionally equivalent products, and require less energy if used in wall systems (Ritter et al. 2011). Replacing other materials with wood products reduces the rate of carbon

Table 11.6—Relative vulnerability to climate change of administrative and recreation infrastructure in the U.S. Forest Service Intermountain Region (see table 11.5). Ratings are approximate and relative, based on coarse generalizations of value of the type of feature, typical exposures to climatic stresses, typical sensitivity to climatic stresses, and consequences of loss.

Type	Feature	Relative vulnerability
Administrative	Documentary site	Moderate
Administrative	Information site/fee station	Moderate
Administrative	Interpretive site	Moderate
Administrative	Interpretive site–administrative	High
Administrative	Interpretive visitor center (large)	High
Administrative	Interpretive visitor center (small)	Moderate
Picnic	Day use area	Moderate
Picnic	Group picnic site	Moderate
Picnic	Picnic site	Low
Camp	Campground	Moderate
Camp	Camping area	Low
Camp	Group campground	Moderate
Recreation	Boating site	High
Recreation	Fishing site	Moderate
Recreation	Horse camp	Low
Recreation	Hotel, lodge, resort	High
Recreation	Lookout/cabin	High
Recreation	Observation site	Low
Recreation	Other recreation concession site	Moderate
Recreation	Swimming site	Moderate
Recreation	Trailhead	Low
Recreation	Wildlife viewing site	Low
Other	Dump station	High
Other	Off-highway vehicle staging area	Moderate
Other	Organization site	Moderate
Snow	Nordic ski area	High
Snow	Snowpark	High
Snow	Snowplay area	Moderate

emissions to the atmosphere. However, increased use of wood structures also increases exposure and potential damage from wildfires.

Potential adjustments in building design to accommodate a warmer climate include modified roof design with respect to snow load, and modified footing depth with respect to the frost protection line (Olsen 2015). In addition, water facilities can be designed to improve efficiency and conserve water, especially in arid locations. Although the USFS uses current building standards for structures, a warmer climate may motivate future changes in design.

Climate Change Effects on Dams

The Intermountain Region contains 317 dams distributed among 12 national forests (table 11.8). Dams are typically sized to withstand the probable maximum flood (PMF, or 10,000-year flood flow). Such a high standard reflects the severe consequences of dam failure in terms of loss of human life and property, as well as damage to aquatic and riparian ecosystems. If climate change causes an increased frequency and magnitude of peakflows as expected, the PMF may increase, although it will be difficult to project the occurrence of rare, extreme events.

Table 11.7—Summary of fire, administrative, and other buildings in national forests in the U.S. Forest Service Intermountain Region (INFRA USFS n.d.).

National forest	Buildings	Total deferred maintenance	Current replacement value
	Number	*Dollars*	
Ashley	117	3,209,244	27,992,597
Boise	278	7,694,875	70,596,571
Bridger-Teton	220	1,697,102	35,884,205
Caribou-Targhee	170	1,222,776	40,343,855
Dixie	98	3,583,176	21,397,194
Fishlake	89	364,549	8,811,909
Humboldt-Toiyabe	255	8,190,928	52,857,539
Manti-La Sal	79	920,872	9,516,946
Payette	237	14,095,341	54,471,482
Salmon-Challis	278	18,677,939	44,905,880
Sawtooth	142	7,781,721	25,255,776
Uinta-Wasatch-Cache	227	7,151,204	45,857,589
Regional	5	396,713	1,656,011
Total	2,195	74,986,439	439,547,553

Increasing temperature in future decades is expected to reduce water supplies for agriculture, industrial uses, human consumption, and fisheries (Chapter 4). Dams are usually a buffer to water shortages, so there may be increased emphasis on maintaining current dams and new applications for additional dams on public lands, particularly upstream from areas where private uses of water have a significant impact on streamflow during critical water-need seasons. Federal agencies will need to respond to these applications and associated environmental assessments, which are typically complex and time consuming.

Table 11.8—Summary of dams in national forests in the U.S. Forest Service Intermountain Region (INFRA USFS n.d.).

National forest	Active	Inactive/disposed	Total
		Number	
Ashley	29	0	29
Boise	4	0	4
Bridger-Teton	16	4	20
Caribou-Targhee	11	0	11
Dixie	39	6	45
Fishlake	36	12	48
Humboldt-Toiyabe	28	1	29
Manti-La Sal	35	7	42
Payette	13	0	13
Salmon-Challis	9	0	9
Sawtooth	3	0	3
Uinta-Wasatch-Cache	47	17	64
Total	270	47	317

Box 11.4—Exposure to Climate Change of Transportation Systems and Access in the Intermountain Adaptation Partnership Region

Current and short-term exposures (less than 10 years)

- Roads and trails will be damaged by floods and inundation because of mismatches between existing designs and current flow regimes.
- Landslides, debris torrents, and sediment and debris movement will block access routes and damage infrastructure.
- Traffic will be affected by temporary closures to clean and repair damaged roads and trails.
- Frequent repairs and maintenance from damages and disruption will incur higher costs and resource demands.

Medium-term exposures (intensifying or emerging in about 10–30 years)

- Flood and landslide damage is likely to increase in late fall and early winter, especially in watersheds with mixed rain and snow.
- Current drainage capacities may become overwhelmed by additional water and debris.
- Increases in surface material erosion are expected.
- Backlogged repairs and maintenance needs will grow with increasing damages.
- Demand for travel accommodations, such as easily accessible roads and trails, is projected to increase.
- Increased road damage will challenge emergency response units, making emergency planning more difficult.

Long-term exposures (emerging in 30–100 years)

- Fall and winter storms are expected to intensify, greatly increasing flood risk and infrastructure damage and creating a greater need for cool-season repairs.
- Higher streamflows will expand channel migration, potentially beyond recent footprints, causing more bank erosion, debris flows, and wood and sediment transport into streams.
- Changes in hydrological response may affect visitation patterns by shifting the seasonality of use.
- Shifts in the seasonality of visitation may cause additional challenges to visitor safety, such as increased use in areas and during seasons prone to floods and avalanches.
- Managers will be challenged to provide adequate flexibility to respond to uncertainty in impacts to access.

Rain-on-snow events, which can intensify peakflows, may become more common at higher elevations, and less common at lower elevations. Flow hydrographs in the lower-elevation snow zones will change from snowmelt dominated to rainfall dominated, thereby increasing peakflows substantially (Chapter 4). Dams that are in the rain-snow transition snow zone and lower-elevation snow zones will be increasingly subject to flows that were not characteristic during their design and construction. Evaluating dams for safety hazards, a responsibility of national forests, may become even more important in the future.

Projected Climate Change Effects

Near-Term Climate Change Effects

Assessing the vulnerability and exposure of infrastructure in the IAP region to climate change requires evaluating projected changes in hydrological processes (boxes 11.3, 11.4). The integrity and operation of the transportation network may be affected in several ways.

Higher streamflow in winter (October through March) and higher peakflows, in comparison to historical conditions, will increase the risk of flooding and impacts on structures, roads, and trails. Many transportation professionals consider flooding and inundation to be the greatest threat to infrastructure and operations because of the damage that standing and flowing water cause to transportation structures (MacArthur et al. 2012; Walker et al. 2011). Floods also transport logs and sediment that block culverts or are deposited on bridge abutments. Isolated intense storms can overwhelm the vegetation and soil water holding capacity and concentrate high velocity flows into channels that erode soils and remove vegetation. During floods, roads and trails can become preferential paths for flood waters, reducing operational function and potentially damaging infrastructure not designed to withstand inundation. If extreme peakflows become more common, they will have a major effect on roads and infrastructure.

In the short term, flooding of roads and trails may increase, threatening the structural stability of crossing structures and subgrade material. Roads near perennial streams are especially vulnerable (fig. 11.3), and many of these roads are located in floodplains and are used for recreation access. Increases in high flows and winter soil moisture may also increase the amount of large woody debris delivered to streams, further increasing damage to culverts and bridges, and in some cases making roads impassable or requiring road and facility closures. Unpaved roads with limited drainage structures or minimal maintenance are likely to undergo increased surface erosion and gully formation, requiring additional repairs or grading.

Increasing incidence of more intense precipitation and higher soil moisture in early winter could increase the risk of landslides in some areas. Landslides also contribute to flooding by diverting water, blocking drainage, and filling channels with debris (Chatwin et al. 1994; Crozier 1986; Schuster and Highland 2003). Increased sedimentation from landslides also causes aggradation within streams, thus elevating flood risk. Culverts filled with landslide debris can cause flooding, damage, or complete destruction of roads and trails (Halofsky et al. 2011). Landslides that connect with waterways or converging drainages can transform into more destructive flows (Baum et al. 2007). Roads themselves also increase landslide risk (Swanson and Dyrness 1975; Swanston 1971), especially if they are built on steep slopes and through erosion-prone drainages. In the western United States, the development of roads increased the rate of debris avalanche erosion by 25 to 340 times the rate found in forested areas without roads (Swanston 1976), and that number of landslides is directly correlated with total miles of roads in an area (Chatwin et al. 1994; Montgomery 1994). Consequently, areas with high road or trail density and projected increases in soil moisture may be vulnerable to increased landslide risks, especially if an area already experiences frequent landslides.

Short-term changes in climate may affect safety and access in the IAP region. Damaged or closed roads reduce agency capacity to respond to emergencies or provide detour routes during emergencies (Olsen 2015). Increased flood risk could make conditions more hazardous for river recreation and campers. More wildfires (Chapter 8) could reduce safe operation of some roads and require additional emergency response to protect recreationists and communities (Strauch et al. 2014). Furthermore, damaged and closed roads can reduce agency capacity to respond to wildfires.

Longer-Term Climate Change Effects

Many of the short-term effects of climate change are likely to increase in the medium (10–30 years) and long term (>30 years) (Strauch et al. 2014) (box 11.4). In the medium term, natural climatic variability may continue to affect outcomes in any given decade, whereas in the long term, the cumulative effects of climate change may become a dominant factor, particularly for temperature-related effects. Conditions thought to be extreme today may be averages in the future, particularly for temperature-related changes (MacArthur et al. 2012).

Flooding in winter is projected to continue to intensify in the long term (Huntington 2006), particularly in mixed rain-and-snow basins, but direct rain-and-snow events may diminish in importance as a cause of flooding (McCabe et al. 2007). At mid- to high elevations, more precipitation falling as rain rather than snow will continue to increase winter streamflow. By the 2080s, peakflows are anticipated to increase in magnitude and frequency (Chapter 4). In the long term, higher and more frequent peakflows are likely to continue to increase sediment and debris transport within waterways. These elevated peakflows could affect stream-crossing structures downstream as well as adjacent structures because of elevated stream channels. Even as crossing structures are replaced with wider and taller structures, shifting channel dynamics caused by changes in flow and sediment may affect lower elevation segments adjacent to crossings, such as bridge approaches. Flooding can cause stream aggradation and degradation. With stream degradation, bridge footings may become exposed, undercut, and possibly unstable.

Projected increases in flooding in fall and early winter will shift the timing of peakflows and affect the timing of maintenance and repair of roads and trails. More repairs may be necessary during the cool, wet, and dark time of year in response to damage from fall flooding and landslides, challenging crews to complete necessary repairs before snowfall. If increased demand for repairs cannot be met, access may be restricted until conditions are suitable for construction and repairs. Delayed repairs have the potential effect of further damaging ecosystems.

Over the long term, higher winter soil moisture may increase landslide risk, especially in areas with tree mortality from fire and insect outbreaks, because tree mortality reduces soil root cohesion and decreases interception and evaporation, further increasing soil moisture (Martin 2007; Montgomery et al. 2000; Neary et al. 2005; Schmidt et al. 2001). Thus, soils may become more saturated and vulnerable to slippage on steep slopes during winter. Although floods and landslides will continue to occur near known hazard areas (e.g., because of high forest road density), they may also occur in new areas (e.g., those areas which are currently covered by deep snowpack in midwinter) (MacArthur et al. 2012). Thus, more landslides at increasingly higher elevations (with sufficient soil) may be a long-term effect of climate change.

Climate change effects on access may create public safety concerns for Federal lands (Olsen 2015). A longer snow-free season may extend visitor use in early spring and late fall at higher elevations (Rice et al. 2012) (Chapter 10). Lower snowpack may lead to fewer snow-related road closures for a longer portion of the year, allowing visitors to reach trails and campsites earlier in the season. However, warmer temperatures and earlier snowmelt may encourage use of trails and roads before they are cleared. Trailheads, which are located at lower elevations, may be snow-free earlier, but hazards associated with melting snow bridges, avalanche chutes, or frozen snowfields in shaded areas may persist at higher elevations along trails. Whitewater rafters may encounter unfavorable conditions from lower streamflows in late summer (Hand and Lawson 2018; Mickelson 2009) and hazards associated with deposited sediment and woody debris from higher winter flows. Warmer winters may shift river recreation to times of year when risk of extreme weather and flooding is higher. In addition, less water may be available for water-based recreation at lakes. Some activities may increase use of unpaved roads in the wet season, which can increase damage and associated maintenance costs.

Climate change may also benefit access and transportation operations in the IAP region over the long term. For example, less snow cover will reduce the need for and cost of snow removal. Earlier access to roads and trails will create opportunities for earlier seasonal maintenance and recreation. Temporary trail bridges installed across rivers may be installed earlier in spring as spring flows decline. A longer snow-free season and warmer temperatures may allow for a longer construction season at higher elevations. Less snow may increase access for summer recreation, but it may reduce opportunities for winter recreation, particularly at low and moderate elevations (Joyce et al. 2001; Morris and Walls 2009) (Chapter 10). The highest elevations will retain relatively more snow than other areas, which may create higher local demand for winter recreation and summertime river rafting over the next several decades.

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Chapter 12: Effects of Climate Change on Cultural Resources

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Introduction

As with all resources on public lands, cultural resources are subject to environmental forces such as climate change. Climate change can affect cultural resources directly (e.g., heat, precipitation) or indirectly (e.g., vegetation, wildfire, flooding). Cultural resources include archaeological sites, cultural landscapes, ethnohistoric and historic structures and artifacts, and ethnographic resources. As weather patterns become more extreme and more unpredictable, they will introduce new risks to the management of cultural resources. In such circumstances, risk management and adaptation options can be complicated because many resources are unique and have strong ties to a specific location. Cultural resources and cultural landscapes are approached differently from a management perspective compared to other resources because they are nonrenewable—once they are lost, they cannot be restored.

The 1906 Antiquities Act requires Federal land management agencies to preserve historic, scientific, commemorative, and cultural values of archaeological and historic sites and structures of public lands for present and future generations (NPS 2011; NPS 2015a). It also gives the President of the United States authority to designate national monuments as a means to protect landmarks, structures, and objects of historic or scientific significance. The Historic Sites Act of 1935, National Historic Preservation Act of 1966, Archaeological Resources Protection Act of 1979, and Native American Graves Protection and Repatriation Act of 1990 reaffirm the importance of cultural resources. Although these laws differ in their focus, they collectively mandate the protection and management of cultural resources on Federal lands. The National Park Service has a particularly strong emphasis on protection of cultural resources (box 12.1).

Protection of cultural resources is focused on physical sites, structures, and artifacts that are associated with the past, as well as ongoing cultural practices of the present. Many cultural resources are vulnerable to natural biophysical factors as well as anthropogenic effects. Wildfire and biological processes degrade and destroy cultural resources, particularly those made of wood or located in erosion-prone environments. Vandalism, illegal artifact digging, arson, and other depreciative human behaviors also damage cultural resources. Although management actions can help protect and mitigate many of these adverse effects, the protection of cultural resources is a resource-intensive task that often exceeds agency capacity.

Box 12.1—The National Park Service and Cultural Resources

The National Park Service (NPS) was assigned the role of preserving historic sites, buildings, and objects of national significance through the National Historic Preservation Act and the Federal Historic Sites Act. Specifically, a cultural resource is considered to be “an aspect of a cultural system that is valued by or significantly representative of a culture, or that contains significant information about a culture” (NPS 2015c). Cultural heritage and its preservation are emphasized in the agency’s Cultural Resources, Partnerships and Science directorate (NPS 2011), which instructs the agency to:

- Preserve cultural resources in cooperation with Indian tribes, Alaska Native villages and corporations, Native Hawaiian organizations, States, territories, local governments, nonprofit organizations, property owners, individuals, and other partners;
- Provide leadership in research and use of advanced technologies to improve the preservation of the Nation’s cultural heritage;
- Establish standards and guidance for managing cultural resources within the National Park System and communities nationwide; and
- Enhance public understanding of and appreciation for the Nation’s cultural heritage.

The NPS emphasizes minimizing loss and disturbance of culturally significant material in management and protection activities, and communicates this focus through educational and interpretive information.

Overview of Cultural Resources

Defining Cultural Resources

Cultural resources located on Federal lands fall into two broad categories. First, resources are categorized as archaeological and historic sites if they represent the tangible story of past human activities on the landscape and are generally over 50 years in age. Second, ongoing relationships between American (and Native American) people and ecology managed by Federal agencies can also be considered to have cultural significance. Ecology is used here in the holistic sense of the landscape, environment, flora-fauna, and extant human interaction, including the management of Native American sacred sites and traditional cultural properties.

According to 36 CFR 60.4 and *The National Register Bulletin: How to Apply the National Register Criteria for Evaluation*, cultural resources may be considered significant and eligible for the National Register of Historic Places if they have a quality that is of significance in American history, architecture, archaeology, engineering, or culture and if that significant quality is present in districts, sites, buildings, structures, and objects that possess integrity of location, design, setting, materials, workmanship, feeling, and association, and

- That are associated with events that have made a significant contribution to the broad patterns of our history; or
- That are associated with the lives of significant persons in our past; or
- That embody the distinctive characteristics of a type, period, or method of construction, or that represent the work of a master, or that possess high artistic values, or that represent a significant and distinguishable entity whose components may lack individual distinction; or
- That have yielded or may be likely to yield, information important in history or prehistory.

The majority of cultural resources located on Federal lands in the Intermountain Adaptation Partnership (IAP) region, especially on national forests, have yet to be identified because most field surveys of cultural resources have focused on the area of potential effect of proposed undertakings; those inventories were not performed solely to identify cultural resources where they are most likely to exist. Most lands within national forests in the U.S. Department of Agriculture Forest Service (USFS) Intermountain Region have not been subject to basic cultural resource inventories. Section 110 of the National Historic Preservation Act (NHPA) broadly spells out the responsibilities of Federal agencies to ensure that historic preservation is an integral part of overall Federal land management programs.

When considering management of cultural resources in light of climate change, we must also consider the future management of landscapes that are likely to contain cultural resources not yet identified. Tangible physical remains of the human past on the landscape are not only objects and features, but also the archaeological, historical, and cultural value we place on them that make them important and worth preserving (NPS 2015a). Changing values and scientific research may change the perceived value of cultural resources over time. Archaeological and historic sites that may not have been considered eligible for the National Register of Historic Places in the past, may now be considered eligible because of changing attitudes about the historic past and the archaeological record.

Not all cultural resources are considered “historic properties.” Designation of a cultural resource as a historic property requires a certain level of Federal management of that resource as described in 36 CFR 800. Nonetheless, other cultural resources are still important and should be managed at a level deemed appropriate in light of recommendations of heritage staff after consultation with tribes, the public, and other stakeholders. In this context, this chapter provides land managers with a climate change assessment that can help inform land management decisions that minimize adverse effects to cultural resources and promote their preservation and interpretation for the public.

Cultural Resources in the Intermountain West

Indigenous Lifeways

North America was colonized by the ancestors of Native Americans sometime in the range of 14,000 to 15,000 years BP. The oldest well-dated archaeological sites located within the area that encompasses the USFS Intermountain Region are Danger Cave, Smith Creek Cave, and Bonneville Estates Rockshelter—located on the western shores of the ancient freshwater Lake Bonneville—dating to 10,600 to 12,800 years BP (Rhode et al. 2005).

Over thousands of years, successive groups of Native Americans either created or adopted different subsistence strategies adapted to the ecology of the area the group inhabited (Smith 2011). Although adaptations included hunting, gathering, foraging, horticulture, and agriculture, the salient characteristic of these strategies was their intrinsic tie to local environmental conditions and locally procured resources (Smith 2011). Even if a group was highly mobile or nomadic, or maintained trade networks with other groups, it still relied on resources from the area in which it lived.

Most of the archaeological record left behind by early peoples consists of stone tools, debris from making stone tools, and pottery from different time periods because organic material degrades. In rare cases, buried archaeological deposits, especially those found in protected rock shelters and caves, contain organic material such as wood, antlers, bones, leather, textiles, basketry, and charcoal (Rhode et al. 2005) (fig. 12.1). Common features that remain on

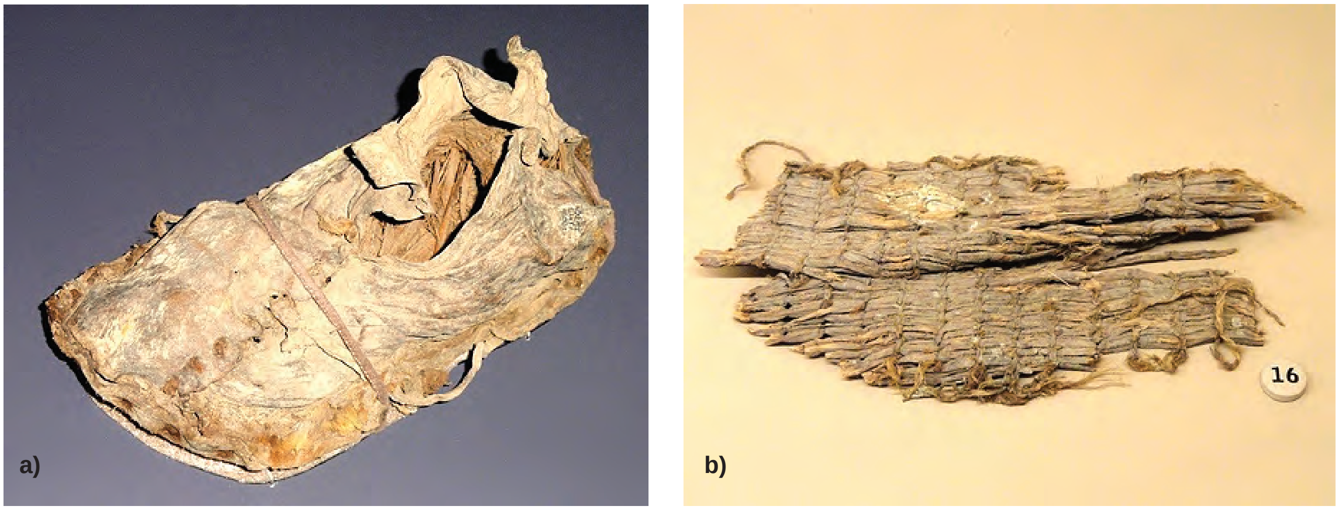

Figure 12.1—Artifacts made of organic materials: (a) Moccasin made of hide and sinew, Hogup Cave, Utah, 420 AD; (b) twined mat, 1225–1275 AD, Promontory Cave I, Utah. Artifacts made of organic materials are typically well preserved only when buried in caves or other shelters. Fluctuations in moisture and temperature cause these materials to decompose relatively quickly, especially when exposed to open air (photos: Courtesy of the Natural History Museum of Utah).

the landscape include rock art, architecture, food storage features, and stone alignments such as teepee rings and pinyon nut storage features. Less common, and dating to the protohistoric and historic period, are animal drive lines created from brush and wood (fig. 12.2), wikiup structures made from branches, brush houses, and culturally modified trees (Simms 1989).

Traces of Past Lifeways

In the IAP region, tangible remains of material culture range from isolated stone tool fragments to village sites with aboveground architecture. Each national forest and national park in the IAP region has its own unique set of archaeological sites, although there are some recurrent patterns in general types of archaeological sites. The most commonly identified type of archaeological remains, which spans all of human prehistory, are prehistoric artifact scatters found on the ground surface. These artifact scatters typically contain waste flakes from making stone tools (or lithic debitage), stone tools (Rhode et al. 2005), pottery sherds, and ground stone tools such as manos and metates, which were used as grinding implements for food processing (Adams 1993; Schlanger 1991). These types of sites are relatively common, often indicating that more cultural material is present, but buried, and not visible during a field survey.

Archaeological sites located in caves and rock shelters often preserve a broad range of artifacts and features that do not typically survive in open-air sites. People used caves and rock shelters throughout prehistory. These places protected not only people but objects from the elements. The high degree of preservation allows leather and hide, basketry, textiles, cordage, and artifacts of wood, bone, antler, and ceramic to persist, along with other organic material such as charcoal and plant material (Beck and Jones 1997).

Figure 12.2—Wichman Corral, Great Basin, Nevada. Deer traps were used to drive animals into a confined area where they could be killed. These cultural features are relatively subtle across the landscape and are susceptible to damage from wildfire (photo: B. Hockett, Bureau of Land Management, Nevada State Office).

Archaeological features defined as nonportable material include rock art, architectural remains, stone alignments such as teepee rings or storage features, trails, and culturally modified trees. In addition, highly distinctive resources are found in the southern portion of the IAP region. Between about 600 and 1250 AD, this area was occupied by the Fremont culture, whose lifeway was tied to maize horticulture (Coltrain and Leavitt 2002). Fremont-era sites often contain the remains of pithouse structures, aboveground and belowground food storage features (granaries), pottery, portable art object (e.g., clay figurines), and rock art (Kloor 2007; Madsen and Metcalf 2000). Most of the easily identifiable Fremont sites are located in Manti-La Sal National Forest, but there are also sites in Ashley, Dixie, Fishlake, Humboldt-Toiyabe, and Uinta-Wasatch-Cache National Forests.

The IAP region also has a significant presence of Puebloan culture related to the Anasazi, also known as the Ancestral Puebloans, which dates to between 300 and 1300 AD (Allen and Baker 2000; Jennings and Norbeck 1955). The Anasazi were focused on maize agriculture; archaeological sites contain aboveground architecture, villages, multiroom structures (pueblos), granaries, kivas (large storage and ceremonial structures), and rock art sites (Lekson 2008; Lyneis 1992). Most Anasazi sites are in Manti-La Sal National Forest, with additional sites in Dixie, Fishlake, and Humbolt-Toiyabe National Forests.

Ethnographic Resources as a Legacy of Indigenous Lifeways Still in Practice

Because indigenous people continue to use traditional landscapes as part of their modern cultural practices, Native Americans have an active relationship with Federal lands in the IAP region. All cultures change with time, and aspects of the active relationship that indigenous people have with the land change as well. The concept that current relationships are as culturally valid as historical ones is an important aspect of contemporary land management.

Given the number of Federally recognized tribes with whom Federal agencies in the IAP region have relationships (table 12.1), incorporating Native American values and perspectives can seem overwhelming. The most effective way to approach this issue is to invite tribes to be partners in management of public lands rather than treating them only as consulting parties. Land managers benefit from an indigenous perspective on ecosystem management, and an ongoing relationship helps land managers to understand current concerns of tribal entities and identify traditional uses that may be affected by climate change. Identifying current cultural practices and resource use allows land managers to make decisions that may mitigate adverse effects on those resources.

Agricultural and Industrial Activities

Euro-American exploration in what is now the IAP region began in the late 1700s, followed by more intensive settlement in the mid-1800s. Thereafter, settlements of people of European, Asian, and African descent expanded quickly in population size and settlement extent. In addition, Native American peoples increasingly participated in the new agricultural and industrial economies brought by European settlers.

Visible footprints from these new economies take primarily three forms. First, there are the remains of the work and residential locations associated with agricultural and industrial activities, generally taking the form of archaeological sites that include homesteads, mines, towns, trash scatters, and campsites. Second, this wave of settlement created landscape features such as roads, dams, railroads, and canal systems. Third, there are remains of changes to landscapes caused by agricultural and industrial activities, including stream channel alteration caused by hydraulic mining, stump fields associated with tie cutting, and field clearing associated with farming (Merritt 2016; South 1977).

These different lines of evidence about past activities inform us about not only past human settlements and activities, but how these activities have affected current human and ecological communities, and how these changes set the stage for the future. They also provide visitors to Federal lands an opportunity to observe the effect of industrialization in the American West. We need to consider the potential effects of climate change on all of these lines of evidence across the current-day landscape. Beyond protecting cultural resources, resource managers may benefit from understanding how past management practices produced current outcomes. Looking into the history of landscape management may help inform future climate change adaptation. Appropriate scales of inquiry include individual archaeological sites as well as larger landscapes where particular activities took place (e.g., a mining district or homesteading area). Even larger landscapes are relevant in some cases, such as watersheds around the Comstock Lode in western Nevada, which was affected by mining, logging that supported the mining, and transportation systems associated with both of these activities.

Activities in the Historic Period

Each location in the IAP region has a unique history affected by the primary economic activities that initially attracted settlers to that area. For example, an emphasis on mining created different types of archaeological sites and landscape features than agriculture or logging. These differences shifted through time, as local economies changed or diversified. The establishment of national reserves, forests, and parks affected the scale and nature of some of these activities. Most national forests contain some of the remains associated with particular economic activities. Others contain resources that are unique to one or more national forests, such as the presence of Chinese communities during and after the building of the Transcontinental Railroad in the mid-19th century (Ambrose 2001).

Table 12.1—Geographic locations in the U.S. Forest Service Intermountain Region where tribal groups have a legacy of natural resource use.

Tribe	Lead national forests for tribal consultation	State
Battle Mountain Band (Shoshone)	Humboldt-Toiyabe	Nevada
Bridgeport Indian Colony (Paiute)	Humboldt-Toiyabe	Nevada, California
Carson Colony (Washoe)	Humboldt-Toiyabe	Nevada
Confederated Tribes of Goshute	Uinta-Wasatch-Cache	Utah
Dresslerville Community (Washoe)	Humboldt-Toiyabe	Nevada
Duckwater Shoshone Tribe	Humboldt-Toiyabe	Nevada
Eastern Shoshone	Bridger-Teton	Wyoming, Utah
Elko Band (Western Shoshone)	Humboldt-Toiyabe	Nevada
Ely Shoshone	Humboldt-Toiyabe	Nevada
Fallon Colony (Paiute and Shoshone)	Humboldt-Toiyabe	Nevada
Fort McDermitt	Humboldt-Toiyabe	Nevada
Las Vegas Paiute	Humboldt-Toiyabe	Nevada
Lovelock Paiute	Humboldt-Toiyabe	Nevada
Moapa Band of Paiute	Humboldt-Toiyabe	Nevada
Navajo Nation	Manti-La Sal	Utah, Arizona, New Mexico
Nez Perce Tribe	Payette, Salmon-Challis, Sawtooth	Idaho
Northern Arapaho	Bridger-Teton	Wyoming, Utah
Northern Ute Tribe	Ashley, Fishlake, Manti-La Sal, Unita-Wasatch-Cache	Utah
Northwestern Band of Shoshoni Nation	Unita-Wasatch-Cache, Sawtooth	Utah
Paiute Indian Tribe of Utah (includes: Shivwits, Cedar City, Koosharem, Kanosh, Indian Peaks Bands	Dixie, Fishlake, Manti-La Sal	Utah
Pyramid Lake Paiute	Humboldt-Toiyabe	Nevada
Reno-Sparks Colony (Washoe, Paiute, Shoshone)	Humboldt-Toiyabe	Nevada
San Juan Southern Paiute	Manti-La Sal	Utah, Colorado
Shoshone-Bannock Tribes	Bridger-Teton, Caribou-Targhee, Payette, Salmon-Challis, Sawtooth	Idaho
Shoshone-Paiute Tribes	Boise, Caribou-Targhee, Humboldt-Toiyabe, Payette, Salmon-Challis, Sawtooth,	Nevada, Idaho
Skull Valley Band of Goshute	Uinta-Wasatch-Cache	Utah
South Fork Band Colony	Humboldt-Toiyabe	Nevada
Stewart Colony (Washoe)	Humboldt-Toiyabe	Nevada
Summit Lake Paiute Tribe	Humboldt-Toiyabe	Nevada
Te-Moak Tribe of Western Shoshone	Humboldt-Toiyabe	Nevada
Ute Mountain Ute Tribe (Weeminuche Band)	Manti-La Sal	Utah, Colorado
Walker River Paiute	Humboldt-Toiyabe	Nevada
Washoe Tribe (includes: Carson, Dresslerville, Stewart, Washoe, Reno-Sparks, Woodsfords Colonies)	Humboldt-Toiyabe	Nevada, California
Wells Band Colony	Humboldt-Toiyabe	Nevada
Winnemucca Indian Colony (Paiute and Shoshone)	Humboldt-Toiyabe	Nevada
Woodsfords Community (Washoe)	Humboldt-Toiyabe	Nevada, California
Yerington Paiute	Humboldt-Toiyabe	Nevada
Yomba Shoshone	Humboldt-Toiyabe	Nevada

Figure 12.3—Cabin used by a railroad tie cutter in the Uinta-Wasatch-Cache National Forest, Utah. Such historic structures are highly susceptible to damage from wildfire (photo: C. Merritt, Uinta-Wasatch-Cache National Forest).

The historic period is generally considered to start when written records began to be available. In the IAP region, it began in the late 1700s with the arrival of Spanish and English explorers (Fernández-Shaw 1999). A historic archaeological site can include sites as recent as 50 years old, because all sites of that age can be considered for inclusion in the National Register of Historic Places.

People involved in all historic period activities needed places to live, acquire supplies, and educate their children. As a result, communities of various sizes and structure are associated with all historic period activities. Some of these communities were located in what are now national forests (e.g., mining towns, dispersed homesteads), and others were located adjacent to national forests, but with infrastructure (e.g., dams, canals, roads) established on National Forest System lands. The archaeological remains of these communities include standing or collapsed houses, commercial buildings, roads, trash scatters, power houses, power lines, rail lines, dams and canals, spring developments, and buried water lines (fig. 12.3).

Agricultural settlements have two patterns: (1) farmers living directly on their land, in which case they are parts of dispersed communities of similar families; or (2) farmers or livestock operators living in clustered communities, then traveling to their farms (Leone 1973). The latter is often associated with Latter-Day Saint (or Mormon)-settled towns in Nevada, Utah, and Idaho (Arrington 1993). Some lands now administered by national forests were originally homesteaded under various homesteading acts. When these homesteads failed in the 1930s, they were purchased by the Federal government and conveyed to National Forest System management. These larger homesteading landscapes include roads, canals, reservoirs, cleared fields, fences, and other features.

Some agricultural features are marked by the presence of cultivated plant species (e.g., fruit trees, flowers) that may have been planted decades ago but still exist. Some failed farmlands were seeded by the USFS with smooth brome (*Bromus inermis*) or crested wheatgrass (*Agropyron cristatum*) to reduce wind erosion. These nonnative crops are a visible reminder of past farming activities even after houses and barns are no longer visible on the landscape.

The archaeological evidence of livestock grazing includes campsites (often artifact scatters), fences, watering troughs, dams, and arborglyphs (signatures and drawings on aspen trees). People from diverse backgrounds participated in this activity, including Basques, other Southern Europeans, Native Americans, Central Americans, and South Americans (Mallea-Olaetxe 2008). Unmanaged livestock grazing altered the composition of some plant communities and led to extreme soil erosion, producing effects that are still visible in some landscapes.

Mineral extraction, which included hard-rock mining and to a lesser degree coal mining, was the primary motivation for settlement in many areas, and its imprint on the landscape is highly visible in many areas. Archaeological remains from mining include entire towns, isolated cabins, tailings piles, headframes, tramways, roads, railroads, water flumes, and ventilation shafts. Hydraulic mining and placer mining moved millions of tons of earth within or next to stream channels, leaving mounds of gravel within highly altered landscapes in Idaho and Nevada and thus severely altering the soil and water processes in these areas.

A significant social component of mining was the many ethnic groups who were drawn to the industry, including Italians, Slavs, Finns, Georgians, Germans, Asians, Spanish-speaking Americans, and Native Americans, who have contributed to the demographic composition of communities in those areas today (Brown 1979; Paul 1963). Chinese and Japanese residents worked in support industries such as restaurants, transportation, logging, and laundry services. These ethnicities are recognized in the archaeological record, providing information critical to understanding the histories of people who were often marginalized in the written record of these mining ventures (Voss and Allen 2008).

Archaeological evidence of rock quarrying can be seen in settlements, but more commonly in road and railroad systems and by the remains of the quarries themselves. The production of lime from limestone was marked by stone kilns, broken limestone, and piles of discarded lime. These kilns were widespread near many historic communities and were in operation until commercially produced lime and cement became available.

Oil and gas development began in national forests in the late 1800s in many parts of the region. Much of this work was largely exploratory, whereas other fields were successfully developed for longer periods of time. These locations are often marked archaeologically by capped wells, cleared pads with associated ponds, artifact scatters, collapsed cabins or derricks, roads, and abandoned pipelines.

Logging was the most widespread form of extractive industry in the IAP region, and continues today. Past logging activity was conducted on a variety of scales, and the associated archaeological remains and environmental effects vary. Logging in support of mining or railroad development left a large footprint, including large camps or commissaries where workers lived, road networks, railroads, water diversions, and sawmills. Smaller scale logging is often marked by smaller camps, sawmills, roads, and water diversions.

The cutting of railroad ties associated with the Transcontinental Railroad and later rail lines was carried out at multiple scales. In addition to the usual archaeological footprint associated with logging, "tie hacking" affected stream channels. In this practice, ties were cut in winter, piled next to streams, and transported down those streams during spring runoff. The resulting rush of water and logs scoured stream channels, altering their character and function.

Charcoal-making produced fuel for railroads, smelters, and household use. It was done on a small scale in many areas, especially in Nevada. Charcoal sites are marked archaeologically by stone or brick kilns, often accompanied by campsites, small settlements, artifact scatters, roads, and rail lines. This work was often conducted by ethnic minorities, including Italians (Straka 2006).

The first travel routes associated with exploration and settlement of the western United States in the 1800s were foot and pack animal trails or wagon routes, some of which are still partially intact and remain historically important. Historic trails in national forests today include the Lewis and Clark Trail, Old Spanish Trail, Oregon Trail, and Mormon Trail. The physical remains of these trails are often ephemeral, and the trail routes are generally considered to include the landscape settings of those trails, often defined as their viewshed.

Road systems developed soon thereafter connected communities with each other and with resources and centers of activity near communities (e.g., sawmills, mines). Although the narrow original footprint of these roads was often covered by modern gravel, asphalt, or concrete roads, native surface historic roads continue to exist in national forests, often associated with historic camping and trash disposal. Completion of the Transcontinental Railroad in 1869 set the stage for development of a network of railroads that connected communities in the IAP region with the rest of the United States, which facilitated the development of mining, logging, and other industries. Narrow-gauge rail lines connected mines, logging districts, quarries, and other industrial operations with major railroad and road systems. Many of these smaller rail lines remain on national forests, marked by railroad grades and cuts, culverts, bridges, tunnels, and work camps.

Some activities described as historic remain important economic activities for people today. For example, hard-rock mining continues in some areas, but global economics and the cost of domestic mining have made most mining ventures unprofitable. Oil and gas development is prevalent in some national forests and adjacent lands (especially Bureau of Land Management and private lands), with on-the-ground activities subject to fluctuation in global energy markets. Logging remains an important economic industry in national forests, but at a much lower level and smaller scale than 30 years ago, often serving as a tool for hazardous fuels reduction and restoration. Livestock grazing is the most widespread historic activity that remains on Federal lands, and is important economically to individual families and some small communities. Tourism is an important economic activity associated with archaeological remains of all historic activities, including visitation at mining districts, historic trail systems, and railroads. Preservation of historic resources that attract visitors contributes to the economies of communities who depend on tourism.

Climate Change Effects on Cultural Resources

Context

Climate change will affect several environmental factors that will in turn potentially alter cultural resources and cultural landscapes. Some areas may experience increased aridity and drought, whereas others may be subject to seasonal flooding. The physical implications of climate change will not be uniform either spatially or temporally.

Areas that are most at risk can be identified by considering the following questions (Rockman et al. 2016): (1) How will climate and environments change over time? (2) How will animal and plant communities change as a result of human use? and (3) How will human use change over time in response to climate change? The following topics can serve as a starting point for land managers to consider when making management decisions relative to climate change and cultural resources: (1) physical traces of past human use, (2) paleoenvironmental data, (3) culturally significant native vegetation, (4) culturally significant native fauna, (5) forest visitor use and pressure areas (change associated with climatic and ecological shifts), and (6) livestock grazing regimes.

The projected effects of climate change through the 21st century include increased temperature and drought, decreased snowpack, and increased ecological disturbance (wildfires, insect outbreaks, floods in some areas) (chapters 3, 4, 8). These effects will have ramifications for the physical cultural resources on the landscape, and, in turn, affect the intangible cultural values that are linked to the physical manifestations of archaeological and historic sites, landscapes, and ongoing traditional use. The National Park Service provides a detailed list of how direct and indirect climate change effects influence cultural resource management (NPS 2017).

Land managers can understand how cultural resources will be affected by changes in climate through systematic monitoring programs. As noted previously, however, the majority of cultural resources have yet to be identified. In the absence of large-scale cultural resource inventory data, managers can use predictive models to identify areas that are likely to contain unidentified cultural resources, and infer the likely character of those resources. These models can be used to direct future inventories and to proactively manage those areas based on their likelihood of containing significant cultural or historic resources. Such geospatial studies have been done at the Bering Land Bridge National Preserve and Cape Krusenstern National Monument, Alaska (NPS 2015b).

This assessment is general because little has been written about the effects of climate change on cultural resources compared to other resources (Morgan et al. 2016; Rockman 2015). The diversity of cultural resources and the locations where they are found make it difficult to infer the spatial extent and timing of specific effects. Therefore, we base inferences on the relevant literature and professional knowledge to project how an altered climate will modify the condition of, and access to, cultural resource sites.

Biophysical Effects on Cultural Resources

Climate change has the potential to exacerbate existing effects from the natural environment on cultural resources (table 12.2). One of the most prominent outcomes of a warmer climate will almost certainly be increased frequency and extent of wildfires across western North America (McKenzie and Littell 2017; McKenzie et al. 2004) (Chapter 8). Wildfires burn cultural resources made of wood and other combustible materials, such as aboriginal shelters and game drives, or historic homesteads, mining ruins, and buildings. Wildfire suppression tactics, including fireline construction using hand tools or heavy equipment, can damage standing structures and archaeological sites in forest soils. Fire retardant can also damage and stain cultural resources (Ryan et al. 2012) (fig. 12.4). In addition, flooding and debris flows after fire can threaten cultural resources that have been exposed by the fire. On a positive note, fire can expose cultural sites that may have been obscured by vegetation or surface soil, allowing these sites to be documented and preserved.

Federal agencies can reduce the effects of wildfire on cultural resources through various actions, such as encasing historic structures in fire-proof material, constructing fireline away from cultural sites, and protecting cultural resources that could be damaged by flooding events. But large wildfires are typically too large for these approaches to have a measurable effect in reducing cultural resource loss. Therefore, higher wildfire frequency in a warmer climate could significantly increase damage to cultural resources in the IAP region. Some climate-induced vegetation shifts in designated cultural landscapes could be partly mitigated through silvicultural treatments and prescribed burning, although the effectiveness of proposed treatments relative to the scope and scale of the cultural landscape is difficult to evaluate. More details on vegetative treatment can be found in Chapter 14.

Seasonal aridity and prolonged drought can exacerbate soil deflation and erosion, thus exposing archaeological sites that may have been previously buried. Wind and water reveal artifacts and features such as cooking hearths and tool-making areas, leaving artifacts vulnerable to illegal collecting and damage. Although dry climate and drought have occurred for millennia in the IAP region, with corresponding episodes of soil erosion (Meltzer 1990; Ruddiman 2007), increasing temperatures outside the historical range of variability (IPCC 2014; Mayewski and White 2002) (Chapter 3) may accelerate cultural resource loss through drought and erosion, particularly in drier areas of the IAP region.

In addition, if winter precipitation increases (Chapter 3) and reduced snowpack leads to higher winter streamflows (Chapter 4), sites that contain cultural artifacts will be vulnerable to flooding, debris flows, and mass wasting. This already occurs to some extent following large wildfires and may become more common in the future (National Research Council 2002).

High-elevation snowfields contain artifacts from hunting and gathering excursions to mountain environments from past centuries (Lee 2012). If snowmelt increases in a warmer climate, previously ice-encased and well-preserved cultural resources such as bone, wood, and fiber artifacts will be exposed. Melting snow and ice patches provide opportunities for discovery and new scientific knowledge, but if the rate of melt exceeds the time available for inspection

Table 12.2—Summary of climate change stressors and potential effects on cultural resources in the Intermountain Adaptation Partnership region (modified from Morgan et al. 2016; see also Rockman 2014, 2015; UNESCO 2007). Human activities can exacerbate some of the expected effects of climate change (see text).

Climate change stressor	Archaeological resources	Cultural landscapes	Ethnographic resources	Museum collections	Buildings and structures
Increased temperature and drought	Microcracking of site contexts from thermal stress Faster deterioration of newly exposed artifacts and sites Deterioration of newly exposed materials from melting snow patches	Decline of some vegetation species Heat stress on culturally significant vegetation Increased stress (e.g. desiccation, warping) in constructed landscape features	Loss of habitat for significant species Loss of significant species due to disease Decreased abundance of culturally relevant species Altered cultural value due to reduced snowpack	Facilities Increased stresses on heating and cooling systems in storage facilities Increased space constraints due to more items requiring storage Increased need for environmental controls in facilities and collections Collections (without climate controls) Increased rate of chemical decay Increased stress due to fluctuations in temperature and humidity	Crystallization of salts due to increased evaporation rates, leading to increased rates of structural cracking, deterioration Increased demand for air conditioning, which can add stress to the building envelope, requiring modified structure (e.g., insulation, ducts)
Increased wildfire frequency and extent	During fire Damage or destruction of associated structures Heat alteration of artifacts Heat fracturing of stone artifacts Paint oxidation, color change Physical damage from firefighting efforts (e.g., firelines) Decreased accuracy of carbon-14 dating due to carbon contamination After fire Damage from treefall due to fire-induced mortality Increased susceptibility to erosion and flooding Increased looting	Loss or damage of associated structures Change in vegetation density and composition Bedrock and border cracking Increased susceptibility to erosion and flooding Loss of soil fertility due to high heat Damage to structure or associated landscape from fire retardant	During fire Discoloration, exfoliation, cracking, and smudging of culturally significant rock images, geoglyphs Change in subsistence resources Loss of traditional knowledge due to alteration of culturally significant resources Loss of significant species due to decreased soil fertility After fire Altered migratory patterns of animals Altered landscape features used for navigating during foraging, hunting, or other movements	Facilities Damage to storage facilities and contents Increased strain on museum facility and staff due to increased preparation and salvage operations Smoke damage, strain on heating and cooling systems Collections Damage to items, disassociation of materials and records during evacuation	During fire Damage or loss of structures, combustible components Cracking, physical damage of masonry components Discoloration caused by smoke and heat Damage from treefall due to fire-induced mortality Damage to structure and landscape from fire retardant After fire Buildings may shift or settle due to associated erosion Pressure to convert character-defining features such as wood shake roofing to fire-resistant alternatives

Table 12.2—*Continued.*

Climate change stressor	Archaeological resources	Cultural landscapes	Ethnographic resources	Museum collections	Buildings and structures
Increased flooding	During flood Physical damage to site materials carried by flood Destruction or loss of artifacts Site erosion from overflow and new channels After flood Increased risk of subsidence Impacts from postflood activities (clean up, construction)	Damage to roads, trails, and landscape features Decline of important vegetation species Loss of landscape features	Loss of cultural places due to inundation Loss or disruption of the use of foraging grounds Loss of species for subsistence, medicine, ceremonies, etc.	Facilities Stress on museum facilities and staff due to salvage operations Damage to items, disassociation of materials and records during evacuation Structural collapse from force of floodwaters Sewage backup and overflow, causing contamination and damage Damage to walls from standing water Damage to utilities, generators, and electrical systems Collections Rusting and corrosion of metals Increased decay, fungi, and insects Swelling of absorbent objects (e.g., wood) due to wetting Direct damage and destruction	During flood Structural collapse from force of floodwater Sewage backup and overflow, causing contamination and damage Damage to walls from standing water Damage to utilities, generators, electrical systems After flood Increased decay, fungi, and insects Swelling of wooden building materials and architectural features Cracking, weathering of wood, brick, and stone due to salt infiltration during drying Pressure to relocate or elevate structures

Figure 12.4—(a) A pictograph damaged by heat and spalling of the rock following the Hammond Fire (2003) in Manti-La Sal National Forest, Utah (photo: C. Johnson, Ashley National Forest); (b) White patch on the rock shows the effect of salts within sandstone following the Long Mesa Fire (2002) in Mesa Verde National Park, Colorado. Efflorescence following contact with fire retardant can pulverize sandstone through crystallization and eventually destroy the stone (photo: D. Corbeil, National Park Service).

by archaeologists, newly exposed artifacts may decay or be removed illegally without adequate documentation.

Climate change also affects cultural landscapes that are valued for both the cultural resources they contain and the environmental context in which they occur (NPS 1994). The cultural and historic value of landscapes is embedded in ecological context; thus, shifts in dominant vegetation could potentially affect the integrity of these landscapes (Melnick 2009). For example, whitebark pine (*Pinus albicaulis*) is an important component of some high-elevation landscapes used as travel routes by both Native Americans and settlers. Whitebark pine is in decline because warmer winter temperatures have accelerated the rate of mountain pine beetle outbreaks (*Dendroctonus ponderosae*) in addition to the effects of white pine blister rust (*Cronartium ribicola*), a nonnative fungal pathogen (Tomback et al. 2001) (Chapter 8). The condition of these landscapes will continue to deteriorate in a warmer climate.

Cultural sites and landscapes recognized for their traditional importance to Native Americans in the IAP region provide foods, medicinal and sacred plants, paints, and other resources, as well as places with spiritual meaning. If a warmer climate alters the distribution and abundance of vegetation, the potential exists to degrade the continuous cultural connectivity and traditional use of these areas by indigenous peoples. Monitoring of specific species of cultural significance can be useful in determining climate change effects, and help inform management actions to maintain species on the landscape. Furthermore, land management can benefit from collaboration with tribes to understand needs and wants for use of the landscape.

Historic buildings and structures may be vulnerable to the indirect effects of climate change, including extreme weather events, wildfire, flooding, and debris flows. In addition, furniture, interpretive media, and artifact collections inside historic (and nonhistoric) buildings may be affected. Subtler influences include increased heat, freeze-thaw events, insect infestation, and microbial activity, all of which can accelerate deterioration of artifacts and structures made of stone or wood and organic materials (UNESCO 2007).

Climate change may reduce the appeal of some cultural sites and landscapes for visitors. For example, large outbreaks of mountain pine beetles, which have been exacerbated by higher temperature, have turned some historic landscapes to “ghost forests” of thousands of dead trees (e.g., Logan and Powell 2001). Dead and dying forests also present hazards to hikers and other forest visitors (Chapter 10). Altered ecological conditions in cultural landscapes in the IAP region may, over time, affect tourism, recreation, and Native American practices, with secondary impacts on local communities and economies (chapters 10, 13).

Risk Assessment Summary

Climate change effects on cultural resources will vary across the IAP region by the end of the 21st century, depending on the stressor and geographic location. Wildfire will create the highest risk for cultural resources, affecting all national forests and national parks, including locations that have burned since the 1990s.

The effects of prolonged drought caused by projected temperature increase may be partly offset if winter precipitation increases in the future (Chapter 3). Although it is difficult to quantify the long-term effects of extreme events (drought, flooding, debris flows) on cultural resources, these natural processes, accelerated by climate change, may create a significant risk for cultural resources and increase the challenge of protecting them. Resource loss will be greatest in those areas prone to major hydrological events (e.g., canyon mouths, river bottoms) where cultural sites are often concentrated. In addition, these areas may be targeted by unauthorized collectors attracted to newly exposed artifacts following a flood or debris flow.

Some climate-related effects on cultural resources will be subtle and occur gradually. For example, climate change may alter tourism and visitation patterns (Fisichelli et al. 2015) (Chapter 10). In addition, altered distribution and abundance of vegetation may affect the visual integrity of some cultural landscapes. Degradation of historic structures will be gradual and cumulative (e.g., decay), and sudden and direct (e.g., structural collapse). Some plant or animal species associated with traditional cultural landscapes that continue to be used by contemporary Native Americans, may be diminished or disappear. However, increased wildfire may increase the abundance of some valued species, such as huckleberries (*Vaccinium* spp.).

Agency efforts to reduce the negative effects of climate change on some natural resources may, in some cases, affect cultural resources. For example, in anticipation of significant flooding in the future, historic-era culverts and bridge abutments made of stone may be replaced with larger metal ones. Although appropriate project design can reduce adverse effects, large-scale landscape restoration may still reduce cultural resource integrity in some locations, creating challenging tradeoffs for resource managers. A robust cultural resource management strategy in response to climate change would include (1) connecting climate effects on resources to scientific information, (2) understanding the scope of effects, (3) integrating practices across management activities (from planning to implementation to monitoring), and (4) collaborating with partners to grow and use the body of knowledge and practices (Rockman et al. 2016).

The effects of climate change on cultural resource tourism are difficult to project because of associated social and economic factors. Visiting historic sites is popular throughout the IAP region, and tourism is an important economic contributor to local communities (Chapter 10). On one hand, extremely hot summer weather could reduce public interest in visiting cultural resources, cultural landscapes, and interpretive sites, particularly in areas recently affected by severe wildfires. On the other hand, warmer winter weather could encourage greater visitation in higher elevation areas and during spring and fall. In either case, the tourism economies of local communities could be affected. Additional research is needed to understand specific effects of climate change that are unique to particular resources and their locations.

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Chapter 13: Effects of Climate Change on Ecosystem Services

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Introduction

Ecosystem services are benefits to humans from the natural environment. These benefits that humans derive from ecosystems are the tangible connection between society and the natural environment. Some of these benefits are timber harvesting, rangeland grazing, municipal water use, carbon sequestration, and pollinators—all discussed in this chapter. The typology developed by the 2005 Millennium Ecosystem Assessment (box 13.1) defines four broad categories of ecosystem services that help to organize our understanding of the relationship between natural resources and human benefits. Although this approach obscures complex relationships between natural and human systems, two important caveats are relevant to discussions of ecosystem services and anticipated climate change effects. First, these categories are not exclusive, and many natural resources fall under multiple categories depending on the context. For example, the consumption of water can be considered a provisioning service, the process of purifying water a regulating service, the use of water for recreation a cultural service, and the role of water in the life cycle of organisms a supporting service. Second, these categories are interdependent, such that individual services would not exist without the functioning of a broad set of ecosystem services.

This assessment provides an understanding of the ability of public lands to sustainably supply ecosystem services, focusing largely on the environmental condition of the land. This chapter is intended to highlight potential climate change effects on ecosystem service flows, for which management decisions can help users mitigate or adapt to these effects, and illustrate tradeoffs in the decision-making process. This approach is consistent with requirements under the Forest Planning Rule of 2012, in which the U.S. Department of Agriculture Forest Service (USFS) is required to formally address ecosystem services in land management plans for National Forests (USDA FS 2012a). The National Park Service does not have specific mandates concerning ecosystem services, but the agency has incorporated ecosystem service considerations into management planning and made ecosystem services a key part of its 2014 Call to Action (NPS 2014). The Bureau of Land Management (BLM) has also identified nonmarket environment values, synonymous with ecosystem services, as an increasingly important consideration for land management (Roberson 2013).

Managing for ecosystem services on public lands involves balancing uses across a wide range of stakeholders, potential impacts, and legal obligations. In rural areas of the Intermountain West, people rely on public lands for fuel, food, water, recreation, and cultural connection. Near urban areas such as Boise, Idaho, and along the Wasatch Front of Utah, recreation opportunities on Federal lands have been an important driver of economic growth, but mandates to manage for multiple use of natural resources can create situations in which some ecosystem services conflict with others. For example, managing lands for nonmotorized recreation may conflict with managing for motorized recreation, timber, and mining, yet it may complement management for biodiversity and some wildlife species.

Stakeholders and workshop participants in the Intermountain Adaptation Partnership (IAP) assessment helped identify and prioritize ecosystem services likely to be affected by both climate change and management decisions.

Box 13.1—Definitions of Ecosystem Services Categories

Provisioning services: products obtained from ecosystems, including timber, fresh water, wild foods, and wild game.

Regulating services: benefits from the regulation of ecosystem processes, including the purification of water and air, carbon sequestration, and climate regulation.

Cultural services: nonmaterial benefits from ecosystems, including spiritual and religious values, recreation, aesthetic values, and traditional knowledge systems.

Supporting services: long-term processes that underlie the production of all other ecosystem services, including soil formation, photosynthesis, water cycling, and nutrient cycling.

We focus on: (1) timber and other wood products, (2) livestock grazing, (3) municipal water, (4) carbon sequestration, and (5) pollinator health.

Timber, Building Materials, Other Wood Products, and Biomass

Broad-Scale Climate Change Effects

Wildfire, drought, and insect outbreaks can cause significant levels of tree mortality (Chapter 8), decreasing potential timber outputs and having a deleterious effect on forest health in general. Although temperature and precipitation may have some effect on regional vegetation, the direct effects on timber are likely to be small. More important to timber are the societal and policy changes that affect timber quotas and levels of actual harvest and silvicultural treatments, such as thinning and fuels reduction. For example, conservation of rare species, protection of riparian areas, and maintenance of viewsheds near populated areas generally limit the amount of timber that can be cut in certain landscapes. This, in turn, affects the economic viability of wood processing operations and the local job market. There will be additional indirect effects on timber if climate change significantly affects wildfire occurrence and insect outbreaks.

Current Conditions—Forest Industry

Timber Harvests on National Forests

Timber production in the IAP region is affected by both regional and national trends in the forest industry, the economy, and policy. Housing starts, a key indicator of demand for sawtimber, are only now beginning to recover from the recent U.S. recession but are still much lower than before 2007 (USDA FS 2016b). Although demand for pulpwood and residues for energy (especially wood pellets) has increased significantly, most of the material comes from the southern United States, not the West.

Timber volume cut on National Forests in the USFS Intermountain Region peaked in 1988 (480 million board feet) and declined by 87 percent through 2005 (63 million board feet) (fig. 13.1). Cut volumes stabilized somewhat after 2005, varying from 80,000 to 113,000 MBF between 2006 and 2014. Cut volumes equaled or exceeded volume sold from the mid–1980s to the early 2000s, but cut volume was generally less than volume sold after 2004 (USDA FS 2015c, 2016b). Cut volumes from National Forests include volume from small sales (less than $300) (accounting for the vast majority of sales), as well products other than log

Figure 13.1—Timber volume harvested in national forests in the U.S. Forest Service Intermountain Region (1980–2014) (USDA FS 2016a). Small sales (<$300) contribute substantial percentages of cut volume and value, and are included here. Nonconvertible forest products (e.g., Christmas trees, boughs) are not included.

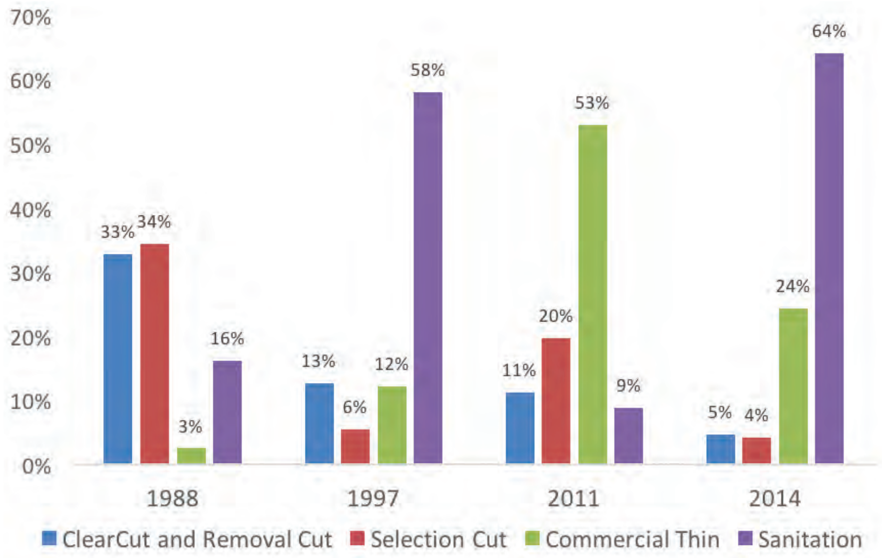

Figure 13.2—Changes in harvest type in national forests in the U.S. Forest Service Intermountain Region (percentage of all commercial harvest acres) (USDA FS 2015). Includes harvests where commercial sales occurred, as compiled by Forest Service TRACS (through 2004) and FACTS (after 2004) systems.

(POL) material. These sources amount to a substantial percentage of cut volume; volume from small sales and non-saw and POL material may not be utilized or processed by larger mills.

Average price of cut timber on National Forest System (NFS) lands (inflation-adjusted) increased after 1988, peaking at $248/thousand board feet (1997). However, prices fell dramatically after 1997 to a low of $17/thousand board feet (2011) and remained low through 2014 (USDA FS 2016b). Prices reflect trends in conditions, availability of timber substitutes, and types of harvesting (and the increasing proportion of non-saw material sold at a very low price). Traditional commercial harvesting (e.g., clear cuts, and removal and selection cuts) accounted for a majority of harvest in 1988 (fig. 13.2) when prices and volumes of cut timber remained high on NFS lands. Commercial thinning and sanitation cuts dominate in later years (1997–2014), altering the mix of merchantable timber harvested. These changes were caused by declining prices of cut timber, declining numbers of mills, and broader-scale market trends, especially after the 2007 recession.

Timber harvest and residue production are projected to increase steadily in the United States through 2060 because of global demand for wood products and bioenergy (Headwaters Economics 2016b). It is unclear whether this projected trend will also occur in the IAP region, and these projections can be affected by national and global economic factors. Improved capability to utilize small-diameter trees, alternative species, and biomass can help restore harvest values, influence markets, and expand capacity of forest management to adapt to changing conditions.

Forest Industry Employment

The sensitivity of local economies to climate-induced shifts in timber supplies is a function of the condition and trend of the forestry and wood products manufacturing sectors within the IAP region. Here we discuss employment in the forestry and logging sector, capacity in the primary wood products manufacturing sector, and timber harvest on NFS lands.

In addition to the sensitivity of timber-related industries to climate change, the capacity for forest management and health to adapt to climate change is also a function of the availability and capacity of harvest and forestry contractors. Forest management in many areas of the Intermountain West is now dominated by forestry service-type work and contracts, targeting thinning and similar projects for improving forest health, reducing fuels, and managing areas affected by fire or insects (e.g., Vaughan and Mackes 2015).

The IAP region includes counties within areas of economic influence for relevant National Forests, as adopted by the “National Forest Economic Contributions” program (USDA FS 2017). Areas of economic influence are based on the flows of goods and services (including labor) that support regional economies and may therefore include counties outside the physical boundaries of National Forests.

Timber employment accounts for a relatively small portion of all private employment (table 13.1). Similar to the U.S. timber industry as a whole, the timber industry in the IAP region has declined considerably, with variation among different subsectors. Growing, managing, and harvesting accounts for 2 to 19 percent of timber employment in the IAP subregions and is highest (by percentage) in the Southern Greater Yellowstone and Middle Rockies subregions. Primary wood products manufacturers (sawmills and paper mills) are firms that process timber into manufactured goods such as lumber or veneer and facilities such as biomass power or particleboard plants that use wood fiber residue directly from harvest sites or timber processors. Employment in primary wood products manufacturing accounts for 25 percent of all forest industry employment in the IAP region, comparable to the national level of 30 percent. Plywood and engineered wood operations rely heavily on mill residues (clean chips) rather than byproducts from forest restoration and fuels treatments. Pulp and chip conversion, biomass and energy use, and pellet-producing operations are more likely

Table 13.1—Summary of timber employment in the IAP region and subregions for 2014. Employment is reported in County Business Patterns, excluding government, agriculture, railroads, and self-employed. From "Profiles of Timber and Wood Products" (Economic Profile System) and U.S. Dept. of Commerce (2014).

	IAP subregions						
Economic sector	**Middle Rockies**	**S. Greater Yellowstone**	**Uintas and Wasatch Front**	**Plateaus**	**Great Basin and Desert**	**IAP region**	**United States**
	Employment (no. full- and part-time jobs)						
Timber (forest industry)	5,155	172	4,289	982	2,897	12,287	840,700
Growing & harvesting (+managing)	726	33	86	46	173	1,035	109,294
Sawmills & paper mills	1,621	57	618	224	814	3,040	254,837
Wood products manufacturing	2,808	82	3,585	712	1,910	8,212	476,569
	Timber employment (percent of total private employment)						
	1.51	0.33	0	0.42	0.25	0.47	0.69
	Percent of timber employment						
Growing & harvesting (+managing)	14	19	2	5	6	8	13
Sawmills & paper mills	31	33	14	23	28	25	30
Wood products manufacturing	54	48	84	73	66	67	57
	Percent change in employment (1998-2014)						
Timber (forest industry)	-43	-39	-14	-5	2	-28	-38
Growing & harvesting (+managing)	-59	-84	-33	-90	-30	-57	-34
Sawmills & paper mills	-51	-20	-26	-24	-20	-43	-41
Wood products manufacturing	-34	-4	-12	8	20	-16	-37

consumers of biomass and roundwood as byproducts from forest restoration and treatments. Pulp and paper mills account for the remaining 1 percent of primary manufacturing employment.

Secondary wood products are converted paper and other wood products typically manufactured after leaving a mill (wood products manufacturing), and they account for more than double the employment of the other two sectors combined. The vulnerability of secondary wood products manufacturing facilities to regional timber supply trends is unknown.

Capacity and Utilization: Primary Wood Products Manufacturing, Residues, and Biomass

The total number of active mills in the IAP region declined 17 percent across the survey periods shown in table 13.2 (BBER 2016). In contrast, the total number of active mills that can handle residue or biomass (e.g., byproducts from wood products manufacturing and forest restoration treatments) increased by 20 percent over the same period. Relatively few mills or processing facilities currently handle biomass or residue (18 for the period 2011–2014) in the IAP region. The number of post and pole mills, which can handle smaller diameter timber, decreased from 15 to 13 over the survey periods.

Table 13.2—Change in number of active timber mills and processing facilities in the IAP region (from BBER 2016). Time periods (2006-2010, 2011-2014) refer to years over which survey data were collected across different States. Residue or biomass uses include wood shavings, pulp and chip conversion, particleboard, fuel pellets, biomass, and bark products.

	2006-2010	2011-2014
Total - residue or biomass users	15	18
Total - all mills	130	108
Shavings - wood	0	1
Sawmills	45	40
Pulp/chip conversion	2	2
Post & small pole	15	13
Plywood	1	1
Pellet mill	1	2
Particleboard/medium-density fiberboard	2	1
Log home	39	30
Log furniture	15	6
Fuel pellets	0	1
Biomass	7	7
Bark products	3	4

Mills are most heavily concentrated in the Middle Rockies, followed by the Uintas and Wasatch Front and Southern Greater Yellowstone subregions (table 13.3). These results are mostly consistent with timber employment data, with the exception of the Southern Greater Yellowstone subregion, where employment in mills and processing facilities is lowest, suggesting that mills may be relatively smaller there.

Although few mills or timber processing facilities handle biomass or residue, evidence from three geographic areas suggests that the number of these facilities may be increasing in three subregions. Most facilities handling biomass or residue are located in the Middle Rockies, where mill numbers have remained static. No facilities handling biomass or residue exist in the Plateaus subregion.

Log capacity decreased 22 percent for the IAP region over the period 2006–2014, mainly because of reduced capacity in the Middle Rockies subregion. Log capacity utilization has been steady (66 percent) for the IAP region (table 13.4). Utilization is lowest for the Plateaus subregion (14 percent), and highest for the Middle Rockies and Great Basin and Semi Desert subregions (70–75 percent) for the most current data (2011–2014). Residue and biomass use capacity in the IAP region has declined 5 percent, from 920,000 (2006–2010) to 870,000 (2011–2014) bone-dry tons per year (BBER 2016). Residue capacity utilization fell from 79 percent to 47 percent over the same period. Although a high capacity utilization may reflect a healthy industry (and a low number may reflect the opposite), it is noteworthy that an industry operating under full capacity typically has a greater ability to respond to changes in market supply and demand. For example, an area with excess capacity may be better able to respond to an influx of material from salvage logging following wildfire.

Sensitivity to Climate Change

Changes in productivity caused by increased temperatures could be significant, with productivity potentially decreasing in lower-elevation, moisture-limited areas (Chapter 6). However, policy has been the driving force behind timber production in the past, and that is likely to continue in the future. The current low level of harvest is not expected to change significantly in the future and will have a minimal effect on vegetation patterns across large landscapes. Strategic areas could be targeted for specific objectives (e.g., fuels, wildlife), but under a changing climate, disturbances such as fire, insects, and diseases will be the major change agent in forests in the IAP region (Chapter 8).

Expected Effects of Climate Change

Primary timber species in the IAP region, such as ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*), are drought tolerant and are expected to undergo only a slight decrease in abundance in the near term. However, potential increases in productivity, particularly in higher-elevation areas, could offset those losses to some

Table 13.3—Change in number of active timber mills and processing facilities in IAP subregions (from BBER 2016). Time periods (2006-2010 and 2011-2014) refer to years over which survey data were collected across different States. Residue or biomass uses include wood shavings, pulp/chip conversion, particleboard, fuel pellets, biomass, and bark products.

	Middle Rockies		S. Greater Yellowstone		Uintas and Wasatch Front		Plateaus		Great Basin and Desert	
	2006-2010	2011-2014	2006-2010	2011-2014	2006-2010	2011-2014	2006-2010	2011-2014	2006-2010	2011-2014
Residue or biomass	10	10	1	2	1	2	nd[a]	nd	3	4
All mills	71	56	12	15	29	24	9	5	9	8

[a] No data.

extent, but overall growth will likely decrease in the long term (Chapter 6). In addition higher-elevation areas may be less accessible for harvesting via existing infrastructure.

The indirect effects of climate change and associated stressors are expected to alter some forests at large spatial scales. For example, increased temperatures and shorter, warmer winters have resulted in large outbreaks of mountain pine beetles (*Dendroctonus ponderosae*) in much of the Intermountain West (Chapter 8). "Insect friendly" conditions, combined with stressed trees, amplified vulnerability to insect infestation. Increased disturbances such as wildfire and possibly some fungal pathogens associated with a warmer climate may reduce merchantable timber and non-timber forest products. Although the primary timber species in this area are fire tolerant, the current elevated fuel loadings from fire exclusion may lead to an increase occurrence of crown fires that will potentially kill mature trees. Such mortality events would produce a short-term positive shock in the timber supply, as fire kill becomes salvaged wood, although salvage logging may be hindered by a number of logistical and permitting hindrances. For example, location of salvageable wood may not be accessible. In addition salvageable wood can be harvested only within a limited time after the disturbance, and logging and mill capacity are unlikely to be able to fully respond to a sudden influx in supply, especially in the case of a large disturbance. Furthermore, the environmental impact assessment process must be factored into timelines for salvage logging.

Forest ecosystems can adapt to changes in climatic conditions by a gradual shift to different mixtures and distribution of species and genotypes, although there may be tradeoffs in productivity in some cases. With respect to social and policy influences, increased utilization of woody biomass can make fuels reduction and other silvicultural treatments more economically feasible, thus promoting healthier and more productive forests.

In some cases, increased wildfire and other disturbances may create a temporary increase in timber supply through salvage logging, but will reduce potential timber output in the long run. Disturbances and the manner in which postdisturbance tree mortality is managed will have implications for carbon dynamics. Thus, although the direct effects of climate change (temperature, precipitation) on timber are likely to be minor, the secondary effects through various disturbances may be significant for the timber industry.

Grazing Forage For Livestock and Wildlife

Broad-Scale Climate Change Effects

Warming temperatures, increased frequency of wildfires, and altered precipitation regimes will affect the health of the vegetation systems on which grazing depends (Chapters 7, 8). Productivity may increase in some grasslands, and decrease in others, and species distribution and abundance are likely to shift. Increased frequency of droughts will be especially influential, reducing the period of time during which cattle can use rangelands for forage.

Current Conditions and Existing Stressors

Livestock grazing is tied to cultural heritage in the West, existing alongside Spanish missions during the first periods of settlement, and playing an important role in the westward expansion of America. Today, livestock grazing is the most widespread use of land in western North America. Over two-thirds of all grazed land in the United States occurs in the Mountain and Southern Plains regions, and over two-thirds of all land in these two regions is grazed (Nickerson et al. 2011). According to the 2012 Census of Agriculture (USDA 2012b), grazing occurs on 76 percent of farmland in Idaho, Wyoming, Utah, and Arizona. Grazing is also the most widespread use of USFS and BLM lands, creating a footprint larger than roads, timber harvest, and wildfires combined (Beschta et al. 2013).

In the early 1900s, forest reserves were created in the IAP region to manage livestock grazing, decrease conflict in grazing areas, and promote scientific management of grazing. One of the first of these was the Manti Forest Reserve (now part of the Manti-La Sal National Forest), established in 1903. That history is still reflected in the Intermountain Region, and some National Forests contain large active livestock allotments.

Table 13.4—Change in log capacity and log capacity utilization (active and inactive mills) for the IAP region and subregions (from BBER 2016). Time periods (2006-2010, 2011-2014) refer to years over which survey data were collected across different states.

	Middle Rockies		**S. Greater Yellowstone**		**Uintas and Wasatch Front**		**Plateaus**		**Great Basin and Desert**		**IAP region**	
	2006-2010	2011-2014	2006-2010	2011-2014	2006-2010	2011-2014	2006-2010	2011-2014	2006-2010	2011-2014	2006-2010	2011-2014
						Thousand board-feet per year						
Log capacity	675,829	486,131	16,808	13,025	75,427	49,011	57,509	41,351	128,783	51,761	954,356	741,279
						Percent						
Log capacity utilization	69	75	94	38	37	38	24	14	83	70	66	67

Table 13.5—Livestock use on National Forests (NFS) and Grasslands in the USFS Intermountain Region (from USDA FS 2015b).

	Permittees	**Cattle**		**Horses and burros**		**Sheep and goats**		**Total**	
	Number	*Number*	*AUM*[a]	*Number*	*AUM*	*Number*	*AUM*	*Number*	*AUM*
NFS permitted commercial livestock	1,693	309,759	1,441,944	1,517	5,823	549,874	463,542	861,150	1,911,309
NFS authorized commercial livestock	1,670	294,476	1,236,510	1,221	4,583	512,649	329,521	808,346	1,570,614
NFS authorized livestock use	20	500	110	70	296	0	0	570	406
Total NFS authorized	1,690	294,976	1,236,620	1,291	4,879	512,649	329,521	808,916	1,571,020
Private lands	50	1,311	6,277	0	0	2,183	1,716	3,494	7,993

[a] Animal unit months.

Table 13.5 shows livestock use for the Intermountain Region in 2015. Permitted numbers are the head-months or animal unit months (AUMS) for which the lease is applicable. Authorized numbers are the numbers in a given year that the USFS or BLM will let the permittee actually run in an allotment. Authorized numbers may decrease during a drought. The number of goats and sheep exceeds that of cattle, horses, and burros, but cattle account for 78 percent of total AUMs.

Cattle, yearlings, and bison make up the majority of authorizations of AUMs in Idaho and Wyoming (table 13.6). Grazing statistics for BLM lands are from the Public Land Statistics for 2014 and are given by State, so they do not match up with the IAP region for these two States. Some permittees run more than one type of livestock and may be included in more than one column for type of grazing.

Despite the prevalence of grazed lands, some studies find the economic contribution of both livestock and public lands for grazing to these regions is modest (Mathews et al. 2002). Profitability has declined for most livestock producers, and total production across all land types is in decline. In Utah, beef production peaked in 1983 with 374,000 cattle, and lamb production peaked in 1930 with 107,000 lambs (McGinty et al. 2009). Mathews et al. (2002) found that only 6 percent of all livestock producers in the 17 States west of the Mississippi River maintain USFS or BLM grazing allotments, and 62 percent of counties in the western United States depend on Federally administered grazing allotments for 10 percent or less of their total livestock forage. Fewer than 10 percent of counties depend on Federal lands for more than 50 percent of the forage (Mathews et al. 2002).

Management of public lands for water, pollinators, threatened and endangered species, sensitive plant species, and cultural and historic objects is increasingly valued and often in conflict with current livestock grazing. These trends

Table 13.6—Authorizations and animal unit months (AUMs) on Bureau of Land Management lands (from BLM 2014).

	Cattle, yearlings, bison	**Horses and burros**	**Sheep and goats**	**Authorization count**
Authorizations		-------------*Number*-------------		
Idaho	1,549	93	99	1,632
Nevada	509	30	59	551
Utah	1,174	40	157	1,278
Wyoming	2,420	249	267	2,568
AUMs authorized		-------------*AUMs*-------------		
Idaho	806,580	3,945	69,778	880,303
Nevada	970,467	2,167	87,056	1,059,690
Utah	635,705	1,441	149,353	786,499
Wyoming	1,075,021	11,219	174,708	1,260,948

Box 13.2—Livestock Grazing Effects

- Summarized from "Initial Review of Livestock Grazing Effects on Select Ecosystems of the Dixie, Fishlake, and Manti-La Sal National Forests" (http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprd3810252.docx):
- Historic grazing rates have led to severe erosion in some allotments, and some allotments may have crossed thresholds that make returning to historic forage levels difficult.
- Monitoring records indicate that grazing standards are often being met. However, the majority of monitoring takes place in uplands, with little monitoring in sensitive riparian and wetland areas. Current standards and guidelines may also not be adequate to address particular resource concerns.
- In many riparian areas where monitoring has taken place, current and historic livestock use has impaired riparian areas and made them less resilient to catastrophic events. Approximately 36 percent of riparian vegetation sites measured in 2012 were not meeting objectives outlined for them.
- Springs and wetlands can receive heavy livestock use that results in trampling and hummocking. The effect of grazing on riparian vegetation has affected streambank integrity and damaged stream channels, which causes resource concerns such as erosion, sedimentation, and stream channel damage. However, where efforts have been made to protect riparian vegetation by exclosure or other methods, riparian vegetation improves quickly.
- Through 2013, long-term vegetation data suggests 60 percent of monitoring sites are meeting site-specific desired conditions, and 63 percent are meeting minimum ground cover values. However, current standards and guidelines may not be adequate in maintaining effective habitat for greater sage-grouse (*Centrocercus urophasianus*).
- Sagebrush communities generally have low diversity and cover of perennial plant species, especially perennial forbs. Managing livestock grazing to maintain residual cover of herbaceous vegetation may be an effective short-term action benefitting sage-grouse populations.
- Persistent browsing by livestock and wild ungulates contributes to long-term aspen decline.

reflect both the growth of the New West and the economic struggles of the Old West. The last few decades have seen a shift in public opinion about management priorities, and the sustainability of current grazing practices is increasingly being called into question. Public disagreement about management practices and existing and desired conditions in National Forests in southern Utah led the Dixie, Fishlake, and Manti-La Sal National Forests to assess the need for revisions to their forest plans, which date back to 1986 (box 13.2).

Federal lands are also grazed by wild native ungulates such as elk (*Cervus elaphus*) and deer. Populations of elk and deer have risen as a result of predator control and protection of game species. When concentrated, however, wild ungulates can overbrowse some vegetation, alter streambanks and riparian vegetation, and generally cause deterioration of land conditions (Beschta et al. 2013).

Foraging capacity is also adversely affected by the spread of invasive species (USFWS 2009). Overgrazing degrades native bunchgrasses and increases the likelihood of introduction and spread of nonnative annual species such as cheatgrass (*Bromus tectorum*). Proliferation of nonnative species also has adverse impacts on nutritional quality (McGinty et al. 2009).

Sensitivity to Climatic Variability and Change

Grazing occurs in some of the most sensitive vegetation regions (e.g., alpine, subalpine forblands, dry sagebrush shrublands, low-elevation riparian and wetland ecosystems), amplifying the effects of drought and other stressors. Temperature, seasonal aridity, and prolonged drought are expected to increase in a warmer climate, accelerating soil deflation and erosion. These impacts are intensified in areas where vegetation has been removed and divots have been created by cattle (Chapter 7). The effects will be heterogeneous across ecosystem types, and depending on their baseline adaptive capacity, some rangelands may have reduced resilience to climate change because of historical grazing.

Expected Effects of Climate Change

A recurring theme during workshops in the IAP region was the need for more flexibility associated with grazing permits. If weather becomes more variable, with more very wet years and more very dry years, expectations about on and off dates for grazing may need to be altered. This variability and user expectations are likely to be even harder to manage in areas that span elevations, where variability in timing of snowmelt also affects dates of the "muddy season." In addition, the direct effects of higher temperatures on cattle (Nardone et al. 2010) and lower forage productivity or quality may compound stresses in some locations.

Other important effects on forage areas include disturbances and social pressures on land use. Increased fire frequency and spread of invasive species have already altered areas formerly suitable for grazing. These impacts are expected to worsen with climate change, leading to both decreased lands available for forage and decreased productivity of some lands that remain open. Even without these changes, there is mounting social pressure for land management priorities to emphasize conservation and recreation over livestock. Decreased value of land for ranching, as well as increased population in the IAP region, has led to fragmentation of grazed lands through conversion of private rangeland to "ranchettes" and suburban developments (Holechek 2001; Resnik et al. 2006).

Municipal Drinking Water Quantity and Quality

Broad-Scale Climate Change Effects

Water temperature, yield, timing, and quality are important for municipal drinking water suppliers and are expected to be altered across the IAP region by a warmer climate. Stream temperatures are projected to increase 12 percent on average in the region by the end of the century (table 13.7) (Chapter 5), the result of increased temperatures and loss of vegetation along streambanks. Stream temperature affects water solubility and biogeochemical cycles, which determine the organisms that can survive in water. Increased number and severity of wildfires will also deposit more sediment and debris into streams, lakes, and reservoirs (Chapter 8), causing further concerns for water quality.

Current Condition and Existing Stressors

Many subwatersheds in the IAP region are already impaired or at risk (table 13.8). Both water quantity and quality are currently classified as impaired or at risk for most of Nevada, and generally as impaired in heavily populated parts of Utah. Urban and exurban development also exacerbates sediment and runoff of pollutants from roads and trails.

Sensitivity to Climatic Variability and Change

Sensitivity to climate change depends on current watershed conditions and future threats to those conditions. The most sensitive watersheds are those already impaired or at risk, based on vegetation and soil conditions. Watersheds that have high fuel loadings are also more sensitive to climate change, as are heavily developed areas. Developed land alters the shape of the landscape, influencing water flow, timing, and quality.

Expected Effects of Climate Change

Earlier stream runoff is expected over much of the region, and summer flows are expected to be significantly lower for most users (Chapter 4). By the end of the 21st century, the median flow date is expected to be over 19 days earlier, and summer flows are predicted to decline over 25 percent, on average (table 13.7). In extreme cases, the median flow date is over a month and a half earlier, and summer flows are projected to decline over 90 percent. Total water yield is expected to increase slightly in the northern portion of the IAP region, but decline over 10 percent in the warmer southern and western parts of the region (fig. 13.3).

Groundwater levels and recharge rates are also affected by climate change. During the summer, high water demand coupled with low water supply already forces many municipal water suppliers to utilize groundwater intakes in order

Table 13.7—Summary statistics of exposure projections for climate change, representing conditions for municipal water system intakes (521 total), characterized as the change relative to a 30-year historical average. Conditions near each water intake are weighted according to the total number of intakes within a system, then aggregated up to the water system scale. Exposure is increasing in temperature, and decreasing in flow and timing.

Variable	Average	Standard deviation	Median	Minimum	Maximum
2040 (2030-2059)					
Mean annual flow (% change)	2.04	5.34	3.62	-15.25	17.26
Mean summer flow (% change)	-20.85	22.08	-14.50	-90.37	21.11
Median flow date (no. days)	-11.34	6.27	-11.59	-28.14	2.21
Water temperature (% change)	6.71	1.70	6.95	2.56	14.00
2080 (2070-2099)					
Mean annual flow (% change)	-0.58	10.51	3.10	-31.24	17.44
Mean summer flow (% change)	-25.69	27.86	-18.27	-92.37	33.11
Median flow date (no. days)	-19.14	10.86	-19.52	-47.09	4.10
Water temperature (% change)	11.73	3.03	12.20	4.53	24.82

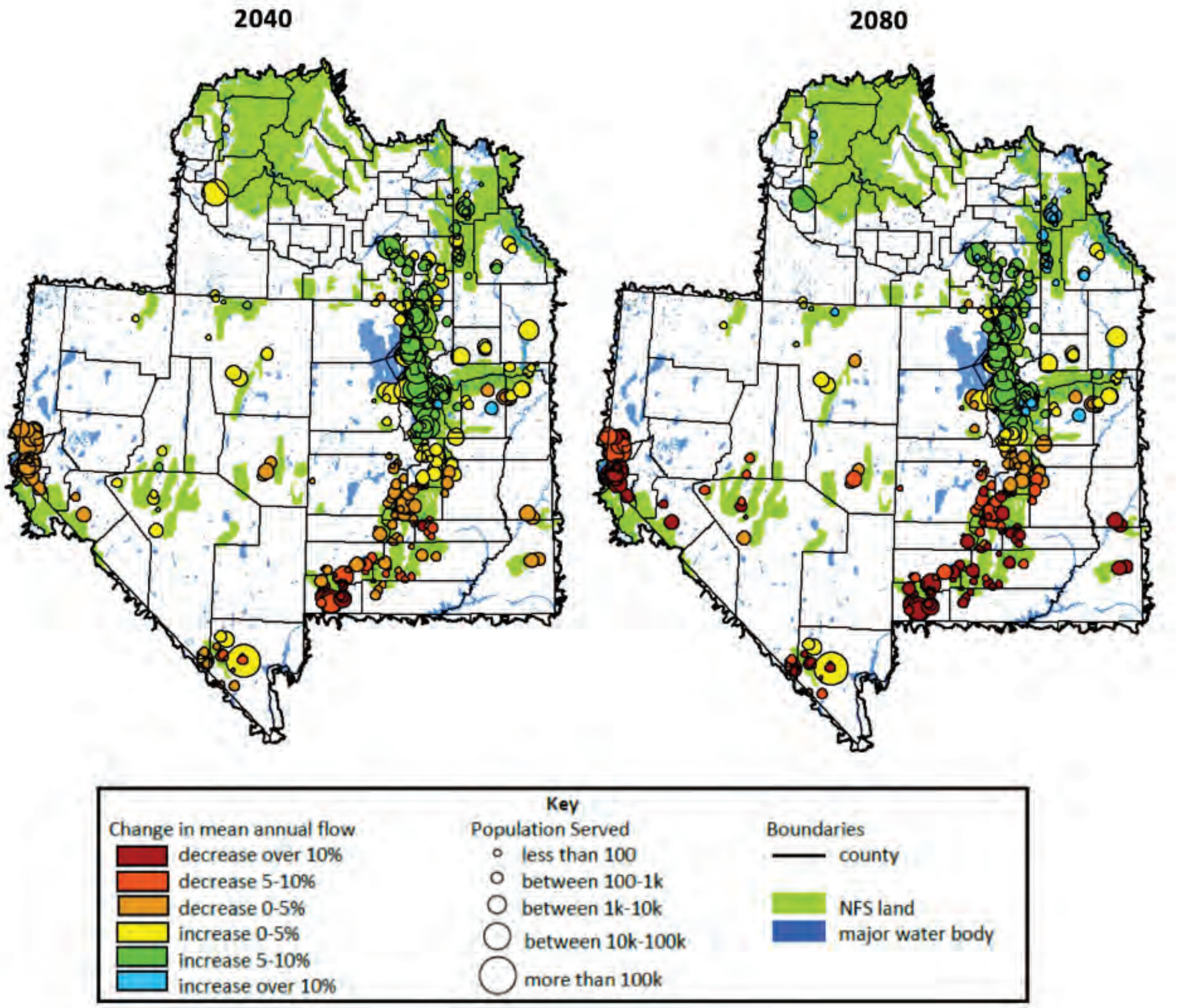

Figure 13.3—Projected changes in mean annual flow for municipal water systems. The center of each circle is the central location of each drinking water system relative to intake locations.

to meet water demand. Higher temperature and population growth will further increase the demand for water and stress water resources in the region, especially in Utah.

Riparian systems are a nexus for the interaction of vegetation and water, and climate change effects on these systems will reduce water quantity and quality in some portions of the landscape. In addition, lower and warmer surface water can affect the abundance and diversity of biota in riparian zones. Any associated reductions in water quality will lead to increased treatment costs for municipal users, as well as potential losses in biological function.

Increased fire frequency and severity would increase sediment delivery, leading to further degradation of water quality. Extreme weather and increased rain-to-snow ratios can also increase runoff from agricultural fields and add pesticides and fertilizers to streams. Changes in timing and summer flow are expected to cause shortages of surface water in some locations, especially during the summer, when demand is high. Many municipal systems are likely to incur increased treatment costs and to depend more heavily on groundwater intakes in order to meet demand. In addition, the effects of warmer water on algal blooms in lakes reduce dissolved oxygen, decrease clarity, and harm some aquatic species, humans, and pets (Moore et al. 2008).

Vulnerability Assessment for Municipal Water Users

We used municipal drinking water intake locations and nearby spatial characteristics to measure drinking water vulnerability for users who depend on National Forests in the Intermountain Region (table 13.9). A water system is defined as any unique supplier of municipal drinking water. Many small systems have only a single water intake, whereas larger systems sometimes have over 20 intakes. Municipal drinking water use is defined as serving the same population year-round (i.e., community water systems). Vulnerability measures are based on stream channel and subwatershed characteristics. We then map the final measures at the water system and National Forest levels. Each water system is analyzed based on the location of intakes and population served. Vulnerability is based on indicators of exposure, sensitivity, and adaptive capacity.

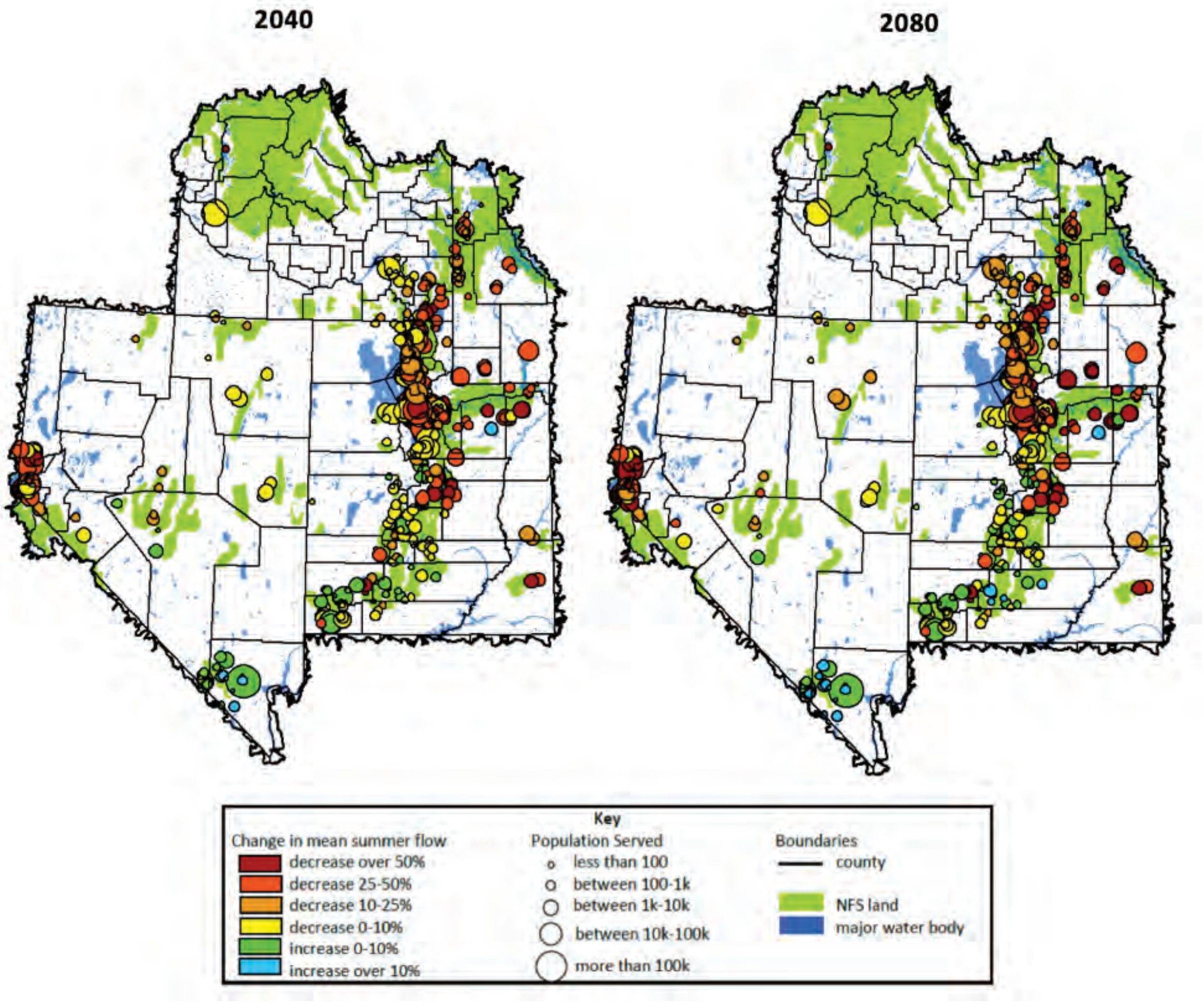

Figure 13.4—Projected changes in mean summer flow for municipal water systems. The center of each circle is the central location of each drinking water system relative to intake locations.

Exposure is measured according to projected changes in annual streamflow (fig. 13.3), summer streamflow (fig. 13.4), runoff timing (fig. 13.5), and stream temperature (fig. 13.6) from downscaled climate scenarios for the 2040s (2030–2059) and 2080s (2070–2099) (see chapters 3–5 for details). The most exposed users are those who experience declines in both mean annual and summer flows. Changes in summer flows are highly related to changes in runoff timing, with earlier runoff leading to lower summer flows. In many cases, however, this also appears to correspond with higher mean annual flows. Figure 13.7 shows total exposure values.

Water system sensitivity and adaptive capacity (SAC) are measured at the Hydrologic Unit Code 6 (10,000–40,000 acres) scale by using factor analysis to compare the variability of each water system to the average system within the Intermountain Region (fig. 13.8). The conditions are applied to any intakes in the subwatershed and then weighted according to the total number of intakes within each respective system. The final components for each system are standardized to a mean of zero and standard deviation of one, so they can be compared to other water systems in units of standard deviation from the mean.

Variables used to describe SAC together were narrowed to seven key factors, explaining over 97 percent of the variation among municipal water systems. Combining the final measures of exposure, sensitivity, and adaptive capacity provides the measure of vulnerability for each water system (fig. 13.9). System vulnerability measures are then averaged across nearby National Forests to map municipal drinking water vulnerability at the National Forest scale (table 13.10, fig. 13.10). Projections of water flows, timing, and temperature are described in chapters 4 and 5.

Summary

A large portion of the water used by human populations in the IAP region originates on National Forests and other public lands. Sensitivity of water supply to climate change depends on several factors, including current watershed conditions and future threats to those conditions. The most sensitive watersheds are those already impaired or at risk, based on vegetation and soil conditions. Increased temperature and reduced snowpack are expected to cause significant reductions in water supply by the 2040s and even higher

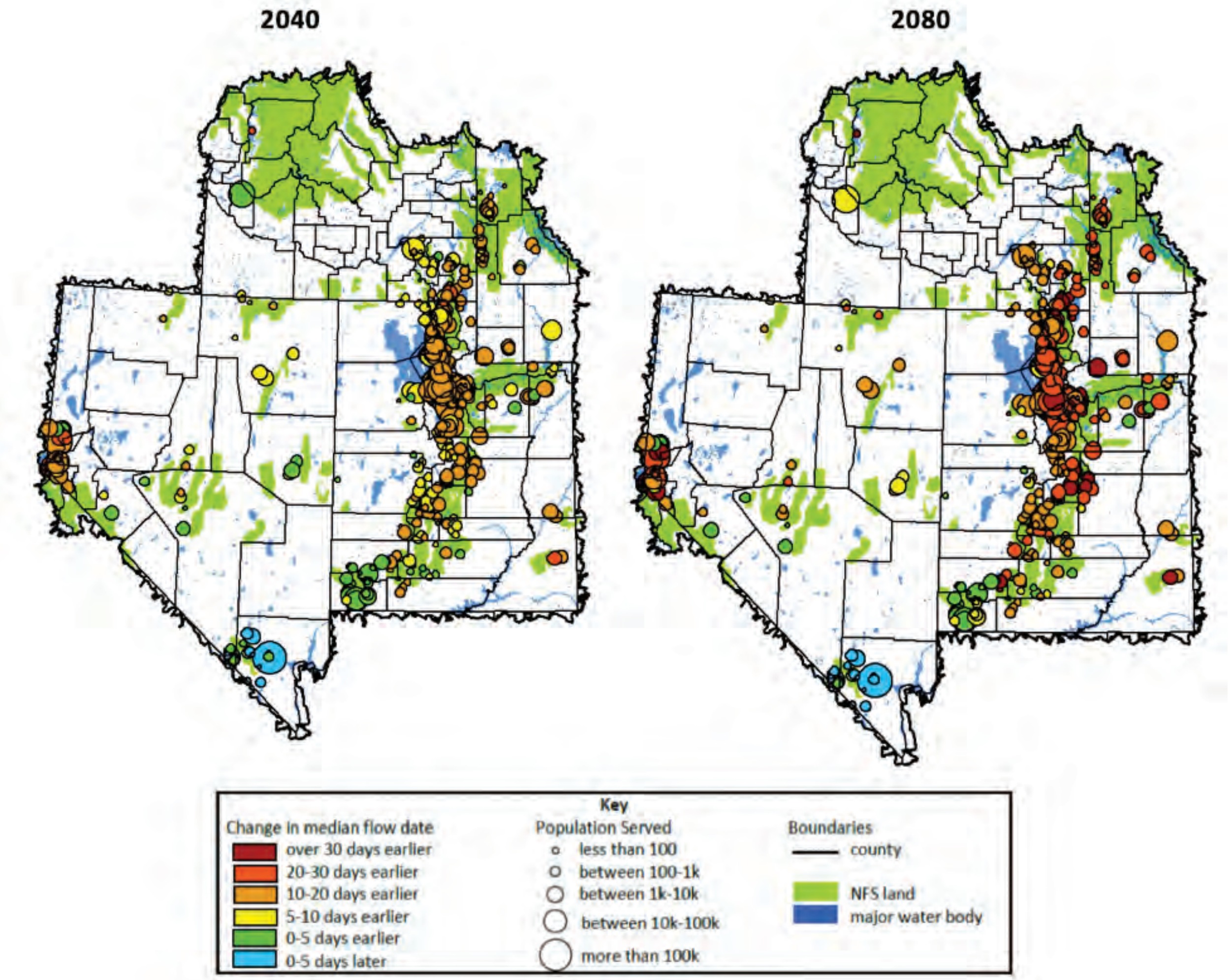

Figure 13.5—Projected changes in runoff timing (median flow date) for municipal water systems. The center of each circle is the central location of each drinking water system relative to intake locations.

reductions by the 2080s. Watershed response to climate change varies as a function of exposure to changing conditions. Geographic distribution of response in the IAP region depends on which variable is measured, specifically mean annual flow, mean summer flow, runoff timing, and stream temperature. Although spatial variability is generally high, watersheds in northern Utah tend to have greater sensitivity to climate change, as a result of lower water supply in areas with high populations (and thus high demand). In addition, watersheds that have high fuel loadings and are at risk for severe wildfires are sensitive to reduced water quality and supply.

Ecosystem Carbon

Ecosystems provide an important service in the form of carbon sequestration, the uptake and storage of carbon in vegetation and wood products. Carbon sequestration is often referred to as a regulating ecosystem service because it mitigates greenhouse gas emissions by offsetting losses through removal and storage of carbon. As such, carbon storage in ecosystems is becoming more valuable as the impacts of greenhouse gas emissions are becoming more fully understood and experienced (Janowiak et al. 2017; USDA FS 2015a).

The NFS constitutes 22 percent of the Nation’s total forested land area and contains 24 percent of the total carbon stored in all U.S. forests, excluding interior Alaska (Heath et al. 2011). Management of these lands and disturbances can influence carbon dynamics. Rates of sequestration may be enhanced through management strategies that retain and protect forest land from conversion to nonforest uses, restore and maintain resilient forests that are better adapted to a changing climate and other stressors, and reforest lands affected by wildfires and other disturbances. Rates of forest carbon sequestration vary strongly across the United States, with eastern forests accounting for 80 percent of historical sequestration and as much as 90 percent of projected sequestration in future decades (USDA FS 2016b).

Carbon stewardship is an important aspect of sustainable land management. The USFS manages forests and grasslands by balancing the tradeoffs of carbon uptake and storage in a broad range of ecosystem services. The

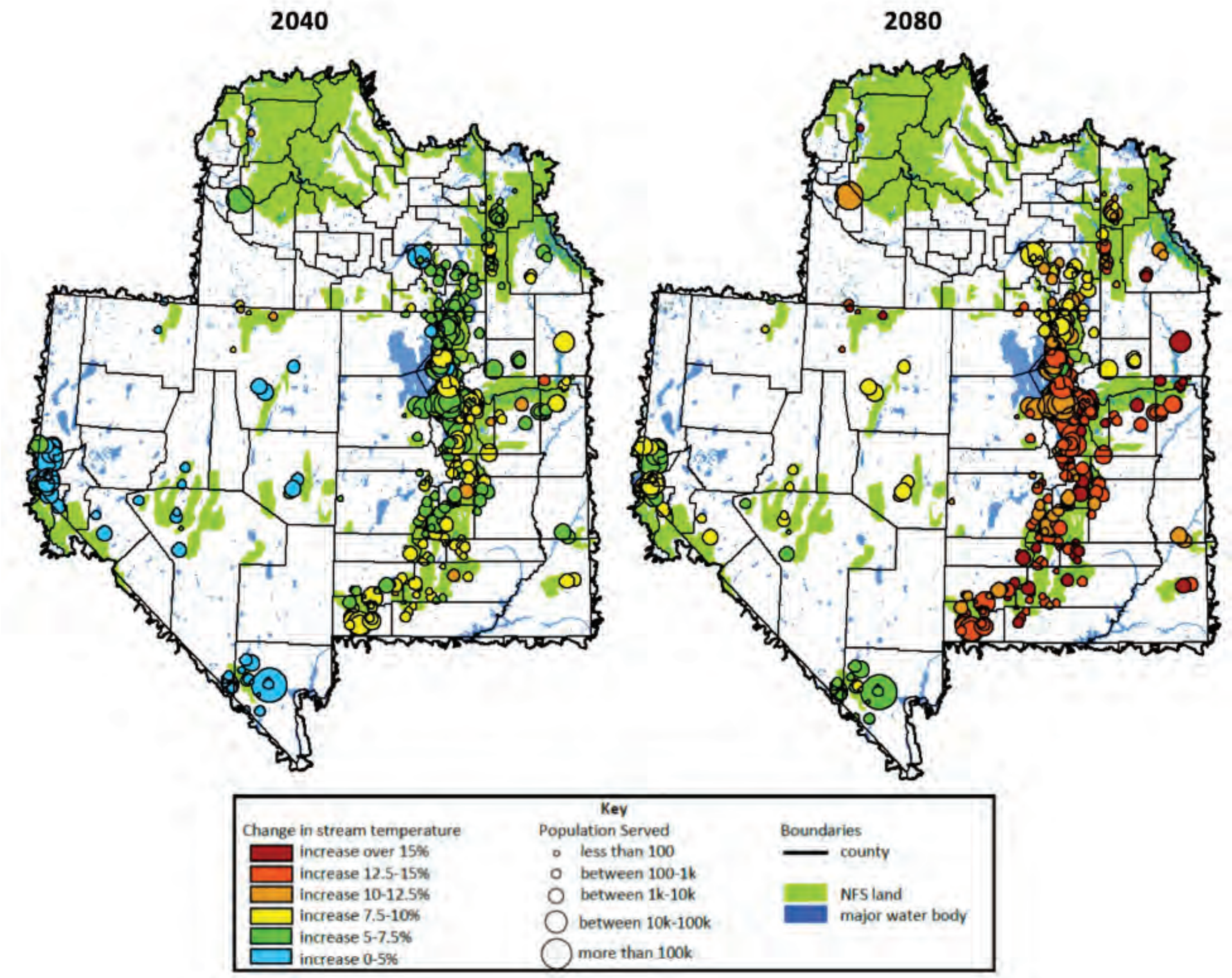

Figure 13.6—Projected changes in stream temperature for municipal water systems. The center of each circle is the central location of each drinking water system relative to intake locations.

goal is to maintain and enhance net storage (if possible) on Federal forests across all carbon pools and age classes. This is accomplished by protecting existing carbon stocks, and building resilience in carbon stocks through adaptation, restoration, and reforestation.

Carbon dynamics vary geographically and by vegetation type, as well as by disturbance regimes that alter vegetation structure and carbon at various spatial and temporal scales. For example, a severe wildfire may initially release carbon dioxide to the atmosphere and cause tree mortality, shifting carbon from living trees to dead wood and the soil. As the forest recovers, new trees establish and grow, absorbing carbon dioxide from the atmosphere. High-severity fires lead not only to a net loss of carbon storage, but also potentially to forest conversion to new landscapes that have lower sequestration rates. Although disturbances may be the predominant drivers of forest carbon dynamics (Pan et al. 2011), environmental factors such as the availability of forest nutrients and climatic variability influence forest growth rates and, consequently, carbon cycling (Pan et al. 2009). In addition, conversion of forests to other uses on private lands greatly reduces the potential for carbon sequestration and cycling processes.

In a warming climate, forests will be increasingly affected by factors such as multiyear droughts, insect outbreaks, and wildfires (e.g., Cohen et al. 2016). It is estimated that the amount of carbon dioxide emitted from fires annually in the United States is equivalent to 4 to 6 percent of anthropogenic emissions, and at the State level, the amount of carbon dioxide from large fires can occasionally exceed levels of carbon dioxide produced from burning fossil fuels (Wiedinmyer and Neff 2007). Maintaining healthy forest structure and composition may not eliminate disturbance, and may in fact entail additional low-magnitude disturbance, but is likely to reduce the risk of large and long-term carbon losses that would have been caused by large-scale disturbances (Millar and Stephenson 2015; Sorensen et al. 2011).

There is mixed evidence on the effect of fuel treatments and forest resilience on the long-term ability of forests to sequester carbon. Fuel treatments are generally effective both in reducing the amount of carbon lost in a fire and in increasing the amount of carbon stored in vegetation postfire (Dore et al. 2010; Finkral and Evans 2008; Meigs et al. 2009; Restaino and Peterson 2013; Stevens-Rumann et al. 2013). Fuel treatments themselves remove large amounts of carbon. Carbon removed during fuel treatments generally

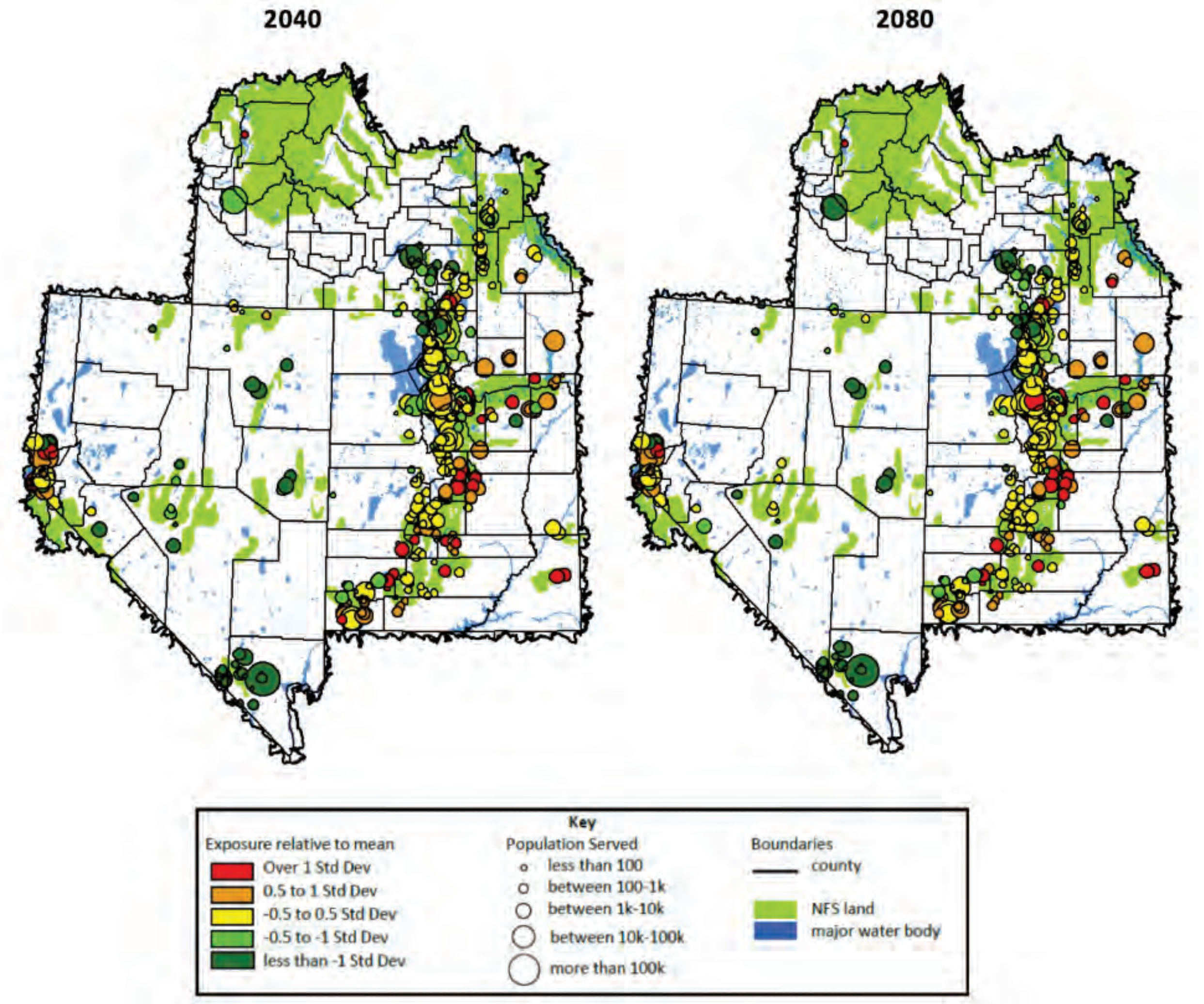

Figure 13.7—Municipal water system exposure. This is a standardized measure of the projected changes in mean annual flow, mean summer flow, runoff timing, and water temperature. Lower annual flow, lower summer flow, earlier median flow date, and higher temperature correspond with greater exposure. Each component is weighted equally. The center of each circle is the central location of each drinking water system relative to intake locations.

slightly exceeds that lost in wildfires over the long term, although the treatments prevent environmental damage associated with severe fires and reduce the size of periodic carbon pulses to the atmosphere (Campbell et al. 2012; Kent et al. 2015; Restaino and Peterson 2013).

Harvested wood products (HWP) (e.g., lumber, panels, paper) can account for a significant amount of offsite carbon storage, and estimates of this pool are important for national accounting and regional reporting (Skog 2008). Products and energy derived from harvest of timber from National Forests extend the storage of carbon or substitute for the use of fossil fuels. To date, few studies have looked at the long-term ability of these activities to sequester carbon, although they are an important component of forest management.

Baseline Estimates

The USFS 2012 Planning Rule and Climate Change Performance Scorecard element 9 (Carbon Assessment and Stewardship) require National Forests to identify baseline carbon stocks and consider that information in planning and management (USDA FS 2012a). The USFS has developed a nationally consistent assessment framework for reporting carbon components within each National Forest. Estimates of total ecosystem carbon and stock change (flux) have been produced at the forest level across the entire country, relying on consistent methodology and plot-level data from the Forest Inventory and Analysis program (USDA FS 2015a).

Carbon stocks reflect the amount of carbon stored in seven ecosystem carbon pools—aboveground live trees, belowground live trees, understory, standing dead trees, down dead wood, forest floor, and soil organic carbon—and in a pool comprising HWP in use and in solid waste disposal. These carbon pools are reported here for the Intermountain Region for the period 2005–2013. Carbon flux reflects year-to-year balance of carbon going into or being removed from the atmosphere (Woodall et al. 2013).

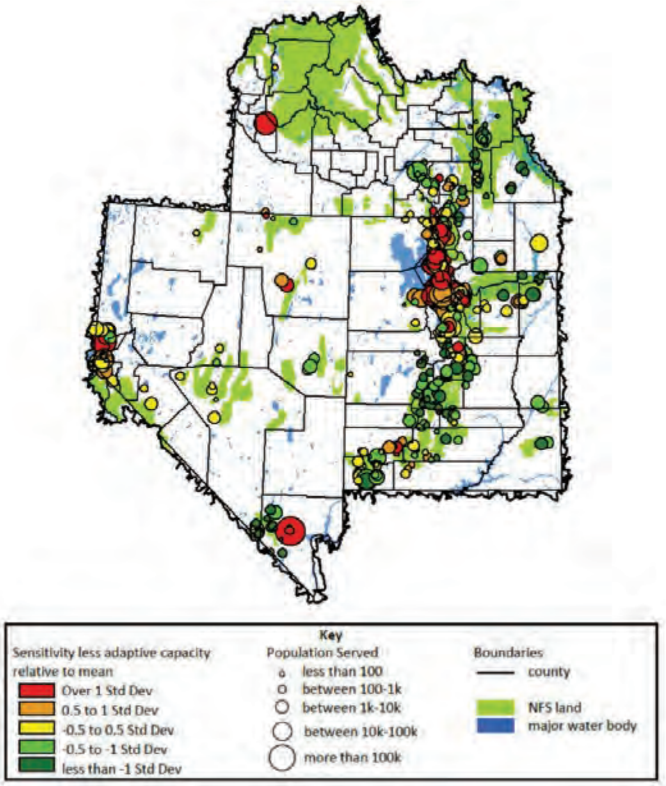

Figure 13.8—Municipal water system sensitivity less adaptive capacity. This is a standardized measure of sensitivity for each municipal system that also takes into account adaptive capacity. The measure is derived using factor analysis with the variables described in table 13.9. The center of each circle is the central location of each drinking water system relative to intake locations.

Salmon-Challis National Forest stored the largest amount of carbon among National Forests in the IAP region (181 million tons in 2005, 183 tons in 2013) (fig. 13.11). During this period, total forest ecosystem carbon in the Ashley, Bridger-Teton, Caribou-Targhee, Humboldt-Toiyabe, and Uinta-Wasatch-Cache National Forests generally increased, but decreased in the Boise, Dixie, and Sawtooth National Forests.

Carbon density is an estimate of forest carbon stocks per unit area. Carbon density barely changed from 2005 to 2013, going from 53.1 to 53.0 tons per acre. In 2013, Bridger-Teton National Forest had the highest carbon density (68.5 tons per acre) of all National Forests in the region, and the Desert Range Experiment Station had the lowest (22.9 tons per acre). Factors such as precipitation, growth rates (site quality), disturbances, and changes in land use, including timber harvest, may be responsible for these observed trends (USDA FS 2016b).

Regionwide, the amount of carbon stored in understory, standing dead, down dead, forest floor, and SOC pools increased between 2005 and 2013 but decreased in aboveground and belowground pools (fig. 13.12). Between these 2 years, the highest percentage change in carbon storage occurred in the standing dead pool (+7 percent), and the lowest in the forest floor pool (+0.9 percent). As of 2013, most of the carbon is concentrated in the aboveground, forest floor, and SOC pools.

Net ecosystem carbon sequestration in the IAP region is projected to remain stable until around 2020, then decrease gradually through around 2030 and level off at slightly less than zero through 2060 (USDA FS 2016b; Wear and Coulston 2015). Total ecosystem carbon stocks are expected to decrease steeply during the 2020–2030 period. If these trends hold (based on assumptions of the projections), the function of carbon retention will change significantly for the foreseeable future. Although these projections contain uncertainty, they appear reasonable in the IAP region, where more droughts and disturbances will make it difficult to retain carbon over the long term.

Cumulative carbon stored in Intermountain Region HWP accelerated around 1955 and increased until 2000, when it peaked at 10.5 million tons in storage. Since 2000, carbon stocks have been in a slow decline, and by 2013, the pool had fallen to 9.9 million tons (fig. 13.13). HWP stocks are decreasing because the amount of HWP carbon harvested and converted to products is less than the amount of carbon emitted through various pathways.

Carbon stocks are affected by disturbances such as wildfires, insect activity, timber harvesting, and weather events. Companion assessments are being completed to understand these influences. Although natural stand processes such as individual tree mortality and more widespread disturbances such as wildfire or droughts can greatly impact the status of forest carbon across NFS landscapes, the high levels of uncertainty associated with these carbon estimates prevent speculation as to the drivers of change. Research is currently underway to refine the spatial and temporal certainty associated with forest carbon baselines at the scale of an individual National Forest.

Pollinator Services and Native Vegetation

Broad-Scale Climate Change Effects

Human influences, such as introduction of invasive species, altered wildfire regimes, habitat modification, land use, and climate change, affect and stress native plant communities and species that depend on them, including both native and managed pollinator species (BLM 2015b). The geographic distribution and size of contemporary ecosystems are shifting, and novel ecosystems may develop in a warmer climate. These changes result in the loss, degradation, or fragmentation of pollinator habitat and other basic pollinator needs such as nesting sites and materials (GBNPP n.d.).

Warming temperatures, decreased snowpack, altered timing of snowmelt and runoff, invasive species, and changing fire behavior affect pollinators and their habitats in the IAP region. Among nonforest ecosystems, alpine, subalpine forblands, dry and dwarf sagebrush shrublands,

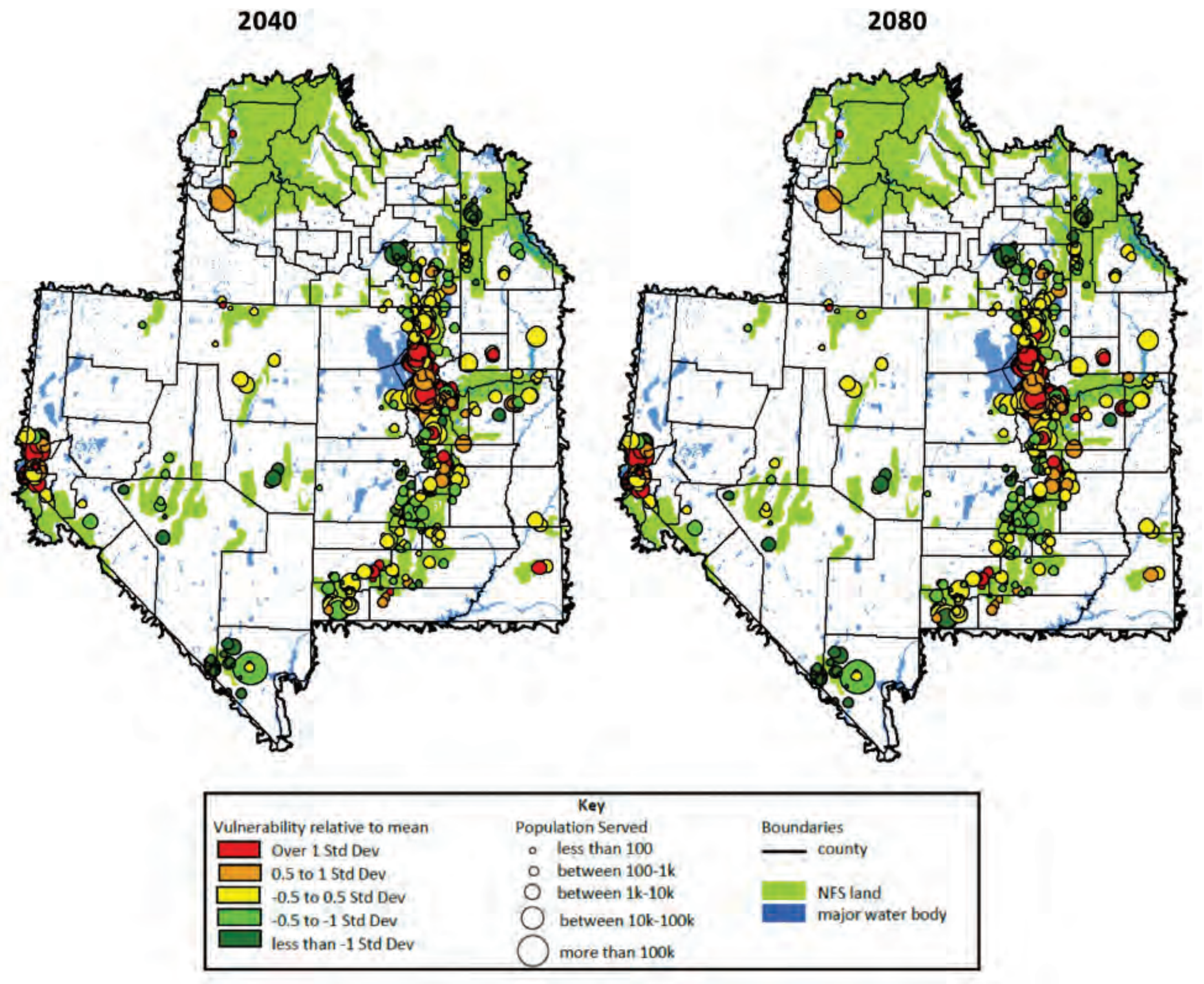

Figure 13.9—Municipal water system vulnerability. This is the final vulnerability measure for each water system. The measure is derived by summing the standardized measures of exposure and sensitivity less adaptive capacity for each system. The center of each circle is the central location of each drinking water system relative to intake locations.

and low-elevation riparian and wetland ecosystems are most at risk from climate change in the IAP region (Chapter 7).

Habitat, Ecosystem Function, or Species

Pollination by animals is a valuable ecosystem service provided to society by the western (or European) honey bee (*Apis mellifera*), native bees, other insect pollinators, birds, and bats (Pollinator Health Task Force 2015). Pollinators in systems ranging from wilderness to farmland serve a crucial role in the U.S. economy, food security, and environmental health. Honey bee pollination ensures crop production in fruits, nuts, and vegetables, adding $15 billion in value to U.S. agricultural crops annually. The value of pollinators in natural systems is more difficult to quantify because maintenance of natural plant communities through pollination contributes to a variety of ecosystem services (NRC 2007). The contribution of bees to ecosystems through pollination makes them a keystone species group in many terrestrial ecosystems (Hatfield et al. 2012).

Current Condition and Existing Stressors

Examples of local pollinator declines or disrupted pollination systems have been reported on every continent except Antarctica. Simultaneous declines in native and managed pollinator populations globally, with highly visible decreases in honey bees, bumble bees (*Bombus* spp.), and monarch butterflies (*Danaus plexippus*), have brought into focus the importance of pollinator conservation (Cameron et al. 2011; NRC 2007; Pettis and Delaplane 2010; van Engelsdorp and Meixner 2010; van Engelsdorp et al. 2010).

In 2014–2015, commercial beekeepers in the United States lost more than 40 percent of their honey bee colonies (Seitz et al. 2015). The parasitic *Varroa destructor* mite, introduced from Asia, has been attacking hives around the country (Traynor et al. 2016). Honey bees often suffer from poor nutrition because their usual diet of native flowers has been replaced in some areas by lawns and monoculture farmland. In addition, a class of pesticides known

Table 13.10—Municipal water system vulnerability in national forests.

National forest	Municipal systems	Population served	Exposure	Sensitivity less adaptive capacity	Vulnerability
Ashley	18	53,322	High	Low	Moderate
Boise	2	186,072	Very Low	Very High	High
Bridger	23	10,782	Moderate	Low	Low
Cache	83	398,296	Moderate	Very High	High
Caribou	22	66,615	Very Low	Moderate	Low
Curlew	2	449	Moderate	Moderate	Moderate
Dixie	50	148,365	Moderate	Moderate	Moderate
Fishlake	38	27,651	Moderate	Very Low	Low
Humboldt	15	21,718	Low	High	Moderate
Manti-La Sal	24	38,934	Very High	Low	Moderate
Payette	1	170	Very High	Moderate	Very High
Targhee	4	245	Moderate	Very Low	Very Low
Teton	22	13,452	Low	Very Low	Very Low
Toiyabe	99	2,070,860	Moderate	Moderate	Moderate
Uinta	54	463,766	Moderate	High	High
Wasatch	64	1,268,218	Moderate	Very High	Very High

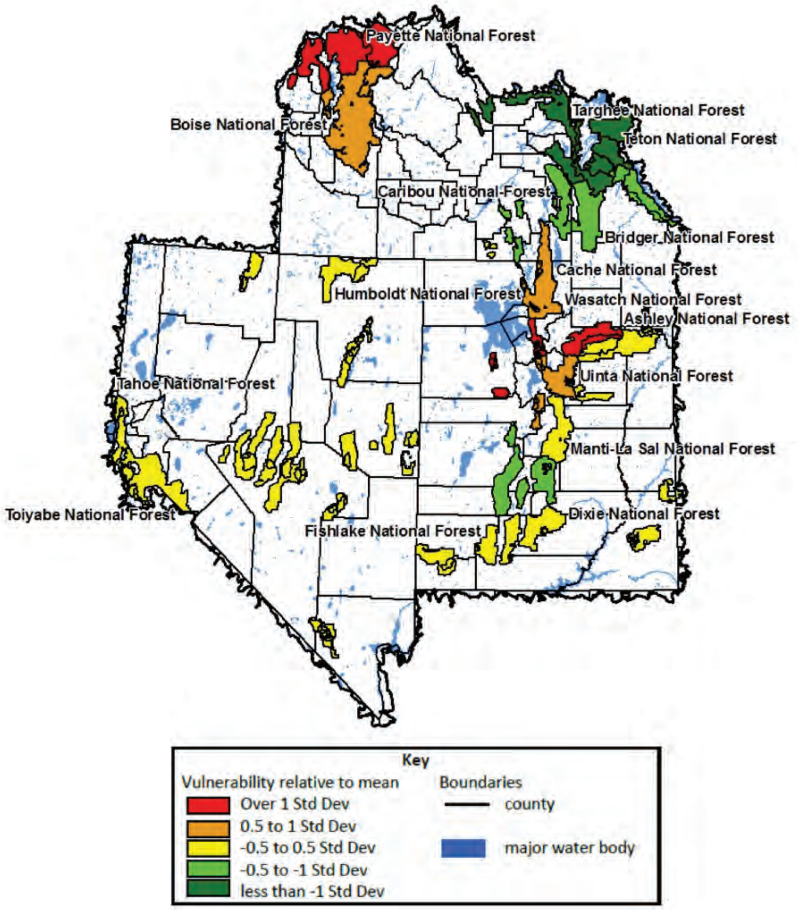

Figure 13.10—Water system vulnerability by national forest. Average vulnerability measure for each municipal water system is aggregated to the national forest level. Only water systems within one subwatershed (Hydrologic Unit Code 12) of national forest lands are included. Due to similarity after aggregation, this represents both 2040 and 2080 projections.

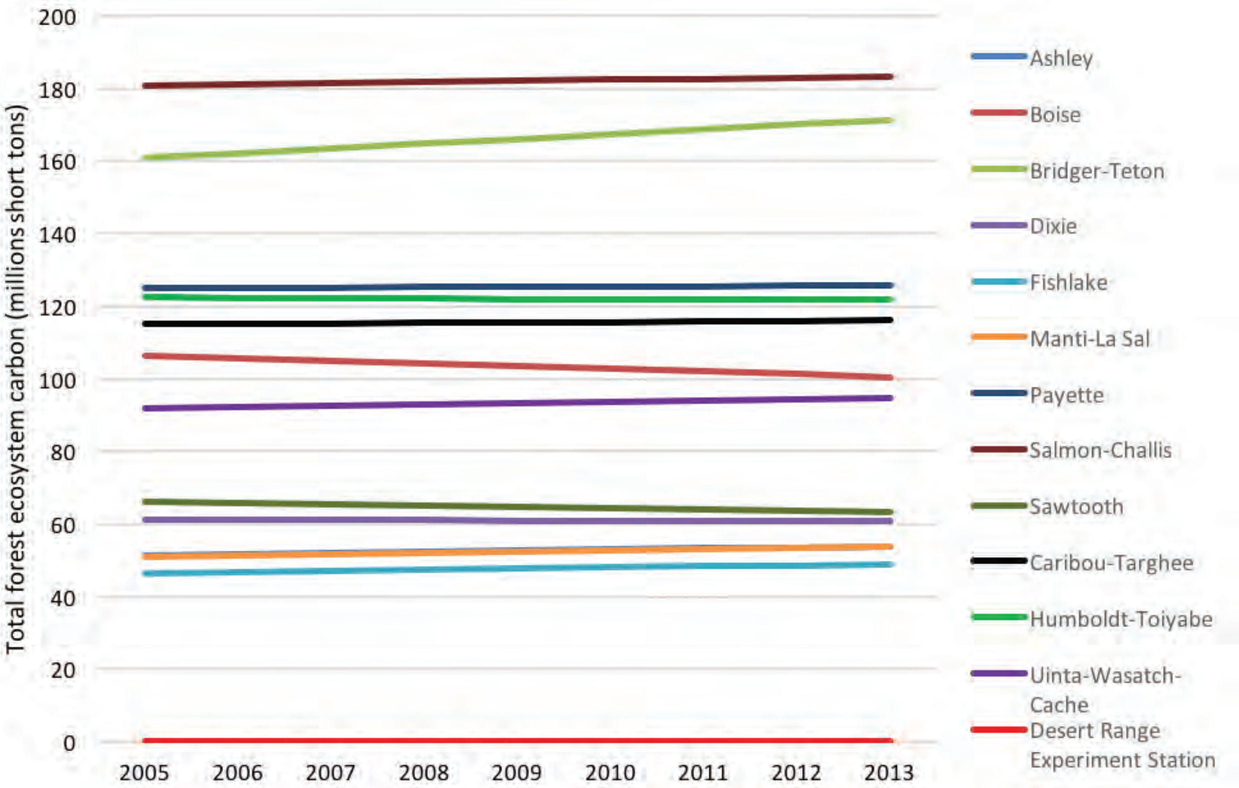

Figure 13.11—Total forest ecosystem carbon for national forests in the U.S. Forest Service Intermountain Region (2005–2013) (from O'Connell et al. [2016]).

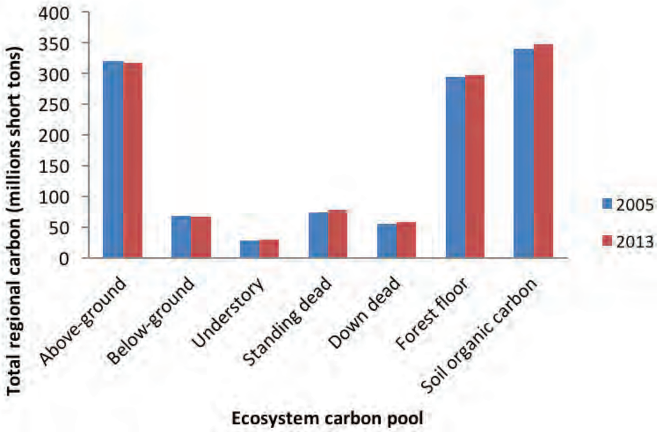

Figure 13.12—Carbon stocks in the seven forest ecosystem pools in national forest lands of the U.S. Forest Service Intermountain Region (2005 and 2013) (from O'Connell et al. [2016]).

as neonicotinoids may be affecting the nervous systems of insects, making them more susceptible to disease and pathogens.

Four species of bumble bees native to North America have declined by up to 96 percent and are estimated to no longer persist in up to 62 percent of ecoregions where they were historically present (Koch et al. 2012). These four historically abundant species are western bumble bee (*B. occidentalis*), *B. affinus, B. pennsylvanicus*, and *B. terricola*. Western bumble bee, native to the Pacific Northwest and Rocky Mountains (including Idaho), has decreased dramatically in abundance and range (Koch et al. 2012). Half of the bumble bee species found historically in the Midwest have declined or been extirpated, supporting observations of broader declines in North America (Grixti et al. 2009). The monarch butterfly population, which ranges throughout the IAP region, has declined to a small fraction of its previous size (Jepson et al. 2015). Monarchs that overwinter along the California coast lost 74 percent of their population in less than 20 years (Pelton et al. 2016).

Fifteen vertebrate pollinator species in the United States are listed as endangered by the U.S. Fish and Wildlife Service. The National Academy of Sciences noted that declines in many pollinator groups are associated with habitat loss, fragmentation, and deterioration; diseases and pathogens; and pesticides (NRC 2007). Availability of a variety of native plants is important because not all pollinators can gain access to the nectar found in introduced flowers. Pollinators also depend on availability of various flowering plants throughout a season. Habitat loss and degradation can negatively affect the timing and amount of food availability, thereby increasing competition for limited resources.

Increased fragmentation of habitats is particularly troublesome for pollinators that travel long distances. Migratory pollinators, such as the monarch butterfly, rufous

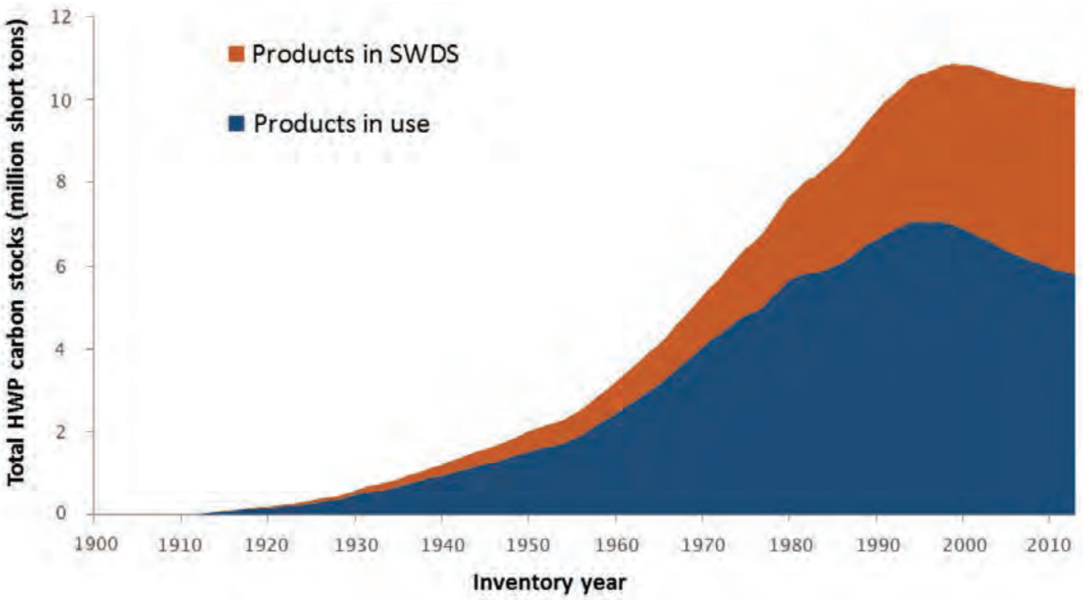

Figure 13.13—Cumulative total carbon stored in harvested wood products (HWP) manufactured from U.S. Forest Service Intermountain Region timber. Carbon in HWP includes products that are still in use and carbon stored at solid waste disposal sites (from Stockmann et al. [2014]).

hummingbird (*Selasphorus rufus*), and lesser long-nosed bat (*Leptonycteris yerbabuenae*), travel hundreds or thousands of miles each year as the seasons change. These trips require high levels of energy, and availability of food resources along the way is critical. Fragmentation of habitat increases the distance between suitable food and shelter sites along migratory routes, thereby disrupting the journey.

Agricultural and Grazing Practices

Monoculture farming and removal of buffer strips reduce suitable habitat for wild pollinators. Improper grazing practices may also adversely affect pollinators by removing pollinator food resources and by destroying underground nests and potential nesting sites, in some cases by trampling. Through allotment management planning, grazing systems can be managed to increase flowering plant diversity.

Pesticides

Insecticides affect pollinators directly through unintentional poisoning, and herbicides affect them indirectly through loss of insect forage and other wildflowers important in maintaining some insect populations. Increased dependence on pesticides is particularly problematic for managed honey bees because of their added exposure as crop pollinators. Overuse of pesticides occurs frequently, reaching unintended areas. In the case of aerial applicators, wind and human carelessness may extend actual coverage beyond the intended area, jeopardizing pollinators in areas within and adjacent to agricultural fields. This problem emphasizes the importance of buffer strips in agricultural areas, not only as habitat for pollinators, but as protection from overspraying of pesticide.

Introduced Species

Invasive plant species are considered by some to be the second most important threat to biodiversity, after habitat destruction (Westbrooks 1998). Introduced pathogens and parasites cause significant declines in both managed and native bee populations in North America. Honey bee colonies, both managed and feral, are being devastated by the parasitic *Varroa destructor* (Traynor et al. 2016). Similarly, the protozoan pathogen *Nosema bombi* causes problems for the western bumble bee and other bumble bees.

The most prevalent example of an introduced pollinator is the European honey bee, which has been imported to virtually every corner of the world. Despite its well-documented benefits to commercial agriculture, there is evidence that the honey bee has disrupted native pollination systems. Through competition for floral resources, honey bees reduce the abundance of native pollinators.

Unauthorized Bee Harvesting

Evidence of illegal harvesting of blue orchard (or mason) bees (*Osmia lignaria*) has been found on National Forests in the Intermountain Region. “Bee boxes” have been found on National Forests to encourage cocoon production in mobile boxes that are sold nationwide to orchard growers. These boxes have been placed long enough (several years) in the same places at high enough concentrations that an impact on sustainability and viability of the bees is probably occurring in multiple watersheds with suitable habitat.

Interactions and Compounded Effects of Stressors

The stressors discussed earlier are likely to interact with one another. For example, a lack of floral resources caused by intensive farming or ecosystem conversion from perennial native vegetation to nonnative annual grasses can lead to nutritional stress in insect pollinators, which, in turn, can make them more vulnerable to insect pests, diseases, and pesticides. The cumulative effects of these interactions are unclear, and more research is needed to identify the underlying causes of pollinator declines and interactions.

Current Management Strategies

Current management strategies focus on determining the status of pollinators and wildflower populations and the potential drivers of changes in these populations. In response to the global pollinator crisis, a 2014 presidential memorandum on pollinators directs Federal agencies to create a native seed reserve of pollinator friendly plants, create or enhance 7 million acres of pollinator habitat over the next 5 years, and incorporate pollinator health as a component of all future restoration and reclamation projects (The White House, Office of the Press Secretary 2014). The national strategy was implemented in May 2015 (box 13.3).

The Intermountain Region recently appointed pollinator coordinators on each of its National Forests, and these coordinators implement objectives of the national pollinator strategy and serve on teams to evaluate conditions and consequences of proposed management actions. If impacts to pollinators are expected, site-specific prescriptions are developed to prevent those impacts. Managing for pollinators involves providing basic habitat elements, including protecting, enhancing, or restoring wildflower-rich foraging habitat, providing hive site locations and nest sites for native bees, providing host plants for butterflies, and providing overwintering refuge for other insects (Mader et al. 2011).

The 2015 “Strategy to Promote the Health of Honey Bees and Other Pollinators” advances Federal commitments to increase and improve habitat for pollinators, directly through a variety of Federal facilities and lands, and indirectly through interactions with States, other organizations, and the public. Actions include planting pollinator gardens, improving land management practices at Federal facilities, and using pollinator friendly seed mixes in land management, restoration, and rehabilitation (box 13.4).

Demand is increasing for genetically appropriate seeds to restore plant communities on both public and private lands in the IAP region and elsewhere. The “National Seed Strategy for Rehabilitation and Restoration” (BLM 2015a) will foster collaboration among 300 non-Federal partners, 12 Federal agencies, private industry, and tribal, State, and local governments to guide the use of seed needed for timely and effective restoration.

The “Native Plant Materials Policy” (USDA FS 2012b) provides new direction on the use, growth, development, and storage of native plant materials. Objectives for the use of native plant materials in revegetation, rehabilitation, and restoration of aquatic and terrestrial ecosystems are to: (1) maintain, restore or rehabilitate native ecosystems so that they are self-sustaining, are resistant to invasion by nonnative species, or provide habitat for a broad range of species, or a combination thereof; (2) maintain adequate protection for soil and water resources through revegetation of disturbed sites that could not be restored naturally; (3) promote the use of native plant materials for the revegetation, rehabilitation, and restoration of native ecosystems; and (4) promote the appropriate use and availability of native and nonnative plant materials.

Box 13.3—Selected Excerpts from the 2014 Presidential Memorandum on Pollinators

Section 3A: Federal agencies will enhance pollinator habitat on managed lands and facilities through increased native vegetation (integrated vegetation and pest management) with application of pollinator friendly best management practices and pollinator friendly seed mixes (table 13.11).

Section 3B: Federal agencies will evaluate permit and management practices on power line, pipeline, utility, and other rights-of-way and easements, and consistent with applicable law, make necessary and appropriate changes to enhance pollinator habitat on federal lands through the use of integrated vegetation and pest management and pollinator friendly best management practices, and by supplementing existing agreements and memoranda of understanding with rights-of-way holders, where appropriate, to establish and improve pollinator habitat.

Section 3C: Federal agencies will incorporate pollinator health as a component of all future restoration and reclamation projects as appropriate, including all annual restoration plans.

Section 3F: Federal agencies will establish a reserve of native seed mixes, including pollinator friendly plants, for use on postfire rehabilitation projects and other restoration activities.

Section 3G: The U.S. Department of Agriculture will substantially increase both the acreage and forage value of pollinator habitat in the Department’s conservation programs, including the Conservation Reserve Program, and provide technical assistance, through collaboration with the land-grant university-based cooperative extension services, to executive departments and agencies, state, local, and tribal governments, and other entities and individuals, including farmers and ranchers, in planting the most suitable pollinator friendly habitats.

Box 13.4—The 2015 National Strategy to Promote the Health of Honeybees and Other Pollinators

From Pollinator Health Task Force (2015):

Goals:

- Reduce honeybee colony losses to economically sustainable levels.
- Increase monarch butterfly numbers to protect the annual migration.
- Restore or enhance 7 million acres of land for pollinators over the next 5 years through Federal actions and public-private partnerships.

The Strategy addresses four themes central to the June 2014 Presidential Memorandum "Creating a Federal Strategy to Promote the Health of Honeybees and Other Pollinators":

- Conduct research to understand, prevent, and recover from pollinator losses.
- Expand public education programs and outreach.
- Increase and improve pollinator habitat.
- Develop public-private partnerships across all these activities.

The Intermountain Region Pollinator Friendly Plant Species

The Intermountain Region has identified 80 pollinator friendly plant species as a priority for seed production (table 13.11). This is a core list of native forbs and shrubs that are beneficial to pollinators and that have a high likelihood of being successfully propagated. The species are suitable for enhancing existing pollinator habitat and improving pollinator habitat in disturbed areas during revegetation activities (USDA FS 2015d).

Seed zones are areas within which plant materials can be transferred with little risk of being poorly adapted to their new location. There are typically two types of seed zones: (1) empirical seed zones determined by genetic studies and common gardens, and (2) provisional seed zones based on climatically similar areas. Seed zones help reduce failure of a seed source used in revegetation, reduce poor performance over time due to geographic and elevation effects, avoid contamination of native gene pools, and prevent seed sources from becoming overly competitive. This approach focuses on making available the most appropriate seed for a given location, providing genetically appropriate materials with a high likelihood of success when planted.

Sensitivity to Climatic Variability and Change

Altered disturbance regimes, habitat disruption from development, inappropriate livestock grazing, and spread of nonnative plant species interact to affect pollinator habitat in the IAP region. If the distribution and abundance of plant species shift significantly in a warmer climate, novel plant communities may develop, requiring an adaptive response by pollinators (Hegland et al. 2009).

Altered temperature and precipitation and their inherent variability have the potential to alter the vegetative landscape in the IAP region (BLM 2013). The timing and amount of precipitation will interact with temperature thresholds to potentially alter the structure and function of plant communities and ecosystems. Although the exact trajectory of this transition is uncertain, pollinator species will need to track changes in plant communities to ensure long-term survival of both the pollinators and plant-pollinator mutualisms.

Expected Effects of Climate Change

Bumble bees are vulnerable to climate change, especially at the edge of their range (Hatfield et al. 2012). Because bumble bees need flowering resources throughout their flight period, any changes in flowering phenology could have significant consequences. Altered temperature and precipitation could lead to unpredictable or unreliable flowering cues. At high elevation, earlier melting of snowpack is expected to reduce water availability in summer, resulting in low soil moisture and associated effects on vegetative productivity and flowering. Even a relatively small change in flowering phenology—a few days to a few weeks—could affect reproduction if flowering is asynchronous with pollinator activity. Pollinators will be most sensitive to altered plant phenology at the beginning and end of their flight seasons.

The ability of pollinators to move upward in elevation would facilitate adaptive response in some cases. In the Colorado Rocky Mountains, bumble bees have shown flexibility in altitudinal distribution in response to warmer temperatures, moving upwards as much as several hundred feet since the 1970s (Koch et al. 2012). In mountainous regions, upslope movement can result in reduced land area with suitable habitat and potentially "mountain top extinctions" (Dullinger et al. 2012). The ability of a plant or pollinator species to shift its range through propagule dispersal and the establishment of new populations will be critical (Dullinger and Hülber 2011; Dullinger et al. 2012),

Table 13.11—Pollinator friendly species designated by the USFS Intermountain Region.

Scientific name	Common name
Achillea millefolium ssp. *occidentalis*	yarrow
Agastache urticifolia	nettleleaf giant hyssop
Agoseris glauca	mountain dandelion
Agoseris grandiflora	big flower agoseris
Agoseris heterophylla	annual agoseris
Amelanchier alnifolia	Saskatoon serviceberry
Antennaria rosea	rosy pussytoes
Argemone munita	flatbud pricklypoppy
Astragalus calycosus	Torrey's milkvetch
Astragalus filipes	basalt milkvetch
Astragalus lonchocarpus	Rushy milkvetch
Asclepias speciose	showy milkweed
Balsamorhiza hookeri	arrowleaf balsamroot
Balsamorhiza sagittata	Hooker's balsamroot
Chaenactis douglasii	Douglas' dustymaiden
Cleome lutea	yellow spiderflower
Cleome serrulata	Rocky Mountain bee plant
Crepis acuminata	tapertip hawksbeard
Crepis intermedia	limestone hawksbeard
Cymopterus bulbosa	bulbous springparsely
Dalea ornata	blue mountain prairie clover
Dalea searlsiae	Searl's prairie
Dasiphora fruticosa	Shrubby cinquefoil
Erigeron clokeyi	Clokey's fleabane
Erigeron pumilus	shaggy fleabane
Erigeron speciosus	aspen/showy fleabane
Eriogonum heracleoides	parsnip flower buckwheat
Eriogonum umbellatum	sulfur-flower buckwheat
Eriogonum racemosum	redroot buckwheat
Erysimum capitatum	sanddune wallflower
Geranium viscossisimum	sticky purple geranium
Hedysarum boreale	Utah sweetvetch
Helianthus annuus	common sunflower
Heliomeris multiflora var. nevadensis	showy goldeneye
Heterothica villosa	hairy golden aster
Ipomopsis aggregata	scarlet gilia
Linum lewisii	Lewis flax
Lomatium grayi	Gray's biscuitroot

Table 13.11—*Continued*.

Scientific name	Common name
Lomatium triternatum	nineleaf biscuitroot
Lupinus argenteus	silvery lupine
Lupinus caudatus	Kellogg's spurred lupine
Lupinus prunophilus	hairy bigleaf lupine
Lupinus sericeus	hairy bigleaf lupine silky lupine
Machaeranthera canescens	tansyaster
Machaeranthera tanacetifolia	tanseyleaf tansyaster
Microseris nutans	nodding microseris
Packera multilobata	lobeleaf groundsel
Penstemon acuminatus	sharpleaf penstemon
Penstemon comarrhenus	dusty penstemon
Penstemon cyananthus	Wasatch beardtongue
Penstemon cyaneus	blue penstemon
Penstemon cyanocaulis	bluestem penstemon
Penstemon deustus	scabland penstemon
Penstemon eatonii	firecracker penstemon
Penstemon leiophyllus	smoothleaf beardtongue
Penstemon ophianthus	coiled anther penstemon
Penstemon pachyphyllus	thickleaf beardtongue
Penstemon palmeri	Palmer's penstemon
Pensetmeon procerus	little flower penstemon
Penstemon rostriflorus	bridge penstemon
Penstemon speciosus	royal penstemon
Penstemon strictus	Rocky Mountain penstemon
Phacelia hastata	silverleaf phacelia
Phlox hoodia	spiny phlox
Phlox longifolia	longleaf phlox
Polemonium foliosissimum	towering Jacob's-ladder
Potentilla crinita	bearded cinquefoil
Purshia tridentata	antelope bitterbrush
Solidago canadensis	Canada goldenrod
Sphaeralcea coccinea	scarlet globemallow
Sphaeralcea grossulariifolia	gooseberryleaf globemallow
Trifolium gymnocarpon	hollyleaf clover
Vicia americana	American vetch

especially for alpine endemics that may have limited life history options.

Nonnative plant species are already degrading and replacing native plant communities in the IAP region, thus reducing availability of floral resources. A warmer climate is expected to make nonnative species even more competitive in some locations, especially lower elevations dominated by shrubs and grasses. Floral resources in spring and fall migration corridors for monarch butterflies between over-wintering habitat (California, Oregon) and summer breeding locations (Nevada, Idaho, Utah) are already degraded, and additional habitat fragmentation in a warmer climate would cause further degradation.

Ecological Restoration

Landscapes that retain functionality in a warmer climate will have greater capacity to survive natural disturbances and extreme events in a warmer climate. Ecological restoration addresses composition, structure, pattern, and ecological processes in terrestrial and aquatic ecosystems, typically with a focus on long-term sustainability relative to desired social, economic, and ecological conditions. Including pollinators as a consideration in climate change adaptation will assist other restoration goals related to genetic conservation, biodiversity, and production of habitat for endemic species. Increasing the capacity of Federal agencies to mitigate current damage to pollinator populations and facilitate improvement of habitat will contribute to both restoration and climate change adaptation (box 13.5).

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Box 13.5—Building Organizational Capacity to Improve Pollinator Habitat

Management of pollinator decline is based on avoiding or reducing the spread of new and existing diseases and pathogens, reducing pesticide use, and improving the resistance and resilience of native plant communities by encouraging or planting a wider variety of regionally appropriate pollinator friendly plant species. The following action items are encouraged:

- Assign a point of contact for pollinators and native plant materials development on each Intermountain Region unit.
- Plant pollinator gardens to raise awareness about pollinator decline for the public, decisionmakers, and resource specialists.
- Interpret/improve best management practices for pollinators.
- Assess pollinator issues of greatest need for different locations.
- Develop revegetation guidelines, including seed mixes by habitat type and seed transfer zones; include this document in updated plans.
- Assess the need for increased seed supply by species.
- Focus seed collection and material development on areas anticipated to have the greatest need.
- Actively engage in outreach and education about pollinator declines and climate change.
- Identify appropriate areas for apiary (honeybee colony) permits.
- Improve and maintain pollinator habitat through appropriate grazing management.

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Chapter 14: Adapting to the Effects of Climate Change

Jessica E. Halofsky

Introduction

Adapting to climate change, or adjusting to current or future climate and its effects (Noble et al. 2014), is critical to minimizing the risks associated with climate change impacts. Adaptation actions can vary from passive (e.g., a "wait and see" approach), to relatively simple (e.g., increasing harvest rotation age), to complex (e.g., managing forest structure and processes across large landscapes for a future range of conditions) (Spittlehouse and Stewart 2003). Many adaptation actions are complementary to other land management goals and actions, and most land managers already have the tools and knowledge to start addressing climate change. However, managers may need to make some adjustments, considering new issues, scale and location of implementation, timing, and prioritization of actions (Swanston et al. 2016). For example, it will be increasingly important to prioritize which management actions to take, and where to take those actions, based on the vulnerability of resources to climate change and the likelihood that actions in those places will be effective.

Federal land and water management agencies are required to consider climate change in planning and project analysis, and to begin preparing for the effects of climate change (Federal Register 2009, 2013; USDA FS 2012). The processes and tools for developing adaptation strategies and tactics have differed within and among Federal agencies (Halofsky et al. 2015). However, as outlined in Peterson et al. (2011b), key steps in the process include: (1) education on basic climate change science, integrated with knowledge of local resource conditions and issues (review); (2) evaluation of the sensitivity of specific natural resources to climate change (rank); (3) development and implementation of adaptation strategies and tactics (resolve); and (4) monitoring of the effectiveness of adaptation options (observe), with adjustments as needed.

The development of climate change adaptation strategies and tactics is conducted in the third ("resolve") step. Adaptation **strategies** describe how adaptation options could be employed, but they are still broad and general in their application across ecosystems. **Tactics** are more specific adaptation responses and can provide prescriptive directions for actions to be applied on the ground. At the broadest level, climate change adaptation strategies can be differentiated into four types: (1) resistance, (2) resilience, (3) response, and (4) realignment strategies (Millar et al. 2007). The resistance strategy includes tactics that forestall impacts to protect highly valued resources. Resistance strategies are only a short-term solution but often describe the intensive and localized management of rare and isolated species (Heller and Zavaleta 2009). The resilience strategy includes tactics that improve the capacity of systems to return to desired conditions after disturbance. The response strategy employs tactics to facilitate transition of systems from current to new desired conditions. Finally, the realignment strategy uses restoration practices to ensure persistence of ecosystem processes and functions in a changing climate.

The Intermountain Adaptation Partnership (IAP) project incorporated all steps in the adaptation process. An initial kickoff meeting with leadership and managers from the U.S. Department of Agriculture Forest Service (USFS) Intermountain Region involved review of basic climate change information set in a local context. The initial meeting was followed by a vulnerability assessment process that evaluated potential effects of climate change on water and soils (Chapter 4), fish and aquatic habitat (Chapter 5), forest vegetation (Chapter 6), nonforest vegetation (Chapter 7), ecological disturbance (Chapter 8), terrestrial species (Chapter 9), outdoor recreation (Chapter 10), infrastructure (Chapter 11), cultural resources (Chapter 12), and ecosystem services (Chapter 13). Vulnerability assessments set the stage for hands-on development of adaptation options (the "resolve" step) by resource managers in a series of five workshops across the IAP region. Managers engaged in facilitated discussions and completed worksheets, adapted from Swanston and Janowiak (2012), identifying key climate change vulnerabilities and related adaptation strategies (overarching approaches for resource planning and management) and tactics (on-the-ground management actions). Participating land managers were encouraged to use the Climate Change Adaptation Library (http://adaptationpartners.org/library.php) for ideas on adaptation strategies and tactics, and to identify several types of strategies, including resilience, response, and realignment strategies. They also identified where tactics could be applied and opportunities for implementation of tactics, where applicable. This chapter describes adaptation strategies and tactics developed in the workshops for each of the 10 resource areas covered in the vulnerability assessment. This chapter covers only adaptation strategies and tactics considered high priority by resource managers and discussed in the workshops. It is thus not intended to be an exhaustive list of possible actions.

Adapting Water Resources Management to the Effects of Climate Change

Across the IAP region, lower snowpack and increased drought with changing climate are likely to lead to lower base flows, reduced soil moisture, wetland loss, riparian area reduction or loss, and more frequent and possibly severe wildfire (Luce and Holden 2009) (table 14.1). In response to these changes, managers identified four main adaptation strategies: (1) conserve water; (2) store water; (3) manage for highly functioning riparian areas, wetlands, and groundwater-dependent ecosystems; and (4) develop policies for water rights (table 14.1). Although these adaptation options may do little to alleviate some of the direct consequences of shifting precipitation, snowpack timing, and temperature changes for ecosystems during drought conditions (e.g.,Vose et al. 2016), they can affect downstream water availability and consequences of hydrological drought.

Lower soil moisture and low flows in late summer, combined with increasing demand for water with population growth, are expected to reduce water availability for aquatic resources, recreation, and municipal uses (Chapter 4). A key adaptation strategy is to improve water conservation (Water Resources and Climate Change Workgroup 2016). For example, identify feasible and effective water-saving tactics. Drought-tolerant plants can be used for landscaping (table 14.1). Livestock water improvements can be managed efficiently (e.g., cattle troughs and float valves). The benefit of water conservation can be communicated to public land user groups, and over the long term, increasing water conservation and reducing user expectations of water availability will help to ensure adequate water supply.

In principle, replacing snowpack storage with storage in constructed reservoirs to carry water over from winter into summer could benefit municipal water supplies and irrigators in locations with irrigated agriculture. However, the degree of potential benefit varies substantially with existing water right regulations, reservoir operating rules, snowpack sensitivity to temperature and precipitation, expectations for future precipitation, and the role and future of summer precipitation. The benefits of replacing snowpack storage with reservoir storage are based on the rationale that only timing is changing and total runoff volumes remain unchanged. If precipitation increases, temperature-induced changes could be compensated for in relatively cold regions (Luce et al. 2014). On the other hand, if precipitation decreases, total flow volume will be reduced, and it will be harder to fill reservoir storage because of other rights for water farther downstream that might not be fulfilled. Given the sizable financial and ecological costs of constructing dams and high-elevation reservoirs, coupled with the uncertainties around precipitation, a cost-benefit analysis is advised before considering dam construction.

Shifting dam operation is another possibility for increasing water storage. It would cost significantly less than constructing reservoirs but would require some investment in monitoring upstream snowpack, soil, and weather. Streamflow forecasting informs management decisions on the balance between water storage for irrigation and maintenance of storage capacity to buffer potential flooding (e.g., Wood and Lettenmaier 2006). The current state of snowpack is more beneficial than climate or weather forecasts for predicting runoff in basins with substantial snowmelt contributions (Wood et al. 2015). In addition to informing reservoir operation, improved runoff forecasting can be used to improve decisions for how to best use available water (Broad et al. 2007).

Reduced overall base flows (especially in summer) are expected to reduce riparian and wetland habitat and water storage. Managing for riparian, wetland, and groundwater-dependent ecosystem function can increase water storage and slow the release of water from the landscape (Peterson and Halofsky 2017). Specifically, ecosystem function can be improved through active or passive restoration and by designing infrastructure to accommodate changes in flows (table 14.1). Some adaptation strategies that could help to maintain and improve groundwater-dependent ecosystems (GDEs) include: decommissioning and improving road systems to increase interception of precipitation and local retention of water, improving grazing management practices, and maintaining more water at developed spring sites through improved engineering practices (e.g., float valves, diversion valves, pumps) (Peterson and Halofsky 2017). Promoting and establishing (where currently extirpated) American beaver populations, water storage in beaver dam complexes and ponds, and beaver-related overbank flow processes could also help increase water storage (Pollock et al. 2014, 2015). Common and scientific names for species mentioned in this chapter are given in Chapters 5, 6, and 8, and Appendix 3.

Vegetation management, such as mechanical treatments and prescribed fire, can be used to achieve vegetation density and composition that are optimum for water balance and healthy watersheds (table 14.1). Harvesting trees to increase water yield has been a practice of interest for some time (e.g., Bates and Henry 1928). In general, removing trees increases water yields, since trees are major consumers of water on the landscape (Brown et al. 2005; Jones and Post 2004; Troendle and King 1987; Troendle et al. 2010) but comes with certain caveats. For example, increases in water yield are generally greater in moister environments or years, with lower increases in drier locations or years (e.g., Brown et al. 2005). In some circumstances in drier climates, canopy removal will reduce water yields because of increased growth of understory plants and increasing solar radiation reaching the soil surface (Adams et al. 2011; Guardiola-Claramonte et al. 2011). Overall, areas where increases in water yield are desired are the same areas in which forest harvest is least effective (Troendle et al. 2010; Vose et al. 2012). Thinning treatments have proven ineffective for

Table 14.1—Water resources adaptation options for the Intermountain Adaptation Partnership region.

Sensitivity to climatic variability and change: Increased drought will lead to lower base flows, higher tree mortality, lower rangeland productivity, loss of habitat, lower soil moisture, wetland loss, riparian area reduction or loss, and more frequent and possibly more severe wildfire			
Adaptation strategy/approach: Conserve water			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Promote xeriscape facilities	Provide conservation education	Better manage livestock water improvements
Where can tactics be applied?	Administrative facilities; campgrounds	In public outreach; communities; Forest websites; kiosks; local environmental programs; Smokey Bear messages	Cattle troughs; float valves; in groundwater-dependent ecosystems (developed and undeveloped)
Adaptation strategy/approach: Store water			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Manage special-use dams on high-elevation mountain lakes; manage proposals for reservoir construction and additions	Conduct vegetation management (e.g., mechanical treatments, prescribed fire, and wildland fire use) to develop appropriate vegetation density and composition for optimal water balance and healthy watersheds (e.g., aspen/conifer and water yield)	Conduct meadow restoration and promote healthy, active beaver colonies
Where can tactics be applied?	Existing facilities; water storage structures	Prioritize watersheds where fire suppression or management has altered vegetation density and composition (e.g., where conifers have replaced aspen); identify areas where wildland fire use could be an appropriate tactic	Existing meadow locations; impacted riparian areas; where there is sufficient habitat for beaver and they will not interfere with infrastructure
Adaptation strategy/approach: Develop policies for water rights			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Develop policies regarding ski-area water rights	Develop policies regarding livestock management water use and water rights	Develop policies regarding ecosystem values and services (e.g., instream use)
Where can tactics be applied?	Ski areas	Grazing allotments	National Forest lands and adjacent lands
Sensitivity to climatic variability and change: Changes in type and amount of precipitation, leading to changes in timing of water availability			
Adaptation strategy/approach: Manage for highly functioning riparian areas that can absorb and slowly release the flow of water off the landscape			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Preserve riparian area functionality through terms and conditions of permitted activities (e.g., grazing), and utilize best management practices for Federal actions	Implement active stream channel and riparian area restoration (e.g., natural channel design, log structures, reconnecting floodplains), or passive restoration (e.g., appropriate management of beaver populations, reduction or removal of activities that are detrimental to riparian function)	Design new infrastructure and rebuild existing infrastructure to accommodate flooding (e.g., place or relocate infrastructure outside of riparian areas; design stream crossings to minimize restriction of flow above bankfull depth; and minimize impervious surfaces)
Where can tactics be applied?	In permits	In degraded riparian ecosystems	Everywhere

increasing water yields in the long term (Lesch and Scott 1997; Wilm and Dunford 1948), but thinning treatments can be useful in augmenting snow accumulation depths, for wildlife or recreational benefit (Sankey et al. 2015; Wilm 1944).

Canopy removal for streamflow augmentation is not always beneficial. Canopy reduction treatments may lead to advanced timing of runoff (Luce et al. 2012). An example of large-scale canopy loss in an area with vegetation and climate similar to the IAP region is the Boise River Basin, where about 45 percent of one basin burned while the other was left relatively unchanged after 46 years of calibration. This allowed for detection of a 5 percent increase in water yield from the 494,211-acre burned basin, providing an average of an additional 50,000 acre-feet of water storage each year. However, the average timing of release advanced by 2 weeks because the exposed snowpack melted faster, and most of the additional runoff was available prior to April, when it would be of little use in bolstering low flows. Large-scale canopy treatments can also affect water quality, for example by warming stream temperatures (Isaak et al. 2010) or increasing sediment from additional road construction and use (Black et al. 2012; Luce and Black 1999).

A comprehensive summary of strategies and tactics for adapting water resource management to the effects of climate change can be found in Appendix 4.

Adapting Soils Management to the Effects of Climate Change

Though there has been a focus on forest soils management to increase carbon storage to mitigate climate change (e.g., Malmsheimer et al. 2008), little information is available on adapting management to maintain soil resistance and resilience to climate change. Changes in soils will take time, but unfortunately, they cannot be restored easily or quickly. Proactive, preventive methods are needed to increase the resistance and resilience of soils to climate change effects. Maintaining and protecting soil cover (both canopy and ground cover) and cryptobiotic crusts are critical to mitigating heating of the soil surface and reducing evaporation and runoff (table 14.2). Utilizing grazing management systems that promote healthy root systems in plants can help them to survive short-term weather events, such as periods of drought and temperature increases, and can protect soils. Other tactics that help to increase soil resilience include promoting native plant species and plant diversity, limiting establishment and expansion of invasive plants that disturb soil processes, and restoring degraded systems. Managers may also want to consider soil climate vulnerability mapping at various scales to categorize soils for their resilience to climate change (table 14.2).

Adapting Fisheries and Aquatic Habitat Management to the Effects of Climate Change

Many options are available to facilitate climate change adaptation and improve the resilience of fish populations. Adaptation for fish conservation has been the subject of several comprehensive reviews (Beechie et al. 2013; Isaak et al. 2012; ISAB 2007; Luce et al. 2013; Mantua and Raymond 2014; Rieman and Isaak 2010; Williams et al. 2015). Resource managers used information from these reviews and a vulnerability assessment for aquatic organisms (Chapter 5) to develop adaptation strategies and tactics for aquatic organisms in the IAP region (table 14.3). Strategies focused on increasing resilience of native fish species by restoring structure and function of streams, riparian areas, and wetlands; monitoring for invasive species and eliminating or controlling invasive populations; understanding and managing for community-level patterns and processes; and conducting biodiversity surveys to describe current baseline conditions and manage changes in fish distribution.

To increase resilience of native fish species and habitats, specific tactics include reconnecting floodplains and side channels to improve hyporheic and base flow conditions, ensuring that passage for aquatic organisms is effective, and maintaining large wood in forested riparian areas for shade and recruitment to streams (Peterson and Halofsky 2017). Accelerating restoration in riparian areas and meadows may be an effective and lasting way to improve hydrological function and water retention. Prioritizing watershed restoration is critical because funds, labor, and time for management of native fish populations are limited (Peterson et al. 2013). Maintaining or restoring American beaver populations provides a “natural” engineering alternative for water retention (Pollock et al. 2014, 2015). Managers may consider augmenting snowpack with snow fences, such as on the Wasatch Plateau, to increase late summer flows.

In stream systems adjacent to grasslands and shrublands, livestock grazing can damage aquatic habitat, causing stress that may be exacerbated by warmer stream temperatures (Peterson and Halofsky 2017). An important adaptation approach is to manage livestock grazing to restore ecological function of riparian vegetation and maintain streambank conditions. Specifically, managers can work to ensure that standards and guidelines for water quality are adhered to and monitored; alter the duration, timing, and intensity of grazing to improve streambank vegetative conditions; and make improvements that benefit water quality (e.g., offsite watering, fencing).

Interactions with nonnative fish species and other aquatic organisms are a significant stress for native cold-water fish species, and brook trout are a particular concern in the IAP region (Chapter 5). Removal of nonnative fish species, although challenging in some locations, may be the best option for maintaining or restoring native fish populations.

Table 14.2—Soils adaptation options for the Intermountain Adaptation Partnership region.

Sensitivity to climatic variability and change: Climate change will result in changes in soil temperature and soil moisture, thus affecting soil processes				
Adaptation strategy/approach: Increase soil resistance and resilience to climate change				
	Specific tactic – A	**Specific Tactic – B**	**Specific tactic – C**	**Specific tactic – D**
Tactic	Maintain or increase soil cover to mitigate heating of the soil and reduce carbon loss, evaporation, and runoff	Categorize soils for their resilience to climate change through completion of soil climate vulnerability mapping at various scales	Utilize grazing management systems that can respond quickly to short term periods of drought and temperature increases	Promote native plant species and plant diversity that is adapted to the projected soil properties
Where can tactics be applied?		National Forest plan revisions and individual project implementation assessments		
	Specific tactic – E	**Specific tactic – F**	**Specific tactic – G**	**Specific tactic – H**
Tactic	Maintain and protect soil cover (canopy and ground cover); manage to maintain or restore biological soil crusts where they are ecologically appropriate	Promote the maintenance and the addition of soil organic matter	Promote native vegetation and minimize the expansion of invasive species	Focus restoration efforts on areas that can support management objectives
Where can tactics be applied?	National, Regional and Forest level planning and guidance; project design; national best management practices	National, Regional and Forest level planning and guidance; project design; national best management practices	National, Regional and Forest level planning and guidance; project design; national best management practices	

Table 14.3—Aquatic organisms adaptation options for the Intermountain Adaptation Partnership region.

Sensitivity to climatic variability and change: Warmer stream temperatures may favor nonnative species			
Adaptation strategy/approach: Increase resilience of native fish species			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Manage livestock grazing to restore ecological function of riparian vegetation and maintain vegetated streambank conditions	Maintain large wood in forested riparian areas for shade and wood recruitment to streams; reconnect floodplains and side channels to improve hyporheic and baseflow conditions; conduct meadow restoration; augment snowpack with snow fences on the Wasatch Plateau to increase late summer flows	Reduce habitat fragmentation of native trout habitat through barrier removal (e.g., culverts and water diversions); restore native trout to high elevation, cold water refugia
Where can tactics be applied?	All perennial and intermittent streams and wetlands	All perennial and intermittent streams and wetlands	Prioritize areas based on site-specific conditions
Adaptation strategy/approach: Monitor for invasive species and suppress/eliminate/control populations			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Conduct environmental DNA (eDNA) monitoring for early detection of invasions	Reduce or suppress brook trout populations	Maintain or construct barriers to prevent spread of non-native species in headwaters
Where can tactics be applied?	High-value populations that are thought to be at significant risk of invasion	Headwater lakes that act as source populations; small, isolated streams where complete eradication is possible.	Southern portions of IAP region where stream habitats are smaller and more fragmented

Table 14.3 (continued)—Aquatic organisms adaptation options for the Intermountain Adaptation Partnership region.

Sensitivity to climatic variability and change: Climate change will lead to shifts in native species distributions and community reorganization			
Adaptation strategy/approach: Conduct biodiversity surveys to describe current baseline conditions and manage distribution shifts			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Formalize, expand and standardize biological monitoring programs (e.g., management indicator species)	Use modern, low-cost technologies like eDNA, DNA barcoding, and digital photo points	Use assisted migration to establish populations in suitable but currently unoccupied habitats
Where can tactics be applied?	Streams, rivers, and lakes throughout the IAP region	Streams, rivers, and lakes throughout the IAP region	Consider habitats outside of historical range (e.g., northern extent of species distributions) in addition to historical range
	Specific tactic – D	**Specific tactic – E**	**Specific tactic – F**
Tactic	Use digital technology in data collection and database uploads	Streamline and integrate field crew data collection protocols	Fully utilize existing corporate databases and legacy datasets
Where can tactics be applied?	Everywhere	Everywhere	Everywhere
Sensitivity to climatic variability and change: Climate change may lead to loss of biodiversity and exceeding ecological type thresholds (because of changes in connectivity, temperature, and water quantity)			
Adaptation strategy/approach: Understand and manage for community level patterns and processes			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Utilize the best available technology to monitor, record, and distribute information regarding the distribution of a broad array of aquatic species (e.g., use eDNA, national databases)	Develop and improve understanding, adaptive actions, and models related to non-game aquatic species (e.g., mussels, dace, sculpin, spring snails, and amphibians)	Continue to refine and improve understanding, adaptive actions, and models related to cold water salmonids
Where can tactics be applied?			

Environmental DNA (eDNA) monitoring can be useful for early detection of invasive species (table 14.3). To increase resilience of native species, maintaining or increasing habitat connectivity will be important to maintain access to summer cold-water refugia (Isaak et al. 2012). In some situations, however, improving habitat connectivity may present a dilemma, because newly accessible waters can be invaded by nonnative fish species that can extirpate native species (Fausch et al. 2009). In some cases, barriers can be installed to prevent nonnative species invasions. Native populations above barriers may be secure but could be susceptible to loss from extreme disturbance events in limited habitats, requiring human intervention to reestablish or supplement populations.

In a warmer climate, it is almost certain that increased wildfire occurrence will contribute to erosion and sediment delivery to streams, thus reducing water quality for fisheries (Luce et al. 2012). Increasing resilience of vegetation to wildfire may reduce the frequency and severity of fires when they occur. Hazardous fuels treatments that reduce forest stand densities and surface fuels are an adaptation tactic that is already widely used in dry forest ecosystems (Halofsky and Peterson 2016). Disconnecting roads from stream networks is especially important because roads are a major source of sediment delivery to streams (Luce et al. 2012). Finally, erosion control measures can reduce postfire sediment delivery and are often a component of Burned Area Emergency Response (commonly known as "BAER") on Federal lands.

Management actions in a changing climate will be more effective when informed by baseline surveys and long-term monitoring (Isaak et al. 2016). More data are needed for streamflow (more sites), stream temperature (annual data from sensors maintained over many years), and distributions of aquatic organisms. These data can be used for improved status-and-trend descriptions and to develop robust (more accurate and precise) models for species to understand the interactions of climate change, natural variation, and land management on aquatic species. The NorWeST stream temperature database (described in Chapter 5) could provide information for monitoring network design. The feasibility of monitoring at small to broad scales is increasing with the advent of rapid, reliable eDNA inventories of aquatic organisms (Thomsen et al. 2012) and the availability of inexpensive, reliable temperature and flow sensors (USEPA 2014).

A comprehensive summary of strategies and tactics for adapting fisheries and aquatic habitat management to the effects of climate change can be found in Appendix 5.

Adapting Forest Vegetation Management to the Effects of Climate Change

In the IAP region, wildfire exclusion, combined with extensive even-aged timber management and other land uses, has resulted in dry forests at risk to wildfire, insects, and disease (Schoennagel et al. 2004). As in other adaptation efforts (Halofsky and Peterson 2016; Peterson and Halofsky 2017), many tactics developed by IAP managers were focused on increasing resilience of forests to disturbance, mainly fire (table 14.4). Thinning and prescribed fire can both be used to reduce forest density and promote drought- and disturbance-resilient species, such as western larch. Promoting landscape diversity, in terms of species, age classes, and structure, is also likely to increase forest resilience to wildfire, insects, and disease (Janowiak et al. 2014). Promoting legacy trees of disturbance-resilient species may help to increase postfire regeneration. Managers may also want to increase seed collection and ensure that adequate nursery stock is available for postdisturbance planting (e.g., serotinous lodgepole pine) (Halofsky and Peterson 2016). Better understanding of potential disturbance regimes of the future and potential thresholds will help managers to better assist in ecosystem transition (Janowiak et al. 2014). With larger fires in the future, it will also be increasingly important for agencies to coordinate and work across boundaries to manage and suppress fire (Spies et al. 2010).

The area of alpine and subalpine vegetation will probably decrease in the IAP region, and frequency of drought and fire is likely to increase in subalpine forests (Chapter 6). Development of a consistent monitoring framework that can capture ecosystem changes with shifting climate is a key adaptation approach (Halofsky and Peterson 2016). For example, tracking tree species regeneration and distribution will help managers to determine how species are responding to climatic changes and how to adjust management accordingly (e.g., guidelines for planting). For species that are currently stressed, such as spruce and fir species in the subalpine zone, seed collection, regeneration treatments, and planting may be necessary to ensure their persistence on the landscape.

Climate change will probably accelerate whitebark pine mortality through increased mountain pine beetle activity, fire, and white pine blister rust (Chapter 8). There is also likely to be a loss of site conditions that support whitebark pine (Chapter 6). To promote resilient whitebark pine communities, managers may want to focus restoration efforts on sites less likely to be affected by climate change (i.e., refugia). A variety of management strategies can be implemented to promote whitebark pine, including fire management with fuelbreaks, removing competing species (e.g., subalpine fir), and increasing structural and age-class diversity of whitebark pine communities (Keane et al. 2017). Genetically selected seedlings can be planted to promote

Table 14.4—Forested vegetation adaptation options for the Intermountain Adaptation Partnership Region.

Sensitivity to climatic variability and change: Increased disturbance with climate change will affect patterns, structure, and species composition at large spatial scales			
Adaptation strategy/approach: Create landscape patterns that are resilient to past and expected disturbance regimes			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Continue research on expected future disturbance regimes; evaluate potential transitions and thresholds	Improve communication across boundaries	Manage for diversity of structure and patch size with fire and mechanical treatments
Where can tactics be applied?	Local, Regional, and National scales	Internally and externally (with partners)	Watershed(s)
Sensitivity to climatic variability and change: Lack of disturbance has caused shifts in species composition and structure in dry mixed-conifer forests, putting them at risk of high-severity fire with climate change			
Adaptation strategy/approach: Maintain and restore species and age-class diversity			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Identify and map highest risk areas at large spatial sales to provide context for prioritization	Reduce stand density and shift composition toward species that are more fire adaptive and drought tolerant	Restore age class diversity while protecting legacy trees
Where can tactics be applied?	All lands	Prioritize highest risk stands in terms of fire, insects, and disease	Prioritize highest risk stands in terms of fire, insects, and disease that currently contain a component of legacy trees
Sensitivity to climatic variability and change: Western larch habitat and regeneration may be reduced with climate change			
Adaptation strategy/approach: Increase the competitive ability of western larch and its resilience to changing fire regimes			
	Specific tactic – A	**Specific tactic – B**	
Tactic	Create gaps in forests to reduce competition and increase larch vigor	Regenerate larch with appropriate site preparation (e.g., prescribed burning, followed by planting); create appropriate fire regimes and fuel loads	
Where can tactics be applied?	Stands with larch	Habitats that can support larch	
Sensitivity to climatic variability and change: Climate change may lead to an incursion of upper treeline into alpine communities			
Adaptation strategy/approach: Acquire information to develop a better understanding of high-elevation system sensitivity to climate change			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Establish monitoring sites	Develop seed transfer guidelines.	Develop seed collection and storage guidelines
Where can tactics be applied?	Research natural areas	Research natural areas	

Sensitivity to climatic variability and change: Climate change may lead to a reduced spruce-fir component in subalpine spruce-fir forests, which will be exacerbated by ongoing spruce beetle outbreaks that have reduced available seed sources

Adaptation strategy/approach: Maintain species and age class diversity in subalpine spruce-fir forests

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Conduct regeneration treatments (e.g., harvest, prescribed fire) that focus on maintaining species diversity; plant a variety of species, including Engelmann spruce, Douglas-fir and lodgepole pine	Collect seed that will cover a wide range of seed zones and species	Plant a genetically diverse mix based on adaptive traits
Where can tactics be applied?	Forest and adjacent lands	Forest and adjacent lands	Forest and adjacent lands

Sensitivity to climatic variability and change: Large-scale disturbance with climate change will affect landscape structural diversity of persistent lodgepole pine and available seeds sources

Adaptation strategy/approach: Maintain landscape heterogeneity to mitigate adverse impacts on lodgepole pine from fire and mountain pine beetles

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Promote structural diversity at multiple scales	Focus attention on collection of viable serotinous lodgepole pine seed sources	Use available mapping products to identify areas of potential serotinous lodgepole pine seed sources
Where can tactics be applied?	Homogeneous landscapes	From serotinous lodgepole pine cones that cover a wide range of elevation bands on forest and adjacent lands	Forest and adjacent landowners

Sensitivity to climatic variability and change: Large-scale disturbances with climate change (e.g., beetles, fire, white pine blister rust) will negatively affect whitebark pine

Adaptation strategy/approach: Increase the competitive ability and resilience of whitebark pine to changing disturbance regimes

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Control beetles (use Verbenone after snowmelt)	Daylight (thin) to reduce competition (usually involves removing subalpine fir)	Regenerate rust-resistant strains; increase seed sources; maintain cache sites
Where can tactics be applied?	Protect trees in high-value areas; important in central Idaho and the Greater Yellowstone Area	Implement in accessible areas and high value areas (best rust resistant areas and areas of high habitat and recreation value)	Areas of disturbance, or areas with low resistance; maintain density for Clark's nutcracker
	Specific tactic – D	**Specific tactic – E**	**Specific tactic – F**
Tactic	Create fuel breaks in locations adjacent to subalpine fir or other lethal fire regime areas	Improve structural and age class diversity of whitebark communities at multiple scales	Restore sites where the species is currently absent
Where can tactics be applied?	In accessible and high value areas	Whitebark pine communities dominated by late successional conifer species	Sites that have present and future potential to support whitebark pine

Table 14.4(continued)—Forested vegetation adaptation options for the Intermountain Adaptation Partnership Region.

Sensitivity to climatic variability and change: Direct and indirect effects of climate change will reduce the capacity for aspen stand regeneration			
Adaptation strategy/approach: Increase the capacity for aspen stand regeneration			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Increase the proportion of the landscape that is in early successional stages	Maximize flexibility in managing herbivory	Maximize genetic diversity
Where can tactics be applied?	Landscapes with high proportion of later-seral aspen in mixed-conifer forest	Focus on sites with good aspen site potential	On landscapes following severe fire
Sensitivity to climatic variability and change: Climate change may lead to reduced water availability on the fringe of persistent aspen communities.			
Adaptation strategy/approach: Focus treatments on areas where persistent aspen communities are expected to expand and maintain communities where future climatic conditions will allow			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Remove competing vegetation (e.g., juniper) and control ungulate browsing to allow for recruitment	Reduce density of conifer species	Use available mapping products to identify areas of potential expansion
Where can tactics be applied?	On existing fringe persistent aspen communities	Outside of existing stands where persistent aspen is expected to expand	Areas adjacent to existing persistent aspen
Sensitivity to climatic variability and change: Climate change will lead to shifts in hydrologic regime, altering the timing and magnitude of flows. Anticipated changes include lower summer flows, higher winter flows, and a potential decrease in riparian vegetation abundance			
Adaptation strategy/approach: Maintain and promote riparian area and wetland processes and functions.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Manage upland vegetation that influences riparian and wetland function and process (e.g., with thinning and prescribed fire)	Restore riparian obligate species	Promote stream channel function
Where can tactics be applied?	Adjacent to riparian vegetation, where conditions do not optimize or promote riparian function and process; where conifers are encroaching in meadows and grasslands	Where upland, invasive or undesirable species are outcompeting natives; locations that have been inappropriately managed in the past	Where stream function is impaired; prioritize treatments where they are most likely to be effective

blister rust resistance. Managers may want to control beetle outbreaks in whitebark pine with Verbenone, particularly in high-value areas.

Recent decline has made quaking aspen a species of concern in the IAP region (Chapter 7), particularly because of its value as wildlife habitat (see the *Adapting Terrestrial Animal Management to the Effects of Climate Change* section below). Direct and indirect effects of future climate change may further stress this species. In older aspen stands, increasing the early-seral component may help to increase resilience. On sites with good aspen potential, managing herbivory by wildlife and livestock will help to ensure aspen regeneration and stand development (Rogers and Mittanck 2014). Removing competing vegetation, such as juniper and other conifers, is likely to help to increase aspen vigor and regeneration. Following fire, maximizing genetic diversity will help to ensure future persistence of aspen (DeRose et al. 2014).

Key climate change vulnerabilities for riparian areas and GDEs include shifts in the hydrological regime (changes in timing and magnitude of flows, lower summer flows) and changing biotic productivity and diversity in springs and wetlands. Maintaining or restoring stream channel form helps to increase hydrological function and store water, thereby benefiting riparian and wetland vegetation, water quality, and aquatic habitat (Peterson and Halofsky 2017). Restoring and protecting riparian vegetation by managing livestock, wild horse and burro, and recreational use similarly helps to protect aquatic habitat and water quality by increasing water storage and providing shade to streams (Peterson and Halofsky 2017). In areas where upland, invasive, or undesirable species are outcompeting native species, restoring riparian and wetland obligate species may help to restore ecological function. Riparian zones will probably burn more frequently with warming climate, and thus managers may want to manage upland vegetation to reduce impacts in riparian areas (Luce et al. 2012). In some riparian areas, managers may want to reintroduce fire to help facilitate the transition to future conditions.

A comprehensive summary of strategies and tactics for adapting forest vegetation management to the effects of climate change can be found in Appendix 6.

Adapting Nonforest Vegetation Management to the Effects of Climate Change

Nonforest vegetation in the IAP region will almost certainly be affected by altered fire regimes, increased drought, and increased establishment of invasive species in a changing climate (Chapter 7). Effects of climate change will also compound existing stressors in nonforest ecosystems caused by human activities (Chapter 7). Thus, adaptation options for nonforest vegetation focus on increasing the resilience of rangeland ecosystems, including sagebrush and persistent pinyon-juniper ecosystems (table 14.5).

To control invasive species in rangelands, managers suggested minimizing spread and using biological controls, herbicides, and mechanical treatments (table 14.5). It may be particularly important to protect refugia, or areas that have not been invaded, and make sure that invasive species do not become established. Proactive management tactics such as early detection and rapid response can be used for new invasions (Reeves et al. 2017). Conducting outreach to educate employees and the public about invasive species and increasing collaboration among landowners and managers will also be necessary to effectively control invasive species (Hellmann et al. 2008).

In addition to invasive species control and prevention, grazing management will be important in maintaining and increasing resilience of nonforest vegetation to climate change. Climatic changes will lead to altered availability of forage and water, requiring some reconsideration of grazing strategies; flexible and perhaps novel grazing management plans may be necessary (Reeves et al. 2017). For example, altering the timing of use from year to year may help encourage recovery of all species by avoiding stress at the same period of growth (or dormancy) every year. Adapting grazing management may be particularly effective in allotments where soils and hydrology will support future sagebrush ecosystems in a warming climate (table 14.5).

To maintain native perennial species in sagebrush ecosystems, native seed sources adapted to future climatic conditions can be used for planting and restoration, fuelbreaks and fencing can be used for protection, and modified grazing strategies can be used to allow for flexibility in season of use (Reeves et al. 2017). Developing modified seed zones and promoting propagation of native seed sources for sagebrush ecosystems will help to ensure the success of restoration efforts. In sagebrush ecosystems where pinyon pine and juniper have encroached, active management (removal) is likely to help increase sagebrush resilience (Creutzburg et al. 2014). Given limited budgets, managers will need to prioritize areas for treatments where they will get the most return on investment (table 14.5).

A comprehensive summary of strategies and tactics for adapting nonforest vegetation management to the effects of climate change can be found in Appendix 7.

Adapting to the Effects of Ecological Disturbances in a Changing Climate

The frequency and extent of wildfire are likely to increase with warming in many dry forest and shrubland ecosystems of the IAP region (Littell et al. 2009). Increased fire activity was identified during the workshops as a primary concern for resource managers in the IAP because of the potential negative effects on species, ecosystems, and

Table 14.5—Non-forested vegetation adaptation options for the Intermountain Adaptation Partnership Region.

Sensitivity to climatic variability and change: Climate change may lead to further loss of sagebrush ecosystems (Wyoming, mountain, basin big sagebrush species)			
Adaptation strategy/approach: Improve resilience and resistance of sagebrush ecosystems			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Control invasive species affecting ecology of sagebrush ecosystems by minimizing spread and using biological controls, herbicides, and mechanical treatments	Maintain native perennials by: utilizing native seed sources for restoration (planting) that will be adapted to future climate conditions; using fuel breaks and fencing for protection; modifying grazing strategies to allow for flexibility in season of use	Map resilience and resistance to climate change to aid in prioritizing areas for treatments
Where can tactics be applied?	Prioritize and implement in areas with high probability of treatment success and in areas of high value	Prioritize and implement in areas with high probability of treatment success and in areas of high value	Across all areas using soil, vegetation and existing information; utilize sagebrush resilience and resistance rating criteria
	Specific tactic – D	**Specific tactic – E**	**Specific tactic – F**
Tactic	Develop seed zones and promote propagation of native seed sources for sagebrush ecosystems	Adapt grazing management to changing climates and ecological potential	Protect refugia; if annuals grasses are not present, keep them out through: repeat monitoring (of experiments with controls); education; seed collection; and genetic analysis
Where can tactics be applied?	Region-wide seed zone mapping	Allotments where soils and hydrology support future sagebrush ecosystems in a warming climate	
	Specific tactic – G	**Specific tactic – H**	**Specific tactic – I**
Tactic	Actively manage pinyon-juniper encroachment to maintain sagebrush ecosystems	Adapt grazing management practices and policies to improve ecological resilience and resistance	Protect existing sagebrush communities from fire
Where can tactics be applied?	Phase 1 and 2 pinyon-juniper communities	All grazing allotments	Areas where dry sagebrush plant communities exist and have long fire return intervals
Sensitivity to climatic variability and change: Climate change may lead to a loss of climatically suitable habitat for persistent pinyon-juniper ecosystems			
Adaptation strategy/approach: Maintain and restore ecological integrity of persistent pinyon-juniper communities			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Identify and map persistent pinyon-juniper communities and assess current conditions	Reduce invasive species; maintain or restore native understory composition	Maintain or restore structural diversity to promote natural disturbance regimes
Where can tactics be applied?	All lands	At-risk persistent communities	At-risk persistent communities

ecosystem services. Managers recommended that fuels treatments be conducted in strategic locations with the goal of protecting the wildland-urban interface and other high-value resources (table 14.6). Effective fire management requires better communication that helps clarify what actions need to occur and in what locations. For example, fire managers need to know when it is acceptable for a fire to cross administrative boundaries (e.g., move from USFS to Bureau of Land Management lands). As noted previously, with larger fires in the future, it will be increasingly important for agencies to coordinate and work across boundaries to both manage (e.g., fire for resource benefit) and suppress fire (Spies et al. 2010).

After fires occur, managers will need to identify, prioritize, and protect values at risk from postfire events such as flooding, erosion, and drought (e.g., soil, water, infrastructure, and vegetation) (table 14.6) (Luce et al. 2012). Programs could be initiated to assess values and determine the best protective actions to prevent negative impacts on species and ecosystems. Proactive, strategic plans for postfire response and restoration would make postfire management more efficient and effective over the long term. Postfire management would also benefit from increased collaboration among agencies.

Native insect species have long played a role in ecosystem dynamics in the IAP (Chapter 8), and it will be important to recognize the role of insects and accept that there will be insect-caused tree mortality under changing climate. However, there are some management actions that may increase ecosystem resilience to native insect outbreaks, such as mountain pine beetle outbreaks. For example, restoring historical fire regimes in dry forests, and increasing diversity of forest structure and age and size classes may help to minimize the impacts of insect outbreaks (Churchill et al. 2013). Increasing tree species diversity may also help to improve resilience to insect outbreaks (Dymond et al. 2014), particularly in low-diversity stands. In high-value areas, tactics such as beetle traps, spraying, and pheromones can be used to control beetles (table 14.6).

To manage invasive insect outbreaks, a first step is to identify nonnative invasive insects currently in the region (e.g., balsam woolly adelgid), monitor them, and consider potential future distribution. Monitoring could also be done for other invasive insects that are not currently present in the region, but that may be a future risk (e.g., spruce aphid, spruce-fir looper). Development of an integrated pest management strategy would help guide strategic monitoring and response to invasive insect outbreaks.

Human activities can also be considered a type of ecosystem disturbance, and climate change may exacerbate stresses to ecosystems and infrastructure caused by more people residing in the forest environment (table 14.6). To mitigate human impacts on ecosystems, managers can work to minimize increases in area of human disturbance and minimize adverse effects of infrastructure (roads, driveways, power lines, water delivery) on National Forest lands. Increasing ecological connectivity and habitat continuity and viability will also help plants and animals adjust to human disturbance and climate change effects (Mawdsley et al. 2009).

A comprehensive summary of strategies and tactics for adapting to the effects of increased disturbance with climate change can be found in Appendix 8.

Adapting Terrestrial Animal Management to the Effects of Climate Change

Effects of climate change on terrestrial animals (wildlife) may already be recognized as threats (e.g., loss of wetlands or old-growth forest) or may point toward novel impacts (e.g., effects of earlier snowmelt). Exacerbation of current threats may require intensified conservation efforts, while threats unique to climate change will require innovative strategies (Bagne et al. 2014). The key to finding effective management actions is to identify the factors responsible for how a species may be vulnerable or resilient. In addition to enhancing single species management, a list of species and their vulnerabilities can make efforts more efficient by identifying common issues among species.

Increased water stress is likely to be a common issue among many animal species in the IAP region in a changing climate (table 14.7) (Chapter 9). Increasing temperatures and changing hydrology will affect riparian areas and, in particular, wetlands. Riparian and wetland habitats are important for many wildlife species across the IAP region (Chapter 9). The primary strategy for improving riparian habitat resilience is to restore or preserve floodplain connectivity appropriate to the landscape setting to promote retention of flood flows and improved storage of groundwater; maintaining healthy American beaver populations is one of several ways that this can be accomplished (Pollock et al. 2014, 2015). Beaver complexes can buffer riparian systems against both low and high streamflows, and provide habitat structure and foraging opportunities for multiple species. As described previously, increasing hydrological function and minimizing stressors (e.g., unmanaged or mismanaged livestock grazing and recreational use) to riparian and wetland systems will help to increase their resilience, and the resilience of species that depend on them, to climate change (Peterson and Halofsky 2017). Promoting connectivity of riparian habitat conditions along stream networks can also help to provide for animal movement and range shifts (Mawdsley et al. 2009).

Removal or control of invasive plants or animals is another strategy that is likely to increase resilience of plant communities and wildlife that depend on them. Climate change may present more opportunities for establishment of invasive species. However, control of invasive species may be more successful when they are stressed by climate extremes (Higgins and Wilde 2005; Rahel and Olden 2008).

Table 14.6—Ecological disturbance adaptation options for the Intermountain Adaptation Partnership region.

Sensitivity to climatic variability and change: Wildfires will increase with warmer and drier conditions under changing climate			
Adaptation strategy/approach: Reduce the adverse effects of fire in the wildland-urban interface (WUI) and other non-negotiable values while allowing fire to play a natural role on the landscape			
	Specific tactic – A	**Specific tactic – B**	
Tactic	Strategically place fuel treatments to manage for wildfire in an ecologically appropriate way depending on vegetation types; some treatments may be out of natural range of variation to protect values	Develop communications strategy to determine what needs to happen and where before fires occur (e.g., need to know when it is acceptable to let fires cross boundaries and when it is not); all partners need to be involved	
Where can tactics be applied?	In the WUI and other strategic locations; consider management boundaries (wilderness), topography, dominant winds	Needs to be an "all lands" approach: counties, states, residents, Bureau of Land Management, National Park Service, etc.; for the Forest Service, both Forests and Districts need to be involved	
Adaptation strategy/approach: Conduct post-fire restoration and manage post-disturbance response			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Identify, prioritize and protect values at risk; initiate programs to assess values and determine best protective actions	Conduct pre-fire planning to improve response time and efficiency, prioritizing key areas at risk to geologic hazard	Conduct post-fire vegetation management and prevent invasives with weed control and monitoring
Where can tactics be applied?	Needs to be done at Forest level, as it will be dictated by local needs; focus on areas threatening public health and safety	Needs to be an "all lands" approach; for Forest Service, both Forests and Districts need to be involved	In key areas identified in pre-planning and Burned Area Emergency Response; monitor invasives in transition zones between ecotypes, south-facing slopes, along road corridors, and campgrounds
Adaptation strategy/approach: To protect values on the landscape, allow for more managed fire to reduce available fuel loadings			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Develop understanding or products that help managers and line officers make decisions on managing long duration fires; incorporate information learned into the Wildland Fire Decision Support System	Utilize a risk benefit model to identify key locations where fuels modifications would benefit the potential use of managed fire	Find opportunities to work with partners to expand use of natural fire ignitions (support network of collaborators); increase education to public on the role of fire on the landscape
Where can tactics be applied?	Anywhere on the landscape	All fire-prone landscapes	Lands adjacent to local communities

Table 14.6 (continued)—Ecological disturbance adaptation options for the Intermountain Adaptation Partnership region.

Sensitivity to climatic variability and change: Climate change will likely result in increased mortality caused by native insects and diseases (bark beetles, defoliators, and dwarf mistletoes)			
Adaptation strategy/approach: Increase resistance and resilience to insects and disease in stands and landscapes			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Manage for age, size class, and species diversity	Protect high value areas with trap tree felling, beetle traps, spraying, reduced basal area, beetle risk rating, and pheromones	Protect and manage areas of special classification
Where can tactics be applied?	High value landscapes with low diversity; limited to where there is access	Areas of high value	Roadless areas, wilderness, and areas restricted to non-mechanical treatments
Sensitivity to climatic variability and change: Invasive insects may increase with changing climate			
Adaptation strategy/approach: Increase resilience and resistance of trees to invasive insects			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Develop an integrated pest management strategy, including identifying insect-resistant seed (balsam woolly adelgid)	Identify current and projected distribution of balsam woolly adelgid and other species	Identify and monitor other non-native, invasive insects (e.g., spruce aphid, spruce-fir looper) not currently present in the region but that may be a future risk
Where can tactics be applied?	In true fir communities and subalpine areas	In true fir communities; Region-wide; areas where loss of subalpine fir would be ecologically significant	Region-wide
Sensitivity to climatic variability and change: More people residing in the forest environment will increase stresses to ecosystems, infrastructure, and biological and physical resources; shifting of utilization of ecosystem services closer to the source			
Adaptation strategy/approach: Manage for the human disturbance footprint caused by higher populations of people living in forests and the forest interface			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Manage the effects of infrastructure (roads, driveways, powerlines, water delivery) on national forest lands	Minimize increases in areas of disturbance	Manage ecological connectivity and energy flow; maintain habitat continuity and viability
Where can tactics be applied?	Apply on roads and driveways and with collaborators responsible for the whole system (e.g., the power company, county transportation department, canal company)	In and around residential and other development	Maintain natural corridors (streams, riparian) where they exist; maintain large habitat blocks; maintain habitat diversity in appropriate proximities

Table 14.7—Terrestrial animal adaptation options for the Intermountain Adaptation Partnership region.

Sensitivity to climatic variability and change: Vegetation and animals will be stressed because of reduced soil moisture with changes in timing and amount of precipitation, drought, and earlier snowmelt under changing climate			
Adaptation strategy/approach: Restore and enhance water resource function and distribution at the appropriate watershed level; prioritize watersheds based on condition and a variety of resource values, including terrestrial animals			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Improve management of existing seep and spring water developments, and design proposed developments for ecological appropriateness	Manage for maintenance of vegetative cover sufficient to retain snowpack within watersheds	Provide enhanced water distribution with appropriate wildlife use designs and balance water use with wildlife needs; protect headwaters, spring heads, riparian areas, etc.
Where can tactics be applied?	Any wasteful or redundant developments, or on sites causing unintended ecological consequences	Particularly within subalpine ecosystems, but also other areas targeted for vegetation management activities	Areas where there is concern about amphibian populations and other wildlife species dependent on water sources
	Specific tactic – D	**Specific tactic – E**	**Specific tactic – F**
Tactic	Reduce biomass to reduce evapotranspiration and mortality resulting from water stress for groundwater-fed systems (with thinning and other vegetation treatments) and maintain shade for non-groundwater fed systems	Increase water storage by managing for beaver populations using a comprehensive beaver strategy, and by reducing cattle impacts on small water sources	Actively restore and maintain functioning wetlands; manage grazing to promote riparian and wetland function
Where can tactics be applied?	Suggested scale of HUC 8 to 12 based on assessment for watershed prioritization	Riparian areas where conditions are appropriate (presence of aspen and willow) that will not result in conflict (culvert damage, flooding roads)	

Table 14.7 (continued)—Terrestrial animal adaptation options for the Intermountain Adaptation Partnership region.

Sensitivity to climatic variability and change: Changing intensity and frequency of fire with climate change will decrease area and connectivity of some habitats, notably late-successional and mature forest and big sagebrush			
Adaptation strategy/approach: Maintain current habitat, restore historical habitat, promote potential future habitat, and increase resilience of these habitats			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Strategically place fuel breaks to minimize risk to important habitat areas	Restore disturbance regimes by reducing accumulated fuel loads; remove pinyon and juniper in sagebrush ecosystems; where there are fire deficits, allow wildfires to burn for resource benefit	Identify areas that will support late-successional and mature forests and big sagebrush in the future, and mange to promote their development and resilience
Where can tactics be applied?	On the windward side of important habitat areas; place in a configuration to minimize risk of fire spread across the landscape	Within the habitats where uncharacteristic fuel loads have developed; balance with other objectives for species dependent on a complex understory	Identify where disturbance regimes associated with your target habitat will shift, and focus restoration on those areas and connectivity to those areas
Sensitivity to climatic variability and change: Climate change may increase uncharacteristic fires in ponderosa pine that result in loss of late-seral forest and snags (affecting Lewis' woodpecker, Allen's big-eared bat, Abert's squirrel, northern goshawk, and Utah prairie dog)			
Adaptation strategy/approach: Maintain current habitat, restore historical structure, and increase mosaic structure (including snags).			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Conduct thinning and prescribed fire treatments; use thinning from below; maintain natural structure (diversity and density); control ladder fuels	Manage grazing to discourage overgrazing of native plants and to maintain fine fuels to carry fire	Plant adapted (locally-sourced) ponderosa pine
Where can tactics be applied?	Existing stands on public and private lands (although thinning is limited in roadless areas and wilderness)	Everywhere ponderosa pine occurs	In areas where stand-replacing fires have occurred, keeping in mind the capacity of the area to support ponderosa pine (soils and water considerations)

Table 14.7 (continued)—Terrestrial animal adaptation options for the Intermountain Adaptation Partnership region.

Sensitivity to climatic variability and change: Climate change will likely lead to increased fire frequency, which may lead to loss of mixed-age aspen stands and loss of mature aspen and snags (affecting ruffed grouse, flammulated owl, goshawk, and many other species)			
Adaptation strategy/approach: Maintain/sustain/retain aspen and encourage recruitment to the overstory			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Remove conifers with prescribed fire and logging	Protect/encourage regeneration using fencing, ungulate management (reduce numbers and change season of use [graze early]), and development plans like that implemented by Wolf Creek Ranch (works closely with Wild Utah Project)	Conduct public outreach to help manage for aspen snags; restrict firewood cutting; target ranchette owners with information; include aspen in public education; use "this is a wildlife home" signs and similar tools
Where can tactics be applied?	Forest, state, and private lands that are with conifer encroachment	Anywhere	Schools, anywhere
Sensitivity to climatic variability and change: Climate change will lead to changes in alpine species composition (of both plants and animals, e.g., spruce-fir encroachment, rodents, humans) because of shrinking snowpack, changes in timing of snowmelt, and increasing temperatures that allow species to move up into alpine ecosystems (affecting pika, endemic plants, pollinators, and black rosy finch)			
Adaptation strategy/approach: Reduce additional stressors in alpine habitats			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Manage human access (e.g., build trails, harden sites, use permit systems or outfitter guides)	Maintain mountain goats at population levels that eliminate adverse impacts (remove goats if needed and discourage continued introduction of goats)	Monitor movement of plants (including both conifers and exotic weeds) and monitor movement of treeline
Where can tactics be applied?	Alpine trailheads; areas of high use (e.g., La Sals)	La Sals, Tushars, Mt. Dunton, Ashley	Everywhere habitat is present

Preventive and early intervention programs to control invasive species can be applied where range expansion is predicted (Davies and Johnson 2011). Targeting the vulnerabilities of undesirable species fits well with “no regrets” and “win-win” strategies of climate change adaptation (Bagne and Finch 2013; Peterson et al. 2011b).

Changing fire regimes are another climate stressor common to many species in the IAP region (Chapter 8). Changing intensity and frequency of fire with climate change are likely to decrease area and connectivity of some habitats, notably late-successional and mature forest and big sagebrush (Chmura et al. 2011). Fuels reduction and strategic placement of fuelbreaks could help to lower fire severity and protect valued habitats (Peterson et al. 2011a). In ponderosa pine forests, where there are currently high levels of fuel loading relative to historical conditions (Chapter 6), creating more open conditions with fewer trees may be desirable for long-term sustainability in areas where increased seasonal drought stress is anticipated. Diverse understory food plants and shrub patches are important components of this habitat, and minimizing grazing impacts and controlling invasive plants can help to maintain characteristic fuel patterns and understory diversity (table 14.7). In areas where stand-replacing fires have occurred, planting adapted (locally sourced) ponderosa pine is likely to enhance survival. A significant challenge will be promoting the development of large tree and open understory conditions in capable areas where large trees of fire-resilient species are not currently present (Stine et al. 2014).

Quaking aspen was identified as important because of its high productivity, role in structural diversity, and habitat for cavity-nesting birds. Ruffed grouse were also identified as strongly tied to aspen habitats. Reduction in the distribution and abundance of aspen is projected for some locations (especially lower elevation) in a warmer climate (Chapter 6). Tactics for promoting aspen resilience are use of prescribed fire and logging to remove conifers from aspen stands, protection from grazing, and public outreach on the importance of aspen for wildlife habitat (table 14.7).

In high-elevation alpine habitats, climate change will probably alter species composition of both plants and animals because of shrinking snowpack, changes in timing of snowmelt, and increasing temperatures that allow species to move into alpine ecosystems (Chapter 6). Minimizing new stressors on alpine ecosystems may help to increase their resilience. For example, mountain goat populations can be maintained at levels that eliminate adverse impacts. As snow-based recreation is concentrated in smaller areas, efforts to minimize human impacts may be needed. Identifying and protecting climate and disturbance refugia can help to maintain high-elevation habitats for wildlife (Morelli et al. 2016). Population monitoring can also be a useful tool when climate effects or management options are uncertain.

A comprehensive summary of strategies and tactics for adapting terrestrial animal and habitat management to the effects of climate change can be found in Appendix 9.

Adapting Outdoor Recreation Management to the Effects of Climate Change

Outdoor recreationists are highly adaptable to changing conditions (Hand and Lawson 2017). For example, water-based recreationists may adapt to climate change by choosing different sites that are less susceptible to changes in water levels (e.g., by seeking higher-elevation natural lakes) and changing the type of water-based recreation activity they engage in (e.g., from motorized boating on reservoirs to nonmotorized boating on natural lakes). Hunters may adapt by altering the timing and location of hunts or by targeting different species. Similarly, wildlife viewers may change the timing and location of viewing experiences and target different species. However, adaptation options for wildlife recreation may be limited if the abundance or distribution of highly valued species decreases the chance of viewing, and if substitute species are not available (Scott et al. 2007).

Management of recreation by Federal agencies may present considerable challenges under climate change (Hand and Lawson 2017). Managers may need to reconsider how infrastructure investments and the provisioning and maintenance of facilities align with changing ecological conditions and demands for recreation settings. The Recreation Opportunity Spectrum (Clark and Stankey 1979) can be used to match changing conditions and preferences to the allocation of available recreation opportunities. Adaptation by managers may take the form of responding to changing recreation patterns, but also helping to shape the settings and experiences that are available to recreation users on public lands in the future (Hand and Lawson 2017).

For winter recreation, a general adaptation strategy is to transition recreation management to address shorter winter recreation seasons and changing recreational use patterns. Specifically, opportunities may exist to expand facilities where concentrated use increases, and options for snow-based recreation can be diversified to include more snowmaking, additional ski lifts, and higher-elevation runs (Scott and McBoyle 2007). In some cases, however, adaptation actions related to the availability and quality of winter recreation opportunities could result in tradeoffs with other activities (e.g., warm-weather access to higher-elevation sites or effects of snowmaking on streamflow) (Hand and Lawson 2017).

With higher temperatures and earlier snowmelt, warm-weather activity seasons are likely to lengthen (Mendelsohn and Markowski 2004). Recreation managers have options for responding to changing patterns in warm season recreation demand in order to provide sustainable recreation opportunities. A first step will be to conduct assessments to understand the changing patterns of use (Hand and Lawson 2017) (table 14.8). Then, adjustments can be made to increase the capacity of recreation sites that are showing

Table 14.8—Recreation adaptation options for the Intermountain Adaptation Partnership region.

Sensitivity to climatic variability and change: Climate change will lead to changes in recreation use patterns (year-round seasons for non-snow activities, shift in snow-dependent activities, changes in use types and demand)			
Adaptation strategy/approach: Increase flexibility and capacity for managing recreation resources to meet shifting demands			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Develop creative budget strategies to support longer/overlapping use seasons; pursue additional grant funding and partnerships and opportunities for new fees (e.g., something similar to Adventure Pass, parking fees, use for peak use times); leverage outfitting and guiding funds	Increase flexibility for year-round use of facilities; redevelop/harden/mitigate existing or new sites (e.g., integrate summer uses into ski area operations); pave access roads for winter and wet uses; install gates or other access control where snow no longer closes areas; change types of infrastructure (e.g., marinas used to be static but now need to be flexible); increase capacity at existing sites to accommodate longer use seasons	Leverage local partnerships to assist with management of recreation facilities (e.g., develop partnerships with local government, other agencies, tribes, and user groups, non-governmental organizations; promote trail adoption; facilitate local economic development opportunities)
Where can tactics be applied?	Forest- and region-wide; all recreation sites	Places with vulnerability to flooding, changing water levels, and expanding summer activities in previously winter-only areas; consider design for year round use (vault versus flush toilets)	Forest- and region-wide; especially important in areas that are far from National Forest facilities
	Specific tactic – D	**Specific tactic – E**	**Specific tactic – F**
Tactic	Implement seasonal use and/or permitting for activities that are usually seasonally constrained but that may have longer seasons with warming climate (e.g., all-terrain vehicles, mountain biking)	Develop capacity for flexibility in seasons (opening dates for campgrounds, access to trails, road closures)	Evaluate impacts to resources and potential conflicts between user groups with changes in seasonal use
Where can tactics be applied?	Especially at higher elevations	Analysis of need done at Regional level, each unit left to carry out in practice	District and Forest level decisions
Sensitivity to climatic variability and change: Season of use, types of recreation, and location of activities may change as the climate changes			
Adaptation strategy/approach: Identify and prioritize recreational sites that are prone to change			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Use predictive modeling that incorporates changing climate conditions (precipitation, temperature, etc.)	Survey the public directly or indirectly to determine use patterns and sensitivity to changing climate patterns	Educate the public about likely impacts of climate change and changing recreational opportunities
Where can tactics be applied?	During long-term planning processes, identify potential user conflicts (e.g., non-motorized versus motorized winter use)	In National Visitor Use Monitoring; trail counters; web-based tools	Focus on National Forest locations/sites in which changes are occurring (e.g., in locations with pine beetle infestations)

Table 14.8 (continued)—Recreation adaptation options for the Intermountain Adaptation Partnership region.

Sensitivity to climatic variability and change: Increased flooding and fire will result in fewer recreational sites, more use of alternative campgrounds, reduced services, and increased use of fewer facilities			
Adaptation strategy/approach: Research and document existing uses			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Inventory–use and update the infrastructure database to assure correct information is available	Manage people–as conditions change, move people to more desirable sites	Communicate–have clear and constant discussions with Forests and Districts
Where can tactics be applied?	All Forests and sites	As weather changes and floods and/or fire increase, may need to utilize underused or new sites	At all levels as need arises
Sensitivity to climatic variability and change: Change in timing of water availability and absolute amount of water available will affect water-based recreation. High temperatures may drive up demand for water recreation			
Adaptation strategy/approach: Plan to account for these changes in demand			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Identify places that are likely to be affected by climate change (either loss of water-based recreation, or where more recreation will be concentrated)	Rethink campground locations to make them more pleasant for hot climates (e.g., spots in the shade) and near existing water resources; use intentional locations to control impacts of dispersed camping	Future reservoirs may be needed to meet municipal water demand that will also be used for recreation, but may also flood existing recreation sites (campgrounds, etc.)
Where can tactics be applied?	On all Forests	Forests especially attractive to recreational vehicles	Near existing water resources, and likely new sites for reservoirs

increased use (e.g., campgrounds can be enlarged, and more fences, signs, and gates can be installed where necessary). However, there may be some limitations to increasing the capacity of some recreation sites. Managers will have to consider how use in the shoulder seasons is managed, adjusting timing of actions such as road and trail openings and closures and special use permits (Strauch et al. 2015). Managers may want to establish defined season of use for activities that were historically most popular in the summer but that may become more common in the spring and fall shoulder seasons, such as all-terrain vehicles and mountain bikes. As an alternative to date-specific closures, recreation managers could continuously monitor conditions and use weather- or condition-specific closures.

As temperatures increase, there may be increased demand for water-based recreation in particular (Mendelsohn and Markowski 2004). With shifts in timing of flow and lower summer streamflows, however, water-based recreation may become unavailable in some locations at certain times (Hand and Lawson 2017). Identifying places that are likely to be affected by climate change (either loss of water-based recreation, or where more recreation will be concentrated) will help managers plan for these changing patterns. Managing lake and river access capacity, and managing public expectations on site availability may also be necessary. Monitoring will be critical to assessing changes in use patterns and identifying demand shifts.

A comprehensive summary of strategies and tactics for adapting outdoor recreation management to the effects of climate change can be found in Appendix 10.

Adapting Infrastructure Management to the Effects of Climate Change

As snowpacks decline and rain-to-snow ratios increase with warming temperatures, flooding may increase in some parts of the IAP region (Chapter 4). Thus, reducing the vulnerability of roads and infrastructure to flooding is a primary concern to managers. National Forests contain thousands of miles of roads, mostly unpaved. Damage to those roads and associated drainage systems reduces access by users and is extremely expensive to repair (Strauch et al. 2015). Road damage often has direct and deleterious effects on aquatic habitats as well, particularly when roads are adjacent to streams (Luce and Black 1999). Resilience to higher peakflows and frequency of flooding can be increased by (1) adapting the design standards where future rain-on-snow events are expected (Halofsky et al. 2011), (2) conducting a risk assessment of vulnerable roads and infrastructure (Strauch et al. 2015), and (3) performing road blading and grading activities during periods when natural moisture conditions are optimum (using water trucks as needed to supplement) (table 14.9).

In addition to flooding, fire and changing recreation demands may affect access to infrastructure for forest use (Strauch et al. 2015). As a first step, it will be important to determine how traffic patterns are changing seasonally. At-risk roads, specifically those that are prone to flooding, have insufficient culverts, or are located on unstable surfaces, can then be identified in high-use locations and be either upgraded or decommissioned (Halofsky et al. 2011). Damaged roads should not necessarily be rebuilt in kind, but rather rebuilt using specifications that account for climate-related changes (e.g., different levels and seasons of precipitation and use) or decommissioned (Halofsky et al. 2011; Strauch et al. 2015) (table 14.9).

Increases in extreme storm events and flooding with climate change may also affect bridges, dams, and levees. It will be important for specialists to consider increases in future extreme storm events when evaluating existing inventory for capacity and structural integrity, in structure design, and when determining location of new infrastructure (Strauch et al. 2015). Infrastructure management in a changing climate will benefit from increased coordination with partners (table 14.9).

Buildings, including recreation residences, may face increased risk from catastrophic events, including fire, snow, flooding, avalanche, and ecological disturbance (Chapters 4, 8). The high cost of relocating buildings from floodplains and other high-risk locations will require that adaptation options focus on prevention of damage. For example, areas surrounding buildings can be examined for hazard trees, and the hazard trees removed. Managers and recreation residence holders can follow recommended practices for keeping buildings safe from fires (e.g., by removing flammable vegetation in areas near buildings) (table 14.9). In some cases, however, risk thresholds may be exceeded, and recreation residences and other buildings may need to be relocated or removed.

A comprehensive summary of strategies and tactics for adapting infrastructure management to the effects of climate change can be found in Appendix 11.

Adapting Cultural Resource Management to the Effects of Climate Change

Climate change poses several threats to cultural resources in the IAP region (Morgan et al. 2016; Rockman 2015). Increased fire will result in increased erosion and loss of vegetation, which may exacerbate damage and other impacts to cultural resources (Davis 2017). Fuels reduction around significant cultural resources already takes place in some locations, but these efforts could be increased to further reduce likelihood of high-severity fire and damage to cultural resources (table 14.10). Fuels treatments are particularly important around flammable wooden structures (Davis 2017). In some cases, wooden shingles on historic buildings can

Table 14.9—Infrastructure adaptation options for the Intermountain Adaptation Partnership region.

Sensitivity to climatic variability and change: Increased temperatures will have broad implications for road design and maintenance			
Adaptation strategy/approach: Increase resilience where roads/streams interact			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Adapt the design standards where future rain on snow events are expected	Develop risk assessment for road infrastructure	Perform road blading/grading activities during periods when natural moisture conditions are optimum, and use water trucks as needed to supplement
Where can tactics be applied?	Agency and partner road systems	Agency and partner road systems	Agency and partner road systems
Sensitivity to climatic variability and change: Climate change may alter access to infrastructure for forest use			
Adaptation strategy/approach: Increase the resilience of transportation infrastructure to climate-related stressors, such as changing recreation demands, fire, and water impacts			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Identify changing traffic patterns and uses in relation to precipitation levels and seasonal distribution	Identify roads prone to flooding based on their location (e.g., in riparian areas) as well as roads with insufficient culverts or which are located on unstable surfaces	Do not rebuild damaged roads in kind; rather, use specifications that account for climate-related changes
Where can tactics be applied?	Public surveys, county meetings, during monitoring, and in locations at which the activities are occurring	Stream crossings and on unstable soil locations	During regularly scheduled maintenance; after catastrophic events
Sensitivity to climatic variability and change: Increased temperatures will have broad implications for building design and maintenance			
Adaptation strategy/approach: Protect existing and future infrastructure by examining present and future hazards on building infrastructure			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Examine surroundings for hazard trees, and remove those that present hazards to facilities	Follow recommended practices for keeping buildings safe from fires	Anticipate where ice dam problems may occur in the future
Where can tactics be applied?	Any building	Any building	Buildings at higher elevations where winter temperature may fluctuate near freezing

Table 14.9—Infrastructure adaptation options for the Intermountain Adaptation Partnership region.

Sensitivity to climatic variability and change: Recreation residences may see increased risk from extreme climatic events (e.g., fire, snow, flooding, avalanche, and ecological disturbance)			
Adaptation strategy/approach: Develop risk assessment tools, and address risk with holders and county Emergency Medical Services			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Communicate with existing recreation resident holders	Develop clear procedures for removing a recreation residence that exceeds a risk threshold	Consider developing in-lieu lots or other recreation tracts
Where can tactics be applied?	All recreation residences	Site-specific and in each District	Agency review of program
Sensitivity to climatic variability and change: Increased storm frequency and intensity will have broad implications for design and maintenance of bridges, dams, canals, and levees			
Adaptation strategy/approach: Protect existing and future infrastructure by examining present and future hazards on bridge and dam infrastructure			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Evaluate existing inventory for capacity and structural integrity using climate model projections for extreme storm events	Incorporate climate models projections for extreme storm events in structure design and bridge location	Facilitate partnerships between private, local, State, and Federal jurisdictions
Where can tactics be applied?	Any existing bridge, dam, canal, or levee	Any planned bridge, dam, canal, or levee	Any existing or planned bridge, dam, canal, or levee

Table 14.10—Cultural heritage adaptation options for the Intermountain Adaptation Partnership region.

Sensitivity to climatic variability and change: Increased fire will result in increased erosion and loss of vegetation, which may increase damage and impacts to cultural resources				
Adaptation strategy/approach: Encourage pre- and post-disturbance strategies to protect cultural resources				
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**	
Tactic	Increase the use of prescribed fire or other vegetation manipulation	Inventory, map, and rate fire risk for cultural resources	Develop a plan to address post-fire impacts to cultural resources that have been affected	
Where can tactics be applied?	In or around cultural resources that are susceptible to impact from severe wildfire	Across Forests	Across burned areas	
Sensitivity to climatic variability and change: Temperature changes bring changes in season, both for people and resources, and may put more pressure on cultural resources and sites (e.g., looting, collecting, inadvertent impacts from users to cultural heritage resources)				
Adaptation strategy/approach: Educate users and protect cultural resources				
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**	**Specific tactic – D**
Tactic	Redirect public to less sensitive cultural areas	Provide education and interpretation to inform the public about why cultural resources are important; engage user groups	Directly protect cultural resources with physical barriers, fencing, vegetation screening, and access management	Inventory high-risk areas and monitor high priority resources
Where can tactics be applied?	Specific sites; need to identify high recreation use locations and where impacts are occurring or may occur in the future	Dispersed recreation sites, system trails	Specific sites	Set strategy at regional level; implement at unit level
Sensitivity to climatic variability and change: Traditional food sources may be lost with increased fire, invasive species establishment, and habitat changes under changing climate				
Adaptation strategy/approach: Integrate traditional ecological knowledge with fire management plans and cultural resource data base to holistically manage for traditional food sources (such as huckleberries, mushrooms, pine nuts, sage-grouse, etc.)				
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**	
Tactic	Emphasize preservation of traditional food sources with tribal and local significance	Enhance resilience of specific habitats to fire and other threats; manage fire to maintain or protect sagebrush rangelands and other sensitive vegetation types	Identify and protect areas suitable for traditional food gathering under future climate conditions	
Where can tactics be applied?	Forest- and region-wide	Forest- and region-wide	Forest- and region-wide	

be replaced with fire-retardant treated wooden shingles, and where appropriate, susceptible structures can be wrapped with fire-retardant material when threatened by a wildfire. However, fire-retardant air drops on cultural resources should be avoided where possible, as they can stain cultural resources such as rock art, prehistoric stone structures, cliff faces and associated resources, historic buildings, and artifacts. Having archaeological resource advisors on fire teams can help ensure that practices which damage cultural resources are avoided whenever possible.

Traditional food sources may also be lost with increased fire, changing habitat conditions, and increased establishment of invasive species under changing climate (Chapter 12). Resilience of specific habitats to fire and other threats could be enhanced through silvicultural treatments and prescribed burning, although the effectiveness of treatments relative to the scope and scale of the cultural landscape is difficult to evaluate (Davis 2017). Careful monitoring and tracking of vegetation stability and change in cultural landscapes will become increasingly important in future decades (Davis 2017). Managers may also want to identify and protect areas that are likely to be suitable for traditional food gathering under future climatic conditions (table 14.10).

An effective defense against losing structures and other cultural resources to fire is for managers to know which resources are under their jurisdiction, and where those resources are located (Rockman 2015). Survey and evaluation in areas where cultural resources are concentrated or likely is ongoing, although intermittent, in the IAP region. It will be possible to locate and monitor cultural resources only if these efforts are significantly expanded. High-elevation melting ice patches are a particular priority, but surveys are also critical in other locations where cultural resources are likely to be affected by fire or flooding and debris flows in mountain canyon and foothills areas (Davis 2017). Correlating areas where cultural resources are common with areas where disturbances are expected will help to focus attention in landscapes at greatest risk. Having postfire management plans in place before events occur will help to ensure efficient and effective postfire actions (table 14.10).

Warming temperatures will extend the warm-weather recreation season, potentially putting more pressure on cultural resources and sites. These impacts can be minimized if land managers work closely with their heritage staff to identify sites that are being damaged due to visitation, implement on-the-ground site monitoring, and have a plan in place to address resources that are anticipated to have more frequent visitation in the future. Managers can also provide education and interpretation to inform the public about why cultural resources are important. Other options include redirecting users to less sensitive areas and protecting cultural resources with physical barriers, fencing, vegetation screening, and access management (table 14.10).

A comprehensive summary of strategies and tactics for adapting management of cultural resources to the effects of climate change can be found in Appendix 12.

Adapting Ecosystem Services to the Effects of Climate Change

The climate change vulnerabilities in ecosystem services that pose the highest concern include availability and quality of forage for livestock, the availability and quality of municipal water, and habitat for pollinators. Many of these vulnerabilities stem from likely climate change impacts on other resources covered in this chapter.

Increased atmospheric carbon dioxide concentrations may increase rangeland productivity by increasing water-use efficiency (Polley et al. 2013; Reeves et al. 2014). In moisture-limited systems, however, increased temperatures will increase evaporative demand and reduce soil moisture and productivity unless precipitation increases significantly (Polley et al. 2013). Increased wildfire area burned and establishment of nonnative species may also decrease rangeland productivity. Managers at the workshops proposed adaptation strategies for grazing that focused on increasing resilience of rangeland vegetation, primarily through nonnative species control and prevention (table 14.11). Demand for grazing on high-elevation National Forest land may increase with warming. Federal land managers identified increasing flexibility in timing, duration, and intensity of authorized grazing as a tactic to prevent ecosystem degradation under changing conditions. They also stressed the importance of developing a holistic approach to grazing management, taking the needs of ranchers into consideration, and developing a collaborative relationship with range permittees that focuses on problem solving rather than rule enforcement.

Climate change is expected to alter hydrological regimes, with impacts on quantity and quality of municipal water supply (Chapter 4). Therefore, strategies developed for water resource management on National Forest lands should consider the timing of water availability as well as the quality of water delivered beyond National Forest System lands. Conducting assessments of potential climate change effects on municipal water supply and identifying potential vulnerabilities will help facilitate adaptive actions that can minimize climate change impacts. Water quality can be addressed by: (1) reducing hazardous fuels in dry forests to reduce the risk of crown fires, (2) reducing other types of disturbances (e.g., off-road vehicles, unregulated livestock grazing), and (3) using road management practices that reduce erosion (Peterson and Halofsky 2017). These tactics should be implemented primarily in high-value locations (near communities and reservoirs) on public and private lands. Communication among agencies, landowners, stakeholders, and governments will be essential to ensure future municipal water supply (Peterson and Halofsky 2017) (table 14.11).

Increasing temperatures are likely to have an effect on the thermoregulation of pollinators and may lead to a mismatch in the timing of emergence of flowers and pollinators (Fagan et al. 2014). Another possible indirect effect of

Table 14.11—Ecosystem services adaptation options for the Intermountain Adaptation Partnership region.

Sensitivity to climatic variability and change: Pollinators and their habitat may be sensitive to climate change			
Adaptation strategy/approach: Enhance pollinator habitat on Federal lands and Federal facilities			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Direct National Forests to improve pollinator habitat by increasing native vegetation and by applying pollinator-friendly forest-wide best management practices and seed mixes	Establish a reserve of native seed mixes, including pollinator-friendly plants that are adapted, available, affordable, and effective	Develop revegetation guidelines that incorporate menu-based seed mixes by habitat type (e.g., species that are good for pollinators, sage-grouse, umbrella species) and by empirical or provisional seed zones
Where can tactics be applied?	Priority areas include alpine, tall forbs, low-elevation wetlands, and dry and dwarf sagebrush communities	IAP geographic areas (e.g., Uintas and Wasatch Front).	Each National Forest
Adaptation strategy/approach: Increase agency and public awareness of the importance of native pollinators			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Establish a pollinator coordinator to communicate with District- and Forest-level teams, Regional Office, and public	Develop a checklist to consider pollinator services in planning, project analysis, and decision making	Establish pollinator gardens
Where can tactics be applied?	Each National Forest	In both the National Forest Management Act and National Environmental Policy Act processes	On Federal facilities or in partnership with other public entities (e.g., public spaces, parks, backyards)
Sensitivity to climatic variability and change: Amount and seasonal distribution of water may shift, thus affecting ability to meet water demand			
Adaptation strategy/approach: Assess and communicate Forest Service ability to help meet water demand			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Conduct integrated assessment of climate effects on water at a watershed scale	Encourage communication and full disclosure of information	Conduct water vulnerability assessments
Where can tactics be applied?		Watershed councils, municipal watersheds, interagency working groups (e.g., Mountain Accord), local communities	Assessments could be done by community, watershed, administrative boundary, etc.

Table 14.11 (continued)—Ecosystem services adaptation options for the Intermountain Adaptation Partnership region.

Sensitivity to climatic variability and change: Higher temperatures and increased fire activity will alter the composition and productivity of forage				
Adaptation strategy/approach: Increase resilience of habitats used by ungulates and that are vulnerable to climate change impacts				
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**	**Specific tactic – D**
Tactic	Reduce conversion of native perennial vegetation to invasive species	Integrate grazing strategies and vegetation treatments (both wild and domestic ungulates)	Emphasize collaborative problem solving with permittees and other interested parties rather than enforcement	Modify flexibility in timing, duration, and intensity of authorized grazing
Where can tactics be applied?	Priority areas include tall forbs, low-elevation wetlands and riparian areas, and dry and dwarf sagebrush communities			Across the National Forest on all grazing allotments; prioritize allotments based vulnerability, soil type, etc.
Sensitivity to climatic variability and change: Climate variability and warming will impact grazing resources and policy				
Adaptation strategy/approach: Develop a holistic approach to grazing management; understand the ranching business approach, lands used, water management, and competing demands from other resources and multiple uses				
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**	
Tactic	Partner with permittee and other managers of lands they use to create a holistic grazing program	Understand changes in water availability to prepare and adjust grazing management	Implement education programs about climate change impacts and sustainable grazing practices (highlight both positive and negative effects)	
Where can tactics be applied?	Public, private and all adjacent lands	Around water resources	Needs to be broadly implemented; partnership opportunities with Cattlemen's Association, Future Farmers of America, Natural Resources Conservation Service, schools, environmental organizations	

climate change on pollinators may be habitat loss and fragmentation with invasive species and vegetation type shifts, leading to a reduction in forage resources or an increase in pests and diseases. Tools to promote native pollinators include directing National Forests and other agency units to improve pollinator habitat by increasing native vegetation and by applying pollinator-friendly best management practices (table 14.11). Establishing a reserve of native seed mixes, including pollinator friendly plants that are adapted, available, affordable, and effective, will help to increase availability of pollinator friendly materials and encourage their use. Revegetation guidelines could be developed that incorporate menu-based seed mixes by habitat type (e.g., species that are good for pollinators, sage-grouse, umbrella species) and by empirical or provisional seed zones. To ensure that pollinators are considered in agency activities, a checklist could be developed that helps managers incorporate pollinator services in planning, project analysis, and decisionmaking.

A comprehensive summary of strategies and tactics for adapting management of ecosystem services to the effects of climate change can be found in Appendix 14.

Conclusions

The IAP vulnerability assessment and workshop process resulted in a comprehensive list of climate change adaptation strategies for natural resource management in the region. Although most of the suggested strategies and tactics focused on increasing resilience, there were some involving resistance (e.g., protection of whitebark pine) and response (e.g., transitioning recreation management to account for changing use patterns with climate change). Adaptation strategies and tactics that have benefits to more than one resource are likely to be most beneficial (Peterson et al. 2011b). Management activities intended to reduce fuels and restore hydrological function are standard practices, suggesting that many current resource management actions are already climate smart. However, the locations where actions are implemented may be different or strategically targeted in the context of climate change. For example, treatments for aspen may be targeted toward persistent aspen communities that are expected to expand and maintain communities where future climatic conditions will allow.

Implementation will be the next challenge for the IAP (Chapter 15). Although implementing all adaptation options described in this chapter may not be feasible, managers can choose from the menu of strategies and tactics presented here. These adaptation strategies and tactics can thus provide the basis for climate-smart management in the region.

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Appendix 5—Water Resource Adaptation Options Developed for the Intermountain Adaptation Partnership Region

The following tables describe climate change sensitivities and adaptation strategies and tactics for water resources, developed in a series of workshops as a part of the Intermountain Adaptation Partnership (IAP). Tables are organized by subregion within the IAP. See Chapter 14 for summary tables and discussion of adaptation options for water resources.

Table 5A.1—Water resource adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: Increased drought will lead to lower base flows, greater tree mortality, reduced rangeland productivity, loss of habitat, reduced soil moisture, wetland loss, riparian area reduction or loss, and more frequent and possibly severe wildfire			
Adaptation strategy/approach: Manage adaptively			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Develop hydrological tools and products to predict or aid in range management with changing climate; explore various options to allow more flexibility in the management of rangelands	Develop hydrological tools and products to predict or aid in the prediction of recreation use (when will roads and other infrastructure be ready for use by the recreating public); explore various options to allow more flexibility in the management of public recreation (e.g., hiring of seasonal workforce)	Plan for possible changes in the calculation of Total Maximum Daily Loads (TMDLs) and the timing of permitted discharge; be able to adapt to those changes in stream flows and timing.
Where can tactics be applied?	Forest range management allotments; National Environmental Policy Act (NEPA) process; forest policy and directives; regional guidance; budget and grant timing	NEPA; forest policy and directives; regional guidance; seasonal hiring guidance and direction; budgeting	Interagency partnerships and coordination; planning
Opportunities for implementation	Best management practices; allotment management plans; annual operating instructions; forest plan direction	Recreation planning; budgeting and planning.	TMDL development or redevelopment; forest planning; water use planning; project design
Sensitivity to climatic variability and change: Soil productivity may decrease			
Adaptation strategy/approach: Identify vulnerabilities to soil processes including temperature, moisture, biological activity and carbon sequestration			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Maintain and protect soil cover (canopy and ground cover)	Promote the maintenance and the addition of soil organic matter	Promote native vegetation and minimize the expansion of invasive species
Where can tactics be applied?	National, regional, and forest-level planning and guidance; project design; national best management practices (BMPs)	National, regional, and forest-level planning and guidance; project design; national BMPs	National, regional, and forest-level planning and guidance; project design; national BMPs
Opportunities for implementation	BMPs; project design and development	BMPs; project design and development	BMPs; project design and development
Comments	May be specific to soil texture; strategize and prioritize based on soil texture; changes in soils will take time—they cannot be restored easily or quickly; need proactive preventive methods	May be specific to soil texture; strategize and prioritize based on soil texture	May be specific to soil texture; strategize and prioritize based on soil texture; may want to prioritize rare plants associated with specific soil types and conditions

Table 5A.1 (continued)—Water resource adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: Increased drought will lead to lower base flows, greater tree mortality, reduced rangeland productivity, loss of habitat, reduced soil moisture, wetland loss, and riparian area reduction or loss			
Adaptation strategy/approach: Conserve water			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Xeriscape facilities	Provide conservation education	Better manage livestock water improvements
Where can tactics be applied?	Administrative facilities; campgrounds	In public outreach; communities; forest Web sites; kiosks; local environmental programs; Smokey Bear messages	Cattle troughs; float valves; in groundwater-dependent ecosystems (developed and undeveloped)
Opportunities for implementation	New construction or remodel and repair projects; sustainable operations programs; forest planning, revision	Partnerships; collaboratives; schools (education programs and outreach, camps); through public information officers	Annual operating instructions; project design; permit renewals; allotment management plans
Comments	Need funding and education	Public outreach and education is critical to explaining the "why"	Need inventory of existing conditions, and locations for developed and undeveloped seeps, springs, troughs, and groundwater-dependent ecosystems
Sensitivity to climatic variability and change: Increased drought will lead to lower base flows, greater tree mortality, reduced rangeland productivity, loss of habitat, reduced soil moisture, wetland loss, and riparian area reduction or loss			
Adaptation strategy/approach: Store water			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Manage special-use dams on high- elevation mountain lakes	Manage proposals for major reservoir construction and additions	Conduct meadow restoration and promote beaver dams
Where can tactics be applied?	Existing facilities; water storage structures	Where they are proposed	Existing meadow locations; impacted riparian areas
Opportunities for implementation	NEPA policies; forest planning and revision; special use permits	NEPA; policies; forest planning and revision; collaboration; coordination with other agencies and partners	Identify restoration opportunities and priorities
Comments	Increased storage may not always be the answer (because of evaporation loss, impacts to water quality, temperature, aquatic organism passage, etc.)	Increased storage may not always be the answer (because of evaporation loss, impacts to water quality, temperature, aquatic organism passage, etc.)	Increased storage may not always be the answer (because of evaporation loss, impacts to water quality, temperature, aquatic organism passage, etc.)

Table 5A.1 (continued)—Water resource adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: Increased drought will lead to lower base flows, greater tree mortality, reduced rangeland productivity, loss of habitat, reduced soil moisture, wetland loss, and riparian area reduction or loss

Adaptation strategy/approach: Develop policies for water rights

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Develop policies regarding ski area water rights	Develop policies regarding livestock management water use and water rights	Develop policies regarding ecosystem values and services (e.g., instream use)
Where can tactics be applied?	Ski areas	Grazing allotments	National forest lands and adjacent lands (e.g., private lands, BLM lands, and wildlife management areas)
Opportunities for implementation	National policy and directives; management plans	National policy and directives; management plans	National policy and directives; management plans
Comments	Higher level policy and direction needed	---	Need to consider groundwater and surface water interactions; consider the impacts of depleted recharge to groundwater systems; develop map products of groundwater systems and possibly inputs and outputs to streams and other groundwater-dependent systems

Sensitivity to climatic variability and change: Increased drought will lead to lower base flows, greater tree mortality, reduced rangeland productivity, loss of habitat, reduced soil moisture, wetland loss, riparian area reduction or loss, and more frequent and possibly severe wildfire

Adaptation strategy/approach: Consider climate change in postdisturbance (fire, disease) restoration

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Develop map products for at-risk soils and vegetation communities	Develop forest or ecological region plans for postdisturbance rehabilitation, adjusted to warmer, drier climate scenarios	Develop forest-level strategies for altered hydrological regimes (related to infrastructure, roads, culverts, bridges, campgrounds, etc.)
Where can tactics be applied?	Forest-level planning; regional guidance	Forest-level planning; regional guidance	Forest-level planning; regional guidance
Opportunities for implementation	Burned Area Emergency Response (BAER); engineering designs; project design and implementation	BAER; engineering designs; project design and implementation	BAER; engineering designs; project design and implementation
Comments	---	---	---

Table 5A.2—Water resource adaptation options developed at the Uintas and Wasatch Front subregion workshop.

Sensitivity to climatic variability and change: Flow regimes will be altered, with earlier snowmelt and lower summer base flows			
Adaption strategy/approach: Restore function of watersheds, riparian areas, wetlands, and groundwater-dependent ecosystems			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Promote and increase beaver populations where appropriate	Promote appropriate livestock grazing management	Improve water diversion and delivery systems for livestock and other uses
Where can tactics be applied?	Where there is sufficient habitat and beaver will not interfere with infrastructure	Grazing allotments, particularly in riparian areas, wetlands, and groundwater-dependent systems (e.g., springs)	Water developments and diversions; divert only what is needed from the natural system
Opportunities for implementation	Use Utah State University Beaver Restoration Assessment Tool (BRAT) to look for opportunities and priorities	Ensure compliance with proper use standards	Use shut-off valves and splitters; locate troughs away from water sources; improve spring developments (e.g., locate head box away from spring source)
Comments	Use living-with-beaver tactics; use education and outreach to promote the benefits of beaver, and address concerns (infrastructure)	---	---
Sensitivity to climatic variability and change: Higher peak flows and earlier runoff will occur with climate change			
Adaptation strategy/approach: Increase watershed resilience by restoring stream and floodplain structure and processes			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Manage for deep-rooted riparian vegetation (controlling invasive species) to increase channel stability	Reduce road and trail density near streams	Increase stream crossing capacity (e.g. culverts, bridges) to accommodate high flows and aquatic organism passage
Where can tactics be applied?	All streams	All streams	All streams
Opportunities for implementation	Manage for appropriate livestock use; manage recreation (e.g., all-terrain vehicles, trails, dispersed campsites)	Use travel analysis process to set priorities and eliminate unneeded roads and trails (both authorized and unauthorized)	Use travel analysis process to set priorities and eliminate unneeded roads and trails (both authorized and unauthorized); incorporate stream simulation tools in culvert and bridge design

Table 5A.2 (continued)—Water resources adaptation options developed at the Uintas and Wasatch Front subregion workshop.

Sensitivity to climatic variability and change: Water temperatures will be higher during the summer low-flow period			
Adaptation strategy/approach: Increase habitat resilience by restoring structure and function of streams, riparian areas, and wetlands			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Manage livestock grazing to restore ecological function of riparian vegetation and maintain streambank conditions	Maintain large wood in forested riparian areas for shade and recruitment	Reconnect floodplains and side channels to improve hyporheic and base flow conditions
Where can tactics be applied?	All perennial and intermittent streams and wetlands	All perennial and intermittent streams and wetlands	All perennial and intermittent streams and wetlands
Opportunities for implementation	Ensure compliance with proper use standards in riparian areas	Ensure compliance with riparian buffer standards and best management practices	Relocate roads out of floodplains, reconnect old channels; reduce habitat fragmentation through barrier removal (e.g., culverts, water diversions); restore native trout to high-elevation, cold-water refugia

Table 5A.3—Water resource adaptation options developed at the Plateaus subregion workshop.

Sensitivity to climatic variability and change: Flow regimes will be altered, with earlier snowmelt and lower summer base flows			
Adaptation strategy/approach: Restore function of watersheds, floodplains, riparian areas, wetlands, and groundwater-dependent ecosystems; restore water quality, quantity, and timing			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Implement transportation system improvements (e.g., general BMPs, travel management implementation, culvert/bridge design with stream simulation, road relocation, permeable fill to encourage subsurface flow); promote and increase beaver populations where appropriate	Promote appropriate livestock grazing management and proper use standards; improve water diversions, delivery systems, and livestock distribution; divert only what is needed from the natural system and minimize impact to spring sources (e.g., use shut-off valves and splitters, locate troughs away from water sources, and locate head boxes away from spring sources)	Conduct vegetation management (e.g., mechanical treatments, prescribed fire, and wildland fire use) to develop appropriate vegetation density and composition for optimal water balance and healthy watersheds (e.g., aspen and conifers, and water yield)
Where can tactics be applied?	Prioritize areas for restoration, based on level of degradation and opportunities for improvement; analyze where funds will make the most difference	All grazing allotments and particularly around drinking water sources	Prioritize watersheds where fire suppression or management has altered vegetation density and composition (e.g., where conifers have replaced aspen); identify areas where wildland fire use could be an appropriate tactic

Table 5A.3—Water resource adaptation options developed at the Plateaus subregion workshop.

Sensitivity to climatic variability and change: Climate change may result in decreased monsoonal moisture in the summer, increased drought, wetland and riparian reduction or loss, and increased fire activity

Adaptation strategy/approach: Improve natural water storage and retention through healthy watersheds, riparian and wetland areas, and groundwater- dependent ecosystems

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Conduct vegetation management (e.g., mechanical treatments, prescribed fire, wildland fire use) to develop appropriate vegetation density and composition for optimal water balance and healthy watersheds (e.g., aspen and conifers, and water yield)	Conduct stream and meadow restoration; promote and increase beaver populations where appropriate	Manage special-use authorizations for water storage (dams on high-elevation mountain lakes) and other water diversions; protect and manage water developments at groundwater-dependent ecosystems (springs, wetlands, fens, etc.)
Where can tactics be applied?	Prioritize watersheds where fire suppression or management has altered vegetation density and composition (e.g., where conifers have replaced aspen); identify areas where wildland fire use could be an appropriate tactic	Where there is sufficient habitat and beaver will not interfere with infrastructure	Existing and proposed facilities; water diversion and storage structures
Opportunities for implementation	---	Use Utah State University Beaver Restoration Assessment Tool (BRAT) to look for opportunities and priorities; use living-with-beaver tactics; conduct education and outreach to promote the benefits of beaver, and address concerns (infrastructure)	Analyze for water conservation and improved efficiency during National Environmental Policy Act process and reissuance of special use permits

Table 5A.4—Water resource adaptation options developed at the Great Basin and Semi Desert subregion workshop.

Sensitivity to climatic variability and change: Changes in type and amount of precipitation will lead to changes in timing of water availability			
Adaptation strategy/approach: Manage for highly functioning riparian areas that can absorb and slowly release the flow of water off the landscape			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Preserve riparian area functionality through terms and conditions of permitted activities, and utilize best management practices for Federal actions	Implement active stream channel and riparian area restoration (e.g., natural channel design, log structures, reconnecting floodplains), or passive restoration (e.g., appropriate management of beaver populations, reduction or removal of activities that are detrimental to riparian function)	Design new infrastructure and rebuild existing infrastructure to accommodate flooding (e.g., place or relocate infrastructure outside of riparian areas; design stream crossings to minimize restriction of flow above bankfull; and minimize impervious surfaces)

Appendix 6—Aquatic Organism Adaptation Options Developed for the Intermountain Adaptation Partnership Region

The following tables describe climate change sensitivities and adaptation strategies and tactics for aquatic organisms, developed in a series of workshops as a part of the Intermountain Adaptation Partnership (IAP). Tables are organized by subregion within the IAP. See Chapter 14 for summary tables and discussion of adaptation options for native fish and other aquatic organisms.

Table 6A.1—Aquatic organism adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: Climate change will affect food web dynamics and nutrient flows in streams

Adaptation strategy/approach: Maintain resilient flow, sedimentation, and thermal regimes

	Specific tactic – A	**Specific tactic – B**
Tactics	Reduce fine sedimentation and substrate embeddedness	Restore anadromous fish runs (or carcass analogs, or both)
Where can tactics be applied?	Basins with high road density and where roads are directly adjacent to stream channels	Former anadromous fish habitats where migrations are blocked
Opportunities for implementation	---	Fish passage past dam that precludes migrations
Comments	Mitigate adverse effects of sedimentation on macroinvertebrate communities	---

Sensitivity to climatic variability and change: Warmer stream temperatures may favor nonnative species

Adaptation strategy/approach: Monitor for invasive species and suppress, eliminate, and control populations

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Use environmental DNA (eDNA) monitoring for early detection of river or stream invasions	Reduce or suppress brook trout populations	Construct barriers that prevent access to and invasion of conservation populations in headwaters
Where can tactics be applied?	High-value populations that are thought to be at significant risk of invasion	Headwater lakes that act as source populations; small, isolated streams where complete eradication is possible	Southern portions of IAP region where stream habitats are smaller and more fragmented
Opportunities for implementation	---	Prioritize among hundreds (thousands?) of headwater streams and lakes across the IAP region	Small headwater streams where barrier construction is cost effective and possible
Comments	Costs of eDNA sampling are low enough to make this broadly applicable	Expensive and risky to implement; public support needed for success	Less useful tactic in areas with anadromous species or fluvial populations of bull trout and cutthroat trout

Table 6A.1 (continued)—Aquatic organism adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: Native species distributions will shift, and communities will realign

Adaptation strategy/approach: Conduct biodiversity surveys to describe current baseline conditions and manage distribution shifts

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Formalize, expand, and standardize biological monitoring programs (e.g., Management Indicator Species	Use modern, low-cost technologies such as eDNA/DNA barcoding and digital photopoints	Assisted migrations
Where can tactics be applied?	Streams/rivers/lakes throughout IAP area	Streams, rivers, lakes throughout IAP region	Suitable but currently unoccupied habitats; consider habitats outside of historical range (e.g., northern extent of species distributions) in addition to historical range
Opportunities for implementation	---	---	Climate Shield fish model can be used to identify high-probability habitats; use eDNA to confirm species presence or absence, and then move fish into high-probability areas based on current/future climate forecasts
Comments	Boise NF, Sawtooth NF, and Salmon-Challis NF have rotating panel monitoring designs that provide good templates because broad-scale status and local trend information are represented	New genomic techniques and technologies are inexpensive and make broad applications more feasible than previously	This is a controversial tactic and care is needed to do it properly; if threatened and endangered species are present, there are permitting procedures that must be followed; there are considerations about whether the system had fish historically or not (e.g., geologic barriers to suitable habitats); if it is a listed species, we may need to designate it as an "experimental population" to be politically feasible

Table 6A.2—Aquatic organism adaptation options developed at the Plateaus subregion workshop.

Sensitivity to climatic variability and change: Warmer stream temperatures may favor nonnative species			
Adaptation strategy/approach: Increase resilience of native fish species			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Manage livestock grazing to restore ecological function of riparian vegetation and maintain streambank conditions	Maintain large wood in forested riparian areas for shade and recruitment; reconnect floodplains and side channels to improve hyporheic and base flow conditions; conduct meadow restoration; augment snowpack with snow fences on the Wasatch plateau to increase late summer flows; maintain vegetation density and composition for optimal water balance and snow accumulation	Remove or control nonnative fish species; maintain or construct barriers to prevent spread of nonnative species; reduce habitat fragmentation of native trout habitat through barrier removal (e.g., culverts and water diversions); restore native trout to high-elevation, cold-water refugia
Where can tactics be applied?	All perennial and intermittent streams and wetlands	All perennial and intermittent streams and wetlands	Prioritize areas based on site specific conditions
Opportunities for implementation	Ensure compliance with proper use standards in riparian areas	---	Work with State fish and game agencies to facilitate nonnative species removal and native trout restoration

Table 6A.3—Aquatic organism adaptation options developed at the Great Basin and Semi Desert subregion workshop.

Sensitivity to climatic variability and change: Transition or loss of biodiversity may occur with crossing of ecological type thresholds (broadly accounting for changes in connectivity, temperature, and water quantity)			
Adaptation strategy/approach: Understand and manage for community-level patterns and processes			
	Specific tactic – A	**Specific tactic – B**	**Specific Ttactic – C**
Tactics	Utilize best available technology to monitor, record, and distribute information about the distribution of a broad array of aquatic species (e.g., environmental DNA, national databases)	Develop and improve understanding, adaptive actions, and models related to nongame aquatic species (e.g., mussels, dace, sculpin, springsnails, and amphibians)	Continue to refine and improve understanding, adaptive actions, and models related to cold-water salmonids

Appendix 7—Forest Vegetation Adaptation Options Developed for the Intermountain Adaptation Partnership Region

The following tables describe climate change sensitivities and adaptation strategies and tactics for forest vegetation, developed in a series of workshops as a part of the Intermountain Adaptation Partnership (IAP). Tables are organized by subregion within the IAP. See Chapter 14 for summary tables and discussion of adaptation options for forest vegetation.

Table 7A.1—Forest vegetation adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: Disturbances will affect landscape-scale patterns, structure, and species composition

Adaptation strategy/approach: Create landscape patterns that are resilient to past and expected disturbance regimes

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Continue research on expected future disturbance regimes; evaluate potential transitions and thresholds	Improve communication across boundaries	Manage for diversity of structure and patch size with fire and mechanical treatments
Where can tactics be applied?	Local, regional, national scales	Internally and externally (with partners)	Watershed(s)
Opportunities for implementation	Use Forest Inventory and Analysis (FIA) program data to improve or establish monitoring	Workshops; collaborative groups; get external partners to do “translational ecology” (telling a layperson story that the public will listen to and accept)	Landscape-scale projects (e.g., thinning, fire)

Sensitivity to climatic variability and change: Shifts in hydrological regime will occur and involve changes in timing and magnitude of flows; expected changes include lower summer flows, higher and more frequent winter flows, and potentially a decrease in riparian vegetation abundance

Adaptation strategy/approach: Maintain and promote riparian processes and functions

	Specific tactic – A	**Specific tactic – B**
Tactics	Manage upland vegetation that influences riparian function and process (e.g., with thinning and prescribed fire)	Restore “true” riparian obligate species
Where can tactics be applied?	Adjacent to riparian vegetation where conditions do not optimize or promote riparian function and process	Aquatic Conservation Strategy priorities (might have listed fish or wildlife); where upland, invasive, or undesirable species are outcompeting native species; locations that have been inappropriately managed in the past
Opportunities for implementation	Thinning and prescribed fire projects	Treatments of invasive species; planting and seeding; thinning and prescribed fire projects

Table 7A.1 (continued)—Forest vegetation adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: The western larch niche may be lost (loss of habitat); regeneration may be reduced by other conifers

Adaptation strategy/approach: Increase competitive ability of western larch and its resilience to changing fire regimes

	Specific tactic – A	**Specific tactic – B**
Tactics	Create gaps in forests to reduce competition and increase larch vigor	Regenerate larch with appropriate site preparation (e.g., prescribed burning, followed by planting); create appropriate fire regime and fuel loads
Where can tactics be applied?	Stands with larch	Habitats that can support larch
Opportunities for implementation	Places with larger landscape management projects	Places with larger landscape management projects

Sensitivity to climatic variability and change: Large-scale disturbances (beetles, fire, white pine blister rust) will impact whitebark pine

Adaptation strategy/approach: Increase competitive ability and resilience of whitebark pine to changing disturbance regimes

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**	**Specific tactic – D**
Tactics	Control beetles	Daylight (thin) to reduce competition (usually involves removing subalpine fir)	Regenerate rust-resistant strains; increase seed sources; maintain cache sites	Create fuelbreaks
Where can tactics be applied?	Protect trees in high-value areas; important in Central Idaho and the Greater Yellowstone area	Implement in accessible areas and high-value areas (best rust-resistant areas and areas of high habitat and recreation value)	Areas of disturbance, or areas with low resistance; maintain density for Clark's nutcracker	In accessible and high-value areas
Opportunities for implementation	Use Verbenone to protect trees from beetles; use after snowmelt (consider seasonal constraints)	---	In accessible areas	In locations adjacent to subalpine fir or other lethal fire regime areas
Comments	---	Think about ladder fuels and fuel mitigation issues when daylighting	Only have small capacity so far. There is a whitebark pine seed orchard in Region 1.	Consider impacts to soils and long-term maintenance

Table 7A.2—Forest vegetation adaptation options developed at the Southern Greater Yellowstone subregion workshop.

Sensitivity to climatic variability and change: Capacity for aspen stand regeneration will be reduced due to direct and indirect impacts from climate change			
Adaptation strategy/approach: Increase capacity for aspen stand regeneration			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Increase the proportion of the landscape that is in early-successional stages	Maximize flexibility in managing herbivory	Maximize genetic diversity
Where can tactics be applied?	Landscapes with high proportion of later-seral aspen mixed conifer	Focus on sites with good aspen site potential	Landscapes following severe fire
Opportunities for implementation	Prescribed fire, wildfire management, cultural treatments	Continue to work with existing partnerships and develop new partnerships	Protecting seedlings
Comments	Reduced snowpack and increased frequency and severity of drought create increased aspen exposure to herbivory during postdisturbance regeneration	---	Currently establishing new aspen clones from seed
Sensitivity to climatic variability and change: Whitebark pine (WBP) communities will be susceptible to changes in disturbance regimes (i.e., fire, insects, and disease)			
Adaptation strategy/approach: Increase resilience of whitebark community types			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Improve structural diversity of WBP communities at multiple scales	Improve age-class diversity of WBP communities at multiple scales	Conduct restoration where WBP is currently absent
Where can tactics be applied?	WBP communities dominated by late-successional coniferous species	WBP communities dominated by late-successional coniferous species	Sites that have present and future potential to support WBP but where it is currently absent
Opportunities for implementation	Prescribed fire and silvicultural treatments	Prescribed fire and silvicultural treatments	Regeneration treatments using disease-resistant WBP
Comments	Although WBP has limited geographic extent, it is considered a keystone species	---	---

Table 7A.2 (continued)—Forest vegetation adaptation options developed at the Southern Greater Yellowstone subregion workshop.

Sensitivity to climatic variability and change: Climate change will result in changes in soil moisture in mesic meadows and riparian grassland and forb communities			
Adaptation strategy/approach: Implement management strategies that retain soil moisture			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Maintain and improve soil function and health	Improve stream channel function	Manage upland forest vegetation
Where can tactics be applied?	Areas contributing to detrimental soil moisture retention	Where stream function is impaired; prioritize where most effective	Conifer encroachment in meadows and grasslands
Opportunities for implementation	Diverting activities away from these areas; prioritize where most effective	Riparian restoration; restore and protect beaver populations; improve livestock management	Cultural treatments
Comments	Plan and implement infrastructure to minimize impacts on mesic and wet meadows		
Sensitivity to climatic variability and change: Upper treeline may move upward in elevation into alpine communities			
Adaptation strategy/approach: Acquire information to develop understanding of sensitivity to climate change			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Establish monitoring sites	Develop seed transfer guidelines	Develop seed collection and storage guidelines
Where can tactics be applied?	Research Natural Areas	Research Natural Areas	---

Table 7A.3—Forest vegetation adaptation options developed at the Uintas and Wasatch Front subregion workshop.

Sensitivity to climatic variability and change: Large-scale disturbances will impact landscape structural diversity of persistent lodgepole pine (LP) and available seeds sources			
Adaptation strategy/approach: Maintain landscape heterogeneity to mitigate adverse impacts from fire and mountain pine beetles			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Promote structural diversity at multiple scales	Focus attention on collection of viable serotinous LP seed sources	Use available mapping products to identify areas of potential serotinous LP seed sources
Where can tactics be applied?	Homogeneous landscapes	From serotinous LP cones that cover a wide range of elevational bands on national forest and adjacent lands	Forest and adjacent landowners
Opportunities for implementation	Regeneration harvest and prescribed fire (including wildfire for ecological benefit) in areas where feasible	The Ashley National Forest has the highest potential for serotinous LP collections in the Uintas and Wasatch Front	Forest Inventory and Analysis
Comments	The north slope of the Ashley National Forest currently has an overabundance of younger age classes	The Uinta-Wasatch-Cache National Forest has limited LP cone serotiny; the Manti-La Sal National Forest does not have LP	---
Sensitivity to climatic variability and change: Reduced water availability will affect the fringe of persistent aspen community types			
Adaptation strategy/approach: Focus on areas where persistent aspen communities are expected to expand and maintain communities where future climatic conditions will allow			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Remove competing vegetation (e.g., common juniper) and control ungulate browsing to allow for recruitment	Reduce density of conifer species	Use available mapping products to identify areas of potential expansion
Where can tactics be applied?	On fringe of existing persistent aspen communities	Outside of existing stands where persistent aspen is expected to expand	Areas adjacent to existing persistent aspen
Opportunities for implementation	Passive management; limited use of cultural treatments, prescribed fire, and fencing	Focus on active management: cultural treatments and prescribed fire	Work with other disciplines to identify potential areas of expansion (e.g., soils, range)
Comments	Scale of treatments needs to be large enough to mitigate effects of ungulates	Where parent material will support persistent aspen (e.g., fine-textured calcareous soils)	Use existing data sources

Table 7A.3 (continued)—Forest vegetation adaptation options developed at the Uintas and Wasatch Front subregion workshop.

Sensitivity to climatic variability and change: Climate change may lead to a reduction in the spruce-fir component in subalpine spruce-fir forests, which will be exacerbated by current spruce beetle outbreaks

Adaptation strategy/approach: Maintain species and age-class diversity

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Regeneration treatments (e.g., harvest, prescribed fire) that focus on maintaining species diversity; plant a variety of species including Engelmann spruce, Douglas-fir, and LP	Collect seed that will cover a wide range of seed zones and species	Plant a genetically diverse mix based on adaptive traits
Where can tactics be applied?	Forest and adjacent landowners	Forest and adjacent landowners	Forest and adjacent landowners
Opportunities for implementation	Timber harvest and prescribed fire in areas where feasible	Areas that still have viable seed sources	Refine seed zone maps based on expected genetic adaptation

Table 7A.4—Forest vegetation adaptation options developed at the Plateaus subregion workshop.

Sensitivity to climatic variability and change: Lack of disturbance has caused shifts in species composition and structure in dry mixed conifer forests, putting them at risk of high-severity fire with climate change

Adaptation strategy/approach: Maintain and restore species and age-class diversity

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Identify and map highest risk areas at the landscape level to provide context for prioritization	Reduce stand density and shift composition toward species that are more fire adaptive and drought tolerant	Restore age-class diversity while protecting legacy trees
Where can tactics be applied?	All lands	Prioritize highest risk stands in terms of fire, insects, and disease	Prioritize, in terms of fire, insects, and disease, the highest risk stands that currently contain a component of legacy trees
Opportunities for implementation	Integration with other resources (e.g., wildlife, aquatics, fire and fuels)	Cultural treatments and prescribed fire	Cultural treatments and prescribed fire
Comments	Will accept and recognize anticipated elevational shifts in species	Insect prevention and suppression treatments	Thin prior to prescribed fire to reduce risk of losing legacy trees

Appendix 8—Nonforest Vegetation Adaptation Options Developed for the Intermountain Adaptation Partnership Region

The following tables describe climate change sensitivities and adaptation strategies and tactics for nonforest vegetation, developed in a series of workshops as a part of the Intermountain Adaptation Partnership (IAP). Tables are organized by subregion within the IAP. See Chapter 14 for summary tables and discussion of adaptation options for nonforest vegetation.

Table 8A.1—Nonforest vegetation adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: Climate change may result in a loss of sagebrush ecosystems (Wyoming, mountain big, basin sagebrush species)			
Adaptation strategy/approach: Improve resilience and resistance of sagebrush ecosystems			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Control invasive species affecting ecology of sagebrush ecosystems, by minimizing spread and using biological controls, herbicides, and mechanical treatments	Maintain native perennials by: utilizing for restoration (planting) native seed sources that will be adapted to future climate conditions; using fuelbreaks and grazing strategies; fencing for protection; and modifying grazing strategies to allow for flexibility on season of use	Map resilience and resistance to climate change to aid in prioritizing areas for treatments
Where can tactics be applied?	Prioritize and implement in areas with high probability of treatment success; also implement in high-value areas	Prioritize and implement in areas with high probability of treatment success; also implement in high-value areas	Across all areas using soil, vegetation, and existing information; utilize sagebrush resilience and resistance rating criteria
Opportunities for implementation	State and County weed management agreements; include in forest and allotment management plans	In postfire rehabilitation, oil and gas restoration sites, transportation and infrastructure, and allotments	In forest planning assessments, and allotment management plans
Comments	Need better monitoring and all-lands partnering	Need better monitoring and all-lands partnering	Need better monitoring and all-lands partnering
	Specific tactic – D	**Specific tactic – E**	
Tactics	Develop seed zones and promote propagation of native seed sources for sagebrush ecosystems	Adapt grazing management to changing climates and ecological potential	
Where can tactics be applied?	Regionwide seed zone mapping	Allotments where soils and hydrology support future sagebrush ecosystems in a warming climate (see resilience and resistance mapping tactic)	
Opportunities for implementation	Collaborate with State, other Federal agencies, nurseries, nongovernmental organizations, and private companies, prioritizing species for propagation	Prioritize sagebrush systems that have potential to maintain ecological components for listed or potentially listed species	

Table 8A.2—Nonforest vegetation adaptation options developed at the Plateaus subregion workshop.

Sensitivity to climatic variability and change: Climatically suitable habitat for persistent pinyon-juniper ecosystems may be lost			
Adaptation strategy/approach: Maintain and restore ecological integrity of persistent pinyon-juniper communities			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Identify and map persistent pinyon-juniper communities (versus encroached pinyon-juniper) and assess current conditions	Reduce invasive species; maintain or restore native understory composition	Maintain or restore structural diversity to promote natural disturbance regimes
Where can tactics be applied?	All lands	At-risk persistent communities	At-risk persistent communities

Table 8A.3—Nonforest vegetation adaptation options developed at the Great Basin and Semi Desert subregion workshop.

Sensitivity to climatic variability and change: Sagebrush (Wyoming, mountain big, basin sagebrush species) ecosystems may be lost to annual grasses			
Adaptation strategy/approach: Improve resilience and resistance of sagebrush ecosystems			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics:	Map resilience and resistance to climate change (specific to annuals) to aid in prioritizing areas for treatments. Where can we make a difference in the short term?	Protect refugia; if annual grasses are not present, keep them out through repeat monitoring (of experiments with controls), education, seed collection, and genetic analysis	Manage sagebrush to resist invasion of annuals; conduct: 1. Education 2. Targeted grazing (not changing permittee) 3. Invasive species control by minimizing spread and using biological controls, herbicides, and mechanical treatments 4. Maintenance of native perennials by: utilizing for restoration (planting) native seed sources that will be adapted to future climate conditions; using fuelbreaks and grazing strategies; fencing for protection; and modifying grazing strategies to allow for flexibility on season of use
Where can tactics be applied?	---	---	---
Opportunities for implementation	---	State and County weed management agreements; include in forest and allotment management plans	Postfire rehabilitation; oil and gas restoration sites; transportation and infrastructure; allotments
Comments	This is the first step; then other tactics can be implemented	Need better monitoring and all-lands partnering	Need better monitoring and all-lands partnering

Sensitivity to climatic variability and change: Sagebrush (Wyoming, mountain big, basin sagebrush species) ecosystems may be lost to annual grasses			
Adaptation strategy/approach: Improve resilience and resistance of sagebrush ecosystems			
	Specific tactic – D	**Specific tactic – E**	**Specific tactic – F**
Tactics	If annual grasses are present, adapt and make use of it; talk with other regions, such as Region 5, to share ideas; conduct research; consider nurse crops, especially after fire	Develop seed zones and promote propagation of native seed sources for sagebrush ecosystems	Adapt grazing management to changing climates and ecological potential
Where can tactics be applied?	Across all areas using soil, vegetation, and other existing information; utilize sagebrush resilience and resistance rating criteria	Regionwide seed zone mapping	Allotments where soils and hydrology support future sagebrush ecosystems in a warming climate (see resilience and resistance mapping tactic)
Opportunities for implementation	In forest planning assessments, and allotment management plans	Collaborate with State, other Federal agencies, nurseries, nongovernmental organizations, and private companies, prioritizing species for propagation	Prioritize sagebrush systems that have potential to maintain ecological components for listed or potentially listed species
Comments	Need better monitoring and all-lands partnering		

Appendix 9—Ecological Disturbance Adaptation Options Developed for the Intermountain Adaptation Partnership Region

The following tables describe climate change sensitivities and adaptation strategies and tactics for ecological disturbance, developed in a series of workshops as a part of the Intermountain Adaptation Partnership (IAP). Tables are organized by subregion within the IAP. See Chapter 14 for summary tables and discussion of adaptation options for ecological disturbances.

Table 9A.1—Ecological disturbance adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: More wildfires will occur with warmer, drier conditions

Adaptation strategy/approach: Conduct postfire restoration and manage postdisturbance response

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Identify, prioritize, and protect values at risk; initiate programs to assess values and determine best protection actions; resources include soil, water, infrastructure, and vegetation for mass wasting prevention	Prefire planning to improve response time and efficiency; prioritizing key areas at risk to geologic hazard and other areas at risk (e.g., infrastructure, threatened and endangered species habitat, areas that may compromise public health and safety and water supply)	Conduct postfire vegetation management and prevent invasive species
Where can tactics be applied?	Needs to be done at forest level, as it will be dictated by local needs; focus on areas threatening public health and safety	Needs to be an all-lands approach; for Forest Service, both forests and districts need to be involved	In key areas identified in preplanning and BAER; needs to be an all-lands approach; for Forest Service, both forests and districts need to be involved
Opportunities for implementation	Postfire; initiate immediate response for physical resources (Burned Area Emergency Response [BAER]); identify values with non-Forest Service stakeholders	Conduct a GIS exercise to identify focal areas for soil stabilization; identify key cold-water refugia (use fish assessment information)	Postdisturbance; if planned ahead of time, fire (and the funding) can be used in a strategic way to improve ecological and other conditions, and public perception and understanding
Comments	---	Need a long-term plan for fire response and restoration; need to take a more strategic approach instead of waiting until after event occurs	Needs to be climate-smart and consider what is appropriate for a given niche

Table 9A.1 (continued)—Ecological disturbance adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: Climate change may result in increased mortality due to native insects and diseases (bark beetles, defoliators, and dwarf mistletoes)

Adaptation strategy/approach: Increase resistance and resilience to beetles in stands and landscapes

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Manage for age- and size-class diversity	Protect high-value areas with trap tree felling, beetle traps, spraying, reduced basal area, beetle risk rating, and pheromones	Manage for species diversity
Where can tactics be applied?	High-value landscapes with low size-class diversity; limited to where there is access	High-value areas	High-value landscapes with low species diversity (especially in monotypic areas); limited to where there is access
Opportunities for implementation	Merchantable timber areas, since there is a need for markets to pay for treatments; this may depend on species and quality (size, form); need to consider ecosystem services to get partner buy-in; biomass energy is a value-added product	Can be applied near campgrounds and other infrastructure and in the wildland-urban interface; can also be applied in seed orchards, progeny areas, and genetically resistant trees (whitebark pine)	In forest-type transition areas; needs to be an all-lands approach and include Counties, States, and residents
Comments	Need for the right timing, public education, and the right activities in the right places; mechanical treatments are limited; there are supply issues	Maintenance necessary; timing is important; need to monitor beetle populations to know when to do things; how do we do this with partners?	May provide opportunities for assisted migration; mechanical treatments are limited; how do we do this with partners?

Table 9A.1 (continued)—Ecological disturbance adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: More people residing in the forest environment will increase stresses to ecosystems, infrastructure, and biological and physical resources and will shift utilization of ecosystem services closer to the source

Adaptation strategy/approach: Manage for the human disturbance footprint caused by higher populations of people living in forests and the forest interface

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Manage the effects of infrastructure (roads, driveways, power lines, water delivery) on Forest Service lands	Minimize increases in areas of disturbance	Manage ecological connectivity and energy flow; maintain habitat continuity and viability
Where can tactics be applied?	Apply on roads and driveways and with collaborators responsible for the whole system (e.g., the power company, County transportation department, canal company)	In and around residential and other development	Maintain natural corridors (streams, riparian) where they exist; maintain large habitat blocks; maintain habitat diversity in appropriate proximities
Opportunities for implementation	Predevelopment planning; take advantage during plan revision cycles; work with County planners—insert information (data, forest management objectives) into partner's planning process; planning for climate scenarios and avoidance of climate-associated disturbance events	Awareness; work with partners generally receptive to the message (minimize footprint)	Collaborate with wildlife protection groups (e.g., Rocky Mountain Elk Foundation, Wild Turkey, Trout Unlimited), recreation groups, and collaborative groups; identify important habitats and corridors
Comments	Also consider emergency services	There are secondary effects such as an increase in impervious surfaces, introduction of ornamental or invasive plants and livestock, pet conflicts with native wildlife, and groundwater drawdown; the extended human footprint is larger than ground disturbance	Consider pretreatment and posttreatment monitoring

Table 9A.2—Ecological disturbance adaptation options developed at the Southern Greater Yellowstone subregion workshop.

Sensitivity to climatic variability and change: Higher elevation fuels will be more available to burn, and more frequent fire will occur at higher elevations

Adaptation strategy/approach: Increase resilience in vegetation types at high elevations

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactics	Increase heterogeneity through prescribed fire	Conduct fire behavior and spatial modeling to identify high-priority areas to break up or maintain fuels	Manage vegetation through silvicultural means (prescribed fire, thinning, daylighting/radial thinning)
Where can tactics be applied?	Supportive wildland-urban interface (WUI) areas; wilderness areas, roadless areas; large continuous patches	All lands, across jurisdictional boundaries; high-value areas and highest risk comparison	High-value areas
Opportunities for implementation	Stanley Wildfire Collaborative; Farm Bill provisions	Same as above	---
Comments	Note differences and challenges by elevation, and by wilderness versus non-wilderness versus WUI	Calibration in models to accommodate observed and future fire behavior	Access, as well as funding, may be a key challenge; need to consider high-value habitat for species (lynx amendment) that require high-elevation forest

Sensitivity to climatic variability and change: More area will burn over a longer fire season

Adaptation strategy/approach: Increase and maintain moderate fire danger conditions on the landscape

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactics	Increase education to public on the role of fire on the landscape (fire today could save your home tomorrow)	Revise Forest Plan to incorporate managed fire for resource objectives	Limit potential for invasive establishment that may increase with increased fire through pretreatments and posttreatments, weed control, and monitoring
Where can tactics be applied?	Across the region	Fire-adapted landscapes (i.e., native plant communities, seed sources, multiple age classes to maintain diversity, homes with defensible space)	Transition zones between different ecotypes; south-facing slopes; along road corridors; high-elevation grazing; campgrounds
Opportunities for implementation	Use forest coalitions and collaboratives, fire protection districts and cooperators, Idaho Conservation League, The Nature Conservancy (TNC)	Use forest coalitions and collaboratives, fire protection districts and cooperators, Idaho Conservation League, TNC	Invasive species program managers, native plant and seed societies, researchers
Comments	Challenges: smoke, outreach delivery to the public	Need to avoid negative effects on other resources (i.e., water quality)	

Table 9A.2 (continued)—Ecological disturbance adaptation options developed at the Southern Greater Yellowstone subregion workshop.

Sensitivity to climatic variability and change: Invasive insects will likely continue to affect native trees in the future.			
Adaptation strategy/approach: Increase resilience and resistance of trees to invasive insects			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Develop an integrated pest management strategy, including identifying insect-resistant seed (balsam woolly adelgid)	Identify current and projected distribution of balsam woolly adelgid and other species	Identify and monitor other nonnative, invasive insects (i.e., spruce aphid, spruce fir looper) not currently present in the region but that may be a future risk
Where can tactics be applied?	True fir communities: subalpine	True fir communities; regionwide; areas where loss of subalpine fir would be ecologically significant	Regionwide
Opportunities for implementation	Biological and insecticide controls; phenotypic and genotypic seed identification and collection; tree gene conservation and diversity; possibly incorporate into project-level forest documents/guidelines; Farm Bill landscape-level analyses	Network of monitored plots to identify connections between insects and wildfire; research community, Forest Service Pacific Northwest Research Station, fire ecologists, entomologists	APHIS, detection and monitoring programs, invasive and disease action plans that prioritize targets for rapid response
Comments	Already present in the region and distribution is currently climate-limited but may expand range under warming conditions		Southwestern species that may expand range into region and may stress trees
Sensitivity to climatic variability and change: Disturbances may interact to affect postdisturbance processes			
Adaptation strategy/approach: Increase postdisturbance planning, management, and implementation			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Create a strategy and criteria to prioritize areas that are more likely to recover (i.e., critical habitats, population served by disturbed habitat, recovery likelihood)	Promote climate-adapted species (i.e., disturbance resistant or resilient) and genotypes; build seed banks for habitats that do not exist on the landscape yet	Identify sites more susceptible to compounding disturbances (i.e., dry fuel loads + beetle kills + invasives + geologic hazard); monitor occurrence and prioritize seed sources to preserve some sites; conduct spatial mapping of sites across landscape; implement proactive treatments of areas more resistant to disturbance
Where can tactics be applied?	Disturbed areas	May need to consider planting in wilderness	---
Opportunities for implementation	See Terrebonne Parish, Louisiana example of systematic prioritization of sites for restoration	Douglas-fir; included in Burned Area Emergency Response process	Forest Inventory and Analysis network of plots to look at compounding disturbances; Research
Comments	Impacts of “no action” option postdisturbance; adaptive and flexible strategies and criteria under future conditions	Challenges of seed translocation policies	---

Table 9A.3—Ecological disturbance adaptation options developed at the Uintas and Wasatch Front subregion workshop.

Sensitivity to climatic variability and change: Increased mortality due to bark beetles will occur in a warming climate			
Adaptation strategy/approach: Increase resistance and resilience to beetles in stands and landscapes			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Manage for age- and size-class diversity	Protect high-value areas by trap tree felling, beetle traps, spraying, reduction of basal area, beetle risk rating, etc.	Manage for species diversity
Where can tactics be applied?	High-value landscapes with low size-class diversity	High-value areas	High-value landscapes with low species diversity (especially in monotypic areas)
Opportunities for implementation	Merchantable timber areas; need markets to pay for treatments; this may depend on species, quality (size, form)	Near campgrounds, other infrastructure, wildland-urban interface (WUI)	In forest-type transition areas
Comments	Timing, public education, right activities, right places	Maintenance necessary; timing is important; need to monitor beetle populations to know when to take action	May provide opportunities for assisted migration

Sensitivity to climatic variability and change: More wildfires will occur with warmer, drier conditions			
Adaptation strategy/approach: Reduce the adverse effects of fire in the WUI and other non-negotiable values while allowing fire to play a natural role on the landscape			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Identify, prioritize, and protect values at risk; programs assess values and determine best protection actions	Reduce fuels in systematic locations; some treatments may be out of natural range of variation to protect values; strategic placement of fuels treatments to manage for wildfire in an ecologically appropriate way depending on vegetation types	Develop communications strategy to determine what needs to happen where, and before fires occur (e.g., need to know when it is acceptable to let fires cross boundaries and when it is not); all partners need to be involved—it is not just a Forest Service or Federal problem
Where can tactics be applied?	Needs to be done at national forest level as it will be dictated by local needs; for example, a campground may require prevention education or "hardening strategies" (fireproof structures); isolated communities in high-risk locations may require well-developed communication strategies	WUI; strategic locations; look at management boundaries (wilderness), topography, dominant winds	Needs to be an all-lands approach: Counties, States, residents, Bureau of Land Management, National Park Service, etc.; for Forest Service, both forests and districts need to be involved
Opportunities for implementation	National forest level; Forest Plans; site-specific National Environmental Policy Act analysis; identify values with non-Forest Service stakeholders	Coordination between Fuels/Fire and all other resource managers; coordination with local agencies, private sector, etc.	Build off principles of National Cohesive Wildland Fire Management Strategy; this is underway already
Comments		Need long-term plan for fuels management and maintenance; what is best way to protect the resource/value?	If planned ahead of time, fire (and the funding) can be used in a strategic way to improve ecological and other conditions, and public perception and understanding

Table 9A.3 (continued)—Ecological disturbance adaptation options developed at the Uintas and Wasatch Front subregion workshop.

Sensitivity to climatic variability and change: High-water events will occur with higher intensity and frequency and with different timing

Adaptation strategy/approach: Identify and prioritize threatened values (infrastructure and ecological) and mitigation activities

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Move it; for example, move campground out of floodplain	Modify it; for example, replace low-flow culvert with larger culvert; floodproof campground structures; increase roughness to reduce velocity and improve safe sites for desired species during floods	Forget it; for example, permanent or seasonal closures of campground; no new structures in floodplains to allow for natural channel movement
Where can tactics be applied?	Stream and waterway corridors; where there are safety concerns or very economically important values	Stream and waterway corridors; where there are safety concerns or very economically important values	Stream and waterway corridors; where there are safety concerns; lower priority areas
Opportunities for implementation	Where there is overlap in values with partner agencies that have funding	Engineer to more extreme events (from 50-year flood specifications to 500-year flood)	Wherever Forest Service identifies a lower priority and where partnership opportunities are limited
Comments	---	---	Public communication and feedback will be issue; public may not see how these issues affect their values until flood occurs

Table 9A.4—Ecological disturbance adaptation options developed at the Southern Great Basin and Semi Desert subregion workshop.

Sensitivity to climatic variability and change: More fire will occur on the landscape			
Adaptation strategy/approach: To protect values on the landscape, allow for more managed fire to reduce available fuel loadings			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Develop understanding or products that help managers and line officers make decisions on managing long-duration fires; incorporate information learned into the Wildland Fire Decision Support System	Utilize a risk-benefit model to identify key locations where fuels modifications would benefit the potential use of managed fire (basically a fire behavior modeling exercise)	Find opportunities to work with partners to expand use of natural fire ignitions (develop greater support network of collaborators)
Where can tactics be applied?	Anywhere on the landscape	All of our fire-prone landscapes	Lands adjacent to local communities
Opportunities for implementation	Opportunities may at first be limited, but the hope is that the available landscape opens up through time	Align with other land management activities or other collaborative efforts; where it would help move toward desired condition	Develop opportunities where there is alignment in the landscapes and social acceptance or willingness to support the use of fire
Comments	Goal of this is to better articulate the benefits of managing a fire event now versus putting it off to the future and balancing the ecological and social benefits of fire	Goal is to prioritize and identify key strategic locations for fuels treatment that would enhance the ability to manage natural ignitions	Goal is to build local support for fire on the landscape and to develop and recognize the benefits and risks that can be realized; use this to help inform fire management decisionmaking
Sensitivity to climatic variability and change: Increased stress on rangeland resources will occur due to less forage production capability from managed and unmanaged ungulate use			
Adaptation strategy/approach: Look for options to improve range condition			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Look at options for changing turnout dates to capture the green-up phase of cheatgrass	Explore options for assisted migration of southern grasses, through either seed zone modifications or enhancement of genetic drift (hybridization)	In a collaborative setting, explore options to reach optimal feral horse numbers
Where can tactics be applied?	Locations that have abundant cheatgrass and that do not have other issues (e.g., threatened and endangered species)	Areas of critical habitat	Areas of critical habitat
Opportunities for implementation	May have limited options	Focus on favorable climate situations or suitable habitats for success	Remain opportunistic on locations where cooperators would be interested
Comments	Goal is to capture the ecosystem service; may be a tool to help with the conversion to native species	Goal is to improve the drought and grazing tolerance of range forage species	This is a controversial topic but an important consideration when thinking about long-term management of both the horses and native species

Appendix 10—Terrestrial Animal Adaptation Options Developed for the Intermountain Adaptation Partnership Region

The following tables describe climate change sensitivities and adaptation strategies and tactics for terrestrial animals, developed in a series of workshops as a part of the Intermountain Adaptation Partnership (IAP). Tables are organized by subregion within the IAP. See Chapter 14 for summary tables and discussion of adaptation options for terrestrial animals.

Table 10A.1—Terrestrial animal adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: Food web and nutrient flows will be affected by changing climate

Adaptation strategy/approach: Maintain resilient flow, sedimentation, and thermal regimes

	Specific tactic – A	**Specific tactic – B**
Tactics	Reduce fine sedimentation and substrate embeddedness	Restore anadromous fish runs (or carcass analogs)
Where can tactics be applied?	Basins with high road density and where roads are directly adjacent to stream channels	Former anadromous fish habitats where migrations are blocked
Opportunities for implementation	---	Fish passage past dam that precludes migrations
Comments	Mitigate adverse effects of sedimentation on macroinvertebrate communities	---

Sensitivity to climatic variability and change: Colonization and expansion of invasive species may occur with climate change

Adaptation strategy/approach: Monitor for invasive species and suppress/eliminate/control populations

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Environmental DNA (eDNA) monitoring for early detection of river and stream invasions.	Reduce or suppress brook trout populations	barriers that prevent access to invasion or invasion of conservation populations in headwaters
Where can tactics be applied?	High-value populations that are thought to be at significant risk of invasion	Headwater lakes that act as source populations; small, isolated streams where complete eradication is possible	Southern portions of IAP region where stream habitats are smaller and more fragmented
Opportunities for implementation	---	Prioritize among hundreds (thousands?) of headwater streams and lakes across the IAP region	Small headwater streams where barrier construction is cost effective and possible
Comments	Costs of eDNA sampling are low enough to make this broadly applicable	Expensive and risky to implement; public support needed for success.	Less useful tactic in areas with anadromous species or fluvial populations of bull trout or cutthroat trout

Table 10A.1 (continued)—Terrestrial animal adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: Colonization and expansion of invasive species may occur with climate change (continued)

Adaptation strategy/approach: Monitor for invasive species and suppress/eliminate/control populations

	Specific tactic – D	**Specific tactic – E**
Tactics	Implement monitoring and boat inspection programs to detect invasive mussel and aquatic plants species in lakes before populations are established	Conduct early-in-life education and educate during the initial stages of invasion (proactive crisis aversion)
Where can tactics be applied?	State borders and near-lake access points (e.g., Sawtooth NF) (e.g., 100th Parallel Initiative)	Schools (e.g., Trout Unlimited's Trout in the Classroom)
Opportunities for implementation	Near high-value resources where funding makes additional staffing possible	Early life experiences to create strong negative attitudes toward invasive species and teach value of native species

Sensitivity to climatic variability and change: Native species distributions will shift, and community realignments will occur with changing climate

Adaptation strategy/approach: Conduct biodiversity surveys to describe current baseline conditions and manage distribution shifts

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Formalize, expand, and standardize biological monitoring programs (e.g., Management Indicator Species)	Use modern, low-cost technologies such as eDNA/DNA barcoding and digital photopoints	Implement assisted migrations
Where can tactics be applied?	Streams, rivers, lakes throughout IAP region	Streams, rivers, lakes throughout IAP region	Suitable but currently unoccupied habitats; consider habitats outside of historical range (e.g., northern extent of species distributions) in addition to historical range
Opportunities for implementation	---	---	Climate Shield fish model can be used to identify high-probability habitats; eDNA used to confirm species presence or absence; then move fish into high-probability areas based on current and future climate forecasts
Comments	Boise NF, Sawtooth NF, and Salmon-Challis NF have rotating panel monitoring designs that provide good templates because broad-scale status and local trend information is represented	New genomic techniques and technologies are inexpensive and make broad applications more feasible than previously	This is a controversial tactic and care is needed to do it properly; if threatened and endangered species are present, there are permitting procedures that must be followed; considerations about whether the system had fish historically or not (e.g., geologic barriers to suitable habitats); if it is a listed species, we may need to designate it as an "experimental population" to be politically feasible

Table 10A.1 (continued)—Terrestrial animal adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: Native species distributions will shift, and community realignments will occur with changing climate (continued)			
Adaptation strategy/approach: Conduct biodiversity surveys to describe current baseline conditions and manage distribution shifts			
	Specific tactic – D	**Specific tactic – E**	**Specific tactic – F**
Tactics	Use digital technology in data collection and database uploads	Streamline and integrate field crew data collection protocols	Fully utilize existing corporate databases and legacy datasets
Where can tactics be applied?	Everywhere	Everywhere	Everywhere
Opportunities for implementation	Field computers for recording data digitally in standardized formats	One crew measures multiple parameters instead of five crews measuring one parameter	File cabinets need to be opened and technicians assigned to data entry task; huge value added by making existing datasets usable
Comments	Technical support staff members are key and need to be well integrated with resource experts	Could some terrestrial and aquatic parameters be measured by same crews?	

Table 10A.2—Terrestrial animal adaptation options developed at the Southern Greater Yellowstone subregion workshop.

Sensitivity to climatic variability and change: Climate change and fire regime shifts will affect persistence of mid- and late-successional sagebrush (affecting sage-grouse, sage thrasher, Brewer's sparrow, pygmy rabbit)

Adaptation strategy/approach: Determine most appropriate management strategies to reduce conifer encroachment

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Determine whether future fire is moving toward or away from historical regime; where we suspect fire regimes are departed from historical, allow wildfires to burn for resource benefit	Use mechanical means to reduce pinyon-juniper; use fire to improve habitat for fire-positive species	Consider future climate envelopes of sagebrush when determining action (avoid investment in managing for sagebrush where it is unlikely to persist)
Where can tactics be applied?	Areas that do not have sage-grouse habitat and where there are few concerns about invasive species	Mechanical treatment where prescribed fire cannot be used	Engage restoration efforts and future investments for sagebrush where future climate is likely to support sagebrush communities; establish alternative plans for areas not likely to support persistent sagebrush
Opportunities for implementation	Areas where natural ignition occurs; condition (conifers encroaching?) and community type (e.g., mountain sagebrush) will determine whether fire will benefit	Already approved tactic for prescribed fire based on precipitation; fire for >12 inches diameter; only mechanical for <12 inches	Consider utility of landscape approach and seek cooperators
Comments	Tradeoff between fire and pinyon-juniper encroachment; increased fire is not always negative (e.g., mountain sagebrush); consider implications of increased fire for invasive species	---	Potentially engage Bureau of Land Management in burning and seeding activities

Table 10A.2 (continued)—Terrestrial animal adaptation options developed at the Southern Greater Yellowstone subregion workshop.

Sensitivity to climatic variability and change: Climate change will have negative effects on amphibians (yellow-legged frogs, Columbian spotted frogs, boreal toad)

Adaptation strategy/approach: Maintain integrity and quality of remaining habitats or habitats that may become suitable as temperatures increase

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Manage for other related stressors: Maintain healthy forests, rangeland, riparian habitat near current or future core habitats; consider land use (e.g., road concentration)	Restore beavers and aspen; provide woody browse; consider restoring willow	Minimize diversion of flow through water range improvement
Where can tactics be applied?	Core areas identified through recent Bridger-Teton capable habitat modeling exercise and inventory work	1. Determined through modeling exercises of where beaver have occurred (e.g., sedimentation studies) 2. Determine where it would be socially acceptable to reintroduce beaver (e.g., prevent undesired consequences such as flooding of campground) and restore aspen 3. Determine where aspen restoration might be feasible 4. Prioritize on areas that may represent future habitat	As determined in tactics A (core areas) and B (feasible areas)
Opportunities for implementation	Determine opportunities through additional modeling exercises to determine future habitat (e.g., higher elevation)	Collaborate with ongoing beaver restoration project; collaborate with ongoing aspen restoration efforts (ongoing with many partners); consistent with Planning Rule that talks about natural range of variation; address this tactic in the Bridger-Teton Forest Plan revision process.	Start with any new range improvements or other water developments; areas where we are currently reconstructing range improvements
Comments	Stressors: disease, motorized routes, camping, reservoirs, water quality, sedimentation, introduced fish, fire, livestock grazing, timber harvest	Aspen restoration has implications for many ecosystem functions far beyond current tactic goals	---

Table 10A.3—Terrestrial animal adaptation options developed at the Uintas and Wasatch Front subregion workshop.

Sensitivity to climatic variability and change: Higher temperatures will alter timing of life history events (e.g., breeding, dispersal, pelage change)			
Adaptation strategy/approach: Identify species where phenology mismatches are relevant, identify areas where phenology difference is currently minimal and is likely to be minimal into the future, prioritize those areas for protection, and manage for habitat resilience; scale: Protect and restore large enough areas to be relevant to the population			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Maximize habitat quality and availability so the population is more resilient, which may help minimize impact of phenology mismatch	In areas that remain matched, prioritize those areas for protection	Identify areas that will become matched in the future and maintain and promote connectivity so animals can migrate to the new habitats; also consider facilitated migration where appropriate
Where can tactics be applied?	Prioritize restoration resources where habitats are optimal or on the leading edge of range shift	Where it remains good habitat	Where it is becoming suitable habitat
Opportunities for implementation	Use a variety of methods to protect, maintain, or restore habitats where appropriate to increase resilience	During forest planning, conduct assessments to identify remaining high-quality habitats most likely to stay matched with phenology; protect these areas in forest plan land management prescriptions	Assess where habitat quality is likely to increase and become matched with phenology, manage to facilitate habitat improvements, and protect in forest plan
Comments	Monitor the most susceptible species to validate population response to these management actions	---	Assisted migration is a last resort; allowing natural migration by maintaining connectivity is preferred

Table 10A.3 (continued)—Terrestrial animal adaptation options developed at the Uintas and Wasatch Front subregion workshop.

Sensitivity to climatic variability and change: Changing intensity and frequency of fire regimes will decrease area and connectivity of some habitats, notably late-successional and mature forest and big sagebrush			
Adaptation strategy/approach: Maintain current habitat, restore historical habitat, promote potential future habitat, and increase resilience of these habitats and surrounding habitats			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Strategically place fuel breaks to minimize risk to important habitat areas	Restore disturbance regimes by reducing accumulated fuel loads	Identify areas in the future that will have the disturbance regimes characteristic of late-successional and mature forests and big sagebrush, and manage to promote their development and resilience
Where can tactics be applied?	Strategically place on the windward side of important habitat areas; place in a configuration to minimize risk of fire spread across the landscape.	Within the habitats where uncharacteristic fuel loads have developed, and balanced with other objectives for species dependent on a complex understory	Identify where disturbance regimes associated with your target habitat will shift, and focus restoration on those areas and connectivity to those areas
Opportunities for implementation	Anywhere these habitats are identified and a break in fuel continuity is needed	Using prescribed fire and fire surrogates to create the conditions to replicate historical frequency and intensity	In areas that are prone to native type conversions resulting from changing ecological conditions
Comments	Species that use late-seral or mature stand characteristics	Recognize that these treatments will cause a short-term impact for long-term benefits	Policy change needed
Sensitivity to climatic variability and change: Increased duration and periodicity of drought and reduced soil moisture will stress vegetation and aquatic wildlife species			
Adaptation strategy/approach: Restore and enhance water resource function and distribution at the appropriate watershed scale; prioritize watersheds based on condition and a variety of resource values, including wildlife			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Reduce biomass to reduce evapotranspiration and mortality resulting from water stress for groundwater-fed systems (thinning and other vegetation treatments) and maintain shade for nongroundwater-fed systems.	Increase water storage by managing for beaver populations using a comprehensive beaver strategy (minimizing conflicts, such as by reducing cattle impacts on small water sources)	Provide enhanced water distribution with appropriate wildlife use designs and balance water use with wildlife needs; protect headwaters, spring heads, riparian areas, etc.
Where can tactics be applied?	Suggested scale of Hydrologic Unit Code 8 to 12 based on assessment for watershed prioritization	Riparian areas where conditions are appropriate (presence of aspen and willow) and conflict will not result (culvert damage, flooding roads)	Areas where there is concern about amphibian populations and other wildlife species dependent on water sources
Opportunities for implementation	Integrated approach with multiple resources (hydrology, fisheries, range, wildlife, etc.)	Partnerships with State, County, water districts, nongovernmental organizations; need public education to foster acceptance	Coordination with range staff; use volunteers to help create ponds and alternative water sources

Table 10A.3 (continued)—Terrestrial animal adaptation options developed at the Uintas and Wasatch Front subregion workshop.

Sensitivity to climatic variability and change: Altered disturbance regimes and water availability and increasing temperatures will continue to facilitate the spread of invasive plant species			
Adaptation strategy/approach: Use an integrated approach to prevent the spread and establishment of invasive species			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Use rapid response to treat and restore newly invaded areas to prevent establishment	Enhance the resistance and resilience of native plant communities by maintaining vigorous growth of native shrub, perennial grass, and other perennial species through restoration activities, appropriate grazing techniques, and fire management treatments	Use integrated pest management to control established infestations, including biocontrol, herbicides, and ecological competition
Where can tactics be applied?	Identify susceptible areas through modeling and monitoring to allow for rapid response	Grazing allotments and known areas of healthy native plant communities	Areas known to be infested
Opportunities for implementation	Educate field employees and public to identify and report invasive occurrence	In areas departed from historical fire regime or identified through watershed assessment and range monitoring	Ongoing annual program of work and partnerships

Table 10A.4—Terrestrial animal adaptation options developed at the Plateaus subregion workshop

Sensitivity to climatic variability and change: Climate change will result in shifts in alpine species composition (of both plants and animals, e.g., spruce-fir encroachment, rodents, humans) due to shrinking snowpack, changes in timing of snowmelt, and increasing temperatures that allow species to move up into alpine ecosystems; species affected include pika, endemic plants, pollinators, and black rosy finch			
Adaptation strategy/approach: Reduce additional stressors in alpine habitats			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Manage human access (e.g., build trails, harden sites, use permit systems or outfitter guides)	Maintain mountain goats at populations that eliminate adverse impacts (remove goats if needed and discourage continued introduction of goats)	Monitor movement of plants (including both conifers and exotic weeds) and monitor movement of treeline
Where can tactics be applied?	Alpine trailheads; areas of high use (e.g., La Sals)	La Sals, Tushars, Mt. Dunton, Ashley NF	Everywhere habitat is present
Opportunities for implementation	Work with recreation staff; consider in development of new forest plans	Work with Utah Division of Wildlife Resources (DWR)	Ongoing treeline study
Sensitivity to climatic variability and change: Climate change will lead to changes in wetland habitat quantity and quality			
Adaptation strategy/approach: Maintain connectivity and habitat quality to promote resilience of wetland habitats			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Actively restore and protect functioning wetlands	Reintroduce beaver; expand or restore habitat where appropriate	Manage grazing to promote good riparian cover and properly functioning riparian habitats
Where can tactics be applied?	All perennial streams	Southeastern Utah; everywhere beavers were historically present	All grazed public lands with perennial streams
Opportunities for implementation	Work with State division of water rights, Utah DWR, conservation groups like Trout Unlimited, and the State watershed restoration initiative	DWR statewide beaver conservation and management plan; State and DWR wildlife action plan	Collaborative groups; grazing permit renewals; sage-grouse land use plan amendments
Comments	Identify, map, and assess important habitats; identify data gaps across all lands; this is relevant for all of the resource areas		

Table 10A.4 (continued)—Terrestrial animal adaptation options developed at the Plateaus subregion workshop.

Sensitivity to climatic variability and change: Uncharacteristic fires in ponderosa pine will result in loss of late-successional forest and snags (affects Lewis's woodpecker, Allen's big-eared bat, Abert's squirrel, northern goshawk, Utah prairie dog)			
Adaptation strategy/approach: Maintain current habitat, restore historical structure, and increase mosaic structure (including snags)			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Conduct thinning and prescribed fire treatments; use thinning from below; maintain natural structure with diversity, density; control ladder fuels	Manage grazing to discourage overgrazing of native plants and to maintain fine fuels to carry fire	Plant adapted (locally sourced) ponderosa pine
Where can tactics be applied?	Existing stands on public and private lands (though thinning is limited in roadless areas and wilderness)	Everywhere ponderosa pine occurs	In areas where stand-replacing fires have occurred, keeping in mind the capacity of the area to support ponderosa pine (soils and water considerations)
Opportunities for implementation	As funding is available; timber stand improvement; consider in public and private land management plans; supporting local businesses (e.g., small diameter processing mills and artisan furniture)	Collaborations (e.g., Four Forests, La Sal Sustainability Collaborative)	After wildfires
Comments	Must keep in mind the preservation of key habitat features of wildlife (e.g., snags)		
Sensitivity to climatic variability and change: Loss of mixed-age stands and loss of mature aspen and snags may occur with increased fire frequency (affects ruffed grouse, flammulated owl, goshawk, many others)			
Adaptation strategy/approach: Maintain and encourage recruitment of aspen to the overstory			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Remove conifers with prescribed fire and logging	Encourage aspen regeneration using fencing, ungulate management (reduce numbers and change season of use [graze early]), and development plans like that implemented by Wolf Creek Ranch (works closely with Wild Utah Project)	Conduct public outreach to help manage for aspen snags; restrict firewood cutting; target information toward ranchette owners; include aspen in public education; use "this is a wildlife home" signs and similar
Where can tactics be applied?	Forest, State, and private lands that are being encroached by conifers	Anywhere	Schools and anywhere
Opportunities for implementation	Monroe Mountain (collaboration on aspen, environmental assessment yet to be implemented)	La Sal Sustainability Collaborative (LSSC)	Southern Utah National Parks, ongoing social media communications, citizen science activities
Comments	---	Must consider both wildlife and livestock	---

Appendix 11—Outdoor Recreation Adaptation Options for the Intermountain Adaptation Partnership Region

The following tables describe climate change sensitivities and adaptation strategies and tactics for outdoor recreation, developed in a series of workshops as a part of the Intermountain Adaptation Partnership (IAP). Tables are organized by subregion within the IAP. See Chapter 14 for summary tables and discussion of adaptation options for recreation.

Table 11A.1— Outdoor recreation adaptation options developed at the Uintas and Wasatch Front subregion workshop.

Sensitivity to climatic variability and change: There is a lack of information on the relationship between climate change and outdoor recreation

Adaptation strategy/approach: Conduct research on visitors who are or will be coming, where they are from, what they are doing, and cultural differences and expectations

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Research all sources; research demographics related to hunting, fishing, nature viewing, hiking, roads, trails, facilities	Assimilate information into resource plans	Prepare information for specific populations that will be affected by climate change and in their respective language(s)
Where can tactics be applied?	All areas: campgrounds, trailheads, day use, wilderness	---	---
Opportunities for implementation	All resource areas		
Comments	Imperative; we do not have enough information available to ascertain specific tactics; which ethnic groups will be affected by climate change?	Lesser amounts of snow are expected	---

Sensitivity to climatic variability and change: People management: Increased flooding and fire will result in fewer recreational sites, more use of alternative campgrounds, reduced services, and increased use of fewer facilities; need flexibility in adapting to changing conditions and in moving people as needed

Adaptation strategy/approach: Research and document existing uses

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Inventory: Use and update the Forest Service INFRA database to assure correct information is available	People management: As conditions change, move people to more desirable sites as needed; think creatively	Communication: Have clear and constant discussions with forests, and establish districts
Where can tactics be applied?	All forests and sites	Underused or new sites that may have to be utilized as weather changes and floods and fire increase; sites where season of use may change	At all levels as need arises
Opportunities for implementation	Annual and constant review of data to assure accuracy	As funding and conditions persist; changes to laws and direction may be affected; prepare for managing garbage and providing enhanced restroom amenities	Watch and monitor as climate changes
Comments	Proper training for data input	National Environmental Protection Act analysis and planning beforehand will be needed; Forest Plans will need to address these changes to be adequately prepared	Can include new technologies for quick exchange of information

Table 11A.1 (continued)—Recreation adaptation options developed at the Uintas and Wasatch Front subregion workshop.

Sensitivity to climatic variability and change: Temperature changes bring changes in season, both for people and resources, and may put more pressure on cultural resources and sites (e.g., looting, collecting, inadvertent impacts from users to cultural resources)

Adaptation strategy/approach: Educate users and protect cultural resources

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Redirect public to less sensitive cultural areas	Provide education and interpretation to inform the public about why these resources are important	Directly protect cultural resources
Where can tactics be applied?	All sites; collaborate with other agencies on strategies; National Park Service is very adept at people management	Developed and sustained sites	Specific sites
Opportunities for implementation	Divert public to more easily sustainable sites while highlighting sites that we want them to visit	Inform public of all ages about the importance of outdoor ethics and respecting outdoor resources	Physical barriers and monitoring
Comments	May need to use plantings, hardscape, etc. to divert visitors to where we want them to go; utilize engineering techniques	Explore all methods of delivery to the public	Law enforcement presence needed; engagement of tribes is vital

Table 11A.2—Outdoor recreation adaptation options developed at the Plateaus subregion workshop.

Sensitivity to climatic variability and change: Season of use, types of recreation, and location of activities may change as the climate changes

Adaptation strategy/approach: Identify and prioritize recreation sites that are prone to change

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Use predictive modeling that incorporates changing climate conditions (e.g., precipitation, temperature)	Survey the public directly or indirectly to determine use patterns, sensitivity to changing climate patterns, trends	Educate the public about likely impacts of changing recreational opportunities
Where can tactics be applied?	During long-term planning processes to identify potential user versus user conflicts (e.g., nonmotorized versus motorized winter use)	National Visitor Use Monitoring, trail counters, Web-based tools	Focus on national forest locations or sites in which changes are occurring (e.g., pine beetle infestations)
Opportunities for implementation	In high-use locations; use information and data from other agencies (e.g., National Park Service)	Collect data from user groups, local interest groups; use social media	As we change road closure dates, for example, provide the "why"; use social media; set up kiosks at scenic overlooks to provide information, especially regarding pine beetle impacts
Comments	See how Recreation Opportunity Spectrum may change with regard to visitation, other variables	Encourage user groups to conduct the surveys	Encourage recreation activities to remove invasive species (e.g., Fish Lake perch tournament)

Table 11A.3—Outdoor recreation adaptation options developed at the Great Basin and Semi Desert subregion workshop.

Sensitivity to climatic variability and change: Changes in recreation use patterns will occur with warming (year-round seasons for non-snow activities, shift in snow-dependent activities, changes in use types and demand)

Adaptation strategy/approach: Increase flexibility and capacity for managing recreation resources to meet shifting demands

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Develop creative budget strategies to support longer and overlapping use seasons; pursue additional grant funding and partnerships and opportunities for new fees (e.g., something similar to Adventure Pass, parking fees, use for peak use times); offer facilities through prospectus for businesses opportunities; leverage outfitting and guiding funds (FDDS42)	Increase flexibility for year-round use of facilities; redevelop or harden existing or new sites (e.g., integrate summer uses into ski area operations); pave access roads for winter and wet uses; install gates or other access control where snow no longer closes areas; change types of infrastructure (e.g., marinas used to be static but now need to be flexible); increase capacity at existing sites to accommodate longer use seasons	Leverage local partnerships to assist with management of recreation facilities (e.g., develop partnerships with local government, other agencies, tribes, and user groups, nongovernmental organizations [Great Basin Institute]; promote trail adoption; facilitate local economic development opportunities)
Where can tactics be applied?	Forestwide and regionwide; all recreation sites	Places with vulnerability to flooding, changing water levels, increased unfrozen saturation, and expanding summer activities in previously winter-only areas; consider design for year-round use (vault versus flush toilets)	Forestwide and regionwide; especially important in areas that are far from Forest Service facilities
Opportunities for implementation	Target most heavily used areas	Existing developed recreation facilities (restore vulnerable sites, change or close some sites) require sustainable facility investments under new prospectus bids; where money is available	Build on existing agreements; reach out for new partners; engage local stewardship groups; work with youth groups; work with tribes more
Comments	Educate public about fees to reduce pushback; support national policies for local fee retention	Flexible management of recreation sites is needed (e.g., change travel management plans to open areas based on condition, not date)	Reducing operational and travel costs is very important because of budget constraints and distances

Appendix 12—Infrastructure Adaptation Options for the Intermountain Adaptation Partnership Region

The following tables describe climate change sensitivities and adaptation strategies and tactics for infrastructure, developed in a series of workshops as a part of the Intermountain Adaptation Partnership (IAP). Tables are organized by subregion within the IAP. See Chapter 14 for summary tables and discussion of adaptation options for infrastructure.

Table 12A.1—Infrastructure adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: Increased temperatures will have broad implications for building design and maintenance			
Adaptation strategy/approach: Protect existing and future infrastructure by examining present and future hazards on building infrastructure			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Examine surroundings for hazard trees, and remove those that present hazards to facilities	Follow recommended practices for keeping buildings safe from fires	Monitor movement of ranges of potential insects; educate those living in and maintaining buildings about the signs and risks of insects
Where can tactics be applied?	Any building	Any building	Any building
Opportunities for implementation	During general maintenance and landscaping, continually evaluate the site for hazards	Evaluate structures for compliance with best practices during building condition surveys	Regionwide education and research dissemination on insect issues
Sensitivity to climatic variability and change: Increased temperatures will have broad implications for building design and maintenance			
Adaptation strategy/approach: Add guidance to existing design standards and consider adjustment of maintenance activities to account for climate change			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Consider future of hotter temperatures during building HVAC design	Design for and install heat- and drought-resistant landscapes (xeriscape)	Anticipate where ice dam problems may occur in the future
Where can tactics be applied?	Any building	Any building	Buildings in higher elevations where winter temperature may fluctuate near freezing
Opportunities for implementation	During new construction and HVAC replacement	During new construction and when funding opportunities are present	During new construction and re-roofing projects, consider the potential for ice dam problems
Comments	Consider designing for increase in temperature of 10 °F by 2100	Concentrate on facilities with highest water use	

Table 12A.1 (continued)—Infrastructure adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: Increased temperatures will have broad implications for road design and maintenance

Adaptation strategy/approach: Increase resilience where roads and streams interact

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Adapt the design standards where future rain-on-snow events are expected	Develop risk assessment for road infrastructure	Perform road blading and grading activities during periods when natural moisture conditions are optimum, and use water trucks as needed to supplement
Where can tactics be applied?	Agency and partner road systems	Agency and partner road systems	Agency and partner road systems
Opportunities for implementation	Smaller project scale implementation and during regular maintenance and replacement	Develop partnership with Federal Highway Administration	Implement during regular maintenance activities
Comments	---	---	Maintenance may need to occur earlier and more often in the field season

Table 12A.2—Infrastructure adaptation options developed at the Southern Greater Yellowstone subregion workshop.

Sensitivity to climatic variability and change: Increased storm frequency and intensity conditions will have broad implications for design and maintenance of bridges, dams, canals, and levees			
Adaptation strategy/approach: Protect existing and future infrastructure by examining present and future hazards on dam infrastructure			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Evaluate existing inventory for capacity and structural integrity using projected climate models for extreme storm events	Incorporate projected climate models for extreme storm events in structure design and bridge location.	Facilitate partnering efforts between private, local, State, and Federal jurisdictions
Where can tactics be applied?	Any existing bridge, dam, canal, levee	Any planned bridge, dam, canal, levee	Any existing or planned bridge, dam, canal, levee
Opportunities for implementation	As part of scheduled inspections, maintenance activities, and as requested by partners	During scoping, planning, and engineering design	Ongoing
Sensitivity to climatic variability and change: Anticipated wildfire intensity conditions will have broad implications for infrastructure design and maintenance			
Adaptation strategy/approach: Protect existing and proposed infrastructure by examining present and future hazards due to increased wildfires and post-wildfire conditions			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Design bridges and culverts to minimize diversion potential	Increase defensible space around infrastructure and discourage development in the wildland-urban interface	Enhance existing public and private fire hazard education and mitigation as related to infrastructure design
Where can tactics be applied?	Any planned bridge or culvert	Existing and proposed structures within and adjacent to Federal lands	Public and private domain as well as local, State, and Federal fire-related agencies
Opportunities for implementation	During scoping, planning, engineering design	During inspection, scoping, planning, engineering design	Ongoing

Table 12A.3—Infrastructure adaptation options developed at the Great Basin and Semi Desert subregion workshop.

Sensitivity to climatic variability and change: Power line infrastructure may be increasingly impacted by ecological disturbances (e.g., wildland fire, insect and disease tree hazards, invasive plants [cheatgrass], and geologic hazards)			
Adaptation strategy/approach: Create plausible risk scenarios to utilize in current permit management			
	Specific tactic – A	**Specific tactic – B**	
Tactics	Communicate with existing power line permit holders and annually in wildland fire sand table exercises	Map all power lines in the IAP region	
Where can tactics be applied?	Emergency response plans for plausible scenarios	GIS project development	
Opportunities for implementation	In high fire risk areas, replace wood poles with steel poles	---	
Comments	Integrated vegetation management with power company	---	
Sensitivity to climatic variability and change: Use of power line infrastructure may change because of changes in power generation and demand (e.g., alternative energy sources such as solar and geothermal)			
Adaptation strategy/approach: Create plausible risk scenarios to utilize in approval process (National Environmental Policy Act process and design)			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Create response plans to risk scenarios	Incorporate risk scenarios in natural resource planning and forest plans	Garner broad support to consider risk assessments
Where can tactics be applied?	---	---	---
Opportunities for implementation	---	---	---
Sensitivity to climatic variability and change: Recreation residences may be subject to increased risk from extreme climatic events (e.g., fire, snow, flooding, avalanche, and ecological disturbance)			
Adaption strategy/approach: Develop risk assessment tools, and address risk with holders and County emergency medical services			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Communicate with existing recreation resident holders	Develop clear procedures for removing a recreation residence that exceeds a risk threshold	Consider developing in-lieu lots or other recreation tracts
Where can tactics be applied?	All recreation residences	Site-specific and in each district	Agency review of program
Opportunities for implementation	Communication during annual inspections and national homeowners association meetings	Annual inspections; national homeowners association meetings	National and regional-level meetings

Table 12A.3 (continued)—Infrastructure adaptation options developed at Great Basin and Semi Desert subregion workshop.

Sensitivity to climatic variability and change: Recreation events and trail infrastructure may face increased risk from extreme climatic events (e.g., fire, snow, flooding, avalanche, and ecological disturbance)

Adaptation strategy/approach: Incorporate changes in extreme climatic events into recreation event planning

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Change timing and location of events	Conduct more indoor events, such as computerized bicycle “spin” events	Cancel events when human safety is at risk
Where can tactics be applied?	Road and mountain bike events	---	---
Opportunities for implementation	---	---	---

Appendix 13—Cultural Resource Adaptation Options for the Intermountain Adaptation Partnership Region

The following tables describe climate change sensitivities and adaptation strategies and tactics for cultural resources, developed in a series of workshops as a part of the Intermountain Adaptation Partnership (IAP). Tables are organized by subregion within the IAP. See Chapter 14 for summary tables and discussion of adaptation options for cultural resources.

Table 13A.1—Cultural resource adaptation options developed at the Southern Greater Yellowstone subregion workshop.

Sensitivity to climatic variability and change: Loss of traditional food sources may occur with severe wildfire			
Adaptation strategy/approach: Integrate traditional ecological knowledge with fire management plans and cultural resource database to holistically manage for traditional food sources (i.e., huckleberries, mushrooms, pine nuts, sage-grouse)			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Emphasize preservation of traditional food sources with tribal and local significance	Enhance resilience of specific habitats to fire and other threats; manage fire to maintain or protect sagebrush rangelands and other sensitive vegetation community types	Identify and protect areas suitable for traditional food gathering during fire suppression and rehab activities
Where can tactics be applied?	Across the national forest and region	Across the national forest and region	Across the national forest and region
Opportunities for implementation	Consult with tribes; eliminate commercial permits in areas with special tribal significance; work with local user groups to identify areas of concern	Consider all vegetation treatments including fire management planning as opportunities for enhancing resilience; consider traditional food sources during fire management planning	Continue to collect data and refine models to better understand location of traditional food-gathering areas
Comments	Need to integrate tribal and local knowledge with existing Forest Service information	Identify these areas as soon as possible	Need to coordinate with researchers, fire managers, tribes, and cultural resource staff
Sensitivity to climatic variability and change: Increased fire will result in increased erosion and loss of vegetation, which may increase damage and impacts to cultural resources			
Adaptation strategy/approach: Encourage predisturbance and postdisturbance strategies to protect cultural resources			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Increase the use of prescribed fire or other vegetation manipulation	Inventory, map, and rate fire risk for cultural resources	Develop a plan to address postfire impacts to cultural resources that have been affected
Where can tactics be applied?	In and around cultural resources that are susceptible to impact from severe wildfire	Across the national forest	Across the burned areas
Opportunities for implementation	At the project planning level; during the annual program of work discussion.	Integrate inventory with other survey needs focusing on high site potential areas across the forest; encourage forest personnel and the public to contribute information on at-risk site locations	Develop long-term stabilization and restoration plans; integrate into Burned Area Emergency Response (BAER) plans and during the forest planning effort.
Comments	Need to identify areas with high stand density	Be creative in finding ways to complete the surveys; utilize existing resource information (LiDAR) to identify cultural resources	Ensure communication between heritage and fire staff

Table 13A.1 (continued)—Cultural resource adaptation options developed at the Southern Greater Yellowstone subregion workshop.

Sensitivity to climatic variability and change: Implementation of adaptation strategies by other resource areas may affect cultural resources

Adaptation strategy/approach: Comply with National Historic Preservation Act (NHPA) before implementation of adaptation strategies

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactics	Large-scale planning effort: Integrate NHPA considerations into the development of adaptation strategies; if considering modification of landscapes or habitats, consider opportunities to preserve or protect cultural resources within the areas considered for treatment	Early initiation of NHPA compliance during specific project planning	Develop a plan to address climate change impacts to cultural resources
Where can tactics be applied?	Must be applied project-wide	Across the national forest	Across the national forest and region
Opportunities for implementation	Ongoing, agency-wide	Project initiation, out year planning	Ensure communication between heritage and other resource areas
Comments	A requirement; tribal consultation also required	Be creative in finding ways to complete the surveys; utilize existing resource information (LiDAR) to identify cultural resources	Explore opportunities for other resource management to help us stabilize and preserve cultural resources

Sensitivity to climatic variability and change: Increased recreation may threaten cultural resources

Adaptation strategy/approach: Educate users and protect cultural resources

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactics	Redirect public to less sensitive cultural area	Education and interpretation to inform the public of why these resources are important; engage user groups	Direct protection with physical barriers, fencing, vegetation screening, access management
Where can tactics be applied?	Specific sites; need to identify high recreation use locations and where impacts are occurring or may occur in the future	Dispersed recreation sites, system trails	Specific sites
Opportunities for implementation	Divert public to more easily sustainable sites while highlighting sites that we want them to visit	Inform public about the importance of cultural resource ethics and respecting these resources	Physical barriers and monitoring
Comments	May need to use plantings, hardscape, etc. to divert visitors to where we want them to go; utilize engineering techniques	Need to work with recreation staff to determine public use patterns	More Forest Service presence, use ambassadors; tribal engagement is vital; NHPA compliance is required

Table 13A.2—Cultural resource adaptation options developed at the Plateaus subregion workshop.

Sensitivity to climatic variability and change: Increased fire will result in increased erosion and loss of vegetation, which may increase damage and impacts to archaeological sites

Adaptation strategy/approach: Encourage predisturbance and postdisturbance strategies to protect high-value archaeological sites and resources

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Increase the use of prescribed fire or other vegetation manipulation	Inventory, map, and rate fire risk for archaeological resources	Develop a plan to address postfire impacts to archaeological sites that have been exposed
Where can tactics be applied?	In and around archaeological resources that are in fire-prone areas	In and around archaeological resources that are in fire-prone areas	Across the national forest
Opportunities for implementation	At the project planning level; during the annual program of work discussion	Focus on the high-risk areas as part of the required annual surveys; pursue partnerships with archaeology groups and organizations	In Burned Area Emergency Response (BAER) plans; during the forest planning effort; in prefire season planning
Comments	May need to prioritize archaeological sites, properties, resources	Be creative in finding ways to complete the surveys; use satellite imagery to identify changing fire risk	Communication with the heritage officer or staff; other major disturbances, such as flooding, can be addressed using these tactics

Table 13A.3—Cultural resource adaptation options developed at the Great Basin and Semi Desert subregion workshop.

Sensitivity to climatic variability and change: Pinyon pine forest may be lost as a cultural resource due to a severe wildfire

Adaptation strategy/approach: Integrate traditional ecological knowledge with Western science to holistically manage for pine nuts and other values (e.g., sage-grouse)

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Emphasize preservation of stands with tribal significance	Enhance resilience of stands to fire and other threats; focus on phase 0/1 pinyon-juniper and isolated pinyon-juniper trees surrounded by good sage-grouse habitat; look for opportunities to create strategic fuelbreaks in contiguous woodland	Identify and protect areas suitable for pinyon under future climate conditions
Where can tactics be applied?	Across the national forest and regionwide	Across the national forest and regionwide	Across the national forest and regionwide
Opportunities for implementation	Attempt consultation with all affected tribes; eliminate commercial permits in areas with special tribal significance	Consider all vegetation treatments as opportunities for enhancing resilience	Continue to collect data and refine models to better understand future pinyon distribution; learn from past management projects
Comments	Work to use local knowledge in determining where pinyon should and should not be removed; need to compare tribal concerns with Western science and GIS information	Identify these areas as soon as possible	Collaborate with researchers, fire managers, and others

Appendix 14—Ecosystem Service Adaptation Options for the Intermountain Adaptation Partnership Region

The following tables describe climate change sensitivities and adaptation strategies and tactics for ecosystem services, developed in a series of workshops as a part of the Intermountain Adaptation Partnership (IAP). Tables are organized by subregion within the IAP. See Chapter 14 for summary tables and discussion of adaptation options for ecosystem services.

Table 14A.1—Ecosystem service adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: Small rural communities are entirely dependent on a single watershed or source that may be exposed to fire, drought, and floods associated with climate change			
Adaptation strategy/approach: Develop preparedness plans for disaster and assess future needs for water			
	Specific tactic – A		
Tactics	Identify key watersheds that are sensitive		
Where can tactics be applied?	Forest and district level		
Opportunities for implementation	Future planning, working in watershed health with discussions on fire planning; include discussion with small communities on their vulnerabilities		
Sensitivity to climatic variability and change: Temperature changes bring changes in season for both people and resources (e.g., snowmobile use changes to ATV use, mountain biking occurs over longer seasons and at higher elevations, hunting and people put pressure on wildlife at sensitive times)			
Adaptation strategy/approach: Align human uses with new seasonalities, and implications for those changes on resources			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Implement seasonal use or other permitting for activities that were constrained by weather (e.g., ATV, mountain biking)	Develop capacity for flexibility in seasons (opening dates for campgrounds, access to trails, road closures)	Evaluate impacts and conflicts to resource and user groups (e.g., livestock) due to recommended changes in seasonal use
Where can tactics be applied?	Especially in higher elevations	Analysis of need done at regional level; each unit left to carry out in practice; problems observed at district level, but empowerment done at national forest level	District- and forest-level decisions
Opportunities for implementation	Permitting or seasonal closures (need to evaluate new need for these); longer operating periods (campgrounds, concessions); education and outreach (public, user groups, trailhead signage)	Planning and approving permitting for multiple sites that span a spectrum of weather outcomes	Public meetings, online surveys, research partners to conduct study of issue
Comments	---	Staffing and funding for extended seasons is problematic; uncertainty in contracts to concessionaires; may be a safety issue as people are in backcountry during shoulder seasons with rapidly changing weather	Noting conflicts between hunters being on the land at the same time cattle are being grazed; this is an issue for hunters that lose access with cows on the land, and ranchers whose livestock are shot; expanded ATV use can conflict with hunters and spread weeds

Table 14A.1 (continued)—Ecosystem service adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: Air quality will be threatened by increased fire extent and frequency, and may adversely affect health, tourism, and opportunity to go outside

Adaptation strategy/approach: Integrate fire planning and response with climate change considerations

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Model which places are susceptible to high smoke, and get that message out to developers, tourists, others	Inform people in advance of and during burn events—more effectively (both for prescription burns and wildfire); improve understanding for prescription burn necessity (habitat vs. logging?); improve messaging regarding natural fire cycles	Minimize impacts to tourism
Where can tactics be applied?	At unit level but have assistance from fire science centers/National Interagency Fire Council (NIFC), and Forest Service Research Centers	National, regional, and unit levels; consider the story-telling approach. Leverage existing messages about fire and the role of smoke in healthy ecosystems; the best place for getting the "webcam/current condition" data is the communities, tourism boards, etc.	Conversations with local public about what the tolerance level is—how to quantify? Communicate with tourists and tourism offices; give them information to pass along to others; add more information on recreation.gov so visitors can access information themselves; emphasize opportunities as well as closures
Opportunities for implementation	Incorporate into existing fire planning, transportation planning, recreation planning, wilderness planning; and communication strategy	Prioritize right before and during fire season (note: this is becoming year round)	---
Comments	---	There is an opportunity to get the message out about what is open as well as what is closed; could install webcams to show current conditions	---

Table 14A.1 (continued)—Ecosystem service adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: Temperature changes bring changes in season, for both people and resources, and may put more pressure on cultural resources and sites (i.e., looting, collecting, inadvertent impacts from users to cultural heritage resources)

Adaptation strategy/approach: (1) Improve state of our knowledge of remote cultural resources at risk from climate change impacts; (2) improve awareness to users before they get out there

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Communicate with users in a variety of ways before they hit the trail	Learn what we have; complete an inventory of high-risk areas	Develop a monitoring program for high-priority resources
Where can tactics be applied?	All levels, Web sites, trailhead signage, trifolds, social media, public service announcements; assess effectiveness! "Leave no trace," "Tread lightly," "Respect and protect" message; partner with interest and advocacy groups, tribes, outfitters	Set strategy at regional level; implement at unit level; funding has rarely been allotted to Section 110 of the National Historic Preservation Act; need to identify opportunities for this	Set strategy at regional level; implement at unit level; identify funding sources in climate change or other sources; again, this has been orphaned in the past
Opportunities for implementation	Consider Chamber of Commerce, other heritage tourism connections; leverage celebrations and centennials to get the message out	Celebrations and centennials may bring funding for awareness; systematic inventories; aerial photography	Collaborate with appropriate parties (tribes, vetted researchers, site steward program, interest groups) for citizen science; remote cameras for enforcement and monitoring of impacts to cultural sites
Comments	At higher geographic and societal scales to avoid revealing sensitive information or increasing risk; strategize using nonsensitive cultural resources in the messaging	Consider social vulnerability angles: at-risk resources and the larger picture of community health and identity	Need to be sensitive to tribes' reluctance to share information about important sites

Sensitivity to climatic variability and change: Fire, erosion, floods, and mass wasting will threaten trails and other recreational features of the landscape, resulting in safety issues

Adaptation strategy/approach: Identify and describe threats; mitigate for threat

	Specific tactic – A	**Specific tactic – B**
Tactics	Use existing data and models to do overlays of highest vulnerability and threat levels (to ecosystem services, in general)	Understand demographic trends and demand for hunting, fishing, and wildlife viewing
Where can tactics be applied?	At unit level with assistance from fire science centers, NIFC, Forest Service Research Stations; potentially U.S. Geological Survey	In partnerships with wildlife groups, State agencies
Opportunities for implementation	Incorporate into existing fire planning, transportation planning, recreation planning, wilderness planning	In national reports such as the Resource Planning Act (RPA) Assessment, partnerships with groups such as Headwaters Economics

Table 14A.1 (continued)—Ecosystem service adaptation options developed at the Middle Rockies subregion workshop.

Sensitivity to climatic variability and change: Change in timing of water availability and absolute amount of water available will affect water-based recreation; high temperatures may drive up demand for water recreation			
Adaptation strategy/approach: Plan to account for these changes in demand			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Identify places that are likely to be affected by climate change: either loss of water-based recreation, or where more recreation will be concentrated	Rethink campground locations to make them more pleasant for hot climates (e.g., spots in the shade) and near existing water resources; use intentional locations to control impacts of dispersed camping	Future reservoirs may be needed to meet municipal water demand that will also be used for recreation, but may also flood existing recreation sites (e.g., campgrounds)
Where can tactics be applied?	All forests	Forests especially attractive to RVs	Near existing water resources, and likely new sites for reservoirs
Opportunities for implementation	Partnering with GIS specialists, recreation specialists, and climate specialists	Will require awareness for future planning; a need for more enforcement to keep people where we want them and limit impacts where we do not; partnering with recreation user groups will be a key to success	Looking ahead to plan for such changes
Comments	A first requirement may be an assessment of current use, in order to forecast future demand	Need to educate people about the sensitivity of water resources to human impacts; it is very difficult to close sites	---

Table 14A.2—Ecosystem service adaptation options developed at the Southern Greater Yellowstone subregion workshop.

Sensitivity to climatic variability and change: Climate change is likely to lead to shift in grazing patterns between Bureau of Land Management (BLM) and Forest Service (FS) lands and may interfere with wildlife phenology (namely sage-grouse nesting)

Adaptation strategy/approach: Develop a holistic approach to grazing management; understand rancher's business approach, lands used, water management, and competing demands from other resources and multiple uses

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**	**Specific tactic – D**
Tactics	Modify flexibility in timing, duration, and intensity of authorized grazing	Use grazing as a tool to achieve desired conditions: holistic grazing, target grazing on noxious weeds	Consider novel ways to manage grazing (e.g., contracting grazing opportunities on Forage Reserves on the Bridger-Teton NF and vacant allotments)	Minimize impacts; design livestock water developments (e.g., shutoff valves for tanks, and protection of spring sources) more efficiently
Where can tactics be applied?	Public, private, and all adjacent lands	Across the national forest on all grazing allotments	Across the national forest on all grazing allotments; especially needed in areas where there is a gap between availability of BLM land and FS land	On grazing areas, in sensitive spring-source ecosystems
Opportunities for implementation	Permit renewals and forest plan revision; collaboration with other governmental entities; regional directives	Partnerships with Natural Resources Conservation Service and with States, weed management groups, Counties	---	An engineering solution to water waste and impacts to riparian areas; partnerships
Comments	---	---	This gives a space for cattle during times when they have nowhere else to go	May need novel ways of funding

Table 14A.2 (continued)—Ecosystem service adaptation options developed at the Southern Greater Yellowstone subregion workshop.

Sensitivity to climatic variability and change: With higher variability in weather, timing of availability of recreation sites may become less predictable; warm temperatures at low elevations trigger desire for recreation, but colder and wet high elevations may not be capable of absorbing the human impact

Adaptation strategy/approach: Change staffing and management in highly variable shoulder seasons to accommodate flexibility in seasons, dates, and travel management; consider tradeoffs between flexibility and predictability

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Add gates to closed areas that may be muddy; use multiple gate system to open lower trails but close off higher elevation trails; harden roads that are likely to be used in muddy season	Use social media and real-time information to communicate to the public the impacts of out-of-season or non-seasonally appropriate recreation	Flexible travel management plans, staffing; flexible dates for road openings
Where can tactics be applied?	Lower elevation access points	Virtually, local-level knowledge; strategic communications; forest-level contacts, Facebook®, Twitter®	Lower-elevation and mid-elevation roads
Opportunities for implementation	Travel plan revisions	In partnership with private and community organizations (e.g., Friends of Pathway); tech-savvy user groups	Travel plan revisions
Comments	---	Users often predict use based on past experiences, which are no longer good predictors of the present and future, so users may get caught off-guard by change in weather and trail conditions; need to educate people on changing hazards	---

Table 14A.3—Ecosystem service adaptation options developed at the Uintas and Wasatch Front subregion workshop.

Sensitivity to climatic variability and change: Pollinators will be sensitive to climate change			
Adaptation strategy/approach: Increase agency and public awareness of the importance of native pollinators			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Establish a pollinator coordinator to communicate with district- and forest-level ID teams, as well as the Regional Office and the public	Develop a checklist to consider pollinator services in planning, project analysis, and decision making	Establish pollinator gardens
Where can tactics be applied?	Each national forest	In both the National Forest Management Act and National Environmental Policy Act processes	On Federal facilities or in partnership with other public entities (e.g., public spaces, parks, backyards)
Opportunities for implementation	---	During project initiation, ID team process, forest planning	Collaborative programs and partnerships, schools, State and private forests, nongovernmental organizations (e.g., Xerces Society), chambers of commerce
Comments	A coordinator can also be established for other ecosystem services that are not well-represented	A similar checklist may be useful at large spatial scales (establish need for change and desired future condition goals and objectives)	Seeds of local origin should be emphasized; encourage awareness of native, pollinator-friendly plants; use local nurseries, seed collectors, restoration ecologists, etc.

Table 14A.3 (continued)—Ecosystem service adaptation options developed at the Uintas and Wasatch Front subregion workshop.

Sensitivity to climatic variability and change: Pollinators will be sensitive to climate change			
Adaption strategy/approach: Enhance pollinator habitat on Federal lands and Federal facilities			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Direct Forest Service units to improve pollinator habitat by increasing native vegetation (via integrated pest management and integrated vegetation management) by applying pollinator-friendly forest-wide best management practices and seed mixes	Establish a reserve of native seed mixes including pollinator-friendly plants that are adapted, available, affordable, and effective	Develop revegetation guidelines that incorporate menu-based seed mixes by habitat type (e.g., species that are good for pollinators, sage-grouse, umbrella species) and by empirical or provisional seed zones
Where can tactics be applied?	High-priority areas include alpine, tall forbs, low-elevation wetlands, and dry and dwarf sagebrush communities, all of which are vulnerable to climate change impacts	IAP geographic areas (e.g., Uintas and Wasatch Front)	Each national forest
Opportunities for implementation	Silvicultural and Burn Area Emergency Response (BAER) treatments, grazing and fuels management, postfire recovery, wildlife habitat improvement projects, or any reclamation or recovery projects; include premonitoring and postmonitoring	Develop empirical seed zones for your core list of native plant materials desired; in the absence of empirical seed zones, use provisional or interim seed zones and Level 3 ecoregions	Whenever revegetation is needed; for example, guidelines would help BAER teams, enterprise teams, forest planning teams
Comments	See tactic B	Reference FSM 2070 (Native plant materials policy) and the national seed strategy; see also Region 4 list of pollinator-friendly restoration species	This product will help us be consistent with FSM 2070 policy and accurately select adapted plant material when implementing revegetation and reclamation projects

Table 14A.3 (continued)—Ecosystem service adaptation options developed at the Uintas and Wasatch Front subregion workshop.

Sensitivity to climatic variability and change: Higher temperatures and increased fire activity will change the composition and alter the productivity of forage			
Adaptation strategy/approach: Increase resilience of habitats that are used by ungulates and that are vulnerable to climate change impacts			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Reduce conversion of native perennial vegetation to invasive species	Integrate grazing strategies and vegetation treatments (both wild and domestic ungulates)	Emphasize collaborative problem solving with permittees and other interested parties rather than enforcement
Where can tactics be applied?	High-priority areas include tall forbs, low-elevation wetlands and riparian areas, and dry and dwarf sagebrush communities, all of which are vulnerable to climate change impacts	---	---
Opportunities for implementation	Vegetation treatments, allotment management plans, meetings with county weed management areas, native plant projects, etc.	Wildlife advisory councils	County weed management areas, collaborative groups, allotment management plans, partnerships, annual operating instruction meetings with interested parties, native plant projects, field trials for innovative grazing
Comments	---	Research and identify new strategies; ensure that results are monitored	Consider payments for ecosystem services and incentives for participation in conservation programs
Sensitivity to climatic variability and change: Amount and seasonal distribution of water will change in relation to demand			
Adaptation strategy/approach: Assess and communicate Forest Service ability to help meet demand			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Conduct integrated assessment of water and local effects of climate change	Encourage communication and full disclosure of information	Conduct vulnerability assessments
Where can tactics be applied?	On a watershed basis; next, identify priorities to further assess timing and quantity at the stream level	Watershed councils, municipal watersheds, interagency working groups (e.g., Mountain Accord), local communities	Assessments could be done by community, watershed, administrative boundary, etc.
Comments	Assessment would focus on needs of a healthy watershed, not maximizing yield		

Table 14A.4—Ecosystem service adaptation options developed at the Great Basin and Semi Desert subregion workshop.

Sensitivity to climatic variability and change: Climatic variability and warming will affect grazing resources and policy

Adaptation strategy/approach: Develop a holistic approach to grazing management; understand rancher's business approach, lands used, water management, and competing demands from other resources and multiple uses

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactics	Partner with permittee and other managers of lands they use to create a holistic grazing program	Understand changes in water availability to prepare and adjust grazing management	Implement education programs about climate change impacts and sustainable grazing practices (highlight both positive and negative effects)
Where can tactics be applied?	Public, private, and all adjacent lands	Around water resources	Needs to be broadly implemented; partnership opportunities with Cattlemen's Association, Future Farmers of America, Natural Resources Conservation Service, schools, environmental organizations
Opportunities for implementation	Whenever looking at Allotment Management Plan or annual operating plans	Improve maps and models of water availability and competing uses; work with partners on water infrastructure changes and funding	Bring message into forest plan revision discussions and when working with public
Comments	Work with extension services, research, others who understand ranching needs		Working ranches preserve large open landscapes and wildlife habitat

Chapter 15: Conclusions

Joanne J. Ho, David L. Peterson, and Natalie J. Little

The Intermountain Adaptation Partnership (IAP) provided significant contributions to assist climate change response in national forests and national parks of the region. The effort synthesized the best available scientific information to assess climate change vulnerability, develop adaptation options, and catalyze a collaboration of land management agencies and stakeholders seeking to address climate change. The vulnerability assessment and corresponding adaptation options provided information to support national forests and national parks in implementing respective agency climate change strategies described in the National Roadmap for Responding to Climate Change (USDA FS 2010a), Climate Change Performance Scorecard (USDA FS 2010b) (Chapter 1), and National Park Service (NPS) Climate Change Response Strategy (NPS 2010). The IAP process allowed all forests in the U.S. Department of Agriculture Forest Service (USFS) Intermountain Region to respond with "yes" to element 6, Assessing Vulnerability, and element 7, Adaptation Actions, on their Climate Change Performance Scorecard. This, in turn, helped all forests to reach a minimum level of accomplishment of "yes" in 7 of 10 elements, with at least one "yes" in each of four dimensions. The IAP process also enabled participating national parks to make progress toward implementing several components (communication, science, adaptation goals) of the NPS Climate Change Response Strategy (NPS 2010).

Relevance to Agency Climate Change Response Strategies

In this section, we summarize the relevance of the IAP process to the climate change strategy of Federal agencies and the accomplishments of participating national forests, national grasslands, and national parks. Information presented in this report is also relevant for other land management agencies and stakeholders in the IAP region. This process can be replicated and implemented by any organization, and the adaptation options are applicable in the USFS Intermountain Region and beyond. Like previous adaptation efforts (e.g., Halofsky and Peterson 2017; Halofsky et al. 2011, 2018, in press; Raymond et al. 2014), a science-management partnership was critical to the success of the IAP. Those interested in utilizing this approach are encouraged to pursue this partnership as the foundation for increasing climate change awareness, assessing vulnerability, and developing adaptation plans.

Communication, Education, and Organizational Capacity

Organizational capacity to address climate change, as outlined in the USFS Climate Change Performance Scorecard, requires building institutional capacity in management units through training and education for employees. Training and education were built into the IAP process through workshops and webinars that provided information about the effects of climate change on water and soil resources, fisheries, forest and nonforest vegetation, disturbance, wildlife, recreation, infrastructure, cultural resources, and ecosystem services. The workshops introduced climate tools and processes for assessing vulnerability and planning for adaptation (Morelli et al. 2012).

In both the webinars and workshops, efforts were made to have a balanced mixture of scientists and land managers presenting together. This approach was also taken during the workshop panels that answered and discussed questions posed by participants. The number of workshop attendees was an average of 50 participants at each of the five 2-day events. The average partner attendance was 30 percent, which facilitated the development of an interdisciplinary and interorganizational network for this complex topic.

The general structure of the 2-day workshops was to share climate change information on the first day and to develop adaptation options in breakout groups on the second day. These workshops helped to develop a common foundation and understanding of information among groups of participants. In turn, this understanding helps to facilitate integration of climate change into thoughts, plans, and actions for resource managers. The entire process helps build organizational capacity to learn, adapt, and possibly even thrive in a changing climatic environment.

The NPS Climate Change Response Strategy challenges NPS staff to increase climate change knowledge among employees and to communicate this information to the public. Although communication about climate change with the public was beyond the scope of the IAP, knowledge generated through this process can be used for outreach and interpretive materials.

Partnerships and Engagement

The IAP science-management partnership and process were as important as the products that were developed, because these partnerships are the cornerstone for successful agency responses to climate change. We built a partnership that included 12 national forests, 22 NPS units, the USFS

Intermountain Regional Office, the USFS Pacific Northwest and Rocky Mountain Research Stations, and the University of Washington. This partnership will remain relevant for ongoing plan revision and restoration conducted by the national forests in collaboration with several stakeholders.

Elements 4 and 5 of the USFS Climate Change Performance Scorecard require units to engage with scientists and scientific organizations to respond to climate change (element 4) and work with partners at various scales across all boundaries (element 5). Similarly, the NPS Climate Change Response Strategy emphasizes the importance of collaboration and building relationships, in addition to products that support decisionmaking and a shared vision. The IAP process therefore allowed both agencies to achieve unit-level compliance in their agency-specific climate responses.

The IAP process encouraged collaboration between the USFS and NPS, strengthening the foundation for a coordinated regional response to climate change. Working with partners enhances the capability to respond effectively to climate change. This collaboration is especially valuable in supporting the use of an all-lands approach, which was an important context for the assessment.

Climate change is a relatively new and evolving aspect of land management, and the workshops provided an opportunity for participants to effectively communicate their professional experiences with climate change and resource management in a collaborative and supportive environment. Because the IAP process covered a broad range of topics, the multidisciplinary large-group discussions resulted in conceptual breakthroughs across disciplines by otherwise isolated specialists who typically do not participate in the same meetings or training.

In August 2016, the Intermountain Region and USFS Rocky Mountain Research Station launched a “Science Partners” program that brought small groups of USFS scientists and land managers together to help bridge the gap between research and National Forest System (NFS) needs for planning and implementation. This program builds on the premise that each can work more effectively through regular communication, leading to collaboration that fosters research designs better suited to address the needs of NFS land managers. Climate change knowledge and implementation in management practices will benefit from this integrative program.

Assessing Vulnerability and Adaptation

Elements 6 and 7 of the USFS Climate Change Performance Scorecard required units to identify the most vulnerable resources, assess the expected effects of climate change on vulnerable resources, and identify management strategies to improve the adaptive capacity of the national forest lands. The IAP vulnerability assessment described the sensitivity of multiple resources in the Intermountain Region. Adaptation options developed for each resource area can be incorporated into resource-specific programs and plans. The identification of key vulnerabilities and adaptation strategies can also inform the national forest plan revision process.

The science-management dialogue identified management practices that are useful for increasing resilience and reducing stressors and threats. Although implementing all options developed in the IAP process may not be feasible, resource managers can still draw from the menu of options as needed. Some adaptation strategies and tactics can be implemented on the ground now. Others may require changes in policies and practices or can be implemented when management plans are revised or as threats become more apparent.

In assessing vulnerability and planning for adaptation, the IAP process used many of the principles and goals identified in the NPS Climate Change Response Strategy, which calls for units to implement adaptation in all levels of planning to promote ecosystem resilience and enhance restoration, conservation, and preservation of resources (NPS 2010). It specifically requires developing and implementing adaptation to increase the sustainability of facilities and infrastructure, and preserve cultural resources.

Science and Monitoring

Monitoring is addressed in Element 8 of the USFS Climate Change Performance Scorecard and in the NPS Climate Change Response Strategy. Where applicable, the IAP products identified information gaps or uncertainties important to understanding climate change vulnerabilities to resources and management influences on vulnerabilities. These identified information gaps could help determine where important monitoring and research would decrease uncertainties inherent in management decisions. In addition, current monitoring programs that provide information for detecting climate change effects, and new indicators, species, and ecosystems that require additional monitoring, were identified for some resource chapters. Working across multiple jurisdictions and boundaries will allow IAP participants to increase collaborative monitoring and research on climate change effects and the effectiveness of implementing adaptation options that increase resilience or reduce stressors and threats. Scientific documentation in the assessment can also be incorporated into large landscape assessments such as forest or grassland planning assessments, environmental analysis for National Environmental Policy Act (NEPA) projects, or project design and mitigations.

Implementation

Although challenging, implementation of adaptation options will gradually occur with time, often motivated by extreme weather and large disturbances, and facilitated by changes in policies, programs, and land management plan revisions. It will be especially important for ongoing restoration programs to incorporate climate change adaptation to ensure effectiveness. A focus on thoroughly vetted and feasible strategies will increase ecosystem function and resilience while minimizing implementation risk. Landowners, management agencies, and Native American tribes will need to work together for implementation to be effective.

In many cases, similar adaptation options were identified for more than one resource sector, suggesting a need to integrate adaptation planning across multiple disciplines. Adaptation options that yield benefits to more than one resource are likely to have the greatest benefit (Halofsky et al. 2011; Peterson et al. 2011; Raymond et al. 2014). However, some adaptation options involve tradeoffs and uncertainties that need further exploration. Assembling an interdisciplinary team to tackle this issue will be critical for assessing risks and developing risk management options. Scenario planning may be a useful next step.

Integration of the information in this assessment in everyday work through "climate-informed thinking" is critical, and can be reflected in resource management and planning (USDA FS 2010c), as well as in management priorities such as safety. Flooding, wildfires, and insect outbreaks may all be exacerbated by climate change, thus increasing hazards faced by Federal employees and the public. Resource management can help minimize these hazards by reducing fuels, modifying forest species composition, and restoring hydrological function. These activities are commonplace, demonstrating that much current resource management is already climate smart. This assessment can improve current management practice by helping to prioritize and accelerate implementation of specific options and locations for adaptation.

Putting adaptation on the ground will often be limited by insufficient human resources, insufficient funding, and conflicting priorities. However, the likelihood of changes occurring in the near future are relatively high for resources such as water, and for disturbances such as wildfire—and some adaptation options may be precluded if they are not implemented soon. This creates an imperative for timely integration of climate change as a component of resource management and agency operations.

The climate change vulnerability assessment and adaptation approach developed by the IAP can be used by the USFS, NPS, and other organizations in many ways. From the perspective of Federal land management (USDA FS 2015, 2016), this information can be integrated into the following aspects of agency operations:

- **Landscape management assessments and planning**: The vulnerability assessment provides information on departure from desired conditions and best science on effects of climate change on resources for inclusion in planning assessments. The adaptation strategies and tactics provide forest or grassland desired conditions, objectives, standards, and guidelines for land management plans and general management assessments.
- **Resource management strategies**: The vulnerability assessment and adaptation strategies and tactics can be used to incorporate IAP science into forest resilience and restoration plans, conservation strategies, fire management plans, infrastructure planning, and State Wildlife Action Plans.
- **Project NEPA analysis**: The vulnerability assessment provides best available science for documentation of resource conditions, analysis of effects, and development of alternatives. Adaptation strategies and tactics provide mitigation and design tactics at specific locations.
- **Monitoring plans**: The vulnerability assessment can help identify knowledge gaps that can be addressed by monitoring in broad-scale strategies, plan-level programs, and project-level data collection.
- **National forest land management plan revision process**: The vulnerability assessment provides a foundation for understanding key resource vulnerabilities caused by climate change for the assessment phase of forest plan revision. Information from vulnerability assessments can be applied in assessments required under the 2012 Planning Rule (USDA FS 2012), describe potential climatic conditions and effects on key resources, and identify and prioritize resource vulnerabilities to climate change in the future. Climate change vulnerabilities and adaptation strategies can inform forest plan components such as desired conditions, objectives, standards, and guidelines.
- **Project design and implementation**: The vulnerability assessment provides mitigation and design tactics at specific locations.

We are optimistic that climate change awareness, climate-informed planning and management, and implementation of adaptation in the IAP region will continue to expand. We anticipate that within a few years:

- Climate change will become an integral component of Federal agency operations;
- The effects of climate change will be continually assessed on natural and human systems;
- Monitoring activities will include indicators to detect the effects of climate change on species and ecosystems;
- Agency planning processes will provide opportunities to manage across boundaries;
- Restoration activities will be implemented in the context of the influence of a changing climate;
- Management of carbon will be included in adaptation planning;
- Institutional capacity to manage for climate change will increase within Federal agencies and local stakeholders; and

- Resource managers will implement climate-informed practices in long-term planning and management.

This assessment provides the foundation for implementing adaptation options that help to reduce the negative impacts of climate change and facilitate transition of resources to a warmer climate. We hope that use of the assessment by existing partnerships will foster collaborative climate change adaptation in resource planning and management throughout the IAP region.

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Climate Change Vulnerability and Adaptation in the Intermountain Region
Part 2

GTR-375