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Chapter 8

- Figures 8.22, 8.23, 8.24, and 8.25 were replaced with higher quality images.
- Figure 8.27 was replaced with the correct figure.
- Minor text changes and corrections on pages 233 and 235.

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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.

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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

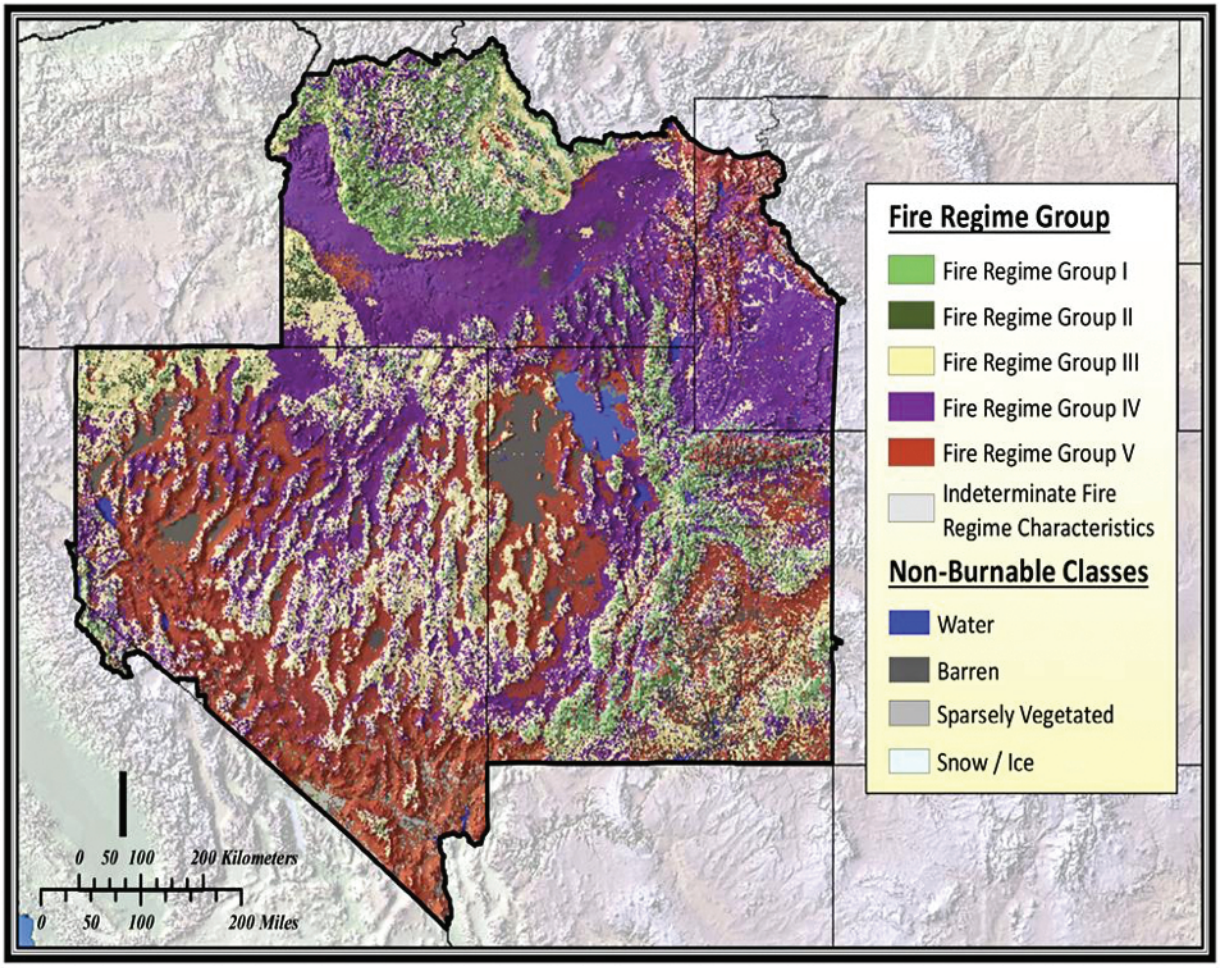


Figure 8.1—Distribution of LANDFIRE Fire Regime Groups in the Intermountain Adaptation Partnership region (Fire Regime Groups IVa and IVb have not been distinguished) (data described in Rollins [2009] and at https://www.landfire.gov/NationalProductDescriptions12.php).

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).

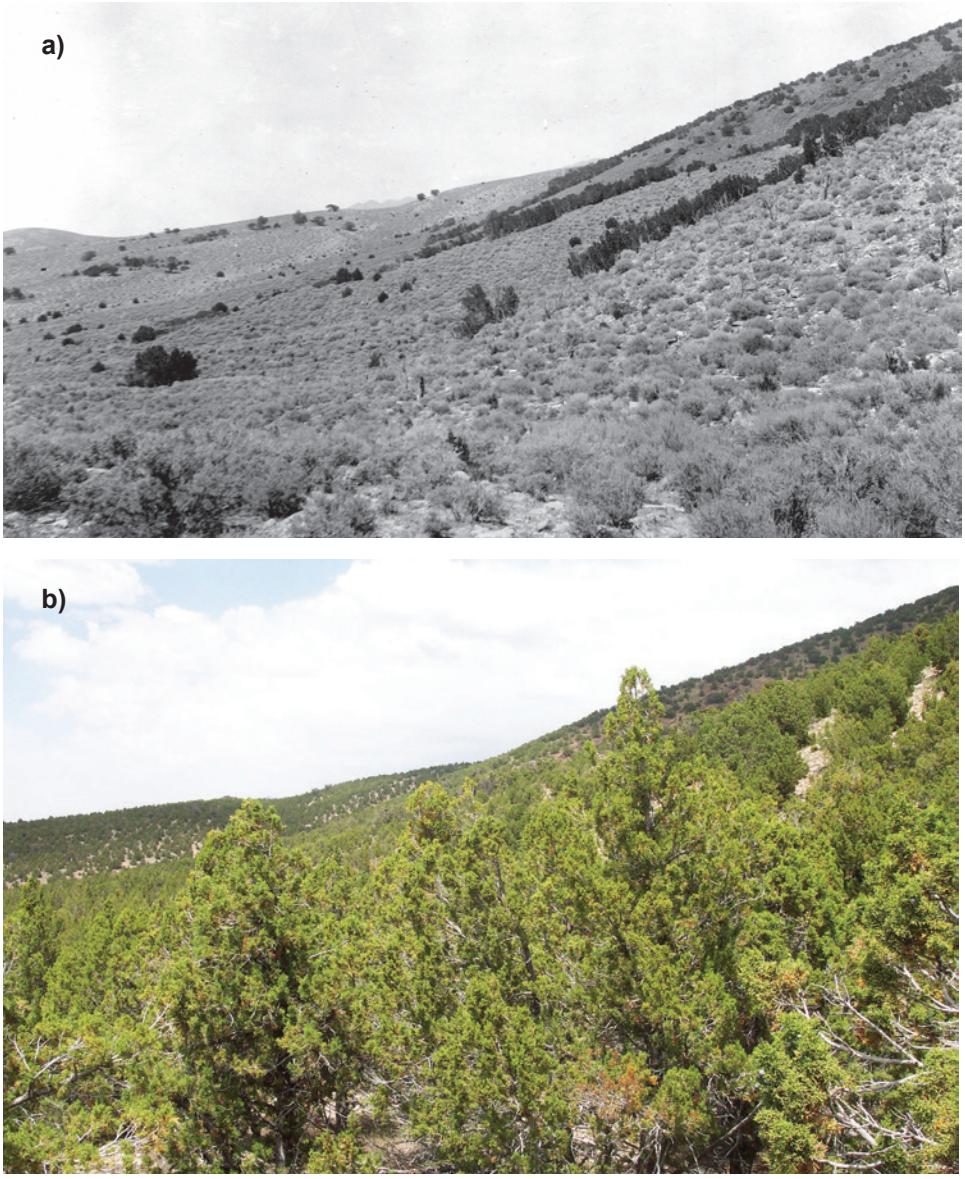


Figure 8.10—Big Creek Canyon on the west side of the Stansbury Mountains in north-central Utah in (a) 1901 and (b) 2004, showing an increase in Utah juniper in the mountain big sagebrush-Wyoming big sagebrush ecotone as a result of fire exclusion (left photo: G. K. Gilbert, U.S. Geological Survey; right 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).

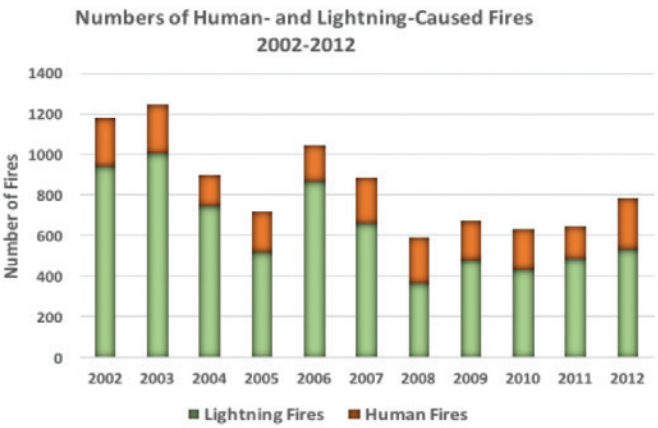


Figure 8.12—Number of human- and lightning-caused fires annually in the U.S. Forest Service Intermountain Region, 2002–2012 (data from FIRESTAT [2015]).

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

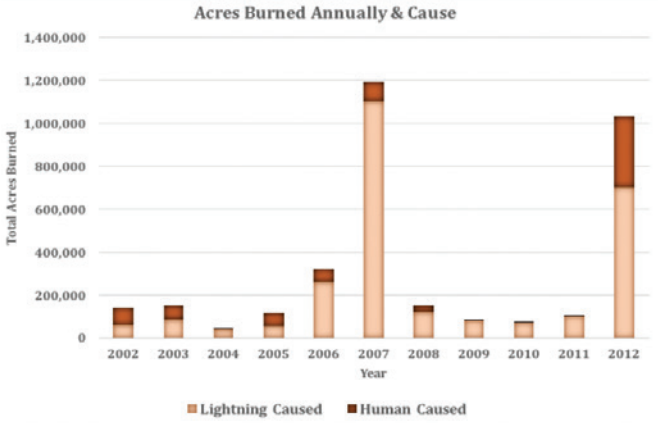


Figure 8.13—Wildfire area burned in the U.S. Forest Service Intermountain Region, 2002–2012 (data from FIRESTAT [2015]).

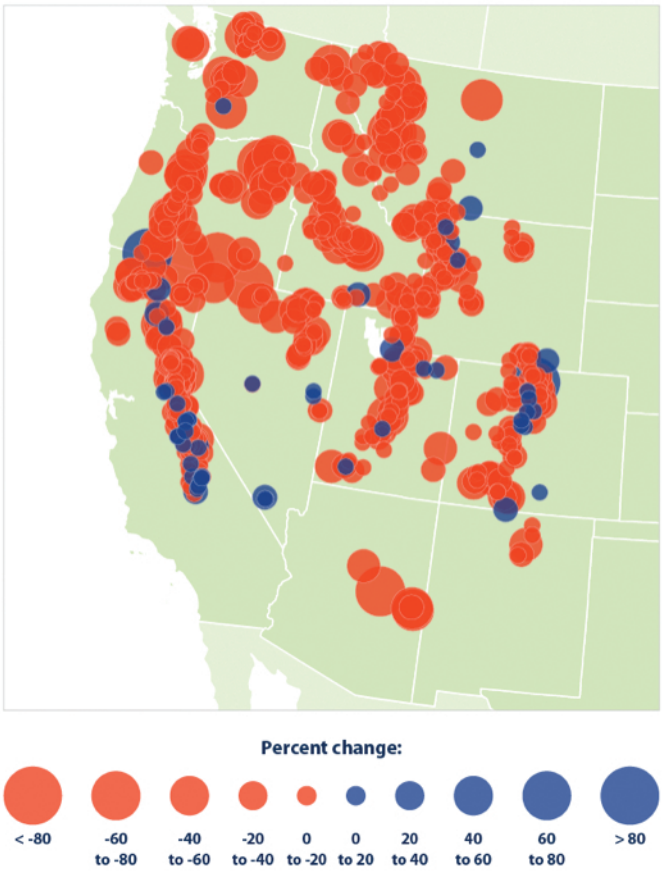


Figure 8.14—April 1 snow water equivalent in the western United States, 1955–2015 (from USEPA [2016]).

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

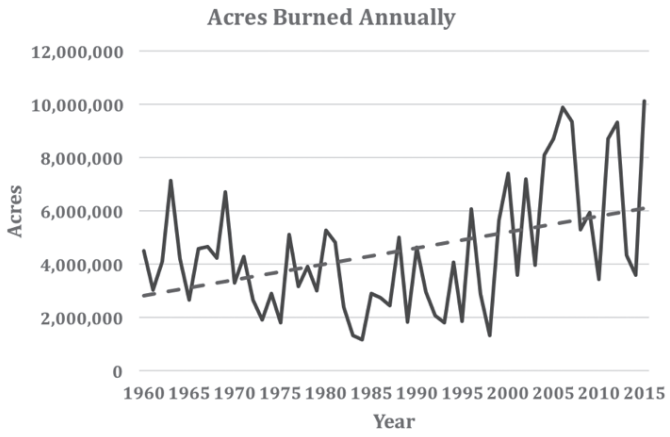


Figure 8.15—Wildfire area burned in the 11 contiguous Western States, 1960–2005 (data from NIFC [2015]).

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).

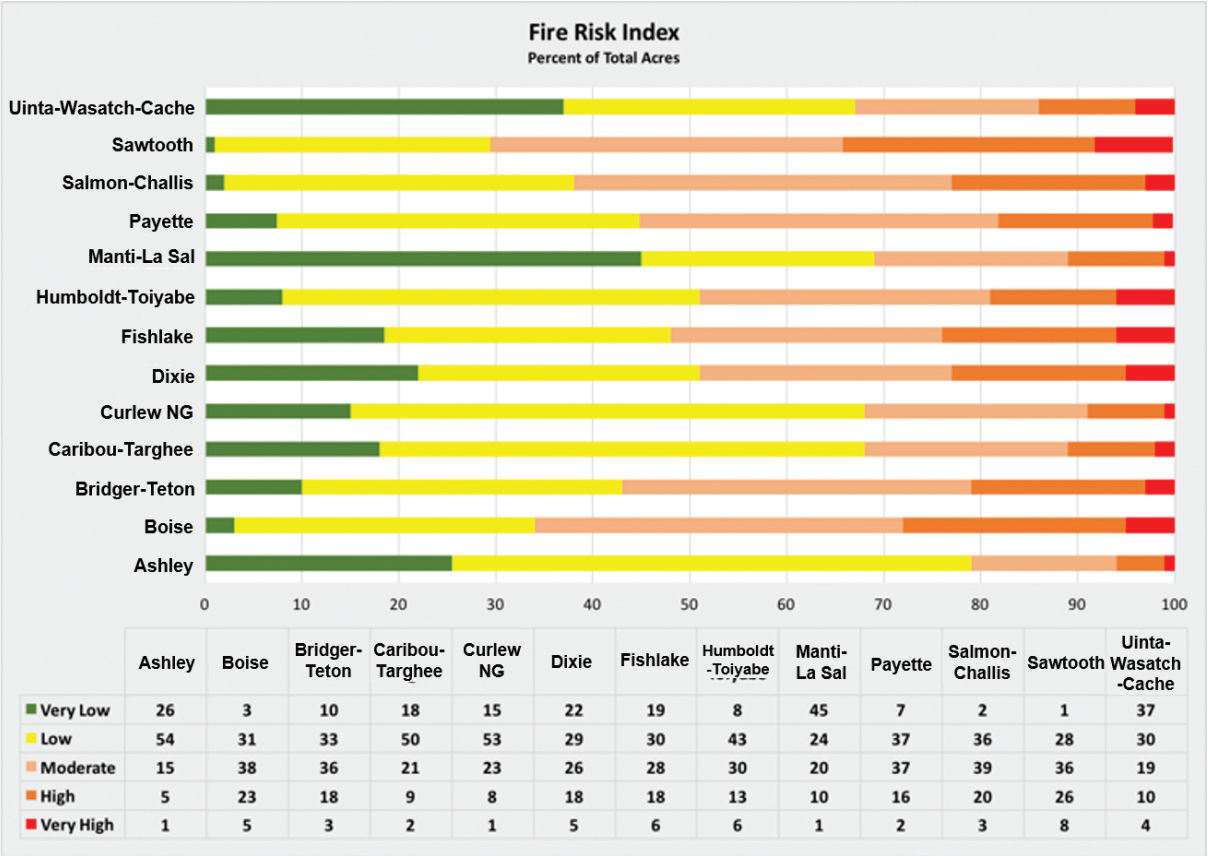
Carbon Sequestration

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.

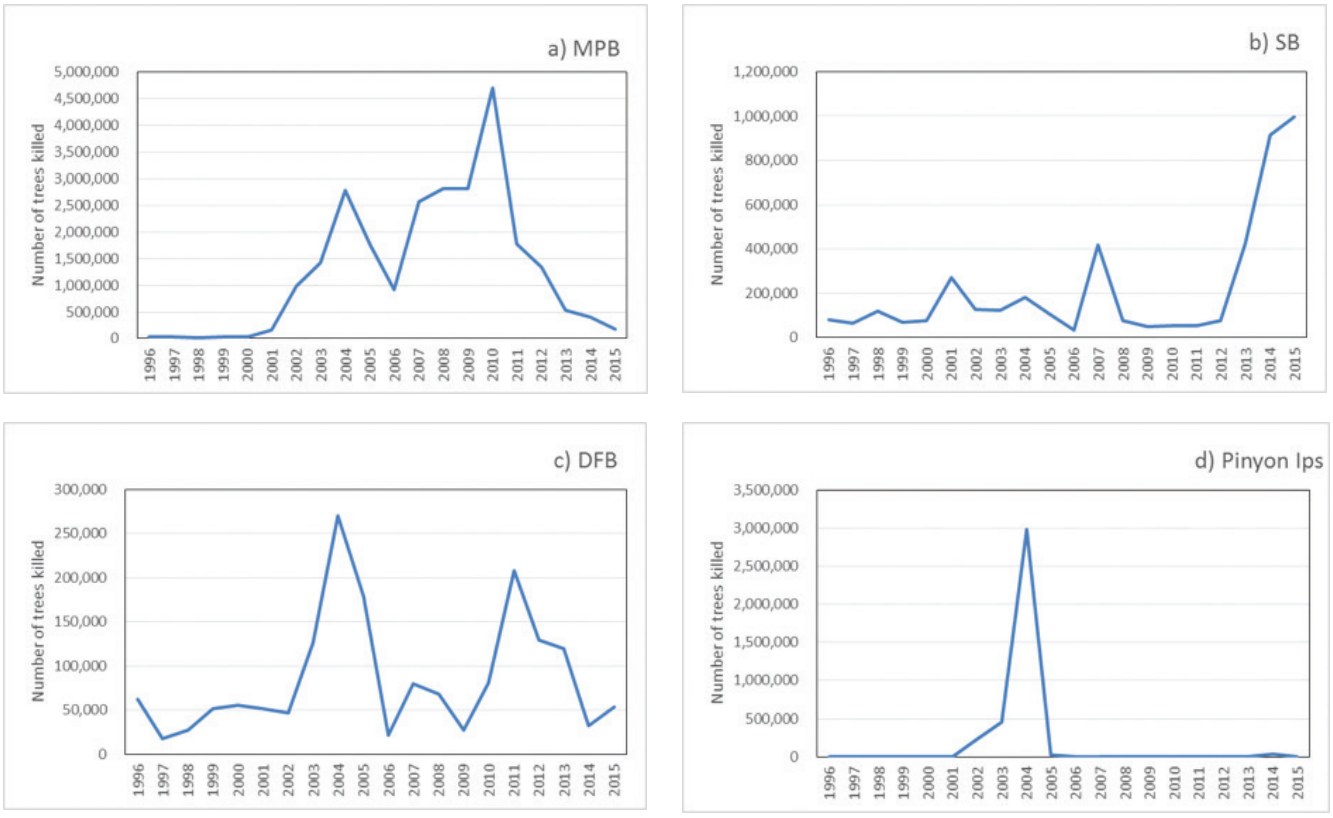


Figure 8.17—Number of trees killed by (a) mountain pine beetle (MPB), (b) spruce beetle (SB), (c) Douglas-fir beetle (DFB), and (d) pinyon ips in the U.S. Forest Service Intermountain Region, 1996–2015. Data are from Aerial Detection Surveys 1996–2015, Intermountain Region, Forest Health Protection.

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

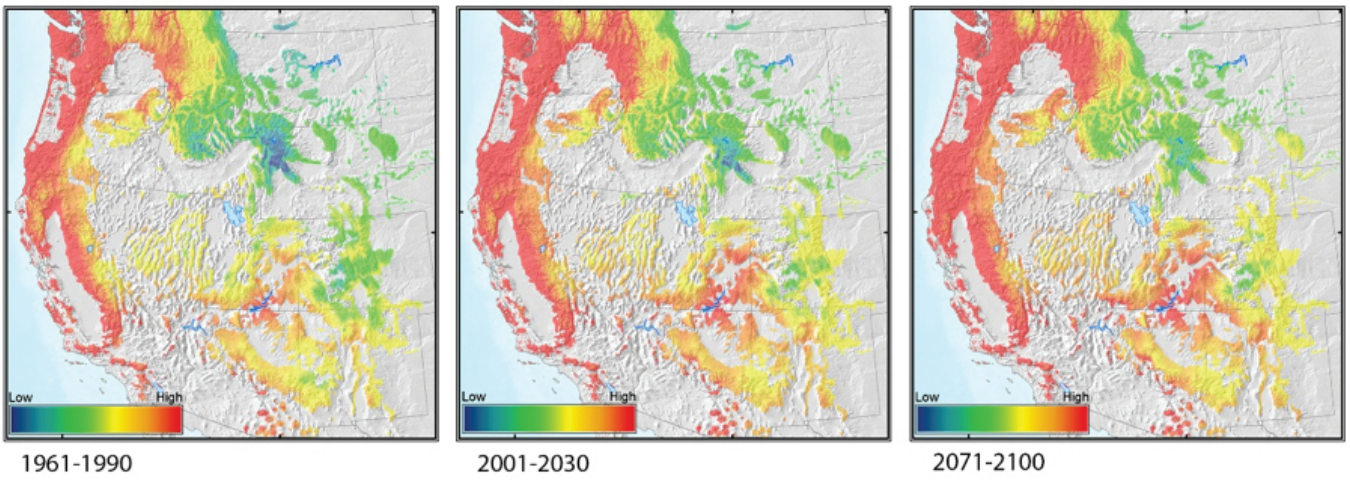


Figure 8.18—Predicted probability of cold survival for mountain pine beetle in pine forests of the western United States during three climate normal periods: 1961–1990, 2001–2030, and 2071–2100. Model results are shown only for areas estimated to be 20th-century spruce habitat (sensu Little [1971]). 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

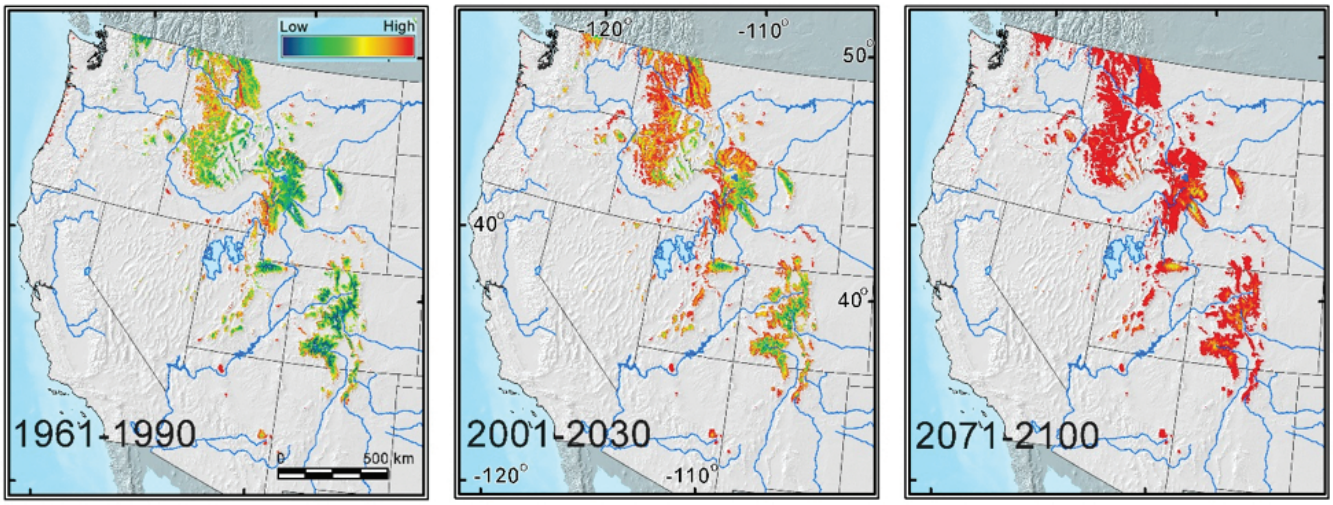


Figure 8.19—Predicted probability of spruce beetle developing in a single year in spruce forests in the western United States during three climate normal periods: 1961–1990, 2001–2030, and 2071–2100. Higher probability of 1-year life cycle duration translates to higher probability of population outbreak 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

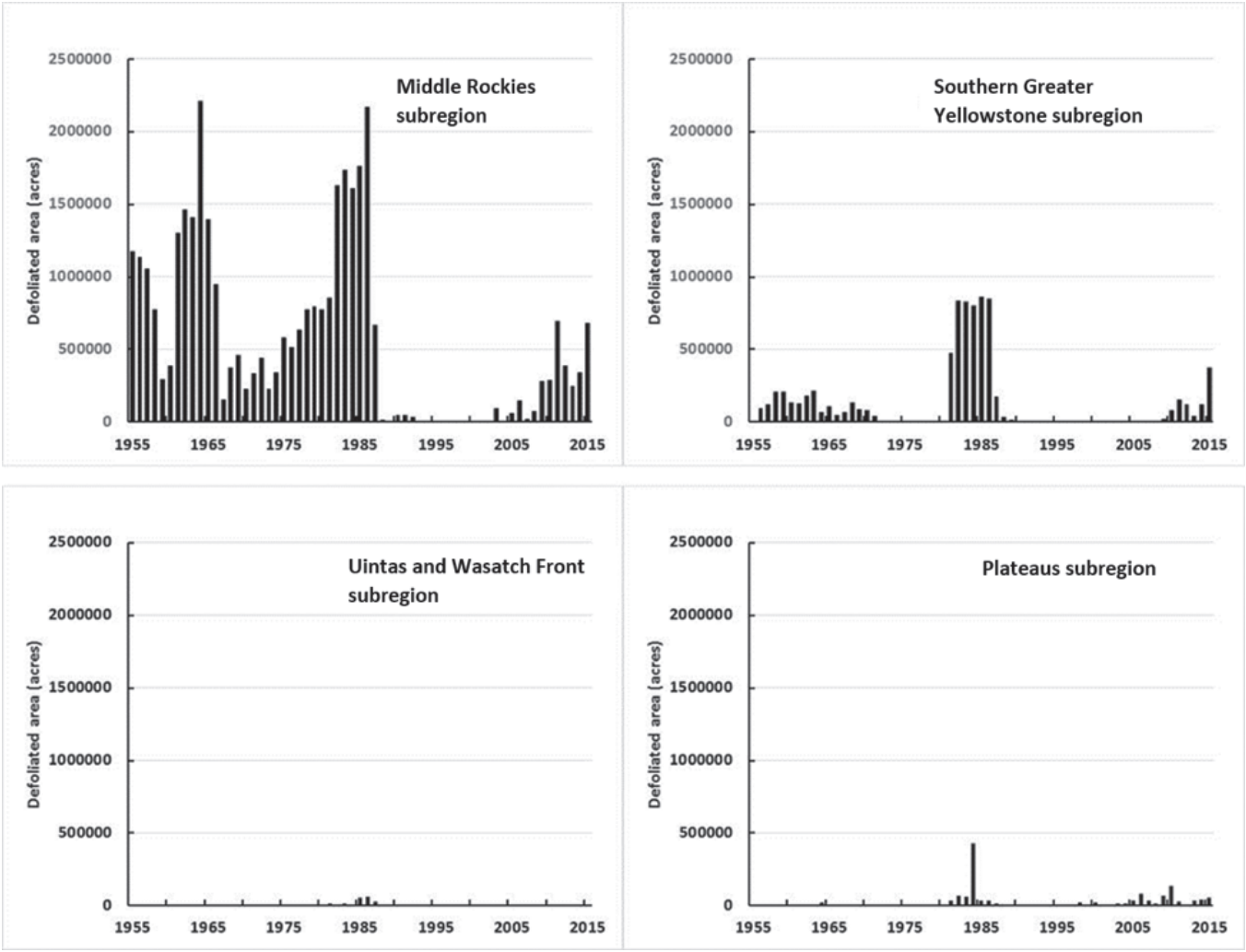


Figure 8.20—Area defoliated by western spruce budworm in four subregions of the Intermountain Adaptation Partnership region, 1955–2015. Johnson and Denton (1975) also documented an extensive but unquantified outbreak in the 1920s in the Greater Yellowstone Area.

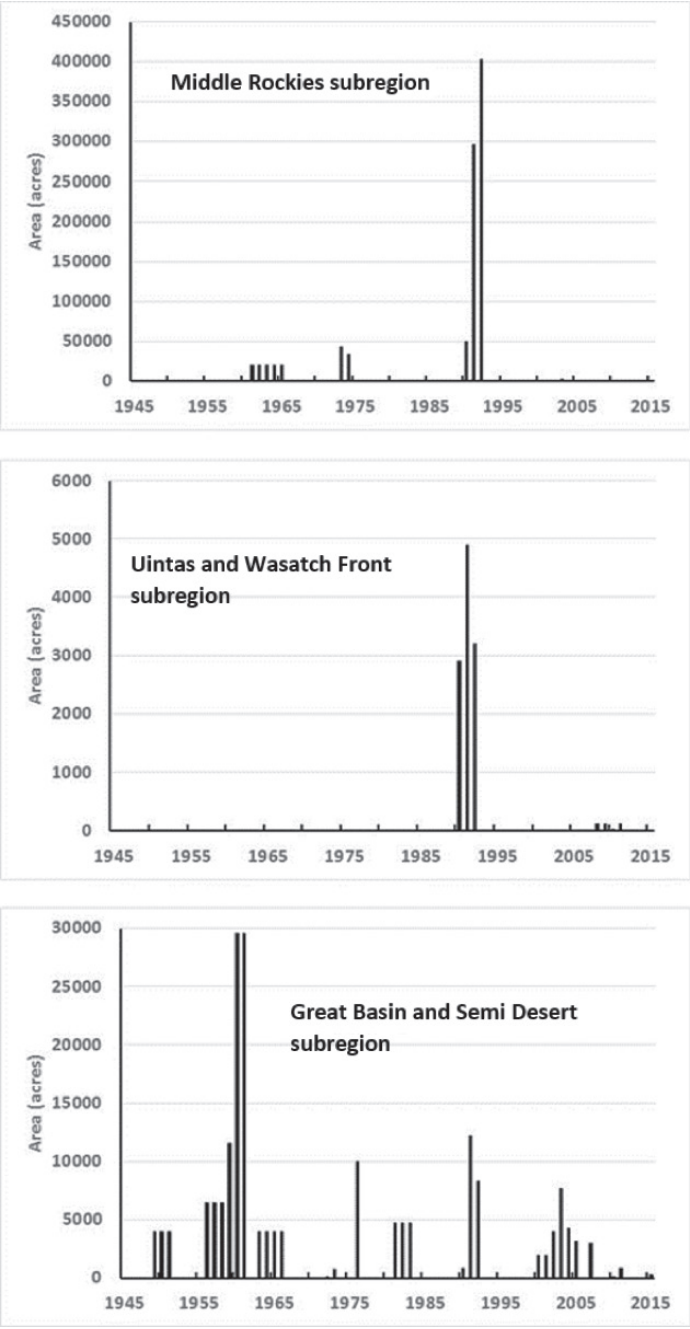


Figure 8.21—Area defoliated by Douglas-fir tussock moth in three subregions of the Intermountain Adaptation Partnership region, 1945–2015. A 500-acre area of Fishlake National Forest in south-central Utah was also defoliated in 1999–2000.

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 shows 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

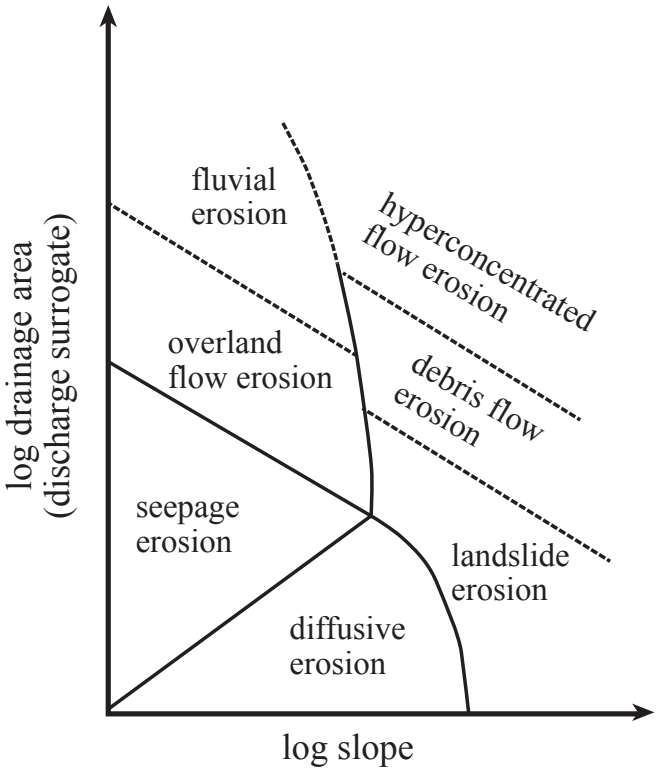


Figure 8.22—Domains for different types of erosional processes on soil-mantled landscapes (modified from Montgomery and Dietrich [1994]).

characteristics (depth, slope, grain size) or reach-scale channel morphology (pool-riffle, plane-bed, step-pool, cascade) as a function of climate-related changes in streamflow or sediment supply. Furthermore, by grouping channels into process domains (fig. 8.25), one can identify which portions of the river network (and associated ecosystems) may be susceptible to climate-related changes in a given type of disturbance.

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.

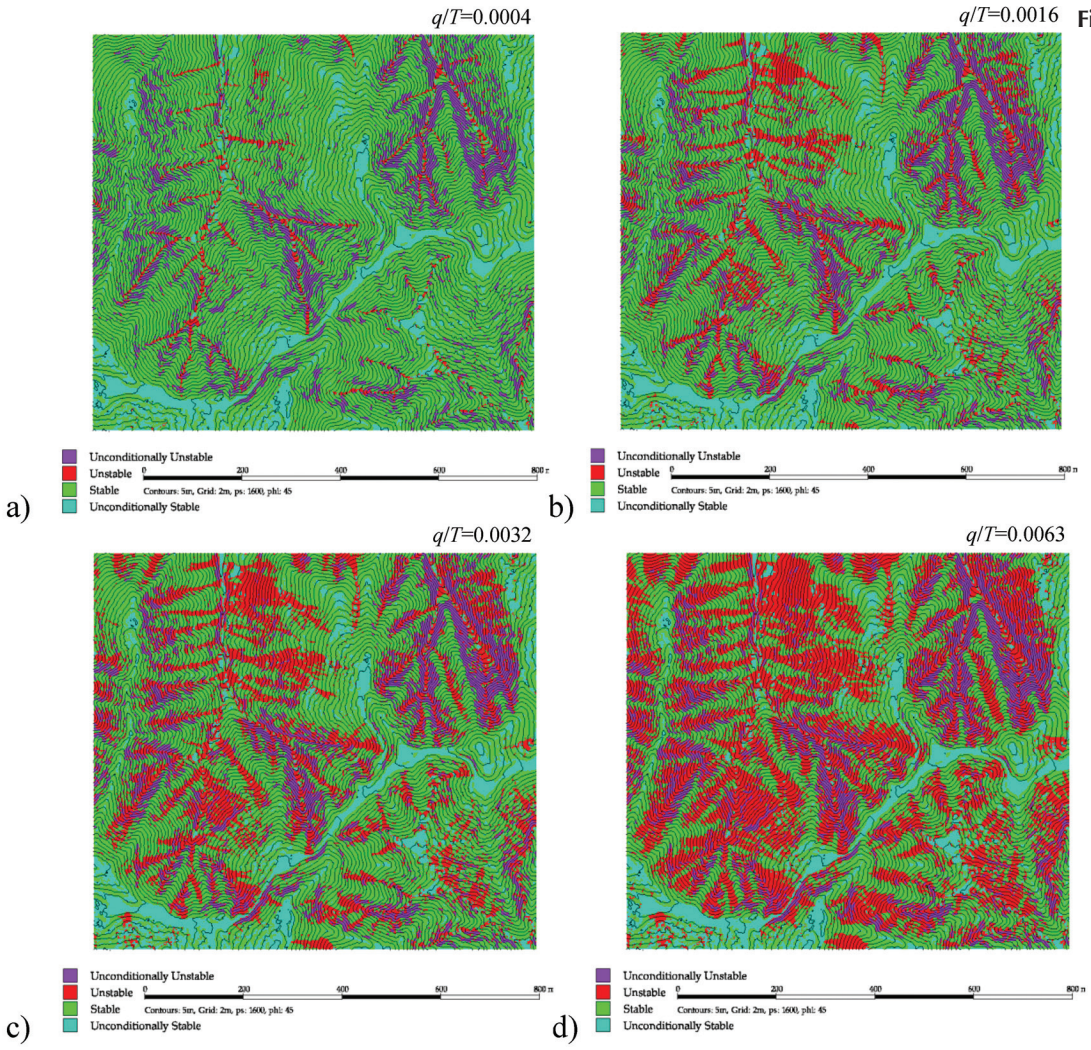


Figure 8.23—Predicted spatial distribution of shallow landsliding at Mettman Ridge, Oregon, for different ratios of effective discharge (q, rainfall minus evapotranspiration) per unit contour width relative to soil transmissivity (T). Results are shown for q/T values of: (a) 0.0004, (b) 0.0016, (c) 0.0032; 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 Montgomery [1998]).

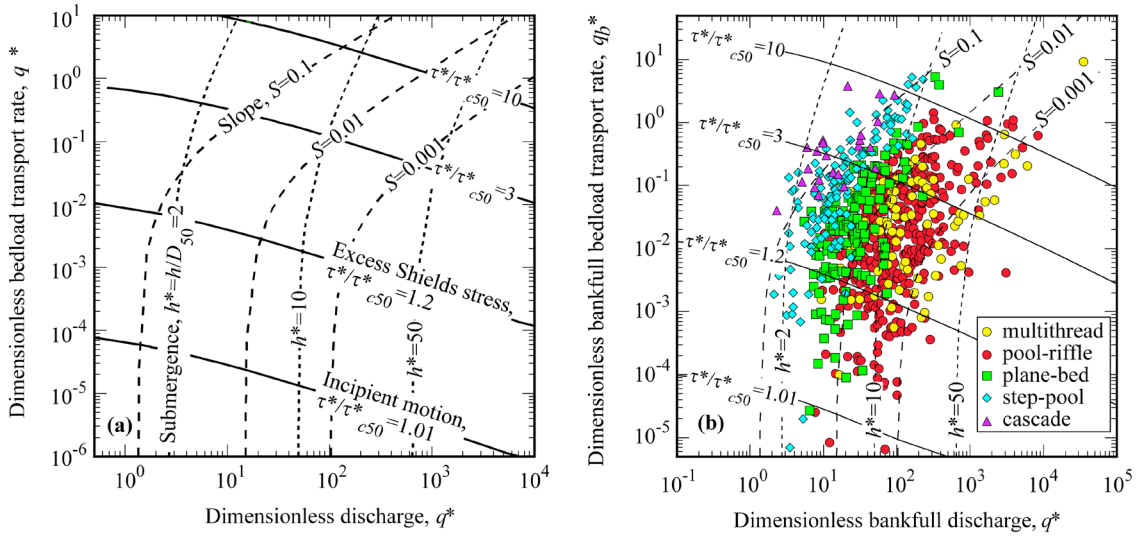


Figure 8.24—State diagram for alluvial rivers showing: (a) contours of equilibrium channel slope (S), relative submergence ($h^* = h/D_{50}$, where h is flow depth and D_{50} is the median surface grain size), and excess Shields stress (τ^*/τ^*_{c50}, where τ^* is the dimensionless shear stress and τ^*_{c50} 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 after Parker [1990]).

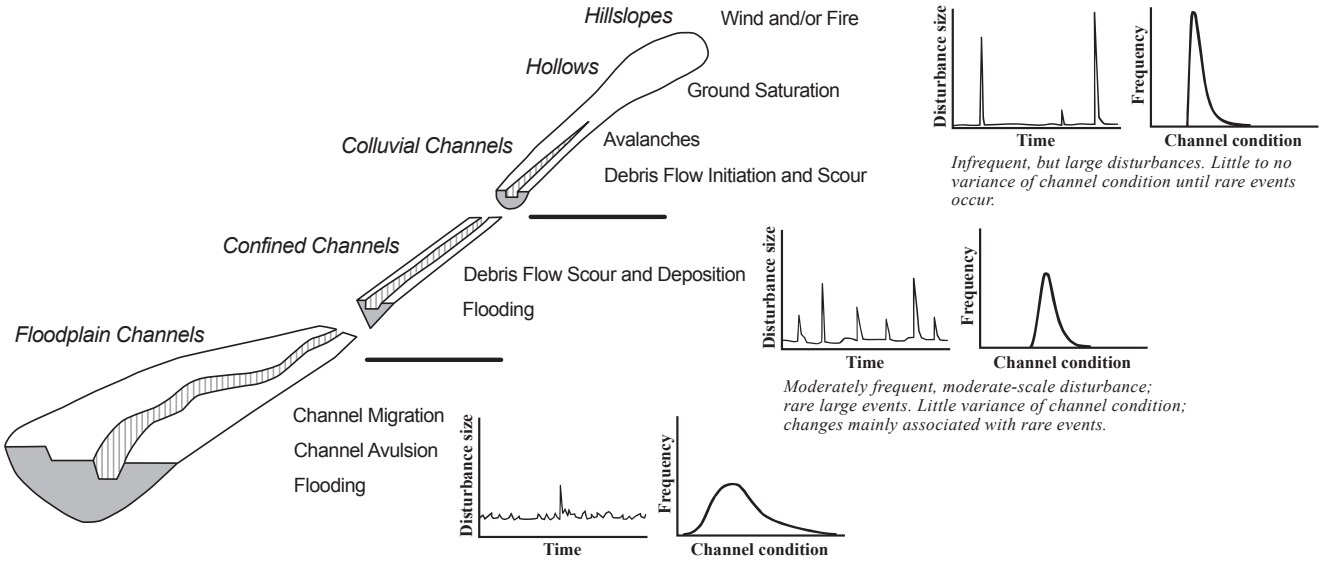


Figure 8.25—Process domains in mountain rivers, showing headwater to lowland channel types and associated disturbance processes (schematic at left). Graphs show disturbance size relative to mean values (first right-hand graph) and variance of channel condition (second right-hand graph) as a function 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 altering 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 on erosional processes and hazards.

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

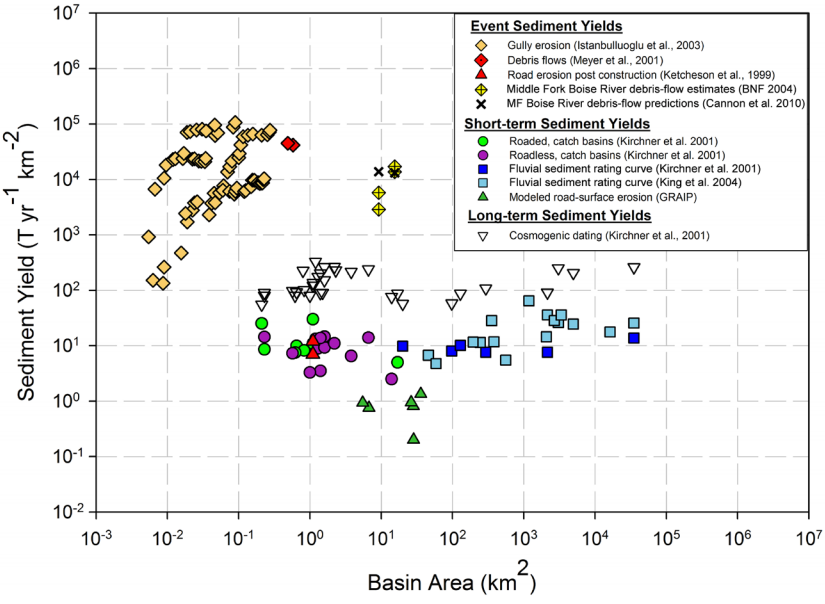


Figure 8.27—Sediment yield as a function of basin area for individual erosional events (including postfire gullying and debris flows), short-term averages, and long-term averages in mountain basins of central Idaho (from Goode et al. [2012]).

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.

References

Adams, D.K.; Comrie, A.C. 1997. The North American monsoon. Bulletin of the American Meteorological Society. 78: 2197–2213.

Addison, A.L.; Powell, J.A.; Six, D.L.; [et al.]. 2013. The role of temperature variability in stabilizing the mountain pine beetle-fungus mutualism. Journal of Theoretical Biology. 335: 40–50.

Agee, J. 1993. Fire ecology of Pacific Northwest forests. Washington, DC: Island Press. 493 p.

Agee, J.K. 1998. The landscape ecology of Western forest fire regimes. Northwest Science. 72: 24–34.

Agee, J.K. 2002. Fire as a coarse filter for snags and logs. In: Laudenslayer, W.F., Jr.; Shea, P.J.; Valentine B.E.; Weatherspoon, P.C.; Lisle, T.E., tech. coords. Proceedings, symposium on the ecology and management of dead wood in western forests; 1999 November 2-4; Reno, NV. Gen. Tech. Rep. PSW-181. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 359–368.

Agne, M.C.; Shaw, D.C.; Woolley, T.J.; Queijeiro-Bolaños, M.E. 2014. Effects of dwarf mistletoe on stand structure of lodgepole pine forests 21-28 years post-mountain pine beetle epidemic in central Oregon. PLoS ONE. 9: e107532.

Aldrich, J.M. 1912. Note on *Theronia fulvescens*. Journal of Economic Entomology. 5: 87–88.

Alexander, R.R.; Shepperd, W.D. 1990. *Picea engelmannii* Parry ex Engelm. In: Burns, R.M.; Honkala, B.H., tech. coords. Silvics of North America, Volume 1: Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service.

Alfaro, R.I.; Taylor, S.P.; Wegwitz, E.; Brown, R.G. 1987. Douglas-fir tussock moth damage in British Columbia. Forestry Chronicle. 63: 351–355.

Alfaro, R.I.; Van Sickle, G.A.; Thomson, A.J.; Wegwitz, E. 1982. Tree mortality and radial growth losses caused by western spruce budworm in a Douglas-fir stand in British Columbia. Canadian Journal of Forest Research. 12: 780–787.

Allen, C.D.; Macalady, A.K.; Chenchouni, H.; [et al.]. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management. 259: 660–684.

Allen, C.D.; Savage, M.; Falk, D.A.; [et al.]. 2002. Ecological restoration of southwestern ponderosa pine ecosystems: A broad perspective. Ecological Applications. 12: 1418–1433.

Amman, G.D. 1977. The role of the mountain pine beetle in lodgepole pine ecosystems: Impact on succession. In: The role of arthropods in forest ecosystems. Berlin: Springer: 3–18.

Amman, G.D.; Ryan, K.C. 1991. Insect infestation of fire-injured trees in the greater Yellowstone area. Res. Note INT-RN-398. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Anderegg, W.R.L.; Berry, J.A.; Smith, D.D.; [et al.]. 2012. The roles of hydraulic and carbon stress in a widespread climate-induced forest die-off. Proceedings of the National Academy of Sciences, USA. 109: 233–237.

Anderson, L. 2011. Holocene record of precipitation seasonality from lake calcite δ18O in the central Rocky Mountains, United States. Geology. 39: 211–214.

Anderson, L.; Carlson, C.E.; Wakimoto, R.H. 1987. Forest fire frequency and western spruce budworm outbreaks in western Montana. Forest Ecology and Management. 22: 251–260.

Anttila, C.K.; Daehler, C.C.; Rannk, N.E.; Strong, D.R. 1998. Greater male fitness of a rare invader (*Spartina alterniflora*, Poaceae) threatens a common native (*Spartina foliosa*) with hybridization. American Journal of Botany. 85: 1597–1601.

Arno, S.F.; Hammerly, R.P. 1984. Timberline: Mountain and arctic forest frontiers. Seattle, WA: The Mountaineers. 304 p.

Ayres, M.P.; Lombardero, M.J. 2000. Assessing the consequences of global change for forest disturbance from herbivores and pathogens. Science of the Total Environment. 262: 263–286.

Azuma, D.L.; Overhulser, D.L. 2008. Effects of a western spruce budworm outbreak on private lands in eastern Oregon, 1980–1994. Western Journal of Applied Forestry. 23: 19–25.

Barbero, R.; Abatzoglou, J.T.; Larkin, N.K.; [et al.]. 2015. Climate change presents increased potential for very large fires in the contiguous United States. International Journal of Wildland Fire. 24: 892–899.

Bartos, D.L.; Campbell, R.B. Jr. 1998. Decline of quaking aspen in the Interior West—Examples from Utah. Rangelands. 20: 17–24.

Baskerville, G.L. 1975. Spruce budworm: Super silviculturist. Forestry Chronicles. 61: 138–140.

Bates, P.D.; Hortt, M.S.; Fewtrell, T.J. 2010. A simple inertial formulation of the shallow water equations for efficient two-dimensional flood inundation modelling, Journal of Hydrology. 387: 33–45.

Beckwith, R.C. 1978. Biology of the insect: Introduction. In: Brookes, M.H.; Stark, R.W.; Campbell, R.W., eds. The Douglas-fir tussock moth: A synthesis. Tech. Bull. 1585. Washington, DC: U.S. Department of Agriculture, Forest Service: 25–30.

Beckwith, R.C.; Burnell, D.G. 1982. Spring larval dispersal of the western spruce budworm (Lepidoptera: Tortricidae) in north-central Washington. Environmental Entomology. 11: 828–832.

Bell, K.L. 2012. Sympatric, allochronic populations of the pine white butterfly (*Neophasia menapia*) are morphologically and genetically differentiated. Master of Science Thesis. San Marcos, Texas: Texas State University. 31 p.

Benda, L.; Dunne, T. 1997a. Stochastic forcing of sediment supply to channel networks from landsliding and debris flow. Water Resources Research. 33: 2849–2864.

Benda, L.; Dunne, T. 1997b. Stochastic forcing of sediment routing and storage in channel networks. Water Resources Research. 33: 2865–2880.

Benda, L.; Miller, D.; Andras, K.; [et al.]. 2007. NetMap: A new tool in support of watershed science and resource management. Forest Science. 53: 206–219.

Bentz B.J.; Bracewell, R.B.; Mock, K.E.; Pfrender, M.E. 2011. Genetic architecture and phenotypic plasticity of thermally-regulated traits in an eruptive species, *Dendroctonus ponderosae*. Evolutionary Ecology. 25: 1269–1288.

Bentz, B.J.; Duncan, J.P.; Powell, J.A. 2016. Elevational shifts in thermal suitability for mountain pine beetle population growth in a changing climate. Forestry. 89: 271–283.

Bentz, B.J.; Jönsson, A.M. 2015. Modeling bark beetle responses to climate change. In: Vega, F.; Hofstetter, R., eds. Bark beetles: Biology and ecology of native and invasive species. London, United Kingdom: Academic Press: 533–553.

Bentz, B.J.; Mullins, D.E. 1999. Ecology of mountain pine beetle (Coleoptera: Scolytidae) cold hardening in the intermountain west. Environmental Entomology. 28: 577–587.

Bentz, B.J.; Powell, J.A. 2014. Mountain pine beetle seasonal timing and constraints to bivoltinism: A comment on Mitton and Ferrenberg (2012). American Naturalist. 184: 787–796.

Bentz, B.; Régnière, J.; Fettig, C.; [et al.]. 2010. Climate change and bark beetles of the western United States and Canada: Direct and indirect effects. Bioscience. 60: 602–613.

Bentz, B.J.; Six, D.L. 2006. Ergosterol content of fungi associated with *Dendroctonus ponderosae* and *Dendroctonus rufipennis* (Coleoptera: Curculionidae, Scolytinae). Annals of the Entomological Society of America. 99: 189–194.

Bentz, B.; Vandygriff, J.; Jensen, C.; [et al.]. 2014. Mountain pine beetle voltinism and life history characteristics across latitudinal and elevational gradients in the western United States. Forest Science. 60: 434–449.

Berger, A.; Loutre, M.F. 1991. Insolation values for the climate of the last 10 million years. Quaternary Science Reviews. 10: 297–317.

Bhattarai, G.P.; Cronin, J.T. 2014. Hurricane activity and the large-scale pattern of spread of an invasive plant species. PLoS One. 9: e98478.

Bigler, C.; Kulakowski, D.; Veblen, T.T. 2005. Multiple disturbance interactions and drought influence fire severity in Rocky Mountain subalpine forests. Ecology. 86: 3018–3029.

Bingham, R.T. 1983. Blister rust resistant western white pine for the Inland Empire: the story of the first 25 years of the research and development program. Gen. Tech. Rep. INT–GTR–146. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 45 p.

Bishop, R.J.; Jacobi, W.R. 2003. Insects associated with black stain root disease centers in pinyon pine stands. Southwestern Entomologist. 28: 55–61.

Bockino, N.K.; Tinker, D.B. 2012. Interactions of white pine blister rust and mountain pine beetle in whitebark pine ecosystems in the southern Greater Yellowstone area. Natural Areas Journal. 32: 31–40.

Bradley, B.A.; Oppenheimer, M.; Wilcove, D.S. 2009. Climate change and plant invasions: Restoration opportunities ahead? Global Change Biology. 15: 1511–1521.

Bradley, T.; Tueller, P. 2001. Effects of fire on bark beetle presence on Jeffrey pine in the Lake Tahoe Basin. Forest Ecology and Management. 142: 205–214.

Bradstock, R.A.; Williams, J.E.; Gill, A.M., eds. 2002. Flammable Australia: The fire regimes and biodiversity of a continent. Cambridge, UK: Cambridge University Press. 462 p.

Breece, C.R.; Kolb, T.E.; Dickson, B.G.; [et al.]. 2008. Prescribed fire effects on bark beetle activity and tree mortality in southwestern ponderosa pine forests. Forest Ecology and Management. 255: 119–128.

Brooks, M.L.; D'Antonio, C.M.; Richardson, D.M.; [et al.]. 2004. Effects of invasive alien plants on fire regimes. BioScience. 54: 667–688.

Brown, P.M.; Heyerdahl, E.K.; Kitchen, S.G.; Weber, M.H. 2008. Climate effects on historical fires (1630–1900) in Utah. International Journal of Wildland Fire. 17: 28–39.

Brown, T.J.; Hall, B.L.; Westerling, A.L. 2004. The impact of twenty–first century climate change on wildland fire danger in the western United States: An applications perspective. Climatic Change. 62: 365–388.

Brown, J.K.; Smith, J.K. 2000. Wildland fire in ecosystems: Effects of fire on flora. Gen. Tech. Rep. RMRS–GTR–42–vol. 2. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 257 p.

Buffington, J.M. 2012. Changes in channel morphology over human time scales. In: Church, M.; Biron, P.M.; Roy, A.G., eds. Gravel-bed rivers: Processes, tools, environments. Chichester, UK: Wiley: 435–463.

Byler, J.W.; Hagle, S.K. 2000. Succession functions of forest pathogens and insects: Ecosections M332a and M333d in northern Idaho and western Montana. Summary. FHP Rep. 00–09. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region, State and Private Forestry, Forest Health Protection. 37 p.

Campbell, R.W. 1963. Some ichneumonid-sarcophagid interactions in the gypsy moth *Porthetria dispar* (L.) (Lepidoptera: Lymantriidae). The Canadian Entomologist. 95: 337–345.

Campbell, R.W. 1993. Population dynamics of the major North American needle-eating budworms. Res. Pap. PNW–RP–463. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 222 p.

Cannon, S.H.; Gartner, J.E.; Parrett, C.; Parise, M. 2003. Wildfire-related debris-flow generation through episodic progressive sediment-bulking processes, western USA. In: Rickenmann, D.; Chen, C., eds. Debris-flow hazards mitigation: Mechanics, prediction, and assessment. Rotterdam: Millpress: 71–82.

Cannon, S.H.; Gartner, J.E.; Rupert, M.G.; [et al.]. 2010. Predicting the probability and volume of postwildfire debris flows in the intermountain western United States. Geological Society of America Bulletin. 122: 127–144.

Cardoza, Y.J.; Klepzig, K.D.; Raffa, K.F. 2006. Bacteria in oral secretions of an endophytic insect inhibit antagonistic fungi. Ecological Entomology. 31: 636–645.

Cardoza, Y.J.; Moser, J.C.; Klepzig, K.D.; Raffa, K.F. 2008. Multipartite symbioses among fungi, mites, nematodes, and the spruce beetle, *Dendroctonus rufipennis*. Environmental Entomology. 37: 956–963.

Carlson, C.E.; Fellin, D.G.; Schmidt, W.C. 1983. The western spruce budworm in northern Rocky Mountain forests: A review of ecology, insecticidal treatments and silvicultural practices. In: O'Loughlin, J.; Pfister, R.D., comps. Management of second-growth forest: The state of knowledge and research needs. Missoula, MT: Montana Forest and Conservation Experiment Station, School of Forestry, University of Montana: 76–103.

Chambers, J.C.; Brooks, M.L.; Pendelton, B.K.; Raish, C.B. 2013. The Southern Nevada agency partnership science and research synthesis: Science to support land management in Southern Nevada. Gen. Tech. Rep. RMRS-GTR-303. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 207 p.

Chambers, J.C. 2008. Great Basin sagebrush ecosystems. In: Chambers, J.C.; Devoe, N.; Evenden, A., eds. Collaborative management and research in the Great Basin—Examining the issues and developing a framework for action. Gen. Tech. Rep. RMRS-GTR-204. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 66 p.

Chapman, T.B.; Veblen, T.T.; Schoennagel, T. 2012. Spatiotemporal patterns of mountain pine beetle activity in the southern Rocky Mountains. Ecology. 93: 2175–2185.

Charlet, D.A. 1996. Atlas of Nevada conifers: A phytogeographic reference. Reno, NV: University of Nevada Press. 320 p.

Chen, Z.; Clancy, K.M.; Kolb, T.E. 2003. Variation in budburst phenology of Douglas-fir related to western spruce budworm (Lepidoptera: Tortricidae) fitness. Journal of Economic Entomology. 96: 377–387.

Church, M. 2002. Geomorphic thresholds in riverine landscapes. Freshwater Biology. 47: 541–557.

Clements, D.R.; Ditomasso, A. 2011. Climate change and weed adaptation: Can evolution of invasive plants lead to greater range expansion than forecasted? Weed Research. 51: 227–240.

Cole, W.E. 1966. Effect of pine butterfly defoliation on ponderosa pine in southern Idaho. Res. Note INT–RN–46. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p.

Cole, W.E. 1956. Surveys and control methods of the pine butterfly during an outbreak in southern Idaho, 1953-1954. Res. Note INT-RN-30. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 12 p.

Coleman, T.W.; Jones, M.J.; Cortial, B.; [et al.]. 2014. Impact of the first recorded outbreak of Douglas-fir tussock moth, *Orgyia pseudotsugata*, in southern California and the extent of its distribution in the Pacific Southwest region. Forest Ecology and Management. 329: 295–305.

Collins, B.J.; Rhoades, C.C.; Hubbard, R.M.; Battaglia, M.A. 2011. Tree regeneration and future stand development after bark beetle infestation and harvesting in Colorado lodgepole pine stands. Forest Ecology and Management. 261: 2168–2175.

Coop, J.D.; Schoettle, A.W. 2009. Regeneration of Rocky Mountain bristlecone pine (*Pinus aristata*) and limber pine (*Pinus flexilis*) three decades after stand-replacing fires. Forest Ecology and Management. 257: 893–903.

Cousens, R.; Mortimer, M. 1995. Dynamics of weed populations. Cambridge, UK: Cambridge University Press.

Cunningham, C.A.; Jenkins, M.J.; Roberts, D.W. 2005. Attack and brood production by the Douglas-fir beetle (Coleoptera: Scolytidae) in Douglas-fir, *Pseudotsuga menziesii* var. *glauca* (Pinaceae), following a wildfire. Western North American Naturalist. 65: 70–79.

Daehler, C.C. 2003. Performance comparison of co-occurring native and alien invasive plants: Implications for conservation and restoration. Annual Review of Ecology, Evolution, and Systematics. 34: 183–211.

Daehler, C.C.; Strong, D.R. 1994. Native plant biodiversity vs. the introduced invaders: Status of the conflict and future management options. In: Majumdar, S.K.; Brenner, F.J.; Lovich, J.E.; [et al.], eds. Biological diversity: Problems and challenges. Easton, PA: Pennsylvania Academy of Science: 92–113.

Dahlsten, D.L.; Luck, R.F.; Schlinger, E.I.; [et al.]. 1977. Parasitoids and predators of the Douglas-fir tussock moth, *Orgyia pseudotsugata* (Lepidoptera: Lymantriidae), in low to moderate populations in central California. Canadian Entomologist. 109: 727–746.

Dale, V.H.; Joyce, L.A.; McNulty, S.; [et al.]. 2001. Climate change and forest disturbances. Bioscience. 51: 723–734.

D'Antonio, C.M.; Vitousek, P.M. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics. 23: 63–87.

Daterman, G.E.; Livingston, R.L.; Robbins, R.G. 1977. How to identify tussock moths caught in pheromone traps. Agricultural Handbook 517. U.S. Department of Agriculture. 15 p.

Daterman, G.E.; Wenz, J.M.; Sheehan, K.A. 2004. Early warning system for Douglas-fir tussock moth outbreaks in the western United States. Western Journal of Applied Forestry. 19: 232–241.

Daubenmire, R. 1969. Ecologic plant geography of the Pacific Northwest. Madroño. 20: 111–128.

Daubenmire, R. 1970. Steppe vegetation of Washington. Tech. Bull. WAES-TB-62. Pullman, WA: Washington Agricultural Experimentation Station. 131 p.

Davies, K.W.; Bates, J.D.; Svejcar, T.J.; Boyd, C.S. 2010. Effects of long-term livestock grazing on fuel characteristics in rangelands: An example from the sagebrush steppe. Rangeland Ecology and Management. 63: 662–669.

Davis, M.A; Grime, J.P.; Thompson, K. 2000. Fluctuating resources in plant communities: A general theory of invisibility. Journal of Ecology. 88: 528–534.

Davis, R.S.; Hood, S.; Bentz, B.J. 2012. Fire-injured ponderosa pine provide a pulsed resource for bark beetles. Canadian Journal of Forest Research. 42: 2022–2036.

Davis, T.S.; Jarvis, K.; Parise, K.; [et al.]. 2011. Oleoresin exudation quantity increases and viscosity declines following a fire event in a ponderosa pine ecosystem. Journal of Arizona-Nevada Academy of Sciences. 43: 6–11.

DeMarco A.T. 2014. Pine butterfly (*Neophasia menapia*) outbreak in the Malheur National Forest, Blue Mountains, Oregon: examining patterns of defoliation. Master of Science Thesis. Corvalis, OR: Oregon State University. 72 p.

DeNitto, G.; Cramer, B.; Gibson, K.; [et al.]. 2000. Survivability and deterioration of fire-injured trees in the northern Rocky Mountains: A review of the literature. Forest Health Protection Report 2000-13. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 27 p.

Derner, J.D.; Schuman, G.E. 2007. Carbon sequestration and rangelands: A synthesis of land management and precipitation effects. Journal of Soil and Water Conservation. 62: 77–85.

DeRose, R.J.; Long, J.N. 2009. Wildfire and spruce beetle outbreak: Simulation of interacting disturbances in the central Rocky Mountains. Ecoscience. 16: 28–38.

DeRose, R.J.; Long, J.N. 2012a. Drought-driven disturbance history characterizes a southern Rocky Mountain subalpine forest. Canadian Journal of Forest Research. 42: 1649–1660.

DeRose, R.J.; Long, J.N. 2012b. Factors influencing the spatial and temporal dynamics of Engelmann spruce mortality during a spruce beetle outbreak. Forest Science. 58: 1–14.

Dewey, J.E.; Campbell, R.W. 1978. Outbreak detection, projection, and evaluation. In: Brookes, M.H.; Stark, R.W.; Campbell, R.W., eds. The Douglas-fir tussock moth: A synthesis. Technical Bulletin 1585. Washington, DC: U.S. Department of Agriculture, Forest Service: 233–235.

Dewey, J.E.; Meyer, H.E.; Lood, R.C.; Kohler, S. 1973. A pine butterfly impact survey on the Bitterroot National Forest and State of Montana lands—1972. Insect Disease Report 73–12. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 10 p.

Dewey, J.E.; Ciesla W.M. 1972. Evaluation of the pine butterfly infestation on the Nezperce National Forest—1972. Insect Disease Report. I-72-11. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 4 p.

Dietrich, W.E.; Montgomery, D.R. 1998. SHALSTAB: A digital terrain model for mapping shallow landslide potential. http://calm.geo.berkeley.edu/geomorph/shalstab/index.htm [Accessed July 16, 2017].

Dietrich, W.E.; Dunne, T.; Humphrey, N.F.; Reid, L.M. 1982. Construction of sediment budgets for drainage basins. In: Swanson, F.J.; Janda, R.J.; Dunne, T.; Swanston, D.N., eds. Sediment budgets and routing in forested drainage basins. Gen. Tech. Rep. PNW-GTR-141. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 5–23.

Diez, J.M.; D'Antonio, C.M.; Dukes, J.S.; [et al.]. 2012. Will extreme climatic events facilitate biological invasions? Frontiers in Ecology and the Environment. 10: 249–257.

Di Giovanni, F.; Cerretti, P.; Mason, F.; [et al.]. 2015. Vertical stratification of ichneumonid wasp communities: The effects of forest structure and life-history traits. Insect Science. 22: 688–699.

Dillon, G.K.; Menakis, J.; Fay, F. 2015. Wildland fire potential: A tool for assessing wildfire risk and fuels management needs. In: Keane, R.E.; Jolly, M.; Parsons, R.; Riley, K. Proceedings, Large Wildland Fire Conference; 2014 May 19–23; Missoula, MT. Proceedings RMRS-P-73. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 345 p.

DiTomaso, J.M. 2000. Invasive weeds in rangelands: Species, impacts, and management. Weed Science. 48: 255–265.

Dooley, E.M.; Six, D.L. 2015. Severe white pine blister rust infection in whitebark pine alters mountain pine beetle (Coleoptera: Curculionidae) attack density, emergence rate, and body size. Environmental Entomology. 44: 1384–1394.

Duda, J.J.; Freeman, D.C.; Emlen, J.M.; [et al.]. 2003. Differences in native soil ecology associated with invasion of the exotic annual chenopod, *Halogeton glomeratus*. Biology and Fertility of Soils. 38: 72–77.

Dudley, T.L. 2009. Invasive plants in the Mojave Desert riparian zones. In: Webb, R.H.; Fenstermaker, L.F.; Heaton, J.S.; [et al.], eds. The Mojave Desert: Ecosystem processes and sustainability. Reno, NV: University of Nevada Press: 125–155.

Dukes, J.S.; Mooney, H.A. 2004. Disruption of ecosystem processes in western North America by invasive species. Revista Chilena de Historia Natural. 77: 411–437.

Dukes, J.S.; Mooney, H.A. 1999. Does global change increase the success of biological invaders? Trends in Ecology and Evolution. 14: 135–139.

Early Detection and Distribution Mapping System [EDDMapS]. 2016. The University of Georgia, Center for Invasive Species and Ecosystem Health. http://www.eddmaps.org/tools/statereport.cfm. [Accessed February 2, 2016].

Ehle, D.S.; Baker W.L. 2003. Disturbance and stand dynamics in ponderosa pine forests in Rocky Mountain National Park, USA. Ecological Monographs. 73: 543–566.

Ehrenfeld, J.G. 2003. Effects of exotic plant invasions on soil nutrient cycling processes. Ecosystems. 6: 503–523.

Elkin, C.M.; Reid, M.L. 2004. Attack and reproductive success of mountain pine beetles (Coleoptera: Scolytidae) in fire-damaged lodgepole pines. Environmental Entomology. 33: 1070–1080.

Evenden, J.C. 1926. The pine butterfly, *Neophasia menapia* Felder. Washington, DC. Journal of Agricultural Research. 33: 339–344.

Evenden, J.C. 1936. Effects of defoliation by the pine butterfly (*Neophasia menapia* Felder) upon ponderosa pine. Forest Engineer Thesis. Corvallis, OR: Oregon State Agricultural College. 55 p.

Evenden, J.C. 1940. Effects of defoliation by the pine butterfly upon ponderosa pine. Journal of Forestry. 38: 949–955.

Fairweather, M.L.; Geils, B.W.; Manthei, M. 2008. Aspen decline on the Coconino National Forest. In: McWilliams, M.G., ed. Proceedings, 55th Western International Forest Disease Work Conference; 2007 October 15–19; Sedona, AZ. Salem, OR: Oregon Department of Forestry: 53–62.

Falk, D.A.; Heyerdahl, E.K.; Brown, P.M.; [et al.]. 2011. Multi-scale controls of historical forest-fire regimes: New insights from fire-scar networks. Frontiers in Ecology and the Environment. 9: 446–454.

Falk, D.A.; Miller, C.; McKenzie, D.; Black, A.E. 2007. Cross-scale analysis of fire regimes. Ecosystems. 10: 809–823.

Fellin, D.G.; Dewey, J.E. 1986. Western spruce budworm. Forest Insect and Disease Leaflet 53. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 9 p.

Fellin, D.G.; Shearer, R.C.; Carlson, C.E. 1983. Western spruce budworm in the northern Rocky Mountains: Biology, ecology and impacts. Western Wildlands. 1: 2–7.

Ferguson, D.E. 1985. Quantifying impacts on forest growth and yield—western United States. In: Sanders, C.J.; Stark, R.W.; Mullins, E.J.; Murphy, J., eds. Recent advances in spruce budworms research. Proceedings, CANUSA Spruce Budworms Research Symposium; 1984 September 16-20; Bangor, MN. Ottawa, Ontario: Canadian Forestry Service: 249–250.

Ferrell, G.T. 1986. Fir engraver (FIDL). Forest Insect and Disease Leaflet 13. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station.

Ferrell, G.T.; Scharpe, R.F. 1982. Stem volume losses in grandfirs topkilled by western spruce budworm in Idaho. Res. Pap. PSW-RP-164. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 10 p.

Fettig, C.; Borys, R.; Dabney, C. 2010. Effects of fire and fire surrogate treatments on bark beetle caused tree mortality in the Southern Cascades, California. Forest Science 56: 60–73.

Fettig, C.J.; Borys, R.R.; McKelvey, S.M.; [et al.]. 2008. Blacks Mountain Experimental Forest: Bark beetle responses to differences in forest structure and application of prescribed fire in interior ponderosa pine. Canadian Journal of Forest Research. 38: 924–935.

Fettig, C.J.; Klepzig, K.D.; Billings, R.F.; [et al.]. 2007. The effectiveness of vegetation management practices for prevention and control of bark beetle infestations in coniferous forests of the western and southern United States. Forest Ecology and Management. 238: 24–53.

Fischer, W.C. 1980. Prescribed fire and bark beetle attack in ponderosa pine forests. Fire Management Notes. Spring: 10–12.

Fire Statistics System [FIRESTAT]. 2015. Washington, DC: U.S. Department of Agriculture, Forest Service. https://fam.nwcg.gov/fam-web-was/Firestat/index.html [Accessed November 1, 2016].

Flannigan, M.D.; Krawchuk, M.A.; de Groot, W.J.; [et al.]. 2009. Implications of changing climate for global wildland fire. International Journal of Wildland Fire. 18: 483–507.

Flannigan, M.D.; Amiro, B.D.; Logan, K.A.; [et al.]. 2006. Forest fires and climate change in the 21st century. Mitigation and Adaptation Strategies for Global Change. 11: 847–859.

Flannigan, M.D.; Stocks, B.J.; Wotton, B.M. 2000. Climate change and forest fires. Science of the Total Environment. 262: 221–229.

Fletcher, J. 1905. Practical and popular entomology, No. 5: Canadian three-colour process illustrations. The Canadian Entomologist. 5: 157–159.

Flower, A.; Gavin, D.G.; Heyerdahl, E.K.; [et al.]. 2014a. Western spruce budworm outbreaks did not increase fire risk over the last three centuries: A dendrochronological analysis of inter-disturbance synergism. PLoS ONE. 9: e114282.

Flower, A.; Gavin, D.G.; Heyerdahl, E.K.; [et al.]. 2014b. Drought-triggered western spruce budworm outbreaks in the interior Pacific Northwest: A multi-century dendrochronological record. Forest Ecology and Management. 324: 16–27.

Follett, R.F.; Kimble, J.M.; Lal, R., eds. 2001. The potential of U.S. grazing lands to sequester carbon and mitigate the greenhouse effect. Boca Raton, FL: Lewis Publishers, CRC Press. 422 p.

Forest Health Protection. 2011. Spruce engraver beetles. Golden, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5341331.pdf [Accessed November 1, 2016].

Fowler, J.F.; Sieg, C.H. 2004. Postfire mortality of ponderosa pine and Douglas-fir: A review of methods to predict tree death. Gen. Tech. Rep. RMRS-GTR-132. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Franceschi, V.R.; Krokene, P.; Christiansen, E.; Krekling, T. 2005. Anatomical and chemical defenses of conifer bark against bark beetles and other pests. New Phytologist. 167: 353–376.

Fredericks, S.E.; Jenkins, M.J. 1988. Douglas-fir beetle (*Dendroctonus Pseudotugae* Hopkins, Coleoptera: Scolytidae) brood production on Douglas-fir defoliated by western spruce budworm (*Choristoneura occidentalis* Freeman, Lepidoptera: Tortricidae) in Logan Canyon, Utah. Great Basin Naturalist. 48: 348–351.

Frey, B.R.; Lieffers, V.J.; Hogg, E.H.T.; Landhäusser, S.M. 2004. Predicting landscape patterns of aspen dieback: mechanisms and knowledge gaps. Canadian Journal of Forest Research. 34: 1379–1390.

Frye, R.H.; Landis, T.D. 1975. Mountain pine beetle and dwarf mistletoe: Lake Creek Area, San Carlos Ranger District, Pike-San Isabel National Forest. Biological Evaluation R 2-75-4. Golden, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region, Forest Insect and Disease Management. 10 p.

Furniss, M.M.; Johnson, J.B. 2002. Field guide to the bark beetles of Idaho and adjacent regions. Moscow, ID: University of Idaho.

Furniss, R.L.; Carolin, V.M. 1977. Western forest insects. Misc. Pub. 1339. Washington, DC: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 702 p.

Furniss, M.M. 1965. Susceptibility of fire-injured Douglas-fir to bark beetle attack in southern Idaho. Journal of Forestry. 63: 8–14.

Gaylord, M.L.; Kolb, T.E.; McDowell, N.G. 2015. Mechanisms of piñon pine mortality after severe drought: A retrospective study of mature trees. Tree Physiology. 35: 806–816.

Gaylord, M.L.; Kolb, T.E.; Pockman, W.T.; [et al.]. 2013. Drought predisposes piñon–juniper woodlands to insect attacks and mortality. New Phytology. 198: 567–578.

Gaylord, M.L.; Williams, K.K.; Hofstetter, R. W.; [et al.]. 2008. Influence of temperature on spring flight initiation for Southwestern ponderosa pine bark beetles (Coleoptera: Curculionidae, Scolytinae). Environmental Entomology. 37: 57–69.

Gedalof, Z.; Peterson, D.L.; Mantua, N.J. 2005. Atmospheric, climatic, and ecological controls on extreme wildfire years in the northwestern United States. Ecological Applications. 15: 154–174.

Geils, B.W.; Tovar, J.C.; Moody, B. 2002. Mistletoes of North American conifers. Gen. Tech. Rep. RMRS-GTR-98. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 123 p.

Geiszler, D.R.; Gara, R.I.; Littke, W.R. 1984. Bark beetle infestations of lodgepole pine following a fire in south central Oregon. Zeitschrift fur Angeqandte Entomologie. 98: 389–394.

Geiszler, D.R.; Gara, R.I.; Driver, C.H.; [et al.]. 1980. Fire, fungi, and beetle influences on a lodgepole pine ecosystem of south-central Oregon. Oecologia. 46: 239–243.

Gibson, K.; Lieser, E.; Ping, B. 1999. Bark beetle outbreaks following the Little Wolf Fire, Tally Lake Ranger District, Flathead National Forest. Report 99-7. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Forest Health Protection. 15 p.

Gillies, R.R.; Wang, S.Y.; Booth, M.R. 2012. Observational and synoptic analyses of the winter precipitation regime change over Utah. Journal of Climate. 25: 4679–4698.

Goheen, D.J.; Cobb, F.W., Jr. 1980. Infestation of *Ceratocystis wageneri*-infected ponderosa pines by bark beetles (Coleoptera: Scolytidae) in the central Sierra Nevada. Canadian Entomologist. 112: 725–730.

Goheen, D.J.; Hansen, E. 1993. Effects of pathogens and bark beetles on forests. In: Schowalter, T.D.; Filip, G.M., eds. Beetle-pathogen interactions in conifer forests. London: Academic Press.

Goode, J.R.; Buffington J.M.; Tonina, D.; [et al.]. 2013. Potential effects of climate change on streambed scour and risks to salmonid survival in snow-dominated mountain basins. Hydrological Processes. 27: 750–765.

Goode, J.R.; Luce C.H.; Buffington J.M. 2012. Enhanced sediment delivery in a changing climate in semi-arid mountain basins: Implications for water resource management and aquatic habitat in the northern Rocky Mountains. Geomorphology. 139–140: 1–15.

Gould, W.A.; Gonzalez, G.; Hudak, A.T.; [et al.]. 2008. Forest structure and downed woody debris in boreal, temperate, and tropical forest fragments. Ambio. 37: 577–587.

Goward, S.N.; Masek, J.G.; Cohen, W.; [et al.]. 2008. Forest disturbance and North American carbon flux. Eos, Transactions, American Geophysical Union. 89: 105–116.

Graham, S.A. 1923. The dying balsam fir and spruce in Minnesota. Special Bulletin 68. Minneapolis, MN: University of Minnesota, Agriculture Extensional Division. 12 p.

Gray, D.H.; Megahan, W.F. 1981. Forest vegetation removal and slope stability in the Idaho Batholith. Res. Pap. INT-271. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 23 p.

Gray, C.A.; Runyon, J.B.; Jenkins, M.J.; [et al.]. 2015. Mountain pine beetles use volatile cues to locate host limber pine and avoid non-host Great Basin bristlecone pine. PLoS ONE. 10: e0135752.

Greenbank, D.O. 1970. Climate and the ecology of the balsam woolly aphid. The Canadian Entomologist. 102: 546–578.

Grime, J.P. 1973. Competitive exclusion in herbaceous vegetation. Nature. 242: 344–347.

Grissino-Mayer, H.D.; Swetnam, T.W. 2000. Century scale climate forcing of fire regimes in the American Southwest. The Holocene. 10: 213–220.

Gruell, G.E. 1999. Historical and modern roles of fire in pinyon-juniper. In: Monsen, S.B.; Stevens, R., comps. Proceedings: ecology and management of pinyon-juniper communities within the Interior West. Proceedings RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 24–28.

Guinta, A. 2016. Douglas-fir mediated changes to fuel complexes, foliar moisture content and terpenes in interior Douglas-fir forests of the central Rocky Mountains. Master of Science Thesis. Logan, UT: Utah State University.

Guyon, J.C. 1992. A biological evaluation of the site related factors associated with the fir engraver outbreak on the Carson and Bridgeport Ranger Districts, Toiyabe National Forest. Intermountain Region Report R4-92-02. Ogden, UT: U.S. Department of Agriculture, Forest Service, State and Private Forestry, Forest Health Protection.

Guyon, J.C. 1997. Root disease conditions in the Dark Valley and Purple Lake area. Intermountain Region Forest Health Report R4-97-05. Ogden, UT: U.S. Department of Agriculture, Forest Service, State and Private Forestry, Forest Health Protection. 23 p.

Guyon, J.; Hoffman, J. 2011. Survey of aspen dieback in the Intermountain Region. R4-OFO-Report 11-01. Ogden, UT: U.S. Department of Agriculture, Forest Service, State and Private Forestry, Forest Health Protection, Intermountain Region.

Hadley, K.S.; Veblen, T.T. 1993. Stand response to western spruce budworm and Douglas-fir bark beetle outbreaks, Colorado Front Range. Canadian Journal of Forest Research. 23: 479–491.

Hann, W.J.; Shlisky, A.; Havlina, D.; [et al.]. 2004. Interagency fire regime condition class guidebook. U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, The Nature Conservancy, and Systems for Environmental Management.

Hansen, E.M. 1996. Western balsam bark beetle, *Dryocoetes confusus* Swaine, flight periodicity in northern Utah. The Great Basin Naturalist. 56: 348–359.

Hansen, E.M.; Amacher, C.M., Miegroet, H.V.; [et al.]. 2015. Carbon dynamics in central U.S. Rockies lodgepole pine type after mountain pine beetle outbreaks. Forest Science. 61: 665–679.

Hansen, E.M.; Bentz, B.J.; Powell, J.A.; [et al.]. 2011. Prepupal diapause and instar IV development rates of spruce beetle, *Dendroctonus ruifpennis* (Coleoptera: Curculionidae, Scolytinae). Journal of Insect Physiology. 57: 1347–1357.

Hansen, E.M.; Bentz, B.J.; Turner, D.L. 2001. Physiological basis for flexible voltinism in the spruce beetle (Coleoptera: Scolytidae*).* The Canadian Entomologist. 133: 805–817.

Hansen, E.M.; Johnson, M.C.; Bentz, B.J.; [et al.]. 2015. Fuel loads and simulated fire behavior in "old-stage" beetle-infested ponderosa pine of the Colorado Plateau. Forest Science. 61: 644–664.

Harrington, T.C.; Cobb, F.W., Jr.; Lownsbery, J.W. 1985. Activity of *Hylastes nigrinus*, a vector of *Verticicladiella wageneri*, in thinned stands of Douglas-fir. Canadian Journal of Forest Research. 15: 579–523.

Hart, S.J.; Veblen, T.T.; Eisenhart, K.S.; [et al.]. 2014. Drought induces sprucebeetle (*Dendroctonus rufipennis*) outbreaks across northwestern Colorado. Ecology. 95: 930–939.

Harvey, B.J.; Donato, D.C.; Romme, W.; [et al.]. 2013. Influence of recent bark beetle outbreak on fire severity and postfire tree regeneration in montane Douglas-fir forests. Ecology. 94: 2475–2486.

Harvey, G.T. 1985. The taxonomy of the coniferophagous *Choristoneura* (Lepidoptera: Tortricidae): A review. In: Sanders, C.J.; Stark, R.W.; Mullins, E.J.; Murphy, J., eds. Recent advances in spruce budworms research: Proceedings of the CANUSA spruce budworms research symposium. Ottawa, Ontario: Canadian Forestry Service: 16–48.

Havstad, K.; Peters, D.; Allen-Diaz, B.; [et al.]. 2009. The western United States rangelands: A major resource. In: Wedin, W.F.; Fales, S.L., eds. Grasslands: Quietness and strength for a new American agriculture. Madison, WI: American Society of Agronomy, Crop Science Society of America and Soil Science Society of America: 75–93.

Hawbaker, T.J.; Radeloff, V.C.; Stewart, S.I.; [et al.]. 2013. Human and biophysical influences on fire occurrence in the United States. Ecological Applications. 23: 565–582

Hawksworth, F.G.; Wiens, D. 1996. Dwarf mistletoes: Biology, pathology, and systematics. Agric. Handb. 709. Washington, DC: U.S. Department of Agriculture, Forest Service. 410 p.

Hebertson, E.G.; Jenkins, M.J. 2008. Climate factors associated with historic spruce beetle (Coleoptera: Curculionidae, Scolytinae) outbreaks in Utah and Colorado. Environmental Entomology. 37: 281–292.

Helfer, S. 2014. Rust fungi and global change. New Phytologist. 201: 770–780.

Heller, N.E.; Zavaleta, E.S. 2009. Biodiversity management in the face of climate change: A review of 22 years of recommendations. Biological Conservation. 142: 14–32.

Helzner, R.; Thier, R.W. 1993. Pine butterfly in southern Idaho 1893-1984. Report No. R4-93-06. Ogden, UT: U.S. Department of Agriculture, Forest Service. 26 p.

Herms D.A.; Mattson. W.J. 1992. The dilemma of plants: To grow or defend. The Quarterly Review of Biology. 67: 283–335.

Hessburg, P.F.; Mitchell, R.G.; Filip, G.M. 1994. Historical and current roles of insects and pathogens in eastern Oregon and Washington forested landscapes. Gen. Tech. Rep. PNW-GTR-327. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Hessburg, P.F.; Salter, R.B.; James, K.M. 2007. Re-examining fire severity relations in pre-management era mixed conifer forests: Inferences from landscape patterns of forest structure. Landscape Ecology. 22: 5–24.

Heyerdahl, E.K.; Brown, P.M.; Kitchen, S.G.; Weber, M.H. 2011. Multicentury fire and forest histories at 19 sites in Utah and eastern Nevada. Gen. Tech. Rep. RMRS-GTR-261WWW. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 192 p.

Hicke, J.A.; Johnson, M.C.; Hayes, J.L.; Preisler, H.K. 2012. Effects of bark beetle-caused tree mortality on wildfire. Forest Ecology and Management. 271: 81–90.

Hicke, J.A.; Meddens, A.J.H.; Kolden, C.A. 2016. Recent tree mortality in the western United States from bark beetles and forest fires. Forest Science. 62: 141–153.

Hinds, T.E.; Fuller, L.R.; Lessard, E.D.; Johnson, D.W. 1984. Mountain pine beetle infestation and Armillaria root disease of ponderosa pine in the Black Hills of South Dakota. Tech. Rep. R2-30. Golden, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. 7 p.

Hitchcox, M. 2015. Safeguarding against future invasive forest insects. Tree Planter's Notes. 58: 27–36.

Hoffman, C.M.; Canfield, J.; Linn, R.R.; [et al.]. 2015. Evaluating crown fire rate of spread predictions from physics-based models. Fire Technology. 52: 221–237.

Hoffman, C.M.; Morgan, P.; Mell, W.; [et al.]. 2012a. Numerical simulation of crown fire hazard immediately after bark beetle-caused mortality in lodgepole pine forests. Forest Science. 58: 178–188.

Hoffman, C.M.; Morgan, P.; Mell, W.; [et al.]. 2013. Surface fire intensity influences simulated crown fire behavior in lodgepole pine forests with recent mountain pine beetle-caused tree mortality. Forest Science. 59: 390–399.

Hoffman, C.M.; Sieg, C.H.; McMillin, J.D.; [et al.]. 2012b. Fuel loadings 5 years after a bark beetle outbreak in south-western USA ponderosa pine forests. International Journal of Wildland Fire. 21: 306–312.

Holsten, E.H.; Thier, R.W.; Munson, A.S.; K.E. Gibson. 1999. The spruce beetle. Insect and Disease Leaflet 127. Washington DC: U.S. Department of Agriculture, Forest Service.

Hood, S.M.; Bentz, B. 2007. Predicting post-fire Douglas-fir beetle attacks and tree mortality in the Northern Rocky Mountains. Canadian Journal of Forest Research. 37: 1058–1069.

Hood, S.M.; Bentz, B.; Gibson, K.; [et al.]. 2007. Assessing post-fire Douglas-fir mortality and Douglas-fir beetle attacks in the northern Rocky Mountains. Gen. Tech. Rep. RMRS-GTR-199. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Hopkins, A.D. 1907. Notable depredations by forest insects. Washington, DC: Yearbook of Department of Agriculture for 1907.

Houston, D.R. 1981. Some dieback and decline diseases of northeastern forest trees: Forest management considerations. In: Proceedings of the Annual Silviculture Workshop, Roanoke, VA. Washington, DC: 248–265.

Hrinkevich, K.H.; Progar, R.A.; Shaw, D.C. 2016. Climate risk modelling of balsam woolly adelgid damage severity in subalpine fir stands of Western North America. PloS One. 11: e0165094.

Huber, J.; Hughes, P.R. 1984. Quantitative bioassay in insect pathology. Bulletin of the Entomological Society of America. 30: 30–34.

Huckaby, L.S. 1991. Forest regeneration following fire in the forest-alpine ecotone in the Colorado Front Range. Master of Science Thesis. Fort Collins, CO: Colorado State University. 53 p.

Hummel, S.; Agee, J.K. 2003. Western spruce budworm defoliation effects on forest structure and potential fire behavior. Northwest Science. 7: 159–169.

Hunt, R.S.; Morrison, D.J. 1986. Black stain root disease on lodgepole pine in British Columbia. Canadian Journal of Forest Research. 16: 996–999.

Huntzinger, M. 2003. Effects of fire management practices on butterfly diversity in the forested western United States. Biological Conservation. 113: 1–12.

Ielmini, M.R.; Hopkins, T.E.; Mayer, K.E.; [et al.]. 2015. Invasive plant management and greater sage-grouse conservation: A review and status report with strategic recommendations for improvement. Cheyenne, WY: Western Association of Fish and Wildlife Agencies. 47 p.

Ignoffo, C.M. 1992. Environmental factors affecting persistence of entomopathogens. Florida Entomologist. 75: 516–525.

Intergovernmental Panel on Climate Change [IPCC]. 2007. Climate change 2007: The physical science basis. Working group I contribution to the fourth assessment report of the IPCC. Cambridge, United Kingdom: Cambridge University Press.

Istanbulluoglu, E.; Tarboton, D.G.; Pack, R.T.; Luce, C.H. 2004. Modeling of the interactions between forest vegetation, disturbances, and sediment yields. Journal of Geophysical Research, Earth Surface. 109: F01009.

Jaques, R.P. 1985. Stability of insect viruses in the environment. In: Maramorosch, K.; Sherman, K.E., eds. Viral insecticides for biological control. New York, NY: Academic Press. 809 p.

Jeffrey, T. 2015. The structural, geographic, and financial impact of wildfire in the United States. Fire Management Today. 74: 33–36.

Jenkins, M.J.; Hebertson, E.; Page, W.; [et al.]. 2008. Bark beetles, fuels, fires and implications for forest management in the Intermountain West. Forest Ecology and Management. 254: 16–34.

Jenkins, M.J.; Runyon, J.B.; Fettig, C.J.; [et al.]. 2014. Interactions among the mountain pine beetle, fires, and fuels. Forest Science. 60: 489–501.

Jenkins, S.E.; Sieg, C.H.; Anderson, D.E.; [et al.]. 2011. Late Holocene geomorphic record of fire in ponderosa pine and mixed-conifer forests, Kendrick Mountain, northern Arizona, USA. International Journal of Wildland Fire. 20: 125–141.

Johnson, A.C.; Swanston, D.N.; McGee, K.E. 2000. Landslide initiation, runout, and deposition within clearcuts and old-growth forests of Alaska. Journal of the American Water Resources Association. 36: 17–30.

Johnson, D.W.; Yarger, L.C.; Minnemeyer, C.D.; Pace, V.E. 1976. Dwarf mistletoe as a predisposing factor for mountain pine beetle attack of ponderosa pine in the Colorado Front Range. Forest Insects and Disease Technical Report R2-4. Golden, CO: U.S. Forest Service, Rocky Mountain Region. 7 p.

Johnson, P.C.; Denton, R.E. 1975. Outbreaks of the western spruce budworm in the American northern Rocky Mountain area from 1922 through 1971. Gen. Tech. Rep. INT-20. Ogden, UT: U.S. Department of Agriculture, Forest Service. 152 p.

Jolly, W.M.; Parsons, R.A.; Hadlow, A.M.; [et al.]. 2012. Relationships between moisture, chemistry, and ignition of *Pinus contorta* needles during the early stages of mountain pine beetle attack. Forest Ecology and Management. 269: 52–59.

Jorgensen, C.A.; Jenkins, M.J. 2011. Fuel complex alterations associated with spruce beetle-induced tree mortality in Intermountain spruce/fir forests. Forest Science. 57: 232–240.

Kaczynski, K.M.; Cooper, D.J. 2013. Susceptibility of *Salix monticola* to Cytospora canker under increased temperatures and decreased water levels. Forest Ecology and Management. 305: 223–228.

Kalinkat, G.; Rall, B.C. 2015. Effects of climate change on the interactions between insect pests and their natural enemies. In: Björkman, C.; Niemelä, P., eds. Climate change and insect pests. Oxfordshire, UK: CAB International: 74–91.

Kashian, D.M.; Romme, W.H.; Tinker, D.B.; [et al.]. 2006. Carbon storage on landscapes with stand replacing fires. Bioscience. 56: 598–606.

Kasischke, E.S.; French, N.H.F.; O'Neill, K.P.; [et al.]. 2000. Influence of fire on long-term patterns of forest succession in Alaskan boreal forests. In: Kasischke, E.S.; Stocks, B.J., eds. Fire, climate change, and carbon cycling in the North American boreal forest. New York, NY: Springer-Verlag: 214–325.

Kay, C.E. 1997. Is aspen doomed? Journal of Forestry. 95: 4–11.

Keane, R.E. 2013. Disturbance regimes and the historical range of variation in terrestrial ecosystems. In: Simon, A L., ed. Encyclopedia of Biodiversity (Second Edition). Waltham: Academic Press: 568–581.

Keane, R.E.; Arno, S.F. 1993. Rapid decline of whitebark pine in Western Montana: Evidence from 20 year remeasurements. Western Journal of Applied Forestry. 8: 44–47.

Keane, R.E.; McKenzie, D.; Falk, D.A.; [et al.]. 2015. Representing climate, disturbance, and vegetation interactions in landscape models. Ecological Modelling. 309–310: 33–47.

Keane, R.E.; Parsons, R.A. 2010. Restoring whitebark pine forests of the northern Rocky Mountains, USA. Ecological Restoration. 28: 56–70.

Keane, R.E.; Tomback, D.F.; Aubry, C.A.; [et al.]. 2012. A range-wide restoration strategy for whitebark pine (*Pinus albicaulis*). Gen. Tech. Rep. RMRS-GTR-279. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 118 p.

Keane, R.E.; Veblen, T.; Ryan, K.C.; [et al.]. 2002. The cascading effects of fire exclusion in the Rocky Mountains. In: Baron, J.S., ed. Rocky Mountain futures: An ecological perspective. Washington, DC: Island Press.

Keeley, J.E.; Aplet, G.H.; Christensen, N.L.; [et al.]. 2009. Ecological foundations for fire management in North American forest and shrubland ecosystems. Gen. Tech. Rep. PNW-GTR-779. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 92 p.

Kegley, S.J.; Livingston, R.L.; Gibson, K.E. 1997. Pine engraver, *Ips pini* (Say), in the western United States. Forest Insect and Disease Leaflet 122. Missoula, MT: U.S. Department of Agriculture, Forest Service. 5 p.

Keith, H.; Mackey, B.G.; Lindenmayer, D.B. 2009. Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. Proceedings of the National Academy of Sciences. 106: 11635–11640.

Kelsey, R.G.; Gallego, D.; Sánchez-García, F.J.; Pajares, J.A. 2014. Ethanol accumulation during severe drought may signal tree vulnerability to detection and attack by bark beetles**.** Canadian Journal of Forest Research. 44: 554–561.

Kelsey, R.G.; Joseph, G. 2003. Ethanol in ponderosa pine as an indicator of physiological injury from fire and its relationship to secondary beetles. Canadian Journal of Forest Research. 33: 870–884.

Kemp, W.P.; Everson, D.O.; Wellington, W.G. 1985. Regional climatic patterns and western spruce budworm outbreaks. Tech. Bull. 1693. Washington, DC: U.S. Department of Agriculture, Forest Service, Cooperative State Research Service, CANUSA Spruce Budworm Program. 31 p.

Kenaley, S.; Mathiasen, R.; Harner, E.J. 2008. Mortality associated with a bark beetle outbreak in dwarf mistletoe-infested ponderosa pine stands in Arizona. Western Journal of Applied Forestry. 23: 113–120.

Kenaley, S.C.; Mathiasen, R.L.; Daugherty, C.M. 2006. Selection of dwarf mistletoe-infected pines by Ips species (Coleoptera: Scolytidae) in northern Arizona. Western North American Naturalist. 66: 279–284.

Kerns, B.K.; Westlind, D.J. 2013. Effect of season and interval of prescribed burn on ponderosa pine butterfly defoliation patterns. Canadian Journal of Forest Research. 43: 979–983.

Killick, H.J.; Warden, S.J. 1991. Ultraviolet penetration of pine trees and insect virus survival. Entomophaga. 36: 87–94.

Kitchen, S.G. 2010. Historic fire regimes of eastern Great Basin (USA) mountains reconstructed from tree rings. Doctoral Dissertation. Provo, UT: Brigham Young University. 156 p.

Kitchen, S.G. 2015. Climate and human influences on historical fire regimes (AD 1400–1900) in the eastern Great Basin (USA). The Holocene. 26: 397–407.

Kitchen, S.G.; McArthur, E.D. 2007. Shrubland ecosystems: importance, distinguishing characteristics, and dynamics In: Sosebee, R.E.; Wester, D.B.; Britton, C.M.; [et al.], comps. Proceedings: shrubland dynamics—Fire and water; 2004 August 10–12; Lubbock, TX. Proceedings RMRS-P-47. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 173 p.

Kitzberger, T.; Brown, P.; Heyerdahl, E.; [et al.]. 2007. Contingent Pacific–Atlantic Ocean influence on multicentury wildfire synchrony over western North America. Proceedings of the National Academy of Sciences, USA. 104: 543–548.

Klein, W.; Bennett, D. 1995. Survey to measure tree damage caused by a western spruce budworm outbreak on the Carson National forest, 1984 and 1991. General Report R3-95-1. Washington, DC: U.S. Department of Agriculture, Forest Service, Southwestern Region.

Kleinman, S.J.; DeGomez, T.E.; Snider, G.B.; Williams, K.E. 2012. Large-scale pinyon ips (*Ips confusus*) outbreak in southwestern United States tied with elevation and land cover. Journal of Forestry. 110: 194–200.

Klepzig, K.; Poland, T.; Gillette, N.; [et al.]. 2010. Invasive insects: Visions for the future. In: Dix, M.E.; Britton, K., eds. A dynamic invasive species research vision: Opportunities and priorities 2009–2029. Gen. Tech. Rep. WO-79. Washington, DC: U.S. Department of Agriculture, Forest Service.

Klepzig, K.D.; Six, D.L. 2004. Bark beetle-fungal symbiosis: context dependency in complex associations. Symbiosis. 37: 189–205.

Kliejunas, J.T. 2011. A risk assessment of climate change and the impact of forest diseases on forest ecosystems in the western United States and Canada. Gen. Tech. Rep. PSW-GTR-236. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 70 p.

Klock, G.O.; Wickman, B.E. 1978. Ecosystem effects. In: Brookes, M.H.; Stark, R.W.; Campbell, R.W., eds. The Douglas-fir tussock moth: A synthesis. Tech. Bull. 1585. Washington, DC: U.S. Department of Agriculture, Forest Service: 90–95.

Klutsch, J.G.; Battaglia, M.A.; West, D.R.; [et al.]. 2011. Evaluating potential fire behavior in lodgepole pine-dominated forests after a mountain pine beetle epidemic in north-central Colorado. Western Journal of Applied Forestry. 26: 101–109.

Koch, F.H.; Yemshanov, D.; Colunga-Garcia, M.; [et al.]. 2011. Potential establishment of alien-invasive forest insect species in the United States: Where and how many? Biological Invasions. 13: 969–985.

Kolb, T.E.; Fettig, C.J.; Bentz, B.J.; [et al.]. 2016a. Forest insect and fungal pathogen responses to drought. In: Vose, J.M.; Clark, J.S.; Luce, C.H.; Patel-Weynand, T., eds. Effects of drought on forests and rangelands in the United States: A comprehensive science synthesis. Gen. Tech. Rep. WO-93b. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office: 113–133.

Kolb, T.E.; Fettig, C.J.; Bentz, B.J.; [et al.]. 2016b. Observed and anticipated impacts of drought on forest insects and diseases in the United States. Forest Ecology and Management. 380: 321–334.

Krawchuk, M.A.; Moritz, M.A.; Parisien, M.A.; [et al.]. 2009. Global pyrogeography: the current and future distribution of wildfire. PLoS one. 4: e5102.

Kulakowski, D.; Jarvis, D. 2011. The influence of mountain pine beetle outbreaks and drought on severe wildfires in northwestern Colorado and southern Wyoming: A look at the past century. Forest Ecology and Management. 262: 1686–1696.

Lafferty, K.D. 2009. The ecology of climate change and infectious diseases. Ecology. 90: 888–900.

Larson, E.R. 2011. Influences of the biophysical environment on blister rust and mountain pine beetle, and their interactions, in whitebark pine forests. Journal of Biogeography. 38: 453–470.

Lazarus, L. 2012. Pine butterfly, *Neophasia menapia*, egg mass survey and predicted 2012 defoliation levels for select areas of the Salmon-Chalis and Boise National Forest. Technical Report BFO-TR-2012-20. Boise, ID: U.S. Department of Agriculture, Forest Service. 9 p.

Lerch, A. 2013. Mountain pine beetle dynamics and lodgepole and ponderosa pine mortality following wildfire in the Uinta Mountains of northern Utah. Master of Science Thesis. Madison, WI: University of Wisconsin. 134 p.

Lerch, A.; Pfammatter, J.A.; Bentz, B.J.; [et al.]. 2016. Mountain pine beetle dynamics and reproductive success in post-fire lodgepole and ponderosa pine forests in northeastern Utah. PloS ONE. 11: 30164738.

Lessard, E.D.; Schmid, J.M. 1990. Emergence, attack densities, and host relationships for the Douglas-fir beetle (*Dendroctonus Pseudotsugae* Hopkins) in Northern Colorado. Great Basin Naturalist. 50: 333–338.

Lewicki, M.; Buffington, J.M.; Thurow, R.F.; Isaak, D.J. 2006. Numerical model of channel and aquatic habitat response to sediment pulses in mountain rivers of central Idaho. Eos, Transactions, American Geophysical Union. 87, Fall Meeting Supplement, Abstract H51B-0481.

Linn, R.R.; Sieg, C.H.; Hoffman, C.M.; [et al.]. 2013. Modeling wind fields and fire propagation following bark beetle outbreaks in spatially-heterogeneous pinyon-juniper woodland fuel complexes. Agricultural and Forest Meteorology. 173: 139–153.

LISFLOOD-FP. 2017. http://www.bristol.ac.uk/geography/research/hydrology/models/lisflood/ [Accessed July 16, 2017].

Little, E.L., Jr. 1971. Atlas of United States trees, volume 1. Conifers and important hardwoods. Misc. Pub. 1146. Washington, DC: U.S. Department of Agriculture, Forest Service.

Littell, J.S.; McKenzie, D.; Kerns, B.K.; [et al.]. 2011. Managing uncertainty in climate driven ecological models to inform adaptation to climate change. Ecosphere. 2: 1–19.

Littell, J.S.; McKenzie, D.; Peterson, D.L.; Westerling, A.L. 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. Ecological Applications. 19: 1003–1021.

Livingston, R.L.; Dewey, J.E.; Beckman, D.P.; Stipe, L.E. 2000. Distribution of balsam woolly adelgid in Idaho. Western Journal of Applied Forestry. 15: 227–231.

Lockman, B.; Hartless, C. 2008. Thinning and pruning ponderosa pine for the suppression and prevention of Elytroderma needle disease on the Bitterroot National Forest. R1 publication 08-03. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region, State and Private Forestry, Forest Health Protection. 13 p.

Loehman, R.A.; Clark, J.A.; Keane, R.E. 2011a. Modeling effects of climate change and fire management on western white pine (*Pinus monticola*) in the Northern Rocky Mountains, USA. Forests. 2: 832–860.

Loehman, R.A.; Corrow, A.; Keane, R.E. 2011b. Modeling climate changes and wildfire interactions: Effects on whitebark pine (*Pinus albicaulis*) and implications for restoration, Glacier National Park, Montana, USA. In: Keane, R.E.; Tomback, D.F.; Murray, M.P.; Smith, C.M., eds. The future of high-elevation, five-needle white pines in Western North America. Proceedings, High five symposium; 28-30 June 2010; Missoula, MT. Proceedings RMRS-P-63. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 176–189.

Loehman, R.A.; Reinhardt, E.; Riley, K.L. 2014. Wildland fire emissions, carbon, and climate: seeing the forest and the trees—A cross-scale assessment of wildfire and carbon dynamics in fire-prone, forested ecosystems. Forest Ecology and Management. 379: 9–19.

Lowrey, L.L. 2015a. Evaluation of the extent of the non-native insect, balsam woolly adelgid, south of the Salmon River in Idaho from 2006-2014 by ground delimitation and aerial detection surveys. Technical Report BFO-PR-2015-01. Boise, ID: U.S. Department of Agriculture, Forest Service, Intermountain Region, Forest Health Protection, Boise Field Office. 9 p.

Lowrey, L.L. 2015b. Monitoring high severity damages to subalpine fir-dominant forests caused by balsam woolly adelgid on the Boise and Payette National Forests. Technical Report BFO-TR-2015-29. Boise, ID: U.S. Department of Agriculture, Forest Service, Intermountain Region, Forest Health Protection, Boise Field Office. 9 p.

Lumley, L.M.; Sperling, F.A.H. 2011. Utility of microsatellites and mitochondrial DNA for species delimination in the spruce budworm (*Choristoneura fumiferana*) species complex (Lepidoptera: Tortricidae). Molecular Phylogenetics and Evolution. 58: 232–243.

Lundquist, J.E.; Reich, R.M. 2014. Landscape dynamics of mountain pine beetles. Forest Science. 60: 464–475.

Lynch, A.M. 2009. Spruce aphid, *Elatobium abietinum* (Walker) life history and damage to Engelmann spruce in the Pinaleño Mountains, Arizona. In: Sanderson, H.R.; Koprowski, J.L., eds. The last refuge of the Mount Graham red squirrel: Ecology and management. Tucson, AZ: The University of Arizona Press: 318–338.

Lynch, A.M. 2012. What tree-ring reconstruction tells us about conifer defoliator outbreaks. In: Barbosa, P.; Letorneau, D.K.; Agrawal, A.A., eds. Insect outbreaks—Revisited. Chichester, UK: Wiley-Blackwell: 125–154.

Lynch, A.M. 2014. Spruce aphid. In: Van Driesche, R.; Reardon, R., eds. The use of classical biological control to preserve forests in North America. Publication FHTET-2013-2. Morgantown, WV: U.S. Department of Agriculture: 259–274.

Lynch, H.J.; Moorcroft, P.R. 2008. A spatiotemporal Ripley's K-function to analyze interactions between spruce budworm and fire in British Columbia, Canada. Canadian Journal of Forest Research. 38: 3112– 3119.

MacDougall, A.S.; Turkington, R. 2005. Are invasive species the drivers or passengers of change in degraded ecosystems? Ecology. 86: 42–55.

Mack, R.N. 1985. Invading plants: Their potential contribution to population biology. In: White, J., ed. Studies on plant demography: John L. Harper festschrift. London, UK: Academic Press: 127–142.

Mack, R.N. 1989. Temperate grasslands vulnerable to plant invasions: Characteristics and consequences. In: Drake, J.A.; Mooney, H.A.; di Castri, F.; Groves, R.H. Biological invasions: A global perspective. Chichester, UK: Wiley. 550 p.

Maclauchlan, L.; Brooks, J.E. 2009. Influence of past forestry practices on western spruce budworm defoliation and associated impacts in southern British Columbia. BC Journal of Ecosystems and Management. 10: 37–49.

Mäkinen, H.; Nöjd, P.; Kahle, H-P.; [et al.]. 2003. Large-scale climatic variability and radial increment variation of *Picea abies* (L.) Karst. in central and northern Europe. Trees. 17: 173–184.

Maloney, P.E.; Smith, T.F.; Jensen, C.E.; [et al.]. 2008. Initial tree mortality and insect and pathogen response to fire and thinning restoration treatments in an old growth mixed-conifer forest of the Sierra Nevada, California. Canadian Journal of Forest Research. 38: 3011–3020.

Manion, P.D. 1991. Tree disease concepts (2nd edition). Edgewood Cliffs, NJ: Prentiss-Hall. 416 p.

Marlon, J.R.; Bartlein, P.J.; Walsh, M.K.; [et al.]. 2009. Wildfire responses to abrupt climate change in North America. Proceedings of the National Academy of Sciences, USA. 106: 2519–2524.

Maron, J.L.; Pearson, D.E.; Potter, T.; Ortega, Y.K. 2012. Seed size and provenance mediate the joint effects of disturbance and seed predation on community assembly. Journal of Ecology. 100: 1492–1500.

Martin, R.E.; Mitchell, R.G. 1980. Possible, potential, probable, and proven fire-insect interactions. In: Proceedings of the convention of the Society of American Foresters. Bethesda, MD: Society of American Foresters.

Mason, R.R. 1974. Population change in an outbreak of the Douglas-fir tussock moth, *Orgyia pseudotsugata* (Lepidoptera: Lymantriidae), in central Arizona. Canadian Entomologist. 106: 1171–1174.

Mason, R.R. 1976. Life tables for a declining population of the Douglas-fir tussock moth in northeastern Oregon. Annals of the Entomological Society of America. 69: 948–958.

Mason, R.R. 1996. Dynamic behavior of Douglas-fir tussock moth populations in the Pacific Northwest. Forest Science. 42: 182–191.

Mason, R.R.; Luck, R.F. 1978. Population growth and regulation. In: Brookes, M.H.; Stark, R.W.; Campbell, R.W., eds. The Douglas-fir tussock moth: A synthesis. Tech. Bull. 1585. Washington, DC: U.S. Department of Agriculture, Forest Service: 41–47.

Mason, R.R.; Wickman, B.E. 1991. The Douglas-fir tussock moth in the interior Pacific Northwest. In: Berryman A.A., ed. Dynamics of forest insect populations: Patterns, causes, implications. New York, NY: Plenum Press: 179–209.

Mason, R.R.; Wickman, B.E.; Paul, G.H. 1997. Radial growth response of Douglas-fir and grand fir to larval densities of the Douglas-fir tussock moth and the western spruce budworm. Forest Science. 43: 194–205.

Masters, R.A.; Sheley, R.L. 2001. Principles and practices for managing rangeland invasive plants. Journal of Rangeland Management. 54: 502–517.

Mattson, W.J.; Addy, N.D. 1975. Phytophagous insects as regulators of forest primary production. Science. 190: 515–522.

Mayaud, J.R.; Bailey, R.M.; Wiggs, G.F.S. 2017. A coupled vegetation/sediment transport model for dryland environments. Journal of Geophysical Research–Earth Surface. 122: 875–900.

McArthur, D.E.; Romney, E.M.; Smith, S.D.; Tueller, P.T., eds. 2009. Proceedings: Symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 5-7 April 1989; Las Vegas, NV. Gen. Tech. Rep. GTR-INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 351 p.

McCambridge, W.F.; Hawksworth, F.G.; Edminster, C.B.; Laut, J.G. 1982. Ponderosa pine mortality resulting from a mountain pine beetle outbreak. Res. Pap. RM-RP-235. Fort Collins, CO: U.S. Department of Agriculture, Forest Service. 7 p.

McCaughey, W.W.; Weaver, T. 1990. Biotic and microsite factors affecting whitebark pine establishment. In: Schmidt, W.C.; McDonald, K.J., comps. Whitebark pine ecosystems: Ecology and management of a high-mountain resource; 29-31 March 1989; Bozeman, MT. Gen. Tech. Rep. INT-GTR-270. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 386 p.

McCullough, D.G.; Werner, R.A.; Neumann, D. 1998. Fire and insects in northern and boreal forest ecosystems of North America. Annual Review of Entomology. 43: 107–127.

McDonald, G.I. 1998. Preliminary report on the ecology of Armillaria in Utah and the Inland west. In: Goheen, E.J.,ed. Proceedings, 46th Western International Forest Disease Work Conference, Breckenrdige, CO; Portland, OR: U.S. Department of Agriculture, Forest Service: 85–92.

McDonald, G.I.; Martin, N.E.; Harvey, A.E. 1987. Occurrence of *Armillaria* spp. in forests of the northern Rocky Mountains. Res. Pap. INT-381. Ogden, UT: U.S. Department of Agriculture, Forest Service. 7 p.

McDowell, N.; Hanson, P.J.; Ibáñez, I.; [et al.]. 2016. Physiological responses of forests to future drought. In: Vose, J.M.; Clark, J.S.; Luce, C.H.; Patel-Weynand, T., eds. Effects of drought on forests and rangelands in the United States: A comprehensive science synthesis. Gen. Tech. Rep. WO-93b. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office: 49–56.

McDowell, N.G. 2011. Mechanisms linking drought, hydraulics, carbon metabolism, and vegetation mortality. Plant Physiology. 155: 1051–1059.

McDowell, N.G.; Beerling, D.J.; Breshears, D.D.; [et al.]. 2011. The interdependence of mechanisms underlying climate-driven vegetation mortality. Trends in Ecology and Evolution. 26: 523–532.

McGregor, M.D.; Oakes, R.D.; Dooling, O.J. 1983. Status of Douglas-fir bark beetle, Madison Ranger District, Beaverhead National Forest, 1982. Cooperative Forestry and Pest Management Report 83-7. Missoula, MT: U.S. Department of Agriculture, Forest Service. 5 p.

McHugh, C.; Kolb, T.E.; Wilson, J.L. 2003. Bark beetle attacks on ponderosa pine following fire in northern Arizona. Environmenal Entomology. 32: 510–522.

McKenzie, D.; Gedalof, Z.; Peterson, D.; Mote, P. 2004. Climatic change, wildfire, and conservation. Conservation Biology. 18: 890–902.

McKenzie, D.; Littell, J.S. 2017. Climate change and the eco-hydrology of fire: Will area burned increase in a warming western U.S.? Ecological Applications. 27: 26–36.

McKinney, M. L. 1998. Introduction. In: Mckinney, M.L.; Drake, J.A., eds. Biodiversity dynamics New York, NY: Columbia University Press: 311–348.

McKinney, M.L.; Lockwood, J.L. 1999. Biotic homogenization: A few winners replacing many losers in the next mass extinction. Trends in Ecology and Evolution. 14: 450–453.

McKinney, S.T.; Tomback, D.F. 2007. The influence of white pine blister rust on seed dispersal in whitebark pine. Canadian Journal of Forest Research. 37: 1044–1057.

McMillin, J.D. 2005. Douglas-fir beetle activity on the San Francisco Peaks, Peaks Ranger District, Coconino National Forest. Forest Health Report Control Number R316-27-05-224. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region. 10 p.

McMillin, J.D.; Allen, K.K. 2003. Effects of Douglas-fir beetle (Coleoptera: Scolytidae) on forest overstory and understory conditions in the Rocky Mountains. Western North American Naturalist. 63: 498–506.

Meigs, G.W.; Zald, H.S.J.; Campbell, J.L.; [et al.]. 2016. Do insect outbreaks reduce the severity of subsequent forest fires? Environmental Research Letters. 11: 045008.

Mercado, J.E. 2011. Bark beetle genera of the United States. http://idtools.org/id/wbb/bbgus/. [Accessed November 2, 2016].

Mielke, J.L. 1950. Rate of deterioration of beetle-killed Engelmann spruce. Journal of Forestry. 48: 882–888.

Mikkelson, K.M.; Bearup, L.A.; Maxwell, R.M.; [et al.]. 2013. Bark beetle infestation impacts on nutrient cycling, water quality and interdependent hydrological effects. Biogeochemistry. 115: 1–21.

Milchunas, D.T.; Lauenroth, W.K. 1995. Inertia in plant community structure: State changes after cessation of nutrient-enrichment stress. Ecological Applications. 5: 452–458.

Miller, C.; Abatzoglou, J.; Brown, T.; Syphard, A. 2011a. Wilderness fire management in a changing environment. In: McKenzie, D.; Miller, C.; Falk, D., eds. The landscape ecology of fire. New York, NY: Springer: 269–294.

Miller, J.M.; Keen, F.P. 1960. Biology and control of the western pine beetle: A summary of the first fifty years of research. Misc. Pub. 800. Washington, DC: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station.

Miller, J.M.; Patterson, J.E. 1927. Preliminary studies on the relation of fire injury to bark-beetle attack in western yellow pine. Journal of Agriculture Research. 34: 597–613.

Miller, R.F.; Baisan, C.; Rose, J.; Pacioretty, D. 2001. Pre- and post-settlement fire regimes in mountain big sagebrush steppe and aspen: the northwestern Great Basin. Final Report 2001 to the National Interagency Fire Center. Burns, OR: Eastern Oregon Agricultural Research Center, Oregon State University. 28 p.

Miller, R.F.; Knick, S.T.; Pyke, D.A.; [et al.]. 2011b. Characteristics of sagebrush habitats and limitations to long-term conservation. In: Knick, S.T.; Connelly, J.W., eds. Greater sage-grouse: ecology and conservation of a landscape species and its habitats. Berkeley, CA: University of California Press. 38 p.

Miller, R.F.; Tausch, R.J. 2001. The role of fire in pinyon and juniper woodlands: A descriptive analysis. In: Galley, K.E.M.; Wilson, T.P., eds. Proceedings, Invasive species workshop: The role of fire in the control and spread of invasive species. Fire Conference 2000: The first national congress on fire ecology, prevention, and management. Misc. Pub. No. 11. Tallahassee, FL: Tall Timbers Research Station: 15–30.

Miller-Pierce, M.; Shaw, D.C.; DeMarco, A.; Oester, P.T. 2015. Introduced and native parasitoid wasps associated with larch casebearer (Lepidoptera: Coleophoridae) in western larch. Environmental Entomology. 44: 27–33.

Mitchell, V.L. 1976. The regionalization of climate in the western United States. Journal of Applied Meteorology. 15: 920–927.

Mitton, J.B.; Ferrenberg, S.M. 2012. Mountain pine beetle develops an unprecedented summer generation in response to climate warming. The American Naturalist. 179: E163-E171.

Mock, C.J. 1996. Climatic controls and spatial variations of precipitation in the western United States. Journal of Climate. 9: 1111–1125.

Mock, C.J.; Brunelle-Daines, A.R. 1999. A modern analogue of western United States summer palaeoclimate at 6000 years before present. The Holocene. 9: 541–545.

Montgomery, D.R. 1999. Process domains and the river continuum. Journal of the American Water Resources Association. 35: 397–410.

Montgomery, D.R.; Dietrich, W.E. 1994. Landscape dissection and drainage area-slope thresholds. In: Kirkby, M.J., ed. Process models and theoretical geomorphology. Chichester, UK: Wiley: 221–246.

Montgomery, D.R.; Schmidt, K.M.; Greenberg, H.M.; Dietrich, W.E. 2000. Forest clearing and regional landsliding. Geology. 28: 311–314.

Mooney, H.A.; Cleland, E.E. 2001. The evolutionary impact of invasive species. Proceedings of the National Academy of Sciences, USA. 98: 5446–5451.

Morgan, P.; Hardy, C.C.; Swetnam, T.W.; [et al.]. 2001. Mapping fire regimes across time and space: understanding coarse and fine-scale fire patterns. International Journal of Wildland Fire. 10: 329–342.

Moritz, M.A.; Hessburg, P.F.; Povak, N.A. 2011. Native fire regimes and landscape resilience. In: McKenzie, D.; Miller, C.; Falk, D.A., eds. The landscape ecology of fire. New York, NY: Springer: 51–86.

Morris, J.L.; Brunelle, A.; Munson, A.S.; [et al.]. 2013. Holocene vegetation and fire reconstructions from the Aquarius Plateau, Utah, USA. Quaternary International. 310: 111–123.

Morris, R.F.; Mott, D.G. 1963. Dispersal and the spruce budworm. In: The dynamics of epidemic spruce budworm populations. Memoirs of the Entomological Society of Canada. 95: 180–189.

Moscardi, F. 1999. Assessment of the application of baculoviruses for control of Lepidoptera. AnnualReview of Entomology. 44: 257–289.

Mote, P.W.; Hamlet, A.F.; Clark, M.P.; Lettenmaier, D.P. 2005. Declining mountain snowpack in western North America. Bulletin of the American Meteorological Society. 86: 39–49.

Mott, D.G. 1963. The analysis of the survival of small larvae in the unsprayed area. In: The dynamics of epidemic spruce budworm populations. Memoirs of the Entomological Society of Canada. 95: 42–53.

Moy, C.M.; Seltzer, G.O.; Rodbell, D.T.; Anderson, D.M. 2002. Variability of El Niño/Southern Oscillation activity at millennial timescales during the Holocene epoch. Nature. 420: 162–165.

National Aeronautics and Space Administration [NASA]. 2005. What‘s the difference between weather and climate? https://www.nasa.gov/mission_pages/noaa-n/climate/climate_weather.html [Accessed February 5, 2015].

National Interagency Fire Center [NIFC]. 2015. Total wildland fires and acres (1960-2015). http://www.nifc.gov/fireInfo/fireInfo_stats_totalFires.html [Accessed on Feb 4, 2015].

National Invasive Species Council [NISC]. 2016. National invasive species council management plan 2016-2018. Washington, DC: National Invasive Species Council. https://www.doi.gov/sites/doi.gov/files/uploads/2016-2018-nisc-management-plan.pdf [Accessed November 2, 2016].

Nealis, V.G. 2005. Diapause and voltinism in western and 2-year-cycle spruce budworms (Lepidoptera: Tortricidae) and their hybrid progeny. Canadian Entomologist. 137: 584–597.

Nealis, V.G. 2008. Spruce budworms, *Choristoneura lederer* (Lepidoptera: Tortricidae). In: Capinera, J.L., ed. Encyclopedia of Entomology (2nd edition). Dordrecht, Netherlands: Springer: 3525–3531.

Nealis, V.G. 2012. The phenological window for western spruce budworm: Seasonal decline in resource quality. Agricultural and Forest Entomology. 14: 340–347.

Negrón, J.F. 1998. Probability of infestation and extent of mortality associated with the Douglas-fir beetle in the Colorado Front Range. Forest Ecology and Management. 107: 71–85.

Negrón, J.F.; Lynch, A.M.; Schaupp Jr., W.C.; Mercado, J.E. 2014. Douglas-fir tussock moth- and Douglas-fir beetle-caused mortality in a ponderosa pine/Douglas-fir forest in the Colorado Front Range, USA. Forests. 5: 3131–3146.

Negrón, J.F.; McMillin, J.D.; Anhold, J.A.; Coulson, D. 2009. Bark beetle-caused mortality in a drought- affected ponderosa pine landscape in Arizona, USA. Forest Ecology and Management. 257: 1353–1362.

Negrón, J.F.; Popp, J.B. 2004. Probability of ponderosa pine infestation by mountain pine beetle in the Colorado Front Range. Forest Ecology and Management. 191: 17–27.

Negrón, J.F.; Wilson, J.L. 2003. Attributes associated with probability of infestation by the piñon ips, *Ips confusus* (Coleoptera: Scolytidae), in piñon pine, *Pinus edulis*. Western North American Naturalist. 440–451.

Negrón, J.F.; Wilson, J.L.; Anhold, J.A. 2000. Stand conditions associated with roundheaded pine beetle (Coleoptera: Scolytidae) infestations in Arizona and Utah. Environmental Entomology. 29: 20–27.

NetMap. 2017. http://www.terrainworks.com/ [Accessed July 16, 2017].

North, M.P.; Hurteau, M.D. 2011. High-severity wildfire effects on carbon stocks and emissions in fuels treated and untreated forest. Forest Ecology and Management. 261: 1115–1120.

O'Connor, C.D.; Lynch, A.M.; Falk, D.A.; Swetnam, T.W. 2015. Post-fire forest dynamics and climate variability affect spatial and temporal properties of spruce beetle outbreaks on a Sky Island mountain range. Forest Ecology and Management. 336: 148–162.

Odion, D.C.; Moritz, M.A.; DellaSala, D.A. 2010. Alternative community states maintained by fire in the Klamath Mountains, USA. Journal of Ecology. 98: 96–105.

Ogle, K.; DuMond, V. 1997. Historical vegetation on National Forest lands in the Intermountain Region.

Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region.

Oregon Department of Forestry. 2013. West wide wildfire risk assessment. Salem, OR: Oregon Department of Forestry. http://www.odf.state.or.us/gis/data/Fire/West_Wide_Assessment/WWA_FinalReport.pdf [Accessed November 2, 2016].

Orr, L.W. 1954. The 1953 pine butterfly outbreak in southern Idaho and plans for its control in 1954. Misc. Pub. No. 1. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station. 10 p.

Ortega, Y.K.; Pearson, D.E.; Waller, L.P.; [et al.]. 2012. Population-level compensation impedes biological control of an invasive forb and indirect release of a native grass. Ecology. 93: 783–792.

Oswalt, C.M.; Fei, S.; Guo, Q.; [et al.]. 2015. A subcontinental view of forest plant invasions. NeoBiota. 24: 49–54.

Pacala, S.; Birdsey, R.; Bridgham, S.; [et al.]. 2007. The North American carbon budget past and present, In: King, A.W.; Dilling, L.; Zimmerman, G.P.; [et al.], eds. The first state of the carbon cycle report (SOCCR): the North American carbon budget and implications for the global carbon cycle. Asheville, NC: National Oceanic and Atmospheric Administration, National Climatic Data Center: 29–36.

Pacala, S.W.; Hurtt, G.C.; Baker, D.; [et al.]. 2001. Consistent land- and atmosphere-based U.S. carbon sink estimates. Science. 292: 2316–2320.

Page, W.; Jenkins, M. 2007. Mountain pine beetle-induced changes to selected lodgepole pine fuel complexes within the Intermountain Region. Forest Science. 53: 507–518.

Paine, T.D.; Raffa, K.F.; Harrington, T.C. 1997. Interactions among Scolytid bark beetles, their associated fungi, and live host conifers. Annual Review of Entomology. 42: 179–206.

Pan, Y.; Birdsey, R.A.; Fang, J.; [et al.]. 2011. A large and persistent carbon sink in the world's forests. Science. 333: 988–993.

Parendes, L.A.; Jones, J.A. 2000. Role of light availability and dispersal in exotic plant invasion along roads and streams in the H. J. Andrews Experimental Forest, Oregon. Conservation Biology. 14: 64–75.

Parker, G. 1990. Surface-based bedload transport relation for gravel rivers. Journal of Hydraulic Research. 28: 417–436.

Parker, T.J.; Clancy, K.M.; Mathiasen, R.L. 2006. Interactions among fire, insects and pathogens in coniferous forests of the interior western United States and Canada. Agricultural and Forest Entomology. 8: 167–189.

Parks, S.A.; Miller, C.; Abatzoglou, J.T.; [et al.]. 2016. How will climate change affect wildland fire severity in the western U.S.? Environmental Research Letters. 11: 035002.

Parks, S.A.; Miller, C.; Parisien, M.A.; Holsinger, LM. 2015. Wildland fire deficit and surplus in the western United States, 1984–2012. Ecosphere. 6: 1–13.

Patton, R.F.; Johnson, D.W. 1970. Mode of penetration of needles of eastern white pine by *Cronartium ribicola*. Phyopathology. 60: 977–982.

Pausas, J.G.; Keeley, J.E. 2014. Abrupt climate-independent fire regime changes. Ecosystems. 17: 1109–1120.

Pechony, O.; Shindell, D.T. 2010. Driving forces of global wildfires over the past millennium and the forthcoming century. Proceedings of the National Academy of Sciences USA. 107: 19167-19170.

Perkins, D.; Swetnam, T.W. 1996. A dendroecological assessment of whitebark pine (*Pinus albicaulis*) in the Sawtooth-Salmon River region of Idaho. Canadian Journal of Forest Research. 26: 2123–2133.

Perrakis, D.D.B.; Agee, J.K.; Eglitis, A. 2011. Effects of prescribed burning on mortality and resin defenses in old growth ponderosa pine (Crater Lake, Oregon): Four years of post-fire monitoring. Natural Areas Journal. 31: 14–25.

Perrakis, D.D.B.; Agee, J.K. 2006. Seasonal fire effects on mixed-conifer forest structure and ponderosa pine resin properties. Canadian Journal of Forest Research. 36: 238–254.

Peters, E.F.; Bunting, S.C. 1994. Fire conditions pre- and post-occurrence of annual grasses on the Snake River Plain. In: Monsen, S.B.; Kitchen, S.G., comps. Proceedings—Ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 31–36.

Peterson, D.L.; Johnson, M.C.; Agee, J.K.; [et al.]. 2005. Forest structure and fire hazard in dry forests of the western United States. Gen. Tech. Rep. PNW-GTR-628. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 30 p.

Peterson, G.; Allen, C.R.; Holling, C.S. 1998. Ecological resilience, biodiversity, and scale. Ecosystems. 1: 6–18.

Pierson, T.C. 1985. Initiation and flow behavior of the 1980 Pine Creek and Muddy River lahars, Mount St. Helens, Washington. Geological Society of America Bulletin. 96: 1056–1069.

Pimentel, D. 2002. Biological invasions: Economic and environmental costs of alien plant, animal, and microbe species. Boca Raton, FL: CRC Press. 384 p.

Pitlick, J. 1994. Relation between peak flows, precipitation, and physiography for five mountainous regions in the western USA. Journal of Hydrology. 158: 219–240.

Pohl, K.; Hadley, K.; Arabas, K. 2006. Decoupling tree-ring signatures of climate variation, fire, and insect outbreaks in Central Oregon. Tree-Ring Research. 62: 37–50.

Powell, D.C. 1994. Effects of the 1980s western spruce budworm outbreak on the Malheur National Forest in northeastern Oregon. Tech. Pub. R6-FI&D-TP-12-94. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 176 p.

Powell, E.N.; Townsend, P.A.; Raffa, K.F. 2012. Wildfire provides refuge from local extinction but is an unlikely driver of outbreaks by mountain pine beetle. Ecological Monographs. 82: 69–84.

Prebble, M.L. 1950. The battle of the budworm. Pulp Paper Magazine of Canada. 51: 150–155.

Preisler, H.K.; Ager, A.A.; Hayes, J.L. 2010. Probabilistic risk models for multiple disturbances: An example of forest insects and wildfires. In: Pye, J.M.; Rauscher, H.M.; Sands, Y.; [et al.], eds. Advances in threat assessment and their application to forest and rangeland management. Gen. Tech. Rep. PNW-GTR-802. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest and Southern Research Stations: 371–379.

Progar, R.A.; Lazarus, L.; Eager, T. 2014. Aspen/willow scale *Diaspidiotus gigas* (Thiem and Gerneck) (Homoptera, Coccoidea, Diaspididae). In: Van Driesche, R.; Reardon, R., eds. The use of classical biological control to preserve forests in North America. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team: 275–279.

Progar, R.A.; Markin, G.; Milan, J. 2011. Population dynamics and impacts of the red-headed leafy spurge stem borer on leafy spurge (*Euphorbia esula*). Invasive Plant Science and Management. 4: 183–188.

Quiring, D.; Ostaff, D.; Hartling, L.; [et al.]. 2008. Temperature and plant hardiness zone influence distribution of balsam woolly adelgid damage in Atlantic Canada. The Forestry Chronicle. 84: 558–562.

Raffa, K.F.; Aukema, B.H.; Bentz, B.J.; [et al.]. 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: The dynamics of bark beetle eruptions. Bioscience. 58: 501–517.

Rasmussen, L.A.; Amman, G.D.; Vandygriff, J.C.; [et al.]. 1996. Bark beetle and wood borer infestation in the Greater Yellowstone Area during four postfire years. Res. Pap. INT-RP-487. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 9 p.

Rau, B.M.; Johnson, D.W.; Blank, R.R.; [et al.]. 2011. Transition from sagebrush steppe to annual grass (*Bromus tectorum*): influence on belowground carbon and nitrogen. Rangeland Ecology and Management. 64: 139–147.

Redak, R.A.; Cates, R.G. 1984. Douglas-fir (*Pseudotsuga mensiesii*), spruce budworm interactions: The effect of nutrition, chemical defenses, tissue phenology, and tree physical parameters on budworm success. Oecologia. 62: 61–67.

Régnière, J.; St-Amant, R.; Duval, P. 2012. Predicting insect distributions under climate change from physiological responses: Spruce budworm as an example. Biological Invasions. 14: 1571–1586.

Régnière, J.; Bentz, B.J.; Powell, J.A.; St-Amant, R. 2015. Individual-based modeling: mountain pine beetle seasonal biology in response to climate. In: Simulation modeling of forest landscape disturbances. New York, NY: Springer International Publishing: 135–164.

Regonda, S.K.; Rajagopalan, B.; Clark, M.; Pitlick, J. 2005. Seasonal cycle shifts in hydroclimatology over the western United States. Journal of Climate. 18: 372–384.

Rehfeldt, G.E.; Crookston, N.L.; Warwell, M.V.; Evans, J.S. 2006. Empirical analyses of plant-climate relationships for the western United States. International Journal of Plant Science. 167: 1123–1150.

Reichenbach, N.G.; Stairs, G.R. 1984. Response of western spruce budworm, *Choristoneura occidentalis* (Lepidoptera: Tortricidae), to temperature: the stochastic nature of developmental rates and diapause termination. Environmental Entomology. 13: 1549–1556.

Reineke A.; Zebitz C.P.W. 1998. Flight ability of gypsy moth females (*Lymantria dispar* L.) (Lep., Lymantriidae): A behavioural feature characterizing moths from Asia? Journal of Applied Entomology. 122: 307–310.

Reinemann, S.A.; Porinchu, D.F.; Bloom, A.M.; [et al.]. 2009. A multi-proxy paleolimnological reconstruction of Holocene climate conditions in the Great Basin, United States. Quaternary Research. 72: 347–358.

Rhymer, J.M.; Simberloff, D. 1996. Extinction by hybridization and introgression. Annual Review of Ecology and Systematics. 83–109.

Richardson, D.M. 2000. Ecology and biogeography of *Pinus*. Cambridge, UK: Cambridge University Press. 527 p.

Ritchie, M.W.; Skinner, C.N.; Hamilton, T.A. 2007. Probability of wildfire-induced tree mortality in an interior pine forest of northern California: effects of thinning and prescribed fire. Forest Ecology and Management. 247: 200–208.

Robichaud, P.R.; William, J.E.; Pierson, F.B.; [et al.]. 2007a. Erosion risk management tool (ERMiT) user manual (version 2006.01.16). Gen. Tech. Rep. RMRS-GTR-188. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 24 p.

Robichaud, P.R.; William, J.E.; Pierson, F.B.; [et al.]. 2007b. Predicting postfire erosion and mitigation effectiveness with a web-based probabilistic erosion model. Catena. 71: 229–241.

Rollins, M.G. 2009. LANDFIRE: A nationally consistent vegetation, wildland fire, and fuel assessment. International Journal of Wildland Fire. 18: 235–249.

Romme, W.H. 1982. Fire and landscape diversity in subalpine forests of Yellowstone National Park. Ecological Monographs. 52: 199–221.

Romme, W.H.; Despain, D.G. 1989. Historical perspective on the Yellowstone fires of 1988. Bioscience. 39: 695–699.

Ropelewski, C.F.; Halpert, M.S. 1986. North American precipitation and temperature patterns associated with the El Niño/Southern Oscillation (ENSO). Monthly Weather Review. 114: 2352–2362.

Rosenthal, J. 2009. Climate change and the geographic distribution of infectious diseases. EcoHealth. 6: 489–495.

Ross, D.A. 1963. Pine butterfly infestation in interior British Columbia. In: Bi-monthly Progress Report 19. Victoria, BC: Canadian Forestry Service, Pacific Forestry Centre: 4.

Runyon, J.B.; Butler, J.L.; Friggens, M.M.; [et al.]. 2012. Invasive species and climate change. In: Finch, D.M. Climate change in grasslands, shrublands, and deserts of the interior American West: A review and needs assessment. Gen. Tech. Rep. RMRS-GTR285. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Ryan, M.G.; Vose, J.M. 2012. Effects of climatic variability and change. In: Vose, J.M.; Peterson, D.L.; Patel-Weynand, T., eds. Effects of climatic variability and change on forest ecosystems: A comprehensive science synthesis for the U.S. forest sector. Gen. Tech. Rep. PNW-GTR-870. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 7–95.

Ryerson, D.E.; Swetnam, T.W.; Lynch, A.M. 2003. A tree-ring reconstruction of western spruce budworm outbreaks in the San Juan Mountains, Colorado, USA. Canadian Journal of Forest Research. 33: 1010–1028.

Safranyik, L.; Carroll, A.L.; Régnière, J.; [et al.]. 2010. Potential for range expansion of mountain pine beetle into the boreal forest of North America. The Canadian Entomologist. 142: 415–442.

Savage, M.; Mast, J.N. 2005. How resilient are southwestern ponderosa pine forests after crown fires? Canadian Journal of Forest Research. 35: 967–977.

Schimel, D.; Braswell, B.H. 2005. The role of mid-latitude mountains in the carbon cycle: Global perspective and a Western U.S. case study. In: Huber, U.M.; Bugmann, H.K.M.; Reasoner, M.A., eds. Global change and mountain regions: An overview of current knowledge. Dordrecht, The Netherlands: Springer: 449–456.

Schlesinger, W.H.; Dietze, M.C.; Jackson, R.B.; [et al.]. 2016. Forest biogeochemistry in response to drought. In: Vose, J.M.; Clark, J.S.; Luce, C.H.; Patel-Weynand, T., eds. Effects of drought on forests and rangelands in the United States: A comprehensive science synthesis. Gen. Tech. Rep. WO-93b. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office: 97–106.

Schmid, J.M.; Mata, S.A. 1996. Natural variability of specific insect populations and their associated effects in Colorado. Gen. Tech. Rep. RMRS-GTR-275. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 14 p.

Schoennagel, T.; Turner, M.G.; Romme, W.H. 2003. The influence of fire interval and serotiny on postfire lodgepole pine density in Yellowstone National Park. Ecology. 84: 2967–2978.

Schoennagel, T.L.; Veblen, T.T.; Romme, W.H. 2004. The interaction of fire, fuels, and climate across Rocky Mountain landscapes. Bioscience. 54: 651–672.

Schoennagel, T.; Veblen, T.T.; Romme, W.H.; [et al.]. 2005. ENSO and PDO variability affect drought-induced fire occurrence in Rocky Mountain subalpine forests. Ecological Applications. 15: 2000–2014.

Schoeneweiss, D.F. 1975. Predisposition, stress and plant disease. Annual Review of Phytopathology. 13: 193–211.

Schowalter, T. 1986. Herbivory in forested ecosystems. Annual Review of Entomology. 31: 177–196.

Schultz, D.; Allison, J. 1982. Tree mortality in the Cleveland National Forest. Forest Pest Management. Report 82–12. San Francisco, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region. 17 p.

Schultz, D.; Kliejunas, J. 1982. A biological evaluation of pine mortality of the San Jacinto Ranger District, San Bernardino National Forest. Forest Pest Management Report 82-5. San Francisco, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region. 10 p.

Schwandt, J.W.; Lockman, I.B.; Kliejunas, J.T.; Muir, J.A. 2010. Current health issues and management strategies for white pines in the western United States and Canada. Forest Pathology. 40: 226–250.

Schwandt, J.; Kegley, S. 2004. Mountain pine beetle, blister rust, and their interaction on whitebark pine at Trout Lake and Fisher Peak in northern Idaho from 2001-2003. Report 04-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region, Forest Health Protection. 6 p.

Schwilk, D.W.; Knapp, E.E.; Ferrenberg, S.M.; [et al.]. 2006. Tree mortality from fire and bark beetles following early and late season prescribed fires in a Sierra Nevada mixed-conifer forest. Forest Ecology and Management. 232: 36–45.

Scott, D.W. 2010. Chronology of pine butterfly, *Neophasia menapia* (Felder and Felder), infestations in western North America. Report No. BMPMSC-10-10. La Grande, OR: U.S. Department of Agriculture, Forest Service, Blue Mountain Pest Management Service Center, Wallowa-Whitman National Forest.

Scott, D.W. 2012. Pine butterfly. Forest Insect and Disease Leaflet 66. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 16 p.

Scott, J.H.; Thompson, M.P.; Calkin, D.E. 2013. A wildfire risk assessment framework for land and resource management. Gen. Tech. Rep. RMRS-GTR-315. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Seneviratne, S.I.; Nicholls, N.; Easterling, D.; [et al.]. 2012. Changes in climate extremes and their impacts on the natural physical environment. In: Field, C.; Barros, V.; Stocker, T.; [et al.], eds. Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of working groups I and II of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press: 109–230.

Sexton, T. 2006. U.S. Federal fuel management programs: Reducing risk to communities and increasing ecosystem resilience and sustainability. In: Andrews, P.L.; Butler, B.W., comps. Fuels management—How to measure success: Conference proceedings. 28-30 March 2006; Portland, OR. Proceedings RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 9–12.

Shankman, D.; Daly, C. 1988. Forest regeneration above tree limit depressed by fire in the Colorado Front Range. Bulletin of the Torrey Botanical Club. 115: 272–279.

Shaw, J.D.; Steed, B.E.; DeBlander, L.T. 2005. Forest inventory and analysis (FIA) annual inventory answers the question: What is happening to pinyon-juniper woodlands? Journal of Forestry. 103: 280–285.

Shellworth, H.C. 1922. The pine white butterfly in southern Idaho. The Timberman. 23: 130, 132.

Shepherd, R.F. 1992. Relationships between attack rates and survival of western spruce budworm, *Choristoneura occidentalis* Freeman (Lepidoptera: Tortricidae), and bud development of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco. Canadian Entomologist. 124: 347–358.

Shepherd, R.F.; Bennett, D.D.; Dale, J.W.; [et al.]. 1988. Evidence of synchronized cycles in outbreak patterns of Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough) (Lepidoptera: Lymantriidae). Memoirs of the Entomological Society of Canada. 120: 107–121.

Shepherd, R.F.; Gray, T.G.; Chorney, R.J.; Daterman, G.E. 1985. Pest management of Douglas-fir tussock moth, *Orgyia pseudotsugata* (Lepidoptera: Lymantriidae): Monitoring endemic populations with pheromone traps to detect incipient outbreaks. The Canadian Entomologist. 117: 839–848.

Shore T.L.; Andrews, R.J.; van Sickle, G.A. 1982. Survey for dwarf mistletoe infection in lodgepole pine regeneration under mountain pine beetle-attacked stands in the Chilcotin. Special Report. Victoria, BC: Environment Canada, Canadian Forestry Service.

Sieg, C.H.; McMillin, J.D.; Fowler, J.F.; [et al.]. 2006. Best predictors for postfire mortality of ponderosa pine trees in the Intermountain West. Forest Science. 52: 718–728.

Simard, M.; Romme, W.H.; Griffin, J.M.; [et al.]. 2011. Do mountain pine beetle outbreaks change the probability of active crown fire in lodgepole pine forests? Ecological Monographs. 81: 3–24.

Simberloff, D.; Von Holle, B. 1999. Positive interactions of nonindigenous species: Invasional meltdown. Biological Invasions. 1: 21–32.

Six, D.L.; Adams, J. 2007. White pine blister rust severity and selection of individual whitebark pine by mountain pine beetle (Coleoptera: Curculionidae, Scolytinae). Journal of Entomological Science. 42: 345–353.

Six, D.L.; Bentz, B.J. 2003. Fungi associated with the North American spruce beetle, *Dendroctonus rufipennis*. Canadian Journal of Forest Research. 33: 1815–1820.

Smith, J.P.; Hoffman, J.T. 2000. Status of white pine blister rust in the Intermountain West. Western North American Naturalist. 2000: 165–179.

Smith, S.D.; Huxman, T.E.; Zitzer, S.F.; [et al.]. 2000. Elevated CO_2 increases productivity and invasive species success in an arid ecosystem. Nature. 408: 79–82.

Sniezko, R.A.; Mahalovich, M.F.; Schoettle, A.W.; Vogler, D.R. 2011. Past and current investigations of the genetic resistance to *Cronartium ribicola* in high-elevation five-needle pines. In: Keane, R.F.; Tomback, D.F.; Murray, M.P.; Smith, C.M., eds. The future of high-elevation, five-needle, white pines in Western North America: Proceedings, High Five Symposium; 28-30 June 2010; Missoula, MT. Proceedings RMRS-P-63. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 246–264.

Sommers, W.T.; Loehman, R.A.; Hardy, C.C. 2014. Wildland fire emissions, carbon, and climate: Science overview and knowledge needs. Forest Ecology and Management. 317: 1–8.

Stange, Erik E.; Ayres, M.P. 2010. Climate change impacts: Insects. In: Encyclopedia of Life Sciences. Chichester, England: John Wiley and Sons, Ltd.

Stavros, E.N.; Abatzoglou, J.; Larkin, N.K.; [et al.]. 2014. Climate and very large wildland fires in the contiguous western USA. International Journal of Wildland Fire. 23: 899–914.

Stehr, G. 1967. On coniferophagous species of *Choristoneura* (Lepidoptera: Tortricidae) in North America: II. Geographic distribution in accordance with forest regions. Canadian Entomologist. 99: 456–463.

Stein, S.J. 1988. Fire history of the Paunsaugunt Plateau in southern Utah. Great Basin Naturalist. 48: 58–63.

Stocks, B. 1987. Fire potential in the spruce budworm-damaged forests of Ontario. The Forestry Chronicle. 63: 8–14.

Stoszek K.J.; Mika P.G.; Moore J.A.; Osborne H.L. 1981. Relationship of Douglas-fir tussock moth defoliation to site and stand characteristics in northern Idaho. Forest Science. 27: 431–442.

Stretch, R.H. 1882. Notes on *Pieris menapia*—Felder. Pipilio. 2: 103–110.

Sturdevant, N.J.; Egan, J.; Hayes, C.; [et al.]. 2012. Effectiveness of western spruce budworm suppression project at Bridger Bowl Ski Area, 2010. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Forest Health Protection. 5 p.

Swaine, J.M.; Craighead, F.E. 1924. Studies on the spruce budworm (*Cacoecia fumiferana* Clem.). Part 1. A general account of the outbreaks, injury and associated insects. Bulletin 37. Ottawa, Canada: Canadian Department of Agriculture: 3–27.

Swanston, D.N. 1970. Mechanics of debris avalanching in shallow till soils of southeast Alaska. Research Paper PNW-103. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 17 p.

Swetnam, T.W.; Lynch, A.M. 1989. A tree-ring reconstruction of western spruce budworm history in the southern Rocky Mountains. Forest Science. 35: 962–986.

Swetnam, T.W.; Lynch, A.M. 1993. Multicentury, regional-scale patterns of western spruce budworm outbreaks. Ecological Monographs. 63: 399–424.

Tabacaru, C.A.; Park, J.; Erbilgin, N. 2016. Prescribed fire does not promote outbreaks of a primary bark beetle at low-density populations. Journal of Applied Ecology. 53: 222–232.

Taylor, A.H.; Skinner, C.N. 2003. Spatial patterns and controls on historical fire regimes and forest structure in the Klamath Mountains. Ecological Applications. 13: 704–719.

Theoharides, K. A.; Dukes, J. S. 2007. Plant invasions across space and time: Factors affecting nonindigenous species success during four stages of invasion. New Phytologist. 176: 256–273.

Thier, R.W. 1985. Effects of defoliation by pine butterfly in southwestern Idaho. Report 85-5. Ogden, UT: U.S. Department of Agriculture, Forest Service, Forest Pest Management, Intermountain Region. 24 p.

Thomson, A.J. 1979. Evaluation of key biological relationships of western spruce budworm and its host trees. BC-X-186. Victoria, BC; Environment Canada, Forestry Service, Pacific Forest Research Centre. 19 p.

Thomson, A.J.; Shepherd, R.F.; Harris, J.W.E.; Silversides, R.H. 1984. Relating weather to outbreaks of western spruce budworm, *Choristoneura occidentalis* (Lepidoptera: Tortricidae) in British Columbia. Canadian Entomologist. 116: 375–381.

Thompson, C.G.; Scott, D.W. 1979. Production and persistence of the nuclear polyhedrosis virus of the Douglas-fir tussock moth, *Orgyia pseudotsugata* (Lepidoptera: Lymantriidae), in the forest ecosystem. Journal of Invertebrate Pathology. 33: 57–65.

Thompson, C.G.; Scott, D.W.; Wickman, B.E. 1981. Long-term persistence of the nuclear polyhedrosis virus of the Douglas-fir tussock moth, *Orgyia pseudotsugata* (Lepidoptera: Lymantriidae) in forest soil. Environmental Entomology. 10: 254–255.

Thuiller, W.; Albert, C.; Araújo, M.B.; [et al.]. 2008. Predicting global change impacts on plant species' distributions: Future challenges. Perspectives in Plant Ecology, Evolution and Systematics. 9: 137–152.

Tkacz, B.M.; Baker, F.A. 1991. Survival of *Inontus tomentosus* in spruce stumps after logging. Plant Disease. 75: 788–790.

Tkacz, B.M.; Schmitz, R.F. 1986. Association of an endemic mountain pine beetle population with lodgepole pine infected by Armillaria root disease in Utah. Res. Note INT-RN-353. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 8 p.

Tomback, D.F.; Achuff, P. 2010. Blister rust and western forest biodiversity: ecology, values and outlook for white pines. Forest Pathology. 40: 186–225.

Tomback, D.F.; Sund, S.K.; Hoffmann, L.A. 1993. Post-fire regeneration of *Pinus albicaulis*: height age relationships, age structure, and microsite characteristics. Canadian Journal of Forest Research. 23: 113–119.

Torn, M.S.; Fried, J.S. 1992. Predicting the impacts of global warming on wildland fire. Climatic Change. 21: 257–274.

Trenberth, K.E.; Dai, A.; Rasmussen, R.M.; Parsons, D.B. 2003. The changing character of precipitation. Bulletine of the American Meteorological Society, 84: 1205–1217.

Trusty, P.E.; Cripps, C.L. 2011. Influence of fire on mycorrhizal colonization of planted and natural whitebark pine seedlings: Ecology and management implications. In: Keane, R.E.; Tomback, D.F.; Murray, M.P.; Smith, C.M., eds. The future of high-elevation, five-needle white pines in Western North America. Proceedings, High five symposium; 28–30 June 2010; Missoula, MT. proceedings RMRS-P-63. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 198–202.

U.S. Department of Agriculture and U.S. Department of the Interior [USDA and DOI]. 2009. Guidance for implementation of federal wildland fire management policy. Washington, DC: U.S. Department of Agriculture and U.S. Department of the Interior. https://www.nifc.gov/policies/policies_documents/GIFWFMP.pdf [Accessed: November 1, 2016].

U.S. Department of Agriculture and U.S. Department of the Interior [USDA and DOI]. 2014. Quadrennial fire review final report. Washington, DC: U.S. Department of Agriculture, Forest Service, Fire and Aviation Management; and U.S. Department of the Interior, Office of Wildland Fire. https://www.forestsandrangelands.gov/QFR/documents/2014QFRFinalReport.pdf [Accessed November 2, 2016].

U.S. Department of Agriculture, Forest Service [USDA FS]. 2011. Forest Service Manual (FSM) 2900, Invasive species management. Washington, DC: U.S. Department of Agriculture, Forest Service. 28 p.

U.S. Environmental Protection Agency [USEPA]. 2016. Climate change indicators: Snowpack. Data source: Mote, P.W.; Sharp, D. 2016. 2015 update to data originally published in: Mote, P.W.; Hamlet, A.F.; Clark, M.P.; Lettenmaier, D.P. 2005. Declining mountain snowpack in Western North America. Bulletin of the American Meteorological Society. 86: 39-49. https://www.epa.gov/climate-indicators/climate-change-indicators-snowpack#ref2 [Accessed November 1, 2016].

U.S. Geological Survey [USGS]. 2017. Emergency assessment of post-fire debris-flow hazards. https://landslides.usgs.gov/hazards/postfire_debrisflow/ [Accessed July 16, 2017].

Valcarce, A.C. 1978. Biological evaluation, larch casebearer, Payette National Forest, 1977. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 7 p.

Van Arsdel, E.P.; Geils, B.W.; Zambino, P.J. 2006. Epidemiology for hazard rating of white pine blister rust. In: Guyon, J. comp. Proceedings, 53rd Western International Forest Disease Work Conference; 26-29 August 2005; Jackson, WY. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region: 49–62.

Van Mantgem, P.J.; Stephenson, N.L.; Byrne, J.C.; [et al.]. 2009. Widespread increase of risks and opportunities. Trends in Ecology and Evolution. 24: 686–693.

Vezina, A.; Petermann, R.M. 1985. Tests of the role of a nuclear polyhedrosis virus in the population dynamics of its host, Douglas-fir tussock moth, *Orgyia pseudotsugata* (Lepidoptera: Lymantriidae). Oecologia. 67: 260–266.

Vilá, M.; Corbin, J.D.; Dukes, J.S.; [et al.]. 2007. Linking plant invasions to global environmental change. In: Canadell, J.; Pataki, D.; Pitelka, L., eds. Terrestrial ecosystems in a changing world. New York, NY: Springer: 93–102.

Vitousek, P.M. 1990. Biological invasions and ecosystem processes: Towards an integration of population biology and ecosystem studies. Oikos. 57: 7–13.

Vogan, P.J.; Schoettle, A.W. 2015. Selection for resistance to white pine blister rust affects the abiotic stress tolerances of limber pine. Forest Ecology and Management. 344: 110–119.

Volney, W.J.A. 1985. Temperature effects on development and survival of western spruce budworms. In: Sanders, C.J.; Stark, R.W.; Mullins, E.J.; Murphy, J., eds. Recent advances in spruce budworms research: Proceedings of the CANUSA spruce budworms research symposium. Ottawa, Ontario: Canadian Forestry Service: 92–93.

Volney, W.J.A. 1989. Biology and dynamics of North American coniferophagous *Choristoneura* populations. Agricultural Zoology Reviews. 3: 133–156.

Volney, W.J.A.; Waters, W.E.; Akers, R.P.; Liebhold, A.M. 1983. Variation in spring emergence patterns among western *Choristoneura* spp. (Lepidoptera: Tortricidae) populations in southern Oregon. Canadian Entomologist. 115: 199–209.

Volney W.J.A.; Fleming R.A. 2007. Spruce budworm (*Choristoneura* spp.) biotype reactions to forest and climate characteristics. Global Change Biology. 13: 1630–1643.

Vygodskaya, N.; Puzachenko, Y.; Kozharinov, A.; [et al.]. 1995. Long-term effects of climate on *Picea abies* communities in the South European taiga. Journal of Biogeography. 22: 433–443.

Wadleigh, L.L.; Parker, C.; Smith, B. 1998. A fire frequency and comparative fuel load analysis in gambel oak of northern Utah. In: Pruden, T.L.; Brennan, L.A. Proceedings, 20th Tall Timbers fire ecology conference: Fire in ecosystem management: Shifting the paradigm from suppression to prescription. Boise, ID: Tall Timbers Research, Inc.: 267–272.

Wallin, K.F.; Kolb, T.E.; Skov, K.R.; [et al.]. 2003. Effects of crown scorch on ponderosa pine resistance to bark beetles in northern Arizona. Environmental Entomology. 32: 652–661.

Walther, G.R.; Roques, A.; Hulme, P.E.; [et al.]. 2009. Alien species in a warmer world: Risks and opportunities. Trends in Ecology and Evolution. 24: 686–693.

Weatherby, J.; Barbouletos, T.; Gardner, B.; Koprowski, C. 1992. A biological evaluation of the Douglas fir tussock moth outbreak on lands administered by the bureau of land management in southern Idaho. Region 4 For. Health Prot. Trip Rep., R4-93-06. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region.

Weatherby, J.D.; Barbouletos, T.; Gardner, B.R.; Mocettini, P. 1997. A follow-up biological evaluation of the Douglas-fir tussock moth outbreak in southern Utah. For. Health Prot. Rep. R4-97-01. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region, State and Private Forestry. 14 p.

Weatherby, J.C.; Progar, R.A.; Mocettini, P.J. 2001. Evaluation of tree survival on the Payette National Forest 1995–1999. For. Health Prot. Rep. R4-01-01. Ogden, UT: U.S. Department of Agriculture, Forest Service.

Weaver, H. 1961. Ecological changes in the ponderosa pine forest of cedar valley in southern Washington. Ecology. 42: 416–420.

Webb, J.L. 1906. Some insects injurious to forests. II. The western pine-destroying bark beetle. Bull. 58, Part 2. Washington, DC: U.S. Department of Agriculture, Bureau of Entomology. 30 p.

Weed, A.S.; Ayres, M.P.; Bentz, B.J. 2015a. Population dynamics of bark beetles. In: Vega, F.; Hofstetter, R., eds. Bark beetles: Biology and ecology of native and invasive species. London, UK: Elsevier: 157–176.

Weed, A.S.; Ayres, M.P.; Hicke, J.A. 2013. Consequences of climate change for biotic disturbances in North American forests. Ecological Monographs. 83: 441–470.

Weed, A.S.; Bentz, B.J.; Ayres, M.P.; Holmes, T.P. 2015b. Geographically variable response of *Dendroctonus ponderosae* to winter warming in the western United States. Landscape Ecology. 30: 1075–1093.

West, N.E. 1994. Effects of fire on salt-desert shrub rangelands. In: Monson, S.B.; Kitchen, S.G., eds. Proceedings, Symposium on ecology, management, of annual rangelands, Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 71–74.

West. N.E. 1999. Synecology and disturbance regimes of sagebrush steppe ecosystems. In: Proceedings of sagebrush steppe ecosystems symposium; 21-23 June 1999. Boise, ID: Boise State University: 15-26.

Westerling, A.L.; Bryant, B.P. 2008. Climate change and wildfire in California. Climatic Change. 87: S231–S249.

Westerling, A.L.; Turner, M.G.; Smithwick, E.A.; [et al.]. 2011. Continued warming could transform Greater Yellowstone fire regimes by mid-21st century. Proceedings of the National Academy of Sciences USA. 108: 13165–13170.

Westerling, A.L.; Hidalgo, H.G.; Cayan, D.R.; Swetnam, T.W. 2006. Warming and earlier spring increase in western U.S. forest wildfire activity. Science. 313: 940–943.

Westerling, A.L.; Swetnam, T.W. 2003. Interannual to decadal drought and wildfire in the western United States. Eos, Transactions American Geophysical Union. 84: 545.

Whisenant, S.G. 1990. Changing fire frequencies on Idaho's Snake River Plains: ecological and management implications. In: McArthur, D.E.; Romney, E.M.; Smith, S.D.; Tueller, P.T., eds. Proceedings, Symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 5-7 April 1989. Gen. Tech. Rep. GTR-INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 4–10.

Wickman, B.E. 1963. Mortality and growth reduction of white fir following defoliation by the Douglas-fir tussock moth. Res. Pap. PSW-7. Berkeley, CA: U.S. Department of Agriculture, Forest Service. 15 p.

Wickman, B.E. 1978a. A case study of a Douglas-fir tussock moth outbreak and stand conditions 10 years later. Res. Pap. PNW-RS-244. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 22 p.

Wickman, B.E. 1978b. Tree mortality and top-kill related to defoliation by the Douglas-fir tussock moth in the Blue Mountains outbreak. Res. Pap. PNW-233. Portland, OR: U.S. Department of Agriculture, Forest Service: 47 p.

Wickman, B.E.; Mason, R.R.; Thompson, C.G. 1973. Major outbreaks of the Douglas-fir tussock moth in Oregon and California. Gen. Tech. Rep. PNW-GTR-5. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 24 p.

Wickman, B.E.; Mason, R.R.; Trostle, G.C. 1981. Douglas-fir tussock moth. Forest Insect and Disease Leaflet 86. Washington, DC: U.S. Department of Agriculture, Forest Service. 11 p.

Wickman, B.E.; Seidel, K.W.; Starr, G.L. 1986. Natural regeneration 10 years after a Douglas-fir tussock moth outbreak in northeastern Oregon. Research Paper. PNW-RP-370. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 15 p.

Wiedinmyer, C.; Neff, J.C. 2007. Estimates of CO_2 from fires in the United States: Implications for carbon management. Carbon Balance and Management. 2: 10.

Wilcove, D.S.; Rothstein, D.; Dubow, J.; [et al.]. 1998. Quantifying threats to imperiled species in the United States. BioScience. 48: 607–615.

Wildland Fire Leadership Council. 2014. National Cohesive Wildland Fire Management Strategy. http://www.forestsandrangelands.gov/strategy/ [Accessed November 2, 2016].

Williams, A.P.; Allen, C.D.; Macalady, A.K.; [et al.]. 2013. Temperature as a potent driver of regional forest drought stress and tree mortality. Nature Climate Change. 3: 292–297.

Williams, K.K.; McMillin, J.D.; DeGomez, T.E.; [et al.]. 2008. Influence of elevation on bark beetle (Coleoptera: Curculionidae, Scolytinae) community structure and flight periodicity in ponderosa pine forests of Arizona. Environmental Entomology. 37: 94–109.

Wise, E.K. 2010. Spatiotemporal variability of the precipitation dipole transition zone in the western United States. Geophysical Research Letters. 37: L07706.

Wittenberg, R.; Cock, M.J.W., eds. 2001. Invasive alien species: A toolkit of best prevention and management practices. Wallingford, UK: CAB International. 228 p.

Wohl, E.E. 2008. Review of effects of large floods in resistant boundary channels. In: Habersack, H.; Piégay, H.; Rinaldi, M., eds. Gravel-bed rivers VI: From process understanding to river restoration. Developments in Earth Surface Processes 11. Amsterdam: Elsevier: 181–211.

Working Group on Invasive Species and Climate Change [WGISCC]. 2014. Bioinvasions in a changing world: A resource on invasive species-climate change interactions for conservation and natural resource management. http://www.invasivespeciesinfo.gov/docs/toolkit/bioinvasions_in_a_changing_world.pdf [Accessed November 2, 2016].

Worrall, J.J.; Egeland, L.; Eager, T.; [et al.]. 2008. Rapid mortality of *Populus tremuloides* in southwestern Colorado, USA. Forest Ecology and Management. 255: 686–696.

Worrall, J.J. 2009. Dieback and mortality of *Alnus* in the Southern Rocky Mountains, USA. Plant Disease. 93: 293–298.

Wright, L.C.; Berryman, A.A.; Wickman, B.E. 1984. Abundance of the fir engraver, *Scolytus ventralis*, and the Douglas-fir beetle, *Dendroctonus pseudotsugae*, following tree defoliation by the Douglas-fir tussock moth, *Orgyia pseudotsugata*. Canadian Entomologist. 116: 293–305.

Wright, L.C.; Berryman, A.A.; Gurusiddaiah, S. 1979. Host resistance to the fir engraver beetle, *Scolytus ventralis* (Coleoptera: Scolytidae): Effect of defoliation on wound monoterpene and inner bark carbohydrate concentrations. The Canadian Entomologist. 111: 1255–1262.

Yensen, D. 1981. The 1900 invasion of alien plants into southern Idaho. Great Basin Naturalist. 41: 176–183.

Young, J.A.; Clements, C.D. 2007. Cheatgrass and grazing rangelands. Rangelands. 29: 15–20.

Young, J.A.; Evans, R.A.; Eckert, R.E., Jr.; Kay, B.L. 1987. Cheatgrass. Rangelands. 9: 266–270.

Young, J.A.; Evans, R.A.; Major, J. 1972. Alien plants in the Great Basin. Journal of Range Management. 25: 194–201.

Young, R.M. 1986. Mass emergences of the pine white, *Neophasia menapia* (Felder and Felder), in Colorado (Pieridae). Journal of the Lepidopterists' Society. 40: 314.

Zambino, P.J. 2010. Biology and pathology of ribes and their implications for management of white pine blister rust. Forest Pathology. 40: 264–291.

Zambino, P.J.; McDonald, G.I. 2004. Resistance to white pine blister rust in North American five-needle pines and *Ribes* and its implications. In: Geils, B.W. Proceedings, 51st western international forest disease work conference; 2003 August 18–22; Grants Pass, OR. Flagstaff, AZ: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 111–125.

Zouhar, K.; Smith, J.K.; Sutherland, S.; Brooks, M.L. 2008. Wildland fire in ecosystems: Fire and nonnative invasive plants. Gen. Tech. Rep. RMRS-GTR-42. Ogden, UT: U.S. Department of Agriculture, Forest Service. Rocky Mountain Research Station. 355 p.

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).

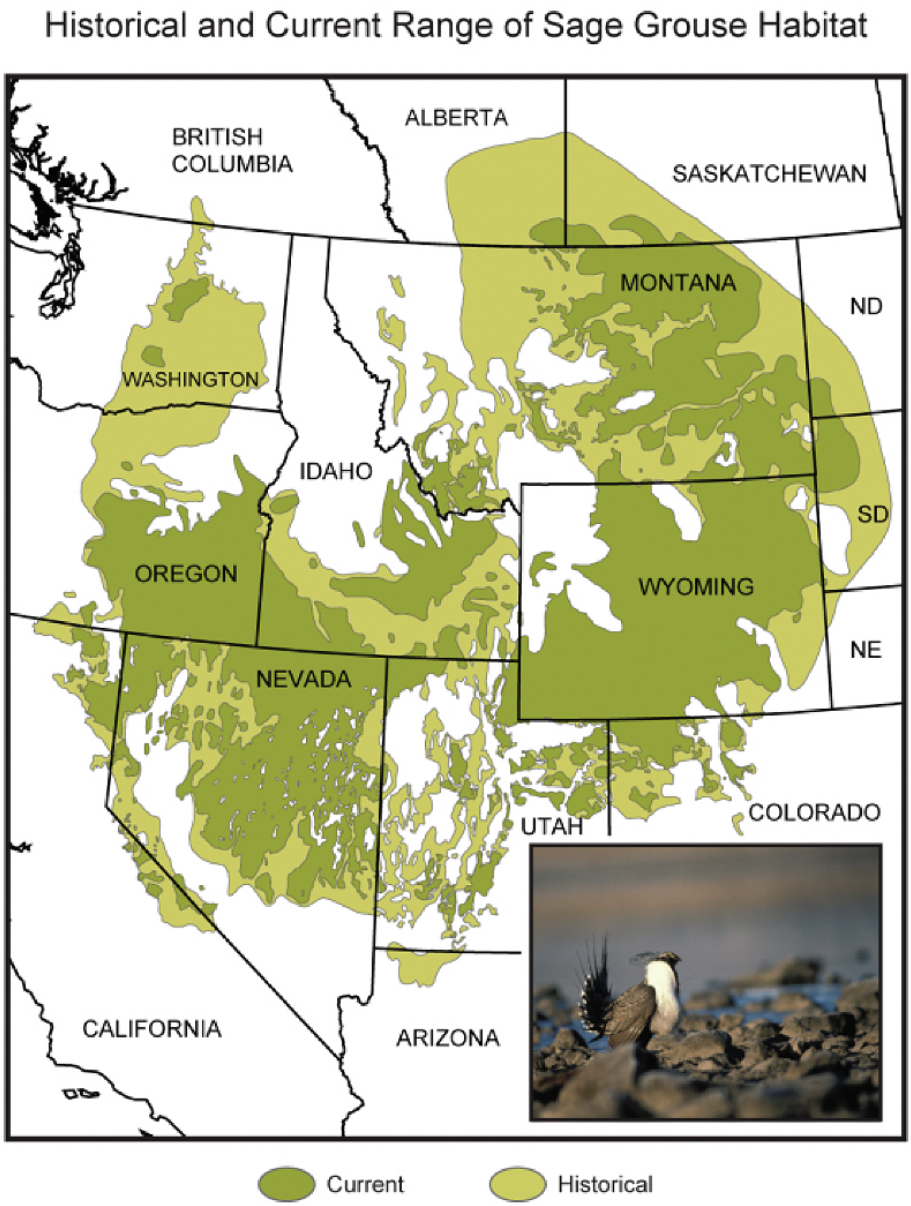


Figure 9.3—Current sagebrush habitat in western North America, which is about 50 percent of its historical extent, as a result of agriculture, livestock grazing, energy development, and other land use practices. Loss of sagebrush across large spatial scales constrains the amount of habitat available 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,

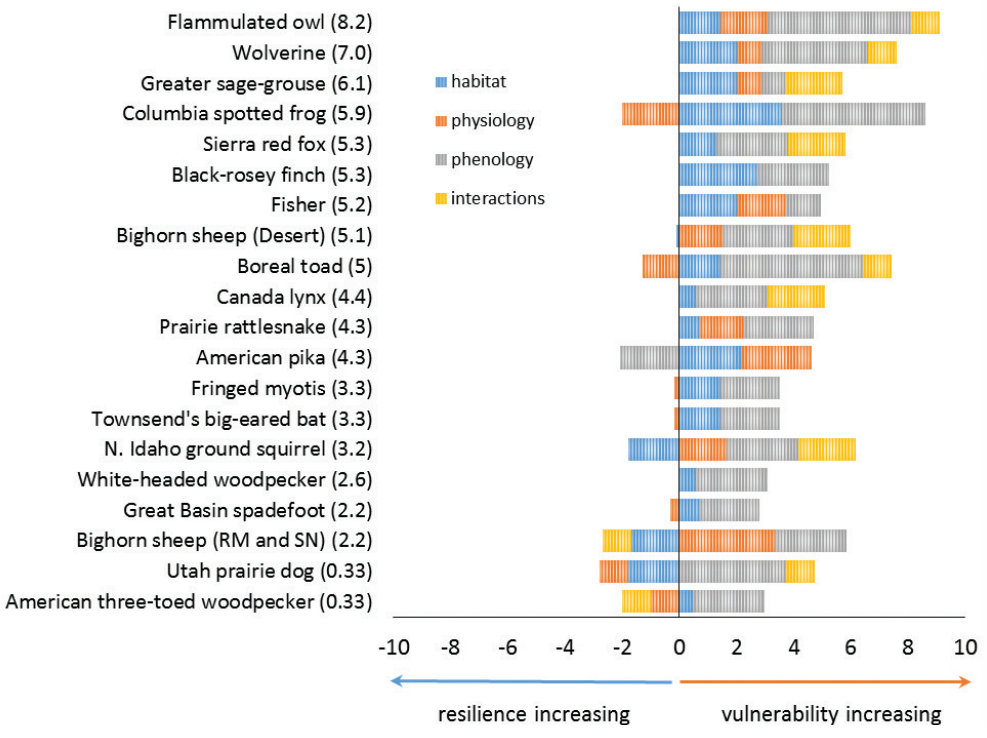


Figure 9.5—Vulnerability scores (value in parentheses) for 20 terrestrial animal species. Positive scores indicate higher vulnerability, negative scores indicate higher resilience, and zero defines a neutral response. Color of bars represents the relative contribution of habitat, physiology, phenology, 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).

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.



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).

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.

References

Abele, S.C.; Saab, V.A.; Garton, E.O. 2004. Lewis's Woodpecker (*Melanerpes lewis*): A technical conservation assessment. Report prepared for the USDA Forest Service, Rocky Mountain Region, Species Conservation Project. Golden, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. 51 p.

Adams, M.J.; Pearl, C.A.; McCreary, B.; [et al.]. 2009. Short-term effect of cattle exclosures on Columbia spotted frog (*Rana luteiventris*) populations and habitat in northeastern Oregon. Journal of Herpetology. 43: 132–138.

Adams, R. 2010. Bat reproduction declines when conditions mimic climate change projections for western North America. Ecology Journal. 91: 2437–2445.

Adams, R.A. 2003. Bats of the Rocky Mountain West. Boulder, CO: University of Colorado Press. 302 p.

Adams, R.V.; Burg, T.M. 2015. Influence of ecological and geological features on rangewide patterns of genetic structure in a widespread passerine. Heredity (Edinburgh). 114: 143–154.

Aho, K.; Huntly, N.; Moen, J.; Oksanen, T. 1998. Pikas (*Ochotona princeps*: Lagomorpha) as allogenic engineers in an alpine ecosystem. Oecologia. 114: 405–409.

Alexander, R.R. 1986. Silvicultural systems and cutting methods for old–growth lodgepole pine forests in the central Rocky Mountains. Gen. Tech. Rep. RM-127. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 31 p.

Alexander, R.R. 1987. Ecology, silviculture, and management of the Engelmann spruce-subalpine fir type in the central and southern Rocky Mountains. Agric. Handb. 659. Washington, DC: U.S. Department of Agriculture, Forest Service. 144 p.

Allen, C.D.; Macalady A.K.; Chenchouni H.; [et al.]. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management. 259: 660–684.

Altendorf, K.B.; Laundre, J.W.; Brown, J.S.; González, C.A.L. 2001. Assessing effects of predation risk on foraging behavior of mule deer. Journal of Mammalogy. 82: 430–439.

Altman, B.; Sallabanks, R. 2000. Olive–sided flycatcher (*Contopus cooperi*). In: Poole, A.; Gill, F., eds. The birds of North America, online. Philadelphia, PA: The Academy of Natural Sciences, and Washington, DC: American Ornithologists Union.

Alward, R.D.; Detling, J.K.; Milchunas, D.G. 1999. Grassland vegetation changes and nocturnal global warming. Science. 283: 229–231.

Anderegg, W.R.; Berry, J.A.; Smith, D.D.; [et al.]. 2012. The roles of hydraulic and carbon stress in a widespread climate-induced forest die-off. Proceedings of the National Academy of Sciences, USA. 109: 233–237.

Anderson, Michelle D. 2002. *Pinus edulis*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). https://www.feis-crs.org/feis/ [Accessed April 21, 2016].

Anderson, M.D. 2003. *Pinus contorta* var. *latifolia*. In: Fire Effects Information System. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. https://www.feis-crs.org/feis/ [Accessed April 21, 2016].

Andrews, R.; Righter, R. 1992. Colorado birds: A reference to their distribution and habitat. Denver, CO: Denver Museum of Natural History. 480 p.

Arsenault, D.P.; Stacey, P.B.; Holzer, G.A. 2005. Mark-recapture and DNA fingerprinting data reveal high breeding site fidelity, low natal philopatry, and low levels of genetic population differentiation in flammulated owls. Auk. 122: 329–337.

Aubry, K.B.; McKelvey, K.S.; Copeland, J.P. 2007. Distribution and broadscale habitat relations of the wolverine in the contiguous United States. Journal of Wildlife Management. 71: 2147–2158.

Bagne, K.E.; Friggens, M.M.; Finch, D.M. 2011. A system for assessing vulnerability of species (SAVS) to climate change. Gen. Tech. Rep. RMRS-GTR-257. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 28 p.

Balda, R.P.; Masters, N. 1980. Avian communities in the pinyon-juniper woodland: A descriptive analysis. In: DeGraaf, R.M., tech. coord. Management of western forests and grasslands for nongame birds: Workshop proceedings; 1980 February 11-14; Salt Lake City, UT. Gen. Tech. Rep. INT-86. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 146–169.

Baldwin, B.D.; Banner, R.E. 2009. Wildlife in Utah. In: Banner, R.E.; Baldwin B.D.; McGinty, E.I.L., eds. Rangeland resources of Utah. Logan, UT: Utah State University, Cooperative Extension Service: 113–137.

Banci, V. 1994. Wolverine. In: Ruggiero, L.F.; Aubry, K.B.; Buskirk, S.W.; [et al.], tech. eds. The scientific basis for conserving forest carnivores: American marten, fisher, lynx, and wolverine in the western United States. Gen. Tech. Rep. RM-254. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 99–127.

Bangert, R.K.; Slobodchikoff, C.N. 2006. Conservation of prairie dog ecosystem engineering may support arthropod beta and gamma diversity. Journal of Arid Environments. 67: 100–115.

Banner, R.E.; Baldwin, B.D.; McGinty, E.I.L. 2009. Rangeland resources of Utah. Logan, UT: Utah State University Cooperative Extension Service. 202 p.

Barnes, V.G., Jr. 1974. Response of pocket gopher populations to silvicultural practices in central Oregon. In: Black, H.C., ed. Wildlife and forest management in the Pacific Northwest: Proceedings of a symposium; 1973 September 11–12; Corvallis, OR. Corvallis, OR: Oregon State University, School of Forestry, Forest Research Laboratory: 167–175.

Barrett, N. 1998. Northern goshawk. In: Kingery, H.E., ed. Colorado breeding bird atlas. Denver, CO: Colorado Bird Atlas Partnership and Colorado Division of Wildlife: 116–117.

Bartelt, P.E. 1998. Natural history notes: *Bufo boreas* mortality. Herpetological Review. 29: 96.

Bartelt, P.E., Klaver, R.W.; Porter, W.P. 2010. Modeling amphibian energetics, habitat suitability, and movements of western toads, *Anaxyrus* (=*Bufo*) *boreas*, across present and future landscapes. Ecological Modeling. 221: 2675–2686.

Battaglia, M.A.; Shepperd, W.D. 2007. Ponderosa pine, mixed conifer, and spruce-fir forests. In: Hood, S.M.; Miller, M., eds. Fire ecology and management of the major ecosystems of southern Utah. Gen. Tech. Rep. RMRS-GTR-202. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 7–37.

Beck, D.D. 1996. Effects of feeding on body temperatures of rattlesnakes: A field experiment. Physiological Zoology. 69: 1442–1455.

Beebee, T.J.C. 1995. Amphibian breeding and climate. Nature. 374: 219–220.

Beecham, J.J. Jr..; Collins, C.P.; Reynolds, T.D. 2007. Rocky Mountain bighorn sheep (*Ovis canadensis*): A technical conservation assessment. U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5181936.pdf [Accessed April 21, 2016].

Beever, E.A.; Brussard, P.F.; Berger, J. 2003. Patterns of apparent extirpation among isolated populations of pikas (*Ochotona princeps*) in the Great Basin. Journal of Mammology. 84: 37–54.

Beever, E.A.; Dobrowski, S.Z.; Long, J.; [et al.]. 2013. Understanding relationships among abundance, extirpation, and climate at ecoregional scales. Ecology. 94: 1563–1571.

Beever, E.A.; Ray, C.; Mote, P.W.; Wilkening, J.L. 2010. Testing alternative models of climate-mediated extirpations. Ecological Applications. 20: 164–178.

Beever, E.A.; Ray, C.; Wilkening, J.L.; [et al.]. 2011. Contemporary climate change alters the pace and drivers of extinction. Global Change Biology. 17: 2054–2070.

Beever, E.A.; Wilkening, J.L.; McIvor, D.E.; [et al.]. 2008. American pikas (*Ochotona princeps*) in northwestern Nevada: A newly discovered population at a low-elevation site. Western North American Naturalist. 68: 8–14.

Benkman, C.W. 1999. The selection mosaic and diversifying coevolution between crossbills and lodgepole pine. The American Naturalist. 153: S75–S91.

Benkman, C.W.; Parchman, T.L.; Favis, A.; Siepielski, A.M. 2003. Reciprocal selection causes a coevolutionary arms race between crossbills and lodgepole pine. The American Naturalist. 162: 182–194.

Bent, A.C. 1939. Life histories of North American woodpeckers. United States National Museum Bulletin 174. 334 p.

Bentz, B.J.; Régnière J.; Fettig C.J.; [et al.]. 2010. Climate change and bark beetles of the western United States and Canada: Direct and indirect effects. Bioscience. 60: 602–613.

Berger, L.; Roberts, A.A.; Voyles, J.; [et al.]. 2016. History and recent progress on chytridiomycosis in amphibians. Fungal Ecology. 19: 89–99.

Bernard, R.F.; Foster, J.T.; Willcox, E.V.; [et al.]. 2015. Molecular detection of the causative agent of white-nose syndrome on Rafinesque's big-eared bats (*Corynorhinus rafinesquii*) and two species of migratory bats in the southeastern USA. Journal of Wildlife Diseases. 51: 519–522.

Bernardo, J.; Spotila, J.R. 2006. Physiological constraints on organismal response to global warming: Mechanistic insights from clinally varying populations and implications for assessing endangerment. Biology Letters. 2: 135–139.

Bielby, J.; Cooper, N.; Cunningham, A.A.; [et al.]. 2008. Predicting susceptibility to future declines in the world's frogs. Conservation Letters. 1: 82–90.

Bilyeu, D.M.; Cooper, D.J.; Hobbs, N.T. 2008. Water tables constrain height recovery of willow on Yellowstone's northern range. Ecological Applications. 18: 80–92.

Bigler, C.; Gavin, D.G.; Gunning, C.; Veblen, T.T. 2007. Drought induces lagged tree mortality in a subalpine forest in the Rocky Mountains. Oikos. 116: 1983–1994.

Blaisdell, J.P.; Holmgren, R.C. 1984. Managing intermountain rangelands salt-desert shrub ranges. Gen. Tech. Rep. INT-163. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 54 p.

Blanchard, B.M. 1980. Grizzly bear–habitat relationships in the Yellowstone area. International Conference on Bear Research and Management. 5: 118–123.

Blaustein, A.R.; Kiesecker, J.M. 2002. Complexity in conservation: lessons from the global decline of amphibian populations. Ecology Letters. 5: 597–608.

Blaustein, A.R.; Romansic, J.R.; Scheessele, E.A.; [et al.]. 2005. Interspecific variation in susceptibility of frog tadpoles to the pathogenic fungus *Batrachochytrium dendrobatidis*. Conservation Biology. 19: 1460–1468.

Blomberg, E.J.; Sedinger, J.S.; Atamian, M.T.; Nonne, D.V. 2012. Characteristics of climate and landscape disturbance influence the dynamics of greater sage-grouse populations. Ecosphere. 3: Art55.

Blowey, R.W.; Weaver, A.D. 2003. Color atlas of diseases and disorders of cattle, 2nd edition. St. Louis, MO: Mosby Incorporated. 268 p.

Boag, D.A.; Sumanik, K.M. 1969. Characteristics of drumming sites selected by ruffed grouse in Alberta. Journal of Wildlife Management. 33: 621–628.

Boccard, B. 1980. Important fish and wildlife habitats of Idaho: An inventory. Boise, ID: U.S. Department of the Interior, Fish and Wildlife Service, Oregon-Idaho Area Office. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. 161 p.

Boggs, C.L.; Inouye, B.D. 2012. A single climate driver has direct and indirect effects on insect population dynamics. Ecology Letters. 15: 502–508.

Bosworth, W.R. 2003. Utah natural heritage program: Vertebrate information. Publication Number 03-45. Salt Lake City, UT: Utah Division of Wildlife Resources. 336 p.

Both, C.; Bouwhuis, S.; Lessells, C.M.; Visser, M.E. 2006. Climate change and population declines in a long-distance migratory bird. Nature. 441: 81–83.

Both, C.; Van Turnhout, C.A.M.; Bijlsma, R.G.; [et al.]. 2010. Avian population consequences of climate change are most severe for long-distance migrants in seasonal habitats. Proceedings of the Royal Society B-Biological Sciences. 277: 1259–1266.

Boutin, S.; Krebs, C.J., Boonstra, R.; [et al.]. 1995. Population changes of the vertebrate community during a snowshoe hare cycle in Canada's boreal forest. Oikos. 74: 69–80.

Boyd, C.S.; Johnson, D.D.; Kerby, J.D.; [et al.]. 2014. Of grouse and golden eggs: Can ecosystems be managed within a species-based regulatory framework? Rangeland Ecology and Management. 67: 358–368.

Bradford, D.F; Franson, S.E.; Neale, A.C.; [et al.]. 1998. Bird species assemblages as indicators of biological integrity in Great Basin rangeland. Environmental Monitoring and Assessment. 49: 1–22.

Bradley, B.A. 2010. Assessing ecosystem threats from global and regional change: Hierarchical modeling of risk to sagebrush ecosystems from climate change, land use and invasive species in Nevada, USA. Ecography. 33: 198–208.

Bradley, B.A.; Curtis, C.A.; Chambers, J.C. 2016. Bromus response to climate and projected changes with climate change. In: Germino, M.J.; Chambers, J.C.; Brown, C.S., eds. Exotic brome-grasses in arid and semiarid ecosystems of the western US. Springer Series on Environmental Management. Geneva, Switzerland: Springer International Publishing: 257–274.

Bradley, B.A.; Oppenheimer, M.; Wilcove, D.S. 2009. Climate change and plant invasions: Restoration opportunities ahead? Global Change Biology. 15: 1511–1521.

Briffa, K.R.; Shishov, V.V.; Melvin, T.M.; [et al.]. 2008. Trends in recent temperature and radial tree growth spanning 2000 years across northwest Eurasia. Philosophical Transactions of the Royal Society B - Biological Sciences. 363: 2271–2284.

Brinkman, K.A.; Roe, E.I. 1975. Quaking aspen: Silvics and management in the Lake States. Agric. Handb. 486. Washington, DC: U.S. Department of Agriculture, Forest Service. 52 p.

Brodie, J.; Post, E. 2009. Nonlinear responses of wolverine populations to declining winter snowpack. Population Ecology. 52: 279–287.

Brodie, J.; Post, E.; Watson, F.; Berger, J. 2012. Climate change intensification of herbivore impacts on tree recruitment. Proceedings of the Royal Society B-Biological Sciences. 279: 1366–1370.

Bronson, F.H. 2009. Climate change and seasonal reproduction in mammals. Philosophical Transactions of the Royal Society of London B-Biological Sciences. 364: 3331–3340.

Brown, T.J.; Hall, B.L.; Westerling, A.L. 2004. The impact of twenty-first century climate change on wildland fire danger in the western United States: An applications perspective. Climatic Change. 62: 365–388.

Buehler, D.A. 2000. Bald Eagle (*Haliaeetus leucocephalus*) In: Poole, A.; Gill, F., eds. The birds of North America, online. Philadelphia, PA: The Academy of Natural Sciences and Washington, D.C: American Ornithologists Union.

Bull, E. L. 1983. Longevity of snags and their use by woodpeckers. In: Davis, J.W.; Goodwin, G.A.; Ockenfeis, R.A., tech. coords. Snag habitat management: Proceedings of the symposium. Gen. Tech. Rep. RM-99. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 64–67.

Bull, E.L.; Hayes, M.P. 2001. Post-breeding season movements of Columbia spotted frogs (*Rana luteiventris*) in northeastern Oregon. Western North American Naturalist. 61: 119–123.

Bunnell, F.L. 2013. Sustaining cavity-using species: Patterns of cavity use and implications to forest management. International Scholarly Research Notes Forestry 2013: Article ID 457698. 33 p.

Bunnell, F.L.; Wind, E.; Boyl, M.; Houde, I. 2002. Diameters and heights of trees with cavities: Their implications to management. In: Laudenslayer Jr., W.F.; Shea, P.J.; Valentine, B.E.; [et al.], eds. Proceedings of the symposium on the ecology and management of dead wood in western forests, 1999; 1999, November 2-4; Reno, NV. Gen. Tech. Rep. PSW-GTR-181. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 717–737.

Buseck, R.S.; Keinath, D.A.; Geraud, M.I. 2005. Species assessment for the Great Basin spadefoot toad (*Spea intermontana*) in Wyoming. Unpub. rep, Cheyenne, WY: Bureau of Land Management State Office.

Buskirk, S.W.; Powell, R.A. 1994. Habitat ecology of fishers and American martens. In: Buskirk, S.W.; Harestad, A.S.; Raphael, M.G.; Powell, R.A., eds. Martens, sables, and fishers: Biology and conservation. Ithaca, NY: Cornell University Press: 283–296.

Buskirk, S.W.; Ruggiero, L.F. 1994. American marten. In: Ruggiero, L.F.; Aubry, K.B.; Buskirk, S.W.; [et al.]. tech. eds. The scientific basis for conserving forest carnivores: American marten, fisher, lynx, and wolverine in the western United States. Gen. Tech. Rep. RM-254. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 7–37.

Buskirk, S.W.; Zielinski, W.J. 2003. Small and mid-sized carnivores. In: Zabel, C.J.; Anthony, R.G., eds. Mammal community dynamics: Management and conservation in the coniferous forests of western North America. Cambridge, UK: Cambridge University Press: 207–249.

Carey, J.H. 1995. *Krascheninnikovia lanata*. In: Fire Effects Information System. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. https://www.feis-crs.org/feis/ [Accessed April 21, 2016].

Casey, D.; Altman. B.; Stringer, D. n.d. Land manager's guide to cavity-nesting bird habitat and populations in ponderosa pine forests of the Pacific Northwest. American Bird Conservancy. 32 p.

Castillo, J.A.; Epps, C.W.; Davis, A.R.; Cushman, S.A. 2014. Landscape effects on gene flow for a climate-sensitive montane species, the American pika. Molecular Ecology. 23: 843–856.

Catford, J.A.; Naiman, R.J.; Chambers, L.E.; [et al.]. 2012. Predicting novel riparian ecosystems in a changing climate. Ecosystems. 16: 382–400.

Center for Biological Diversity. 2011. Petition to list a distinct population segment of the boreal toad (*Anaxyrus boreas boreas*) as endangered or threatened under the endangered species act. 25 May 2011. http://www.biologicaldiversity.org/species/amphibians/boreal_toad/pdfs/Boreal_Toad_Listing_Petition_5-24-2011.pdf [Accessed January 26, 2016].

Chessman, B.C. 2013. Identifying species at risk from climate change: Traits predict the drought vulnerability of freshwater fishes. Biological Conservation. 160: 40–49.

Chimner, R.A.; D.J. Cooper. 2002. Modeling carbon accumulation in Rocky Mountain fens. Wetlands. 22: 100–110.

Chimner, R.A.; D.J. Cooper. 2003a. Carbon dynamics of pristine and hydrologically modified fens in the southern Rocky Mountains. Canadian Journal of Botany. 81: 477–491.

Chimner, R.A.; D.J. Cooper. 2003b. Influence of water table levels on CO_2 emissions in a Colorado subalpine fen: An in situ microcosm study. Soil Biology and Biochemistry. 35:345–351.

Clark, R.W.; Brown, W.S.; Stechert, R.; Zamudio, K.R. 2010. Roads, interrupted dispersal, and genetic diversity in timber rattlesnakes. Conservation Biology. 24: 1059–1069.

Collier, G.D.; Spillett, J.J. 1975. Factors influencing the distribution of the Utah prairie dog, *Cynomys parvidens* (Sciuridae). The Southwestern Naturalist. 20: 151–158.

Collins, G.H.; Bauman, B.T. 2012. Distribution of low-elevation American pika populations in the northern Great Basin. Journal of Fish and Wildlife Management. 3: 311–318.

Connelly, J.W.; Knick, S.T.; Schroeder, M.A.; Stiver, S.J. 2004. Conservation assessment of greater sage-grouse and sagebrush habitats. Unpub. Rep. Cheyenne, WY: Western Association of Fish and Wildlife Agencies. 610 p.

Contreras, G.P.; Evans, K.E., comps. 1986. Proceedings–grizzly bear habitat symposium; 1985 April 30-May 2; Missoula, MT. Gen. Tech. Rep. INT-207. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 252 p.

Coop, J.D.; Givnish, T.J. 2007. Spatial and temporal patterns of recent forest encroachment in montane grasslands of the Valles Caldera, New Mexico, USA. Journal of Biogeography. 34: 914–927.

Copeland, J.P.; McKelvey, K.S.; Aubry, K.B.; [et al.]. 2010. The bioclimatic envelope of the wolverine (*Gulo gulo*): Do climatic constraints limit its geographic distribution? Canadian Journal of Zoology. 88: 233–246.

Corkran, C.; Wind, E. 2008. Juniper and pinyon-juniper woodlands. In: Pilliod, D.S.; Wind, E., eds. Habitat management guidelines for amphibians and reptiles of the Northwestern United States and Western Canada. Tech. Pub. HMG-4. Birmingham, AL: Partners in Amphibian and Reptile Conservation: 65–67.

Cornely, J.E.; Carraway, L.N.; Verts, B.J. 1992. *Sorex preblei*. Mammalian Species. 416: 1–3.

Craig, G.R.; Enderson, J.H. 2004. Peregrine falcon biology and management in Colorado. Tech. Pub. 43. Denver, CO: Colorado Division of Wildlife. 80 p.

Crocker-Bedford, D.C.; Chaney, B. 1988. Characteristics of goshawk nesting stands In: Glinski, R.; Pendleton, B.G.; Moss, M.B.; [et al.], eds. Proceedings of the southwest raptor management symposium and workshop. National Wildlife Federation Science and Technical Series. 11: 210–217.

Cryan, P.M. 2003. Seasonal distribution of migratory tree bats (*Lasiurus* and *Lasionycteris*) in North America. Journal of Mammalogy. 84: 579–593.

Curtis, J.A.; Flint, L.E.; Flint, A.L.; [et al.]. 2014. Incorporating cold-air pooling into downscaled climate models increases potential refugia for snow-dependent species within the Sierra Nevada ecoregion, California. PLoS ONE. 9(9): e106984.

Daszak, P.; Scott, D.E.; Kilpatrick, A.M.;; [et al.]. 2005. Amphibian population declines at Savannah River site are linked to climate, not chytridiomycosis. Ecology. 86: 3232–3237.

Davis, J.N.; Brotherson, J.D. 1991. Ecological relationships of curlleaf mountain-mahogany (*Cercocarpus ledifolius* Nutt.) communities in Utah and implications for management. Great Basin Naturalist. 51: 153–166.

Debinski, D.M.; Wickham, H.; Kindscher, K.; [et al.]. 2010. Montane meadow change during drought varies with background hydrologic regime and plant functional group. Ecology 91: 1672–1681.

DeByle, N.V. 1981. Songbird populations and clearcut harvesting of aspen in northern Utah. Res. Note INT-302. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 7 p.

DeByle, N.V. 1985a. Animal impacts. In: DeByle, N.V.; Winokur, R.P., eds. Aspen: Ecology and management in the western United States. Gen. Tech. Rep. GTR-RM-119. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 115–123.

DeByle, N.V. 1985b. Wildlife. In: DeByle, N.V.; Winokur, R.P., eds. Aspen: Ecology and management in the western United States. Gen. Tech. Rep. GTR-RM-119. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 135–152.

Decker, K.; Fink, M. 2014. Colorado wildlife action plan enhancement: Climate change vulnerability assessment. Fort Collins, CO: Colorado Natural Heritage Program, Colorado State University. 129 p.

Degenhardt, W.G.; Painter, C.W.; Price, A.H. 1999. Amphibians and reptiles of New Mexico. Albuquerque, NM: University of New Mexico Press. xvii + 431 p.

DelCurto, T.; Porath, M.; Parsons, C.T.; Morrison, J.A. 2005. Management strategies for sustainable beef cattle grazing on forested rangelands in the Pacific Northwest. Rangeland Ecology & Management. 58: 119–127.

Delgiudice, G. D., Peterson, R.O.; Samuel, W.M. 1997. Trends of winter nutritional restriction, ticks, and numbers of moose on Isle Royale. Journal of Wildlife Management. 61: 895–903.

DeLoach, C.J.; Carruthers, R.I.; Lovich, J.E.; [et al.]. 2000. Ecological interactions in the biological control of saltcedar (*Tamarix* spp.) in the United States: Toward a new understanding. In: Spencer, N.R., ed. Proceedings of the X International Symposium on Biological Control of Weeds. Bozeman, MT: Montana State University: 819–873.

DeLuca, W.V. 2012. Ecology and conservation of the high elevation forest avian community in northeastern North America. Amherst, MA: University of Massachusetts—Amherst. Dissertation. 112 p.

DeLuca, W.V.; King, D.I. 2017. Montane birds shift downslope despite recent warming in the northern Appalachian Mountains. Journal of Ornithology. 158: 493–505.

Diffenbaugh, N.S.; Giorgi, F. 2012. Climate change hotspots in the CMIP5 global climate model ensemble. Climatic Change. 114: 813–822.

Doeskin, N.J.; Pielke, R.A.; Bliss, O.A.P. 2003. Climate of Colorado. Climatology of the United States No. 60. Fort Collins, CO: Colorado Climate Center, Atmospheric Science Department, Colorado State University. 14 p.

Douglas, M.E.; Douglas, M.R.; Schuett, G.W.; [et al.]. 2002. Phylogeography of the western rattlesnake (*Crotalus viridis*) complex, with emphasis on the Colorado Plateau. In: Schuett, G.W.; Höggren, M.; Douglas, M.E.; Greene, H.W., eds. Biology of the vipers. Eagle Mountain, UT: Eagle Mountain Publishing: 11–55.

Drake, B.G.; Hughes, L.; Johnson, E.A.; [et al.]. 2005. Synergistic effects. In: Lovejoy, T.E.; Hannah, L., eds. Climate change and biodiversity. New Haven, CT: Yale University Press: 296–316.

Drost, C.A.; Fellers, G.M. 1996. Collapse of a regional frog fauna in the Yosemite area of the California Sierra Nevada, USA. Conservation Biology. 10: 414–425.

Dwire, K.A.; Kauffman, J.B., 2003. Fire and riparian ecosystems in landscapes of the western USA. Forest Ecology and Management. 178: 61–74.

Eldridge, D.J. 2004. Mounds of the American badger (*Taxidea taxus*): Significant features of North American shrub-steppe ecosystems. Journal of Mammalogy. 85: 1060–1067.

Elliott, S.E. 2009. Subalpine bumble bee foraging distances and densities in relation to flower availability. Environmental Entomology. 38: 748–756.

Environment Canada. 2014. Recovery strategy for the white-headed woodpecker (*Picoides albolarvatus*) in Canada. Species at Risk Act Recovery Strategy Series. Ottawa, Ontario, Canada: Environment Canada. iv + 17 p.

Epps, C.W.; Palsbøll, P.J.; Wehausen, J.D.; [et al.]. 2005. Highways block gene flow and cause a rapid decline in genetic diversity of desert bighorn sheep. Ecology Letters. 8: 1029–1038.

Erb, L.P.; Ray, C.; Guralnick, R. 2011. On the generality of a climate-mediated shift in the distribution of the American pika (*Ochotona princeps*). Ecology. 92: 1730–1735.

Esque, T.A.; Nussear, K.E.; Drake, K.K.; [et al.]. 2010. Effects of subsidized predators, resource variability and human population density on desert tortoise populations in the Mojave Desert, USA. Endangered Species Research. 12: 167–177.

Evans, R.A. 1988. Management of pinyon-juniper woodlands. Gen. Tech. Rep. INT-249. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 34 p.

Everett, R.L.; Meeuwig, R.O.; Stevens, R. 1978. Deer mouse preference for seed of commonly planted species, indigenous weed seed, and sacrifice foods. Journal of Range Management. 31: 70–73.

Fautin, R.W. 1946. Biotic communities of the northern desert shrub biome in western Utah. Ecological Monographs. 16: 251–310.

Fayt, P.; Machmer, M.M.; Steeger, C. 2005. Regulation of spruce bark beetles by woodpeckers—A literature review. Forest Ecology and Management. 206: 1–14.

Ferguson, D.E. 1999. Effects of pocket gophers, bracken fern, and western coneflower on planted conifers in northern Idaho—An update and two more species. New Forests. 18: 199–217.

Festa-Bianchet, M. 1988. Seasonal range selection in bighorn sheep: Conflicts between forage quality, forage quantity, and predator avoidance. Oecologia. 75: 580–586.

Finch, D.M., Rothstein, S.I.; Boren, J.C.; [et al.]. 2002. Final recovery plan: Southwestern willow flycatcher (*Empidonax traillii extimus*). Albuquerque, NM: U.S. Fish and Wildlife Service. 210 p.

Fisher, J.T.; Bradbury, S.; Anholt, B.; [et al.]. 2013. Wolverines (*Gulo gulo luscus*) on the Rocky Mountain slopes: Natural heterogeneity and landscape alteration as predictors of distribution. Canadian Journal of Zoology. 91: 706–716.

Floyd, M.L.; Hanna, D.D. 1990. Cone indehiscence in a peripheral population of piñon pines (*Pinus edulis*). The Southwestern Naturalist. 35: 146–150.

Flueck, W.T.; Smith-Flueck, J.M.; Mionczynski, J.; Mincher, B.J. 2012. The implications of selenium deficiency for wild herbivore conservation: A review. European Journal of Wildlife Research. 58: 761–780.

Franken, R.J.; Hik, D.S. 2004. Influence of habitat quality, patch size and connectivity on colonization and extinction dynamics of collared pikas *Ochotona collaris*. Journal of Animal Ecology. 73: 889–896.

Freed, L.A.; Cann, R.L.; Goff, M.L.; [et al.]. 2005. Increase in avian malaria at upper elevation in Hawai'i. Condor. 107: 753–764.

French, N.R. 1959. Life history of the black rosy finch. Auk. 76: 159–180.

Friggens, M.M.; Finch, D.M.; Bagne, K.E. [et al.]. 2013. Vulnerability of species to climate change in the Southwest: Terrestrial species of the Middle Rio Grande. Gen. Tech. Rep. RMRS-GTR-306. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Fulé, P.Z.; Covington, W.W.; Moore, M.M.; [et al.]. 2002. Natural variability in forests of the Grand Canyon, USA. Journal of Biogeography. 29: 31–47.

Funk, W.C.; Greene, A.E.; Corn, P.S.; Allendorf, F.W. 2005. High dispersal in a frog species suggests that it is vulnerable to habitat fragmentation. Biology Letters. 1: 13–16.

Furniss, M.M. 1971. Mountain-mahogany looper. For. Pest Leafl. 124. Ogden, UT: U.S. Department of Agriculture, Forest Service. 5 p.

Gahr, M.L. 1993. Natural history, burrow habitat and use, and homerange of the pygmy rabbit (*Brachylagus idahoensis*) of Sagebrush Flat, Washington. Seattle, WA: University of Washington. Thesis. 125 p.

Galbreath, K.E.; Hafner, D.J.; Zamudio, K.R. 2009. When cold is better: Climate-driven elevation shifts yield complex patterns of diversification and demography in an alpine specialist (American pika, *Ochotona princeps*). Evolution. 63: 2848–2863.

Ganey, J.L.; Block, W.M.; Jenness, J.S.; Wilson, R.A. 1999. Mexican spotted owl home range and habitat use in pine-oak forest: implications for forest management. Forest Science. 45: 127–135.

Gannon, V.P.J.; Secoy, D.M. 1985. Seasonal and daily activity patterns in a Canadian population of the prairie rattlesnake, *Crotalus viridus viridis*. Canadian Journal of Zoology. 63: 86–91.

Garrett, K.L.; Raphael, M.G.; Dixon. R.D. 1996. White-headed Woodpecker (*Picoides albolarvatus*). In Poole, A., ed. The birds of North America online. Ithaca, NY: Cornell Lab of Ornithology.

Gese, E.M.; Rongstad, O.J.; Mytton, W.R. 1988. Home range and habitat use of coyotes in southeastern Colorado. Journal of Wildlife Management. 52: 640–646.

Gibbons, J.W.; Scott, D.E.; Ryan, T.J.; [et al.]. 2000. The global decline of reptiles, déjà vu amphibians. BioScience. 50: 653–666.

Gibson, K.E.; Skov, K.; Kegley, S.; [et al.]. 2008. Mountain pine beetle impacts in high-elevation five-needle pines: Current trends and challenges. Rep. R1-08-020. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Forest Health Protection. 32 p.

Gilgert W.; Vaughan, M. 2011. The value of pollinators and pollinator habitat to rangelands: Connections among pollinators, insects, plant communities, fish, and wildlife. Rangelands. 33: 14–19.

Gilman, S.E.; Urban M.C.; Tewksbury, J.; [et al.]. 2010. A framework for community interactions under climate change. Trends in Ecology and Evolution. 25: 325–331.

Gilpin, M.E.; Soulé, M.E. 1986. Minimum viable populations: Processes of species extinction. In: Soulé, M.E., ed. Conservation biology: The science of scarcity and diversity. Sunderland, MA: Sinauer & Associates: 19–34.

Gitay, H.; Brown, S.; Easterling, W.; Jallow, B. 2001. Ecosystems and their goods and services. In: McCarthy, J.J.; Canziani, O.F.; Leary, N.A.; [et al.], eds. Climate change 2001: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press: 237–342.

Glenn, E.P.; Nagler, P.L. 2005. Comparative ecophysiology of *Tamarix ramosissima* and native trees in western U.S. riparian zones. Journal of Arid Environments. 61: 419–446.

Goheen, J.F.; Swihart, R.K. 2005. Resource selection and predation of North American red squirrels in deciduous forest fragments. Journal of Mammalogy. 86: 22–28.

Goldenberg, J.R. 2013. Multilocus species delimitation and species tree inference within the western rattlesnake (*Crotalus viridis*) species complex. San Diego, CA: San Diego State University. Thesis. 90 p.

Graham, R.T.; Rodriguez, R.L.; Paulin, K.M.; [et al.]. 1999. The northern goshawk in Utah: Habitat assessment and management recommendations. Gen. Tech. Rep. RMRS-GTR-22. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 48 p.

Graves, B.M.; Duvall, D. 1993. Occurrence and function of prairie rattlesnake mouth gaping in a non-feeding context. Journal of Experimental Zoology. 227: 471–474.

Green, J.S.; Flinders, J.T. 1980. Habitat and dietary relationships of the pygmy rabbit. Journal of Range Management. 33: 136–142.

Greenway, S.H. 1990. Aspen regeneration: A range management problem. Rangelands. 12: 21–23.

Gruell, G.; Bunting, S.; Neuenschwander, L. 1985. Influence of fire on curlleaf mountain-mahogany in the Intermountain West. In: Lotan, J.E.; Brown, J.K., comps. Fire's effects on wildlife habitat—Symposium proceedings; 1984 March 21; Missoula, MT. Gen. Tech. Rep. INT-186. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 58–72.

Gucker, C.L. 2006a. *Cercocarpus ledifolius*. In: Fire Effects Information System. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. http://www.fs.fed.us/database/feis [Accessed April 21, 2016].

Gucker, C.L. 2006b. *Cercocarpus montanus*. In: Fire Effects Information System. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. https://www.feis-crs.org/feis/[Accessed April 21, 2016].

Gullion, G.W.; Svovoda, F.J. 1972. The basic habitat resource for ruffed grouse. Aspen: Symposium proceedings. Gen. Tech. Rep. GTR-NC-1. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 113–119.

Gunnison Sage-Grouse Rangewide Steering Committee (GSRSC). 2005. Gunnison sage-grouse rangewide conservation plan. Denver, CO: Colorado Division of Wildlife. 359 p.

Gutzler, D.S.; Robbins, T.O. 2011. Climate variability and projected change in the western United States: Regional downscaling and drought statistics. Climate Dynamics. 37: 835–849.

Haak, B.; Howard, R.; Rautsaw, B.; [et al.]. 2003. Recovery plan for the northern Idaho ground squirrel (*Spermophilus brunneus brunneus*). Portland, OR: U.S. Fish and Wildlife Service. 68 p.

Hahn, B.; Saab, V.A.; Bentz, B.; [et al.]. 2014. Ecological consequences of the MPB epidemic for habitats and populations of wildlife. In: Matonis, M.; Hubbard R.; Gebert, K.; [et al.], eds. Future forests webinar series, webinar proceedings and summary: Ongoing research and management responses to the mountain pine beetle outbreak. RMRS-P-70. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 39–48.

Hall, L., Balda R.P. 1988. The role of scrub jays in pinyon regeneration. Final rep. Coop. Agree. 28-06-397. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 36 p.

Hanberg, M.B. 2000. Willow flycatcher and yellow-billed cuckoo surveys along the Green River (Sand Wash–Ouray) Utah, 2000. In: Howe, F.P.; Hanberg, M. 2000. Willow flycatcher and yellow-billed cuckoo surveys along the Green and San Juan rivers in Utah, 2000. Pub. 00-31. Salt Lake City, UT: Utah Division of Wildlife Resources: 1–27.

Hancock, N. 1966. Wildlife use of the salt desert shrub areas of the Great Basin. In: Salt desert shrub symposium proceedings; 1966 August 1-4; Cedar City, UT. U.S. Department of the Interior, Bureau of Land Management: 101–112.

Hansen, E.M.; Negrón, J.F.; Munson, A.S.; Anhold, J.A. 2010. A retrospective assessment of partial cutting to reduce spruce beetle-caused mortality in the southern Rocky Mountains. Western Journal of Applied Forestry. 25: 81–87.

Harrigan, R.J., Thomassen, H.A.; Buermann, W.; Smith, T.B. 2014. A continental risk assessment of west Nile virus under climate change. Global Change Biology. 20: 2417–2425.

Harvey, D.S.; Weatherhead, P.J. 2010. Habitat selection as the mechanism for thermoregulation in a northern population of massasauga rattlesnakes (*Sistrurus catenatus*). Ecoscience. 17: 411–419.

Hayward, G.D. 1989. Habitat use and population biology of boreal owls in the Northern Rocky Mountains, USA. Doctoral Dissertation. Moscow, ID: University of Idaho. 113 p.

Hayward, G.D. 1997. Forest management and conservation of boreal owls in North America. Journal of Raptor Research. 31: 114–124.

Hayward, L.C., Cottam, C.; Woodbury, A.M.; Frost, H.H. 1976. Birds of Utah. Great Basin Naturalist Memoirs No.1. 229 p.

Hayward, G.D.; Hayward, P.H. 1993. Boreal owl. In: Poole, A.; Gill, F., eds. The birds of North America, online. Philadelphia, PA: The Academy of Natural Sciences and Washington, DC: The American Ornithologists Union.

Hayward, G.D.; Verner J., tech. eds. 1994. Flammulated, boreal, and great gray owls in the United States: A technical conservation assessment. Gen. Tech. Rep. RM-253. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 214 p.

Helmuth, B.; Kingsolver, J.G.; Carrington, E. 2005. Biophysics, physiological ecology, and climate change: Does mechanism matter? Annual Review of Physiology. 67: 177–201.

Hendricks, P. 2003. Spring snow conditions, laying date, and clutch size in an alpine population of American Pipits. Journal of Field Ornithology. 74: 423–429.

Hester, S.G.; Grenier, M.B. 2005. A conservation plan for bats in Wyoming. Laramie, WY: Wyoming Game and Fish Department.

Hoberg, E.P.; Polley, L.; Jenkins, E.J.; Kutz, S.J. 2008. Pathogens of domestic and free-ranging ungulates: Global climate change in temperate to boreal latitudes across North America. Revue Scientifique et Technique. 27: 511–528.

Hof, C.; Araújo, M.B.; Jetz, W.; [et al.]. 2011. Additive threats from pathogens, climate and land-use change for global amphibian diversity. Nature. 480: 516–519.

Hoffman, R.W. 2006. White-tailed ptarmigan (*Lagopus leucura*): A technical conservation assessment. Golden, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. 71 p.

Hoffman, R.W.; Thomas, A.E. 2007. Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*): A technical conservation assessment. Golden, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. 131 p.

Holechek, J.L. 1981. Brush control impacts on rangeland wildlife. Journal of Soil and Water Conservation. 36: 265–269.

Hollenbeck, J.P.; Saab, V.A.; Frenzel, R.W. 2011. Habitat suitability and nest survival of white-headed woodpeckers in unburned forests of Oregon. Journal of Wildlife Management. 75: 1061-1071.

Holmes, J.A; Johnson, M.J. 2005. Brewer's Sparrow (*Spizella breweri*): A technical conservation assessment. Golden, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. 57 p.

Hoogland, J.L. 1981. The evolution of coloniality in white-tailed and black-tailed prairie dogs (Sciuridae: *Cynomys leucurus* and *C. ludovicianus*). Ecology. 62: 252–272.

Hoogland, J.L. 2009. Nursing of own and foster offspring by Utah prairie dogs (*Cynomys parvidens*). Behavioral Ecology and Sociobiology. 63: 1621–1634.

Hossack, B.R.; Pilliod, D.S. 2011. Amphibian responses to wildfire in the western United States: Emerging patterns from short-term studies. Fire Ecology. 7: 129–144.

Howard, J.L. 1996. *Populus tremuloides*. In: Fire Effects Information System, online. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. https://www.feis-crs.org/feis/ [Accessed April 21, 2016].

Howard, J.L. 2003. *Atriplex canescens*. In: Fire Effects Information System. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. https://www.feis-crs.org/feis/ [Accessed April 21, 2016].

Hu, J.; Moore, D.J.P.; Burns, S.P.; Monson, R.K. 2010. Longer growing seasons lead to less carbon sequestration by a subalpine forest. Global Change Biology. 19: 771–783.

Hülber, K.; Winkler, M.; Grabherr, G. 2010. Intraseasonal climate and habitat specific variability controls the flowering phenology of high alpine plant species. Functional Ecology. 24: 245–252.

Humphrey, S.R.; Kunz, T.H. 1976. Ecology of a Pleistocene relict, the western big-eared bat (*Plecotus townsendii*), in the southern Great Plains. Journal of Mammalogy. 57: 470–494.

Humphries, M.M.; Thomas, D.W.; Speakman, J.R. 2002. Climate-mediated energetic constraints on the distribution of hibernating mammals. Nature. 418: 313–316.

Hungerford, K.E. 1951. Ruffed grouse populations and cover use in northern Idaho. In: Quee, E.M., ed. Transactions of the 16th North American wildlife conference, Milwaukee, WI, March 5-7, 1951: 216–224.

Hupp, C.R.; Osterkamp, W.R. 1996. Riparian vegetation and fluvial geomorphic processes. Geomorphology. 14: 277–95.

Hurley, M.A.; Hebblewhite, M.; Gaillard, J.M.; [et al.]. 2014. Functional analysis of normalized difference vegetation index curves reveals overwinter mule deer survival is driven by both spring and autumn phenology. Philosophical Transactions of the Royal Society B-Biological Sciences. 369: 20130196.

Hutto, R.L. 2008. The ecological importance of severe wildfires: Some like it hot. Ecological Applications. 18: 1827–1834.

Hutto, R.L. 2014. Time budgets of male calliope hummingbirds on a dispersed lek. Wilson Journal of Ornithology. 126: 121–128.

Hutto, R.L.; Bond, M.L.; DellaSala, D.A. 2015. Using bird ecology to learn about the benefits of severe fire. In: DellaSala, D.A.; Hanson, C.T., eds. The ecological importance of mixed-severity fires: Nature's phoenix. New York, NY: Elsevier: 55–88.

Ibanez, I.; Clark, J.S.; Dietze, M.C. 2008. Evaluating the sources of potential migrant species: Implications under climate change. Ecological Applications. 18: 1664–1678.

Idaho Fish and Game (IDFG). 2005. Fringed Myotis (*Myotis thysanodes*). http://fishandgame.idaho.gov/ifwis/cwcs/pdf/Fringed%20Myotis.pdf [Accessed April 21, 2016].

Inman, R. M.; Magoun, A.J.; Persson, J.; Mattisson, J. 2012. The wolverine's niche: Linking reproductive chronology, caching, competition, and climate. Journal of Mammalogy. 93: 634–644.

Inouye, D. 2008. Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. Ecology. 89: 353–362.

Inouye, D.W.; Barr, B.; Armitage, K.B.; Inouye, B.D. 2000. Climate change is affecting altitudinal migrants and hibernating species. Proceedings of the National Academy of Sciences, USA. 97: 1630–1633.

Inouye, D.W.; McGuire, A.D. 1991. Effects of snowpack on timing and abundance of flowering in *Delphinium nelsonii* (Ranunculaceae): Implications for climate change. American Journal of Botany. 78: 997–1001.

Interagency Lynx Biology Team. 2013. Canada lynx conservation assessment and strategy. 3rd edition. For. Serv. Pub. R1-13. Missoula, MT: U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Fish & Wildlife Service, Bureau of Land Management, and National Park Service. 128 p.

Isaak, D.J.; Luce, C.H.; Rieman, B.E.; [et al.]. 2010. Effects of climate change and wildfire on stream temperatures and salmonid thermal habitat in a mountain river network. Ecological Applications. 20: 1350–1371.

Jacobson, E.R.; Gaskin, J.M.; Brown, M.B.; [et al.]. 1991. Chronic upper respiratory tract disease of free-ranging desert tortoises (*Xerobates agassizii*). Journal of Wildlife Diseases. 27: 296–316.

Jeffress, M.R.; Rodhouse, T.J.; Ray, C.; [et al.]. 2013. The idiosyncrasies of place: Geographic variation in the climate-distribution relationships of the American pika. Ecological Applications. 23: 864–878.

Jenkins, M.J.; Dicus, C.A.; Godfrey, J.E. 1998. Restoration of mixed conifer communities using prescribed fire in Bryce Canyon National Park. In: Pruden, T.L.; Brennan, L.A., eds. Fire in ecosystem management: Shifting the paradigm from suppression to prescription: Proceedings, Tall Timbers fire ecology conference; 1996 May 7-10; Boise, ID. No. 20. Tallahassee, FL: Tall Timbers Research Station: 231–235.

Jenkins, C.L.; Peterson, C.R.; Cossel Jr., J.O. 2008. Sagebrush steppe/desert shrublands. In: Pilliod, D.S.; Wind, E., eds. Habitat management guidelines for amphibians and reptiles of the northwestern United States and western Canada. Tech. Pub. HMG-4. Birmingham, AL: Partners in Amphibian and Reptile Conservation: 68–70.

Jennings, M.R. 1988. *Rana onca* Cope, relict leopard frog. Catalogue of American amphibians and reptiles. 417.1-417.2. Salt Lake City, UT: Society for the Study of Amphibians and Reptiles.

Jennings, R.D.; Riddle, B.R.; Bradford, D.F. 1995. Rediscovery of *Rana onca*, the relict leopard frog, in southern Nevada with comments on the systematic relationships of some southwestern leopard fogs (*Rana pipiens* complex) and the status of populations along the Virgin River. Silver City, NM: Western New Mexico University, Department of Natural Science. 71 p.

Jiguet, F.; Gadot, A.; Julliard, R.; [et al.]. 2007. Climate envelope, life history traits, and the resilience of birds facing global change. Global Change Biology. 13: 1672–1684.

Johnson, R.E. 2002. Black rosy-finch (*Leucosticte atrata*). In: Poole, A., ed. The birds of North America, online. Ithaca, NY: Cornell Laboratory of Ornithology.

Johnson, G.D. 2005. A review of bat mortality at wind-energy developments in the United States. Bat Research News. 46: 45–49.

Johnson, M.J.; Durst S.L.; Calvo, C.M.; [et al.]. 2008. Yellow-billed cuckoo distribution, abundance, and habitat use along the lower Colorado River and its tributaries, 2007 annual report. Open-File Rep. 2008-1177. Reston, VA: U.S. Geological Survey. 274 p.

Johnson, J.S.; Lacki, M.J.; Thomas, S.C.; Grider, J.F. 2012. Frequent arousals from winter torpor in Rafinesque's big-eared bat (*Corynorhinus rafinesquii*). PloS ONE. 7: e49754.

Johnson, P.T.J.; Lunde, K.B.; Thurman, E.M.; [et al.]. 2002. Parasite (*Ribeiroia ondatrae*) infection linked to amphibian malformations in the western United States. Ecological Monographs. 72: 151–168.

Johnston, K.M.; Schmitz, O.J. 1997. Wildlife and climate change: Assessing the sensitivity of selected species to simulated doubling of atmospheric CO_2. Global Change Biology. 3: 531–544.

Keinath, D. 2003. Species assessment for fringed myotis (*Myotis thysanodes*) in Wyoming. Cheyenne, WY: Bureau of Land Management, State Office. 71 p.

Keinath, D.A. 2004. Fringed myotis (*Myotis thysanodes*): A technical conservation assessment. Golden, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. 63 p.

Kennedy, P.L. 2003. Northern Goshawk (*Accipiter gentilis atricapillus*): A technical conservation assessment. Golden, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. 142 p.

Kiesecker, J.M.; Blaustein, A.R.; Belden, L.K. 2001. Complex causes of amphibian population declines. Nature: 401: 681–684.

Kindschy, R.R. 1986. Rangeland vegetative succession—implications to wildlife. Rangelands. 8: 157–159.

King, M.B.; Duvall, D. 1990. Prairie rattlesnake seasonal migrations: Episodes of movement, vernal foraging and sex differences. Animal Behaviour. 39: 924–935.

Kitchen, S.G.; Jorgensen, G.L. 1999. Annualization of rodent burrow clusters and winterfat decline in a salt-desert community. In: McArthur, E.D.; Ostler, W.K.; Wambolt, C.L., comps. Proceedings: Shrubland ecotones; 1998 August 12-14; Ephraim, UT. Proc. RMRS-P-11. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 175–180.

Klenner, W.; Huggard, D. 1997. Three-toed woodpecker nesting and foraging at Sicamous Creek. In: Hollstedt, C.; Vyse, A., eds. Sicamous Creek silvicultural systems project: Workshop proceedings; 1999, April 24-25; Kamloops, BC, Canada. Victoria, BC, Canada: Research Branch, British Columbia Ministry of Forests: 224–233.

Knick, S.T.; Hanser, S.E.; Preston, K.L. 2013. Modeling ecological minimum requirements for distribution of greater sage-grouse leks: Implications for population connectivity across their western range, USA. Ecology and Evolution. 3: 1539–1551.

Koch, P. 1996. Lodgepole pine in North America. Madison, WI: Forest Products Society. 329 p.

Koehler, G.M. 1990. Population and habitat characteristics of lynx and snowshoe hares in north central Washington. Canadian Journal of Zoology. 68: 845–851.

Kotliar, N.B.; Baker, B.W.; Whicker, A.D.; Plumb, G. 1999. A critical review of assumptions about the prairie dog as a keystone species. Environmental Management. 24: 177–192.

Kovalchik, B.L. 1987. Riparian zone associations: Deschutes, Ochoco, Fremont, and Winema National Forests. R6 ECOL TP-279-87. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 171 p.

Kozma, J.M. 2009. Nest-site attributes and reproductive success of white-headed and hairy woodpeckers along the east-slope of the Cascades in Washington state. In: Rich, T.D.; Arizmendi, C.; Demarest, D.W.; Thompson, C., eds. Proceedings of the fourth international Partners in Flight conference: Tundra to tropics. Cooper Ornithological Society: 52–61. http://www.partnersinflight.org/pubs/McAllenProc/index.cfm [Accessed September 9, 2017].

Kufeld, R.C.; Wallmo, O.C.; Feddema, C. 1973. Foods of the Rocky Mountain mule deer. Res. Pap. RM-111. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 31 p.

Laing, S.P. 1988. Cougar habitat selection and spatial use patterns in southern Utah. Laramie, WY: University of Wyoming. Thesis. 68 p.

LaManna, J.A.; Hemenway, A.B.; Boccadori, V.; Martin, T.E. 2015. Bird species turnover is related to changing predation risk along a vegetation gradient. Ecology. 96: 1670–1680.

Lambert, A.M.; Miller-Rushing, A.J.; Inouye, D.W. 2010. Changes in snowmelt date and summer precipitation affect the flowering phenology of *Erythronium grandiflorum* (Glacier Lily; Liliaceae). American Journal of Botany. 97: 1431–1437.

Lane, J.E.; Kruuk, L.E.; Charmantier, A.; [et al.]. 2012. Delayed phenology and reduced fitness associated with climate change in a wild hibernator. Nature. 489: 554–557.

Lanner, R.M. 1981. The piñon pine: A natural and cultural history. Reno, NV: University of Nevada Press. 208 p.

Lanner, R.M. 1983. Trees of the Great Basin: A natural history. Reno, NV: University of Nevada Press. 215 p.

Lanner, R.M. 1996. Made for each other: A symbiosis of birds and pines. New York, NY: Oxford University Press. 160 p.

Lanner, R.M.; Vander Wall, S.B. 1980. Dispersal of limber pine seed by Clark's nutcracker. Journal of Forestry. 78: 637–639.

Larrison, E.J.; Johnson, D.R. 1981. Mammals of Idaho. Moscow, ID: University Press of Idaho. 166 p.

Latif, Q.S.; Saab, V.A.; Mellen-McLean, K.; Dudley, J.G. 2014. Evaluating habitat suitability models for white-headed woodpeckers in unburned forests. Journal of Wildlife Management. 79: 1–11.

Laundre, J.W.; Hernandez, L. 2003. Winter hunting habitat of pumas *Puma concolor* in northwestern Utah and southern Idaho, USA. Wildlife Biology. 9: 123–129.

Lawing, A.M.; Polly, P.D. 2011. Pleistocene climate, phylogeny, and climate envelope models: An integrative approach to better understand species' response to climate change. PloS ONE. 6: e28554.

Leonard, D.L., Jr. 2001. American three-toed woodpecker (*Picoides dorsalis*). In: Poole, A., ed. The birds of North America, online. Ithaca, NY: Cornell Laboratory of Ornithology.

Lillywhite, H.B.; Licht, P.; Chelgren, P. 1973. The role of behavioral thermoregulation in the growth energetics of the toad, *Bufo boreas*. Ecology. 54: 375–83.

Linkhart, B.D. 2001. Life history characteristics and habitat quality of flammulated owls in Colorado. Boulder, CO: University of Colorado. Dissertation. 206 p.

Linkhart, B.D.; Fox, J.W.; Yanco, S.W. 2016. Migration timing and routes, and wintering areas of flammulated owls. Journal of Field Ornithology. 87: 42–54.

Linkhart, B.D.; McCallum, D.A. 2013. Flammulated owl (*Psiloscops flammeolus*). In: Poole, A., ed. The birds of North America, online. Ithaca, NY: Cornell Laboratory of Ornithology.

Linkhart, B.D.; Reynolds, R.T. 2004. Longevity of flammulated owls: Additional records and comparisons to other North American strigiforms. Journal of Field Ornithology. 75: 192–195.

Littell, J.S.; McKenzie, D.; Peterson, D.L.; Westerling, A.L. 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916-2003. Ecological Applications. 19: 1003–1021.

Littell, J.S.; Oniel, E.E.; McKenzie, D.; [et al.]. 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. Climatic Change. 102: 129–158.

Logan, K.A.; Irwin, L.L. 1985. Mountain lion habitats in the Big Horn Mountains, Wyoming. Wildlife Society Bulletin. 13: 257–262.

Long, Z.L.; Prepas, E.E. 2012. Scale and landscape perception: The case of refuge use by Boreal Toads (*Anaxyrus boreas boreas*). Canadian Journal of Zoology. 90: 1015–1022.

Lonner, T.N.; Pac, D.F. 1990. Elk and mule deer use of whitebark pine forests in southwest Montana: An ecological perspective. In: Schmidt, W.C.; McDonald, K.J., comps. Proceedings: Symposium on whitebark pine ecosystems: Ecology and management of a high-mountain resource; 1989 March 29-31; Bozeman, MT. Gen. Tech. Rep. INT-GTR-270. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 237–244.

Lotan, J.E.; Critchfield, W.B. 1990. *Pinus contorta* Dougl. ex. Loud. Lodgepole pine. In: Burns, R.M.; Honkala, B.H., technical coordinators. Silvics of North America, Volume 1. Conifers. Agric. Handbk 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 302–315.

Lucas, J.; Barsugli, J.; Doesken, N.; [et al.]. 2014. Climate change in Colorado: A synthesis to support water resources management and adaptation. Second edition. Rep. for Colorado Water Conserv. Board. Boulder, CO: Western Water Assessment, University of Colorado. 52 p.

Luce, R.J.; Keinath, D. 2007. Spotted bat (*Euderma maculatum*): A technical conservation assessment. Golden, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. 51 p.

MacArthur, R.A.; Wang, C.H. 1973. Physiology of thermoregulation in the pika, *Ochotona princeps*. Canadian Journal of Zoology. 51: 11–16.

MacArthur, R.A.; Wang, C.H. 1974. Behavorial thermoregulation in the pika, *Ochotona princeps*: A field study using radio-telemetry. Canadian Journal of Zoology. 52: 353–358.

Maher, S.P.; Kramer, A.M.; Pulliam, J.T.; [et al.]. 2012. Spread of white-nose syndrome on a network regulated by geography and climate. Nature Communications. 3: 1306.

Maloney, E.D.; Camargo, S.J.; Chang, E.; [et al.]. 2014. North American climate in CMIP5 experiments: Part III: Assessment of twenty-first-century projections. Journal of Climate. 27: 2230–2270.

Marti, C.D. 1977. Avian use of an oakbrush community in northern Utah. The Southwestern Naturalist. 22: 367–374.

Marti, C.D. 1997. Flammulated owls (*Otus flammeolus*) breeding in deciduous forests. In: Duncan, J.R.; Johnson, D.H.; Nicholls, T.H., eds. Biology and conservation of owls of the Northern Hemisphere. Gen. Tech. Rep. GTR-NC-190. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 262–266.

Martin, T.E. 2007. Climate correlates of 20 years of trophic changes in a high elevation riparian system. Ecology. 88: 367–380.

Martin, T.E. 2015. Consequences of habitat change and resource selection specialization for population limitation in cavity-nesting birds. Journal of Applied Ecology. 52: 475–485.

Martin, A.C.; Zim, H.S.; Nelson, A.L. 1951. American wildlife and plants. New York, NY: McGraw-Hill. 500 p.

Martin, T.E.; Maron, J.L. 2012. Climate impacts on bird and plant communities from altered animal-plant interactions. Nature Climate Change. 2: 195–200.

Marzluff, J.M.; Knick, S.T.; Vekasy, M.S.; [et al.]. 1997. Spatial use and habitat selection of golden eagles in southwestern Idaho. The Auk. 114: 673–687.

Masters, R.A.; Sheley, R.L. 2001. Principles and practices for managing rangeland invasive plants. Journal of Range Management. 54: 502–517.

Matthews, J.H. 2008. Anthropogenic climate change in the Playa Lakes Joint Venture Region: Understanding impacts, discerning trends, and developing responses. Unpub. rep. Lafayette, CO: Playa Lakes Joint Venture. 40 p.

Mattson, D.J.; Blanchard, B.M.; Knight, R.R. 1992. Yellowstone grizzly bear mortality, human habituation, and whitebark pine seed crops. Journal of Wildlife Management. 56: 432–442.

Mattson, D.J.; Reinhart, D.P. 1996. Indicators of red squirrel (*Tamiasciurus hudsonicus*) abundance in the whitebark pine zone. Great Basin Naturalist. 56: 272–275.

Mauk, R.L.; Henderson, J.A. 1984. Coniferous forest habitat types of northern Utah. Gen. Tech. Rep. INT-170. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 89 p.

McArthur, E.D; Sanderson, S.C.; Webb, B.L. 1994. Nutritive quality and mineral content of potential desert tortoise food plants. Res. Pap. INT-473. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 26 p.

McCaffery, R.M.; Maxell, B.A. 2010. Decreased winter severity increases viability of a montane frog population. Proceedings of the National Academy of Sciences, USA. 107: 8644–8649.

McCallum, D.A. 1994. Review of technical knowledge: Flammulated owls. In: Hayward, G.D.; Verner, J., eds. Flammulated, boreal, and great gray owls in the United States: A technical conservation assessment. Gen. Tech. Rep. RM-253. U.S. Department of Agriculture, Forest Service Rocky Research Station: 14–46.

McCarty, J.P. 2001. Ecological consequences of recent climate change. Conservation Biology. 15: 320–331.

McDowell, N.G.; Allen, C.D. 2015. Darcy's law predicts widespread forest mortality under climate warming. Nature Climate Change. 5: 669–672.

McKelvey, K.S.; Copeland, J.P.; Schwartz, M.K.; [et al.]. 2011. Climate change predicted to shift wolverine distributions, connectivity, and dispersal corridors. Ecological Applications. 21: 2882–2897.

McKenzie, D.; Gedalof, Z.E.; Peterson, D.L; Mote, P. 2004. Climatic change, wildfire, and conservation. Conservation Biology. 18: 890–902.

McKenzie, D.; Miller, C.; Falk, D.A., eds. 2011. The landscape ecology of fire. Dordrecht, The Netherlands: Springer. 312 p.

McKinney, S.T.; Fiedler, C.E.; Tomback, D.F. 2009. Invasive pathogen threatens bird-pine mutualism: Implications for sustaining a high-elevation ecosystem. Ecological Applications. 19: 597–607.

McMenamin, S.K.; Hadly, E.A.; Wright, C.K. 2008. Climatic change and wetland desiccation cause amphibian decline in Yellowstone National Park. Proceedings of the National Academy of Sciences of the United States of America. 105: 16988–16993.

Means, R.E. 2011. Synthesis of lower treeline limber pine (*Pinus flexilis*) woodland knowledge, research needs, and management considerations. In: Keane, R.F.; Tomback, D.F.; Murray, M.P.; Smith, C.M., eds. The future of high-elevation, five-needle white pines in western North America: Proceedings of the high five symposium; 2010 28-30 June; Missoula, MT. Proc. RMRS-P-63. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 29–36.

Medin, D.E. 1986. Grazing and passerine breeding birds in a Great Basin low-shrub desert. Great Basin Naturalist. 46: 567–572.

Medin, D.E. 1990. Birds of a shadscale (*Artriplex confertifolia*) habitat in east central Nevada. Great Basin Naturalist. 50: 295–298.

Meeuwig, R.O.; Budy, J.D.; Everett, R.L. 1990. *Pinus monophylla* Torr. & Frem. singleleaf pinyon. In: Burns, R.M.; Honkala, B.H., tech. coords. Silvics of North America. Volume 1. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 380–384.

Mehringer, P.J., Jr.; Wigand, P.E. 1987. Western juniper in the Holocene. In: Everett, R.L., comp. Proceedings—Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 108–119.

Melillo, J.M.; Richmond, T.C.; Yohe, G.W., eds. 2014. Climate change impacts in the United States: Third National Climate Assessment. Washington, DC: U.S. Global Change Research Program. 829 p.

Mellen-McLean, K.; Wales, B.; Bresson, B. 2013. A conservation assessment for the white-headed woodpecker (*Picoides albolarvatus*). Portland, OR: U.S. Department of Agriculture, Forest Service, Northern Region and Bureau of Land Management, Oregon State Office. 41 p.

Memmott, J.; Craze, P.G.; Waser, N.M.; Price, M.V. 2007. Global warming and the disruption of plant-pollinator interactions. Ecology Letters. 10: 710–717.

Millar, C.I.; Westfall, R.D. 2010. Distribution and climatic relationships of the American pika (*Ochotona princeps*) in the Sierra Nevada and western Great Basin, U.S.A.; Periglacial landforms as refugia in warming climates. Arctic, Antarctic, and Alpine Research. 42: 76–88.

Miller, N.L.; Bashford, K.E.; Strem, E. 2003. Potential impacts of climate change on California hydrology. Journal of American Water Resources Association. 39: 771–784.

Miller, R.F.; Eddleman, L. 2000. Spatial and temporal changes of sage grouse habitat in the sagebrush biome. Tech. Bull. 151. Corvallis, OR: Oregon State University, Agricultural Experiment Station. 39 p.

Miller, D.S.; Hoberg, E.; Weiser, G.; [et al.]. 2012. A review of hypothesized determinants associated with bighorn sheep (*Ovis canadensis*) die-offs. Veterinary Medicine International. 2012: Art796527.

Miller, R.F.; Freeman, L. 2001. Spatial and temporal changes of sage grouse habitat in the sagebrush biome. Tech. Bul. 151. Corvallis, OR: Oregon State University Agricultural Experiment Station. 39 p.

Mills, L.S.; Zimova, M.; Oyler, J.; [et al.]. 2013. Camouflage mismatch in seasonal coat color due to decreased snow duration. Proceedings of the National Academy of Sciences, USA. 110: 7360–7365.

Moir, W.H.; Huckaby, L.S. 1994. Displacement ecology of trees near upper timberline. International Conference for Bear Research and Management. 9: 35–42.

Morelli, T.L.; Carr, S.C. 2011. A review of the potential effects of climate change on quaking aspen (*Populus tremuloides*) in the western United States and a new tool for surveying sudden aspen decline. Gen. Tech. Rep. PSW-GTR-235. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 31 p.

Morelli, T.L., Smith, A.B., Kastely, C.R.; [et al.]. 2012. Anthropogenic refugia ameliorate the severe climate-related decline of a montane mammal along its trailing edge. Proceedings of the Royal Society B. doi: 10.1098/rspb.2012.1301.

Morey, S.R. 1994. Age and size at metamorphosis in spadefoot toads: A comparative study of adaptation to uncertain environments. Riverside, CA: University of California. Dissertation. 235 p.

Morgan, J.A.; Lecain, D.R.; Mosier, A.R.; Milchunas, D.G. 2001. Elevated CO_2 enhances water relations and productivity and affects gas exchange in C3 and C4 grasses of the Colorado shortgrass steppe. Global Change Biology. 7: 451–466.

Moriarty, K.M.; Zielinski, W.J.; Gonzales, A.G.; [et al.]. 2009. Wolverine confirmation in California after nearly a century: Native or long-distance immigrant? Northwest Science. 83: 154–162.

Moritz, C.; Patton, J.L.; Conroy, C.J.; [et al.]. 2008. Impact of a century of climate change on small mammal communities in Yosemite National Park, USA. Science. 322: 261–264.

Morrison, M.L.; Hall, L.S. 1999. Habitat relationships of amphibians and reptiles in the Inyo-White Mountains, California and Nevada. In: Monsen, S.B.; Stevens, R., comps. Sustaining and restoring a diverse ecosystem: Proceedings: Ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15-18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 233–237.

Mower, K.J.; Smith, H.D. 1989. Diet similarity between elk and deer in Utah. Great Basin Naturalist. 49: 552–555.

Moyle, P.B.; Kiernan, J.D.; Crain, P.K.; [et al.]. 2013. Climate change vulnerability of native and alien freshwater fishes of California: A systematic assessment approach. PLoS ONE. 8: e63883.

Munroe, J.S. 2012. Physical, chemical, and thermal properties of soils across a forest-meadow ecotone in the Uinta Mountains, Northeastern Utah, U.S.A. Arctic, Antarctic, and Alpine Research. 44: 95–106.

Murphy, D.D.; Freas, K.E.; Weiss, S.B. 1990. An environment–metapopulation approach to population viability analysis. Conservation Biology. 4: 41–50.

Murray, D.L.; Steury, T.D.; Roth, J.D. 2008. Assessment of Canada lynx research and conservation needs in the Southern Range: Another kick at the cat. Journal of Wildlife Management. 72: 1463–1472.

Muths, E.; Corn, P.S.; Pessier; A.P.; Green, D.E. 2003. Evidence for disease-related amphibian decline in Colorado. Biological Conservation. 110: 357–365.

Muths, E.; Pilliod, D.S.; Livo, L.J. 2008. Distribution and environmental limitations of an amphibian pathogen in the Rocky Mountains. Biological Conservation. 141: 1484–1492.

Nagler, P.L.; Glenn, E.; Jarnevich, C.; Shafroth, P. 2011. Distribution and abundance of salt cedar and Russian olive in the western United States. Critical Reviews in Plant Sciences. 30: 508–523.

Nakazawa, Y.; Williams, R.; Peterson, A.T.; [et al.]. 2007. Climate change effects on plague and tularemia in the United States. Vector Borne Zoonotic Diseases. 7: 529–540.

Naugle, D.E.; Aldridge, C.L.; Walker, B.L.; [et al.]. 2004. West Nile virus: Pending crisis for greater sage-grouse. Ecology Letters. 7: 704–713.

Neuweiler, G. 2000. The biology of bats. New York, NY: Oxford University Press. 320 p.

Nilsson, C.; Svedmark, M. 2002. Basic principles and ecological consequences of changing water regimes: Riparian plant communities. Environmental Management. 30: 468–80.

Nydegger, N.C.; Smith, G.W. 1986. Prey populations in relation to *Artemisia* vegetation types in southwestern Idaho. In: McArthur, E.D.; Welch, B.L.; comps. Proceedings: Symposium on the biology of *Artemisia* and *Chrysothamnus*; 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 152–156.

Ogden, V.T.; Hornocker, M.G. 1977. Nesting density and success of prairie falcons in southwestern Idaho. Journal of Wildlife Management. 41: 1–11.

Oliver, G.V. 2000. The bats of Utah. Pub. 00-14. Salt Lake City, UT: Utah Division of Wildlife Resources. 141 p.

Oliver, G.V.; Tuhy, J. 2010. Ecological integrity tables of Utah animals of conservation concern. Salt Lake City, UT: Utah Division of Wildlife Resources. 630 p.

Olson, D.H. 2008. Riparian areas. In: Pilliod, D.S.; Wind E., eds. Habitat management guidelines for amphibians and reptiles of the Northwestern United States and Western Canada. Tech. Pub. HMG-4. Birmingham, AL: Partners in Amphibian and Reptile Conservation: 82–86.

Olson, R. 1992. Mule deer habitat requirements and management in Wyoming. B-965. Laramie, WY: University of Wyoming, Cooperative Extension Service. 15 p.

Olson, LE.; Sauder, J.D.; Albrecht, N.M.; [et al.]. 2014. Modeling the effects of dispersal and patch size on predicted fisher (*Pekania [Martes] pennant*) distribution in the U.S. Rocky Mountains. Biological Conservation. 169: 89–98.

O'Regan, S.M.; Palen, W.J.; Anderson, S.C. 2014. Climate warming mediates negative impacts of rapid pond drying for three amphibian species. Ecology. 95: 845–855.

Ostler, W.K.; Harper, K.T.; McKnight, K.B.; Anderson, D.C. 1982. The effects of increasing snowpack on a subalpine meadow in the Uinta Mountains, Utah, USA. Arctic and Alpine Research. 14: 203–214.

Ostoja, S.M.; Brooks, M.L.; Chambers, J.C.; Pendleton, B.K. 2013. Species of conservation concern and environmental stressors: local, regional, and global effects. In: Chamber, J.C.; Brooks, M.L.; Pendleton, B.K.; Raish, C.B., eds. The southern Nevada agency partnership science and research synthesis: science to support land management in southern Nevada. Gen. Tech. Rep. RMRS-GTR-303. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 91–124.

Ozgul, A.; Childs, D.Z.; Oli, M.K.; [et al.]. 2010. Coupled dynamics of body mass and population growth in response to environmental change. Nature. 466: 482–485.

Paige, C.; Ritter, S.A. 1999. Birds in a sagebrush sea: Managing sagebrush habitats for bird communities. Boise, ID: Partners in Flight, Western Working Group. 47 p.

Paprocki, N.; Glenn, N.F.; Atkinson, E.C.; [et al.]. 2015. Changing habitat use associated with distributional shifts of wintering raptors. Journal of Wildlife Management. 79: 402–412.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution, and Systematics. 37: 637–669.

Patton, D.R. 1975. Abert squirrel cover requirements in southwestern ponderosa pine. Res. Pap. RM-145. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 12 p.

Patton, D.R.; Green, W. 1970. Abert's squirrels prefer mature ponderosa pine. Res. Note RM-169. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 3 p.

Paxton, E.H.; Sogge, M.K.; Durst, S.L.; [et al.]. 2007. The ecology of the southwestern willow flycatcher in central Arizona—A 10-year synthesis report. Open-File Rep. 2007-1381. Reston, VA: U.S. Geological Survey. 143 p.

Peacock, S. 2011. Projected 21st century climate change for wolverine habitats within the contiguous United States. Environmental Research Letters. 6: 014007.

Pearl, C.A.; Adams, M.J.; Wente, W.H. 2007. Characteristics of Columbia spotted frog (*Rana luteiventris*) oviposition sites in northeastern Oregon, USA. Western North American Naturalist. 67: 86–91.

Pearl, C.A.; Bowerman, J.; Adams, M.J.; Chelgren, N.D. 2009. Widespread occurrence of the chytrid fungus *Batrachochytrium dendrobatidis* on Oregon spotted frogs (*Rana pretiosa*). EcoHealth. 6: 209–218.

Pederson, J.C.; Farentinos, R.C.; Littlefield, V.M. 1987. Effects of logging on habitat quality and feeding patterns of Abert squirrels. The Great Basin Naturalist. 47: 252–258.

Peek, J.M. 1974. Initial response of moose to a forest fire in northeastern Minnesota. American Midland Naturalist. 91: 435–438.

Perala, D.A. 1977. Manager's handbook for aspen in the north central states. Gen. Tech. Rep. GTR-NC-36. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 30 p.

Perfors, T.; Harte, J.; Alter, S.E. 2003. Enhanced growth of sagebrush *Artemisia tridentata* in response to manipulated ecosystem warming. Global Change Biology. 9: 736–742.

Perrine, J.D. 2005. Ecology of red fox (*Vulpes vulpes*) in the Lassen Peak region of California, USA. Berkeley, CA: University of California. Dissertation. 251 p. https://www.nps.gov/rlc/craterlake/upload/Perrine_2005.pdf

Perrine, J.D.; Campbell, L.A.; Green, G.A. 2010. Sierra Nevada red fox (*Vulpes vulpes necator*): A conservation assessment. R5-FR-010. U.S. Department of Agriculture, Forest Service, Pacific Southwest Region. 42 p.

Perry, L.G.; Andersen, D.C.; Reynolds, L.V.; [et al.]. 2012. Vulnerability of riparian ecosystems to elevated CO_2 and climate change in arid and semi-arid western North America. Global Change Biology. 18: 821–842.

Peterson, D.L.; Littell, J.S. 2012. Risk assessment for wildfire in the Western United States. In: Vose, J.M.; Peterson, D. L.; Patel-Weynand, T., eds. Effects of climatic variability and change on forest ecosystems: A comprehensive science synthesis for the U.S. forest sector. Gen. Tech. Rep. PNW-GTR-870. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 249–252.

Pettorelli, N.; Pelletier, F.; Hardenberg, A.V.; [et al.]. 2007. Early onset of vegetation growth vs. rapid green-up: Impacts on juvenile mountain ungulates. Ecology. 88: 381–390.

Pierson, E.D.; Wackenhut, M.C.; Altenbach, J.S; [et al.]. 1999. Species conservation assessment and strategy for Townsend's big-eared bat (*Corynorhinus townsendii townsendii* and *Corynorhinus townsendii pallescens*). Boise, ID: Idaho Department of Fish and Game. 73 p.

Pilliod, D.S.; Muths, E.; Scherer, R.D.; [et al.]. 2010. Effects of amphibian chytrid fungus on individual survival probability in wild boreal toads. Conservation Biology. 24: 1259–1267.

Pilliod, D.S.; Peterson, C.R.; Ritson, P.I. 2002. Seasonal migration of Columbia spotted frogs (*Rana luteiventris*) among complementary resources in a high mountain basin. Canadian Journal of Zoology. 80: 1849–1862.

Pilliod, D.S.; Wind, E. 2008. Habitat management guidelines for amphibians and reptiles of the Northwestern United States and Western Canada. Tech. Pub. HMG-4. Birmingham, AL: Partners in Amphibian and Reptile Conservation. 139 p.

Platt, J.B. 1976. Sharp-shinned hawk nesting and nest site selection in Utah. Condor. 78: 102–103.

Plummer, A.P.; Christensen, D.R.; Monsen, S.B. 1968. Restoring big-game range in Utah. Pub. 68-3. Ephraim, UT: Utah Division of Fish and Game. 183 p.

Poff, N.L.; Brinson, M.M.; Day, J.W. 2002. Aquatic ecosystems and global climate change: Potential impacts on inland freshwater and coastal wetland ecosystems in the United States. Washington, DC: Pew Center on Global Climate Change. 56 p.

Portier, C.; Festa-Bianchet, M.; Gaillard, J.M.; [et al.]. 1998. Effects of density and weather on survival of bighorn sheep lambs (*Ovis canadensis*). Journal of Zoology. 245: 271–278.

Pounds, J.A.; Bustamante, M.R.; Coloma, L.A.; [et al.]. 2006. Widespread amphibian extinctions from epidemic disease driven by global warming. Nature. 439: 161–167.

Powell, R.A. 1993. The fisher: Life history, ecology and behavior. Second edition. Minneapolis, MN: University of Minnesota Press. 237 p.

Puschendorf, R.; Carnaval, A.C.; VanDerWal, J.; [et al.]. 2009. Distribution models for the amphibian chytrid *Batrachochytrium dendrobatidis* in Costa Rica: Proposing climatic refuges as a conservation tool. Diversity and Distributions. 15: 401–408.

Pyle, P.; Nur, N.; DeSante, D.F. 1994. Trends in nocturnal migrant landbird populations at southeast Farallon Island, California, 1968-1992. In: Jehl, J.R.; Johnson, N.K., eds. A century of avifaunal change in western North America. Cooper Ornithological Society, Studies in Avian Biology. 15: 58–74.

Ramsey, R.D.; West N.E. 2009. Vegetation of Utah. In: Banner, R.E.; Baldwin B.D.; McGinty, E.I.L., eds. Rangeland resources of Utah. Logan, UT: Utah State University, Cooperative Extension Service: 49–94.

Rawley, E.V.; Bailey, W.J.; Mitchell, D. L.; [et al.]. 1996. Utah upland game. Pub. 63-12. Salt Lake City, UT: Utah Division of Wildlife Resources.

Ray, C.; Beever, E. 2007. Distribution and abundance of the American pika (*Ochotona princeps*) within Lava Beds National Monument. Final rep. Indian Wells, CA: U.S. Department of the Interior, National Park Service, Lava Beds National Monument. 62 p.

Ray, C., Beever, E.A. and Rodhouse, T.J., 2016. Distribution of a climate-sensitive species at an interior range margin. Ecosphere. 7(6) DOI:10.1002/ecs2.1379.

Reading, C.J. 2007. Linking global warming to amphibian declines through its effects on female body condition and survivorship. Oecologia. 151: 125–131.

Reaser, J.K. 2000. Demographic analysis of the Columbia spotted frog (*Rana luteiventris*): Case study in spatiotemporal variation. Canadian Journal of Zoology. 78: 1158–1167.

Reeves, M.C.; Moreno, A.L; Bagne, K.E.; Running, S.W. 2014. Estimating climate change effects on net primary production of rangelands in the United States. Climatic Change. 126: 429–442.

Rehfeldt, G.E.; Crookston, N.L.; Saenz-Romero, C.; Campbell, E.M. 2012. North American vegetation model for land-use planning in a changing climate: A solution to large classification problems. Ecological Applications. 22: 119–141.

Rehfeldt, G.E.; Ferguson, D.E.; Crookston, N.L. 2009. Aspen, climate, and sudden decline in western USA. Forest Ecology and Management. 258: 2353–2364.

Rennecker, L.A.; Hudson, R.G. 1986. Seasonal energy expenditure and thermo-regulatory response of moose. Canadian Journal of Zoology. 64: 322–327.

Rhea, B.; Bidwell, M.D.; Livensperger, C. 2013. Sensitive species assessment of vulnerability to climate change on San Juan public lands, Colorado. Silverton, CO: Mountain Studies Institute. 153 p.

Ritchie, B.W. 1978. Ecology of moose in Fremont County, Idaho. Wildl. Bull. 7. Boise, ID: Idaho Department of Fish and Game. 33 p.

Rogers, P.C.; Mittanck, C.M. 2014. Herbivory strains resilience in drought-prone aspen landscapes of the western United States. Journal of Vegetation Science. 25: 457–469.

Romero-Lankao, P.; Smith, J.B; Davidson, D.J.; [et al.]. 2014. Chapter 26: North America. In: Barros, V.R.; Field, C.B.; Dokken, D.J.; [et al.], eds. Climate change 2014: Impacts, adaptation, and vulnerability. Part B: Regional aspects. Contribution of working group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press: 1439–1498.

Romme, W.H.; Turner, M.G.; Wallace, L.L.; Walker, J.S. 1995. Aspen, elk, and fire in northern Yellowstone Park. Ecology. 76: 2097–2106.

Ronco, F.P., Jr. 1990. *Pinus edulis* Engelm. pinyon. In: Burns, R.M.; Honkala, B.H., tech. coords. Silvics of North America. Volume 1. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 327–337.

Ross, D.A.; Stanger, M.C.; McDonald, K.; [et al.]. 1994. Distribution, habitat use, and relative abundance indices of spotted frogs in the West Desert, Utah, 1993. Pub. 93-15. Salt Lake City, UT: Utah Division of Wildlife Resources. 47 p.

Rotenberry, J.T.; Patten, M.A.; Preston, K.L. 1999. Brewer's sparrow (*Spizella breweri*). In: Poole, A.; Gill, F., eds. The birds of North America, online. Philadelphia, PA: The Academy of Natural Sciences, and Washington, DC: American Ornithologists Union.

Rowe, R.J., 2009. Environmental and geometric drivers of small mammal diversity along elevational gradients in Utah. Ecography. 32: 411–422.

Rowe, R.J.; Finarelli, J.A.; Rickart, E.A. 2010. Range dynamics of small mammals along an elevational gradient over an 80-year interval. Global Change Biology. 16: 2930–2943.

Rowe, R.J.; Terry, R.C.; Rickart, E.A. 2011. Environmental change and declining resource availability for small-mammal communities in the Great Basin. Ecology. 92: 1366–1375.

Ruggiero, L.F.; Aubry, K.B.; Buskirk, S.W.; [et al.]. 1999. Ecology and conservation of lynx in the United States. Gen. Tech. Rep. RMRS-GTR-30. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 474 p.

Ruggiero, L., Aubry, K., Buskirk, S.; [et al.]. 1994. The scientific basis for conserving forest carnivores: American marten, fisher, lynx, and wolverine in the western United States. Gen. Tech. Rep. RM-254. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 184 p.

Russell, D.M.; Goldberg, C.S.; Waits, L.P.; Rosenblum, E.B. 2010. *Batrachochytrium dendrobatidis* infection dynamics in the Columbia spotted frog *Rana luteiventris* in north Idaho, USA. Diseases of Aquatic Organisms. 92: 223–230.

Saab, V.A.; Latif, Q.S.; Rowland, M.M.; [et al.]. 2014. Ecological consequences of mountain pine beetle outbreaks for wildlife in Western North American forests. Forest Science. 60: 539–559.

Salkeld, D.J.; Salathé, M.; Stapp, P.; Jones, J.H. 2010. Plague outbreaks in prairie dog populations explained by percolation thresholds of alternate host abundance. Proceedings of the National Academy of Sciences of the United States of America. 107: 14247–14250.

Salzer, M.W.; Hughes, M.K.; Bunn, A.G.; Kipfmueller, K.F. 2009. Recent unprecedented tree-ring growth in bristlecone pine at the highest elevations and possible causes. Proceedings of the National Academy of Sciences of the United States of America. 106: 20348–20353.

Sauer, J.R.; Hines, J.E.; Fallon, J. 2008. The North American breeding bird survey, results and analysis 1966–2007. Version 5.15.2008. Laurel, MD: USGS Patuxent Wildlife Research Center. http://www.mbr-pwrc.usgs.gov/bbs/bbs.html [Accessed April 21, 2016].

Saunders, J.K. 1955. Food habits and range use of the Rocky Mountain goat in the Crazy Mountains, Montana. Journal of Wildlife Management. 19: 429–437.

Schlaepfer, D.R.; Lauenroth, W.K.; Bradford, J.B. 2012. Effects of ecohydrological variables on current and future ranges, local suitability patterns, and model accuracy in big sagebrush. Ecography. 35: 374–384.

Scholer, M.N.; Leu, M.; Belthoff, J.R. 2014. Factors associated with flammulated owl and northern saw-whet owl occupancy in southern Idaho. Journal of Raptor Research. 48: 128–141.

Schroeder, R.L. 1984. Habitat suitability index models: Blue grouse. FWS/OBS-82/10.81. Washington, DC: U.S. Fish and Wildlife Service. 19 p.

Schroeder, M.A.; Young, J.R.; Braun, C.E. 1999. Greater sage-grouse (*Centrocercus urophasianus*). In: Rodewald, P.G., ed. The birds of North America. NY: Cornell Laboratory of Ornithology.

Schwartz, M.K.; Copeland, J.P.; Anderson, N.J.; [et al.]. 2009. Wolverine gene flow across a narrow climatic niche. Ecology. 90: 3222–3232.

Schwartzberg, E.G.; Jamieson, M.A.; Raffa, K.F.; [et al.]. 2014. Simulated climate warming alters phenological synchrony between an outbreak insect herbivore and host trees. Oecologia. 175: 1041–1049.

Scott, V.E.; Crouch, G.L.; Whelan, J.A. 1982. Responses of birds and small mammals to clearcutting in a subalpine forest in central Colorado. Res. Note RM-422. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 6 p.

Scott, V.E.; Whelan, J.A.; Alexander, R.R. 1978. Dead trees used by cavity-nesting birds on the Fraser Experimental Forest: A case history. Res. Note RM-360. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 4 p.

Seager, R.; Ting, M.; Held, I.; [et al.]. 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. Science. 316: 1181–1184.

Seager, R.; Vecchi, G.A. 2010. Greenhouse warming and the 21st century hydroclimate of southwestern North America. Proceedings of the National Academy of Sciences, USA. 107: 21277–21282.

Seidl, R.; Schelhaas, M.J.; Lindner, M; Lexer, M.J. 2009. Modelling bark beetle disturbances in a large scale forest scenario model to assess climate change impacts and evaluate adaptive management strategies. Regional Environmental Change. 9: 101–119.

Seigel, R.A.; Sheil, C.A.; Doody, J.S. 1998. Changes in a population of an endangered rattlesnake *Sistrurus catenatus* following a severe flood. Biological Conservation. 83: 127–131.

Sekercioglu, C.H.; Schneider, S.H.; Fay, J.P.; [et al.]. 2008. Climate change, elevational range shifts, and bird extinctions. Conservation Biology. 22: 140–150.

Semlitsch, R.D. 2000. Principles for management of aquatic-breeding amphibians. Journal of Wildlife Management. 64: 615−631.

Senft, R.L.; Coughenour, M.B.; Bailey, D.W.; [et al.]. 1987. Large herbivore foraging and ecological hierarchies. Bioscience. 37: 789–799.

Settele, J.; Scholes, R.; Betts, R.; [et al.]. 2014. Terrestrial and inland water systems. In: Field, C.B.; Barros, V.R.; Dokken, D.J.; [et al.], eds. Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press: 271–359.

Shaffer, S.L.; Bartlein, P.J.; Thompson, R.S. 2001. Potential changes in the distributions of western North America tree and shrub taxa under future climate scenarios. Ecosystems. 4: 200–215.

Sheffield, J.; Wood, E.F. 2008. Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations. Climate Dynamics. 31: 79–105.

Shepperd, W.D. 1986. Silviculture of aspen forests in the Rocky Mountains and Southwest. RM-TT-7. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 38 p.

Sherman, P.W.; Runge, M.C. 2002. Demography of a population collapse: The northern Idaho ground squirrel (*Spermophilus brunneus brunneus*). Ecology. 83: 2816–2831.

Short, H.L.; McCulloch, C.Y. 1977. Managing pinyon-juniper ranges for wildlife. Gen. Tech. Rep. RM-47. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 10 p.

Sierra Nevada Red Fox Interagency Working Group (SNRFIWG). 2010. Sierra Nevada red fox fact sheet. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5282562.pdf [Accessed December 28, 2016].

Simonin, K.A. 2000. *Quercus gambelii*. In: Fire Effects Information System. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. http://www.fs.fed.us/database/feis/ [Accessed April 21, 2016].

Simpson, W.G. 2009. American pikas inhabit low-elevation sites outside the species' previously described bioclimatic envelope. Western North American Naturalist. 69: 243–250.

Sinervo, B.; Mendez-De-La-Cruz, F.; Miles, D.B.; [et al.]. 2010. Erosion of lizard diversity by climate change and altered thermal niches. Science. 328: 894–899.

Singer, M.; Parmesan, C. 2010. Phenological asynchrony between herbivorous insects and their hosts: Signal of climate change or pre-existing adaptive strategy? Philosophical Transactions of the Royal Society B-Biological Sciences. 365: 3161–3176.

Small-Lorenz, S.L.; Culp, L.A.; Ryder, T.B.; [et al.]. 2013. A blind spot in climate change vulnerability assessments. Nature Climate Change. 3: 91–93.

Smith, A.T. 1974. The distribution and dispersal of pikas: Consequences of insular population structure. Ecology. 55: 1112–1119.

Smith, B.E.; Keinath, D.A. 2007. Northern leopard frog (*Rana pipiens*): A technical conservation assessment. Unpublished report prepared for the USDA Forest Service, Rocky Mountain Region, Species Conservation Project. Golden, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. 66 p.

Smith, D.W.; Tyers, D.B. 2008. The beavers of Yellowstone. Yellowstone Science. 16: 4–15.

Smith, R.L. 1990. Ecology and field biology. New York, NY: Harper and Row. 720 p.

Squires, J.; Ruggiero, L. 2007. Winter prey selection of Canada lynx in northwestern Montana. Journal of Wildlife Management. 71: 310–315.

Squires, J.R.; DeCesare, N.J.; Kolbe, J.A.; Ruggiero, L.F. 2010. Seasonal resource selection of Canada lynx in managed forests of the northern Rocky Mountains. Journal of Wildlife Management. 74: 1648–1660.

Squires, J.R.; DeCesare, N.J.; Olson, L.E.; [et al.]. 2013. Combining resource selection and movement behavior to predict corridors for Canada lynx at their southern range periphery. Biological Conservation. 157: 187–195.

Stahelin, R. 1943. Factors influencing the natural restocking of high altitude burns by coniferous trees in the central Rocky Mountains. Ecology. 24: 19–30.

Stauffer, D.F.; Peterson, S.R. 1985. Ruffed and blue grouse habitat use in southeastern Idaho. Journal of Wildlife Management. 49: 459–466.

Steele, R.; Pfister, R.D.; Ryker, R.A.; Kittams, J.A. 1981. Forest habitat types of central Idaho. Gen. Tech. Rep. INT-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 138 p.

Steenhof, K.; Kochert, M.N. 1988. Dietary responses of three raptor species to changing prey densities in a natural environment. Journal of Animal Ecology. 57: 37–48.

Steenhof, K.; Yensen, E.; Kochert, M.N.; Gage, K.L. 2006. Populations and habitat relationships of Piute ground squirrels in Southwestern Idaho. Western North American Naturalist. 66: 482–491.

Still, S.M.; Richardson, B.A. 2015. Projections of contemporary and future climate niche for Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*): A guide for restoration. Natural Areas Journal. 35: 30–43.

Stille, W.T. 1954. Observations on the reproduction and distribution of the green snake, *Opheodrys vernalis* (Harlan). Nat. Hist. Misc. Chicago Academy of Sciences. 127: 1–11.

Stone, W.E. 1995. The impact of a mountain pine beetle epidemic on wildlife habitat and communities in post-epidemic stands of a lodgepole pine forest in northern Utah. Logan, UT: Utah State University. Dissertation. 229 p.

Stricklan, D.; Flinders, J.T.; Cates, R.G. 1995. Factors affecting selection of winter food and roosting resources by porcupines in Utah. The Great Basin Naturalist. 55: 29–36.

Stubbendieck, J.; Hatch, S.L.; Hirsch, K.J. 1997. North American range plants, 5th edition. Lincoln, NE: University of Nebraska Press. 465 p.

Sullivan, T.P. 1985. Small mammal damage agents which affect the intensive silviculture of lodgepole pine. In: Baumgartner, D.M.; Krebill, R.G.; Arnott, J.T.; Weetman, G.F., eds. Lodgepole pine: The species and its management: symposium proceedings; 1984 May 8-10; Spokane, WA and 1984 May 14-16; Vancouver, BC, Canada. Pullman, WA: Washington State University, Cooperative Extension Service: 97–105.

Sullivan, T.P.; Coates, H.; Jozsa, L.A.; Diggle, P.K. 1993. Influence of feeding damage by small mammals on tree growth and wood quality in young lodgepole pine. Canadian Journal of Forest Research. 23: 799–809.

Sutherst, R.W.; Maywald, G.F.; Bourne, A.S. 2007. Including species interactions in risk assessments for global change. Global Change Biology. 13: 1843–1859.

Suttle, K.B.; Thomsen, M.A.; Power, M.E. 2007. Species interactions reverse grassland responses to changing climate. Science. 315: 640–642.

Teste, F.P.; Lieffers, V.J.; Landhausser, S.M. 2011. Seed release in serotinous lodgepole pine forests after mountain pine beetle outbreak. Ecological Applications. 21: 150–162.

Thackeray, S.J.; Sparks, T.H.; Frederiksen, M.; [et al.]. 2010. Trophic level asynchrony in rates of phenological change for marine, freshwater and terrestrial environments. Global Change Biology. 16: 3304–3313.

Thorup, K.; Tottrup, A.P.; Rahbek, C. 2007. Patterns of phenological changes in migratory birds. Oecologia. 151: 697–703.

Tomback, D.F. 1978. Foraging strategies of Clark's nutcracker. Living Bird. 16: 123–161.

Tomback, D.F.; Achuff, P. 2010. Blister rust and western forest biodiversity: Ecology, values and outlook for white pines. Forest Pathology. 40: 186–225.

Tomback, D.F.; Kendall, K.C. 2001. Biodiversity losses: The downward spiral. In: Tomback, D.F.; Arno, S.F.; Keane, R.E., eds. Whitebark pine communities: Ecology and restoration. Washington, DC: Island Press. 243–262.

Tomback, D.F.; Linhart, Y.B. 1990. The evolution of bird-dispersed pines. Evolutionary Ecology. 4: 185–219.

Uchytil, R.J. 1991. *Picea engelmannii* and *Abies lasiocarpa*. In: Fire Effects Information System. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. http://www.fs.fed.us/database/feis [Accessed April 21, 2016].

U.S. Department of Agriculture, Forest Service [USDA FS]. 2014. Fringed myotis M013 (*Myotis thysandoes*). http://www.fs.fed.us/psw/publications/documents/psw_gtr037/mammals/m013.pdf [Accessed March 16, 2016].

U.S. Fish and Wildlife Service [USFWS]. 2003. Recovery plan for the northern Idaho ground squirrel (*Spermophilis brunneus brunneus*). 78 p. http://ecos.fws.gov/docs/recovery_plan/030916b.pdf [Accessed January 21, 2016].

U.S. Fish and Wildlife Service [USFWS]. 2007. Recovery plan for the Sierra Nevada bighorn sheep. Sacramento, CA. xiv + 199 p.

U.S. Fish and Wildlife Service [USFWS]). 2011. Revised recovery plan for the Mojave population of the desert tortoise (*Gopherus agassizii*). Sacramento, CA: U.S. Department of the Interior, Fish and Wildlife Service, Region 8, Pacific Southwest Region. 246 p. http://www.fws.gov/nevada/desert_tortoise/documents/recovery_plan/RRP%20for%20the%20Mojave%20Desert%20Tortoise%20 -%20May%202011.pdf [Accessed October 30, 2012].

U.S. Fish and Wildlife Service [USFWS]. 2015. Species report: Sierra Nevada red fox (*Vulpes vulpes necator*). https://www.fws.gov/sacramento/outreach/2015/10-07/docs/20150814_SNRF_SpeciesReport.pdf [Accessed April 20, 2016].

Utah State Department of Natural Resources (UDNR). 2015. Utah sensitive species list. UDNR: Salt Lake City, UT. 150 p.

Valdez, E.W.; Cryan, P.W. 2009. Food habits of the hoary bat (*Lasiurus cinereus*) during spring migration through New Mexico. The Southwestern Naturalist. 54: 195–200.

Van de Ven, C.M.; Weiss, S.B.; Ernst, W.G. 2007. Plant species distributions under present conditions and forecasted for warmer climates in an arid mountain range. Earth Interactions. 11: 1–33.

Van Horne, B.; Olson, G.S.; Schooley, R.L.; [et al.]. 1997. Effects of drought and prolonged winter on Townsend's ground squirrel demography in shrub steppe habitats. Ecological Monographs. 67: 295–315.

Vander Wall, S.B.; Hoffman, S.W.; Potts, W.K. 1981. Emigration behavior of Clark's nutcracker. The Condor. 83: 162–170.

Virkkala, R. 1991. Spatial and temporal variation in bird communities and populations in north-boreal coniferous forests: A multiscale approach. Oikos: 59–66.

Visser, M.E.; Both, C.; Lambrechts, M.M. 2004. Global climate change leads to mistimed avian reproduction. Advances in Ecological Research. 35: 89-110.

Visser, M.E. 2008. Keeping up with a warming world: Assessing the rate of adaptation to climate change. Proceedings of the Royal Society of London B-Biological Sciences. 275: 649–659.

Wagner, G.D.; Peek, J.M. 2006. Bighorn sheep diet selection and forage quality in Central Idaho. Northwest Science. 80: 246–258.

Walker, B.L.; Naugle, D.E. 2011. West Nile virus ecology in sagebrush habitat and impacts on greater sage-grouse populations. In Knick, S.T.; Connelly, J.W., eds. Greater sage-grouse: Ecology and conservation of a landscape species and its habitats. Studies in Avian Biology (vol. 38). Berkley, CA: University of California Press: 127–142.

Walsberg, G.E. 2000. Small mammals in hot deserts: Some generalizations revisited. BioScience. 50: 109–120.

Walters, R.E.; Sorensen, E. 1983. Utah bird distribution: Latilong study. Resour. Pub. 83-10. Salt Lake City, UT: Utah Division of Wildlife. 97 p.

Wasserman, T.N.; Cushman, S.A.; Shirk, A.S.; [et al.]. 2011. Simulating the effects of climate change on population connectivity of American marten (*Martes americana*) in the northern Rocky Mountains, USA. Landscape Ecology. 27: 211–225.

Webb, C.T.; Brooks, C.P.; Gage, K.L.; Antolin, M. F. 2006. Classic flea-borne transmission does not drive plague epizootics in prairie dogs. Proceedings of the National Academy of Sciences, USA. 103: 6236–6241.

Weed, A.S.; Ayres, M.P.; Hicke, J.A. 2013. Consequences of climate change for biotic disturbances in North American forests. Ecological Monographs. 83: 441–470.

Wente, W.H.; Adams, M.J.; Pearl, C.A. 2005. Evidence of decline for *Bufo boreas* and *Rana luteiventris* in and around the northern Great Basin, western USA. Alytes. 22: 95–108.

West, N.E. 1983. Intermountain salt-desert shrubland. In: West, N.E., ed. Ecosystems of the world, volume 5: Temperate deserts and semideserts. Amsterdam, Netherlands: Elsevier: 351–374.

Whitfield, S.M.; Bell, K.E.; Philippi, T.; [et al.]. 2007. Amphibian and reptile declines over 35 years at La Selva, Costa Rica. Proceedings of the National Academy of Sciences. 104: 8352–8356.

Wiens, J.D.; Noon, B.R.; Reynolds, R.T. 2006. Post-fledging survival of northern goshawks: The importance of prey abundance, weather, and dispersal. Ecological Applications. 16: 406–418.

Wiggins, D. 2004. American three-toed woodpecker (*Picoides dorsalis*): A technical conservation assessment. Golden, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. 40 p.

Wiggins, D. 2005. Loggerhead shrike (*Lanius ludovicianus*): A technical conservation assessment. Golden, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. 41 p.

Williams, M.I.; Paige, G.B.; Thurow, T.L.; [et al.]. 2011. Songbird relationships to shrub-steppe ecological site characteristics. Rangeland Ecology and Management. 64: 109–118.

Williams, M.W.; Losleben, M.V.; Hamann, H.B. 2002. Alpine areas in the Colorado Front Range as monitors of climate change and ecosystem response. Geographical Review. 92: 180–191.

Wilson, K.W.; Mills, M.D.; DuRoss, E.M. 2005. Columbia spotted frog (*Rana luteiventris*) chytrid monitoring summary. Springville, UT: Utah Division of Natural Resources, Central Region. ftp://ftp.utah.gov/dnrpub/dwr/Spotted_Frog/Grey_Literature/UDWR/N4610.C701.005F.Wil%20%20Columbia%20Spotted%20Frog%20Chytrid%20Monitoring%20Summary%20CRO%20report%202005.pdf [Accessed February 5, 2016].

Wilson, R.J.; Maclean, I.M.D. 2011. Recent evidence for the climate change threat to Lepidoptera and other insects. Journal of Insect Conservation. 15: 259–268.

Winter, T.C. 2000. The vulnerability of wetlands to climate change: A hydrologic landscape perspective. Journal of the American Water Resources Association. 36: 305–311.

Wolf, E.C.; Cooper, D.J.; Hobbs, N.T. 2007. Hydrologic regime and herbivory stabilize an alternative state in Yellowstone National Park. Ecological Applications. 17: 1572–1587.

Wolfe, L.L.; Diamond, B.; Spraker, T.R.; [et al.]. 2010a. A bighorn sheep die-off in southern Colorado involving a Pasteurellaceae strain that may have originated from syntopic cattle. Journal of Wildlife Diseases. 46: 1262–1268.

Wolfe, M.L.; Hersey, K.R.; Stoner, D.C. 2010b. A history of moose management in Utah. Alces. 46: 37–52.

Worrall, J.J.; Rehfeldt, G.E.; Hamann, A.; [et al.]. 2013. Recent declines of *Populus tremuloides* in North America linked to climate. Forest Ecology and Management. 299: 35–51.

Woyda, A.L.; Kessler, W.B. 1982. The response of selected owl species to silvicultural treatments on the Dixie National Forest, Utah. Final Rep. on Coop. Agreem. INT-81-129-CA. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 46 p.

Yanishevsky, R.; Petring-Rupp, S. 1998. Management of breeding habitat for selected bird species in Colorado. Denver, CO: Colorado Division of Wildlife. 791 p.

Yensen, E.; Quinney, D.L.; Johnson, K.; [et al.]. 1992. Fire, vegetation changes, and population fluctuations of Townsend's ground squirrels. American Midland Naturalist. 128: 299–312.

Youngblood, A.P.; Mauk, R.L. 1985. Coniferous forest habitat types of central and southern Utah. Gen. Tech. Rep. INT-187. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 89 p.

Zeigenfuss, L.C.; Schonecker, K.A.; Van Amburg, L.K. 2011. Ungulate herbivory on alpine willow in the Sangre de Cristo Mountains of Colorado. Western North American Naturalist. 71: 86–96.

Zielinski, W.J. 2014. The forest carnivores: Marten and fisher. In: Long, J.W.; Quinn-Davidson, L.; Skinner, C.N., eds. Science synthesis to support socioecological resilience in the Sierra Nevada and Southern Cascade Range. Gen. Tech. Rep. PSW-GTR-247. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 393–435.

Zielinski, W.J.; Spencer, W.D.; Barrett, R.H. 1983. Relationship between food habits and activity patterns of pine marten. Journal of Mammalogy. 64: 387–396.

Zlatnik, E. 1999. *Juniperus osteosperma*. In: Fire Effects Information System. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. http://www.fs.fed.us/database/feis/plants/tree/pinedu/all.html [Accessed April 21, 2016].

Zouhar, K.L. 2001. *Pinus monophylla*. In: Fire Effects Information System. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. http://www.fs.fed.us/database/feis/plants/tree/pinedu/all.html [Accessed April 21, 2016].

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

Michael S. Hand, Jordan W. Smith, David L. Peterson, Nancy A. Brunswick, and Carol P. Brown

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

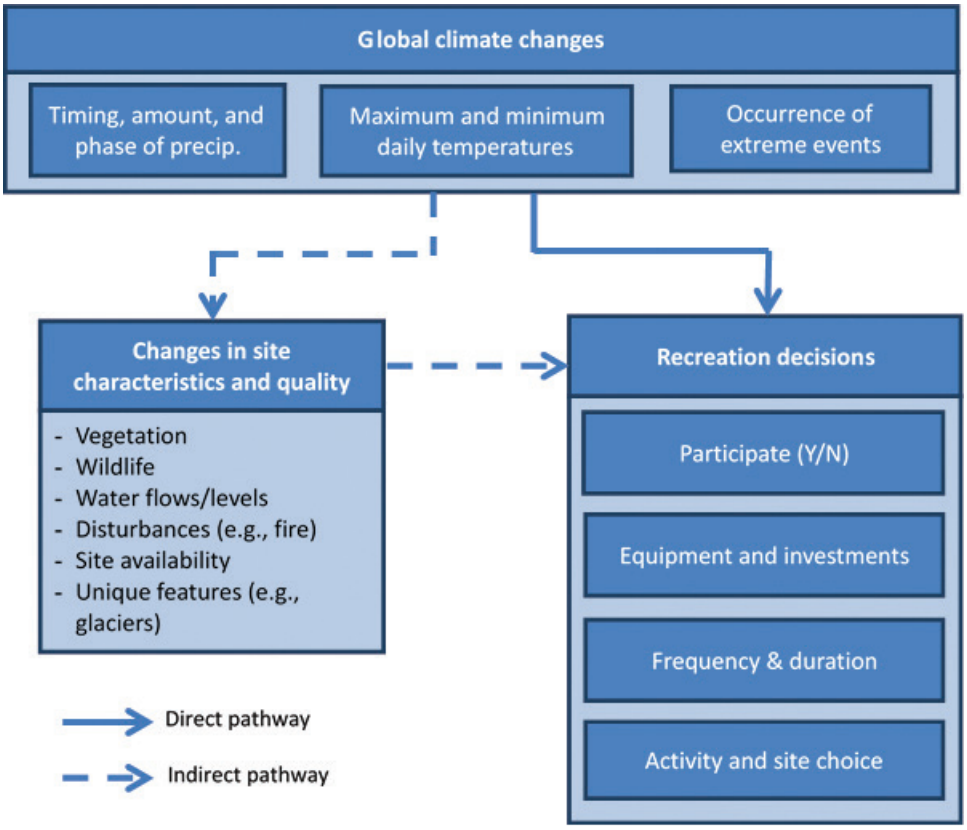


Figure 10.1—Conceptual model of the effects of climate change on recreation, showing direct and indirect pathways of effects.

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.

Spending category	Non-local spending[a,b]		Local spending[b]	
	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).

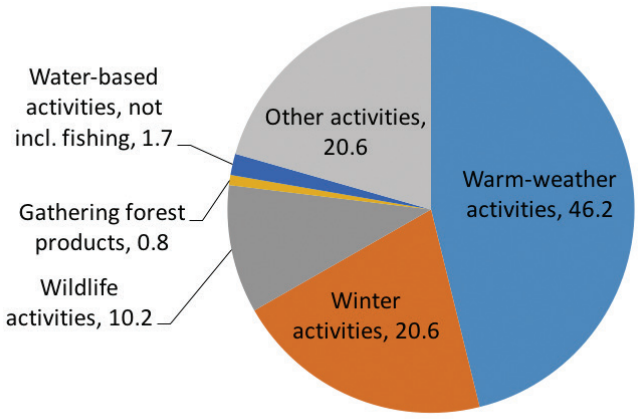


Figure 10.2—Percentage of total visits to national forests in the U.S. Forest Service Intermountain Region, by climate-sensitive primary activity (USDA FS n.d.).

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, inter-regional 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; inter-regional 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.

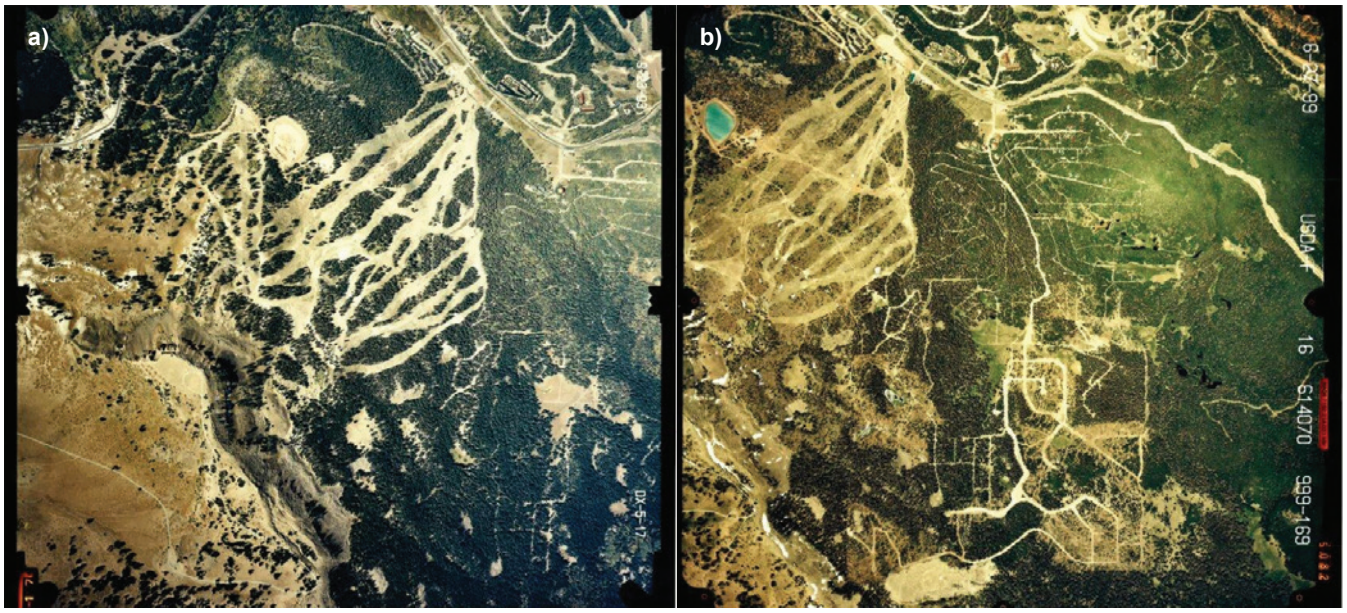


Figure 10.5—Aerial photos of Brian Head Ski Resort (Dixie National Forest) in 1993 (a) and 1999 (b), showing extensive mortality of Engelmann spruce caused by spruce beetle (photos: Dixie National Forest).

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.

References

Albano, C.M.; Angelo, C.L.; Strauch, R.L.; [et al.]. 2013. Potential effects of warming climate on visitor use in three Alaskan national parks. Park Science. 30: 37–44.

Anderson, C.; Taylor, G. 2014. Economic importance of off-highway vehicle recreation: An analysis of Idaho counties. CIS 1195. Moscow, ID: University of Idaho Extension.

Associated Press. 2012. Climate change poses challenges for water managers. News report, May 9, 2012. http://magicvalley.com [Accessed October 2, 2016].

Bark, R.H.; Colby, B.G.; Dominguez, F. 2010. Snow days? Snowmaking adaptation and the future of low latitude, high elevation skiing in Arizona, USA. Climatic Change. 102: 467–491.

Bernales, H.H.; Harvey, K.R.; Shannon, J. [n.d.]. Utah big game annual report 2013. Pub. 14-22. Salt Lake City, UT: State of Utah, Department of Natural Resources, Division of Wildlife Resources.

Bowker, J.M.; Askew, A.E.; Cordell, H.K.; [et al.]. 2012. Outdoor recreation participation in the United States—Projections to 2060: A technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. GTR-SRS-160. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 42 p.

Bowker, J.M.; Askew, A.E.; Poudyal, N.C.; [et al.]. 2013. Climate change and outdoor recreation participation in the Southern United States. In: Vose, J.M.; Klepzig, K.D., eds. Climate change adaptation and mitigation management options: A guide for natural resource managers in the southern forest ecosystems. Boca Raton, FL: CRC Press: 421–450.

Bowler, D.E.; Buyung-Ali, L.M.; Knight, T.M.; [et al.]. 2010. A systematic review of evidence for the added benefits to health of exposure to natural environments. BMC Public Health 10: 456.

Clark, R.N.; Stankey, G.H. 1979. The Recreation Opportunity Spectrum: A framework for planning, management, and research. Gen. Tech. Rep. PNW-GTR-098. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 32 p.

Cui, Y.; Mahoney, E.; Herbowicz, T. 2013. Economic benefits to local communities from national park visitation, 2011. Nat. Res. Rep. NPS/NRSS/ARD/NRR-2013/632. Fort Collins, CO: U.S. Department of the Interior, National Park Service.

Dawson, J.; Scott, D.; McBoyle, G. 2009. Climate change analogue analysis of ski tourism in the northeastern USA. Climate Research. 39: 1–9.

Duffield, J.W.; Neher, C.J.; Patterson, D.A.; [et al.]. 2013. Effects of wildfire on national park visitation and the regional economy: A natural experiment in the Northern Rockies. International Journal of Wildland Fire. 22: 1155–1166.

Englin, J.; Moeltner, K. 2004. The value of snowfall to skiers and boarders. Environmental and Resource Economics. 29: 123–136.

Englin, J; Boxall, P.C.; Chakraborty, K; [et al.]. 1996. Valuing the impacts of forest fires on backcountry forest recreation. Forest Science. 42: 450–455.

Englin, J.; Loomis, J.; González-Cabán, A. 2001. The dynamic path of recreational values following a forest fire: A comparative analysis of states in the Intermountain West. Canadian Journal of Forest Research. 31: 1837–1844.

Fisichelli, N.A.; Schuurman, G.W.; Monahan, W.B.; [et al.]. 2015. Protected area tourism in a changing climate: Will visitation at US national parks warm up or overheat? PLoS ONE 10: e0128226.

Gardner Policy Institute. 2016. The state of Utah's travel and tourism industry. Salt Lake City, UT: University of Utah, Kem C. Gardner Policy Institute.

Hamlet, A.F. 2000. Effects of climate change scenarios on ski conditions at Snoqualmie Pass, Stevens Pass, Mission Ridge, and Schweitzer Mountain ski areas. Internal report. Seattle, WA: University of Washington, Joint Institute for the Study of Atmosphere and Oceans, Climate Impacts Group.

Hand, M.S.; Lawson, M. 2018. Effects of climate change on recreation in the northern Rockies region. In: Halofsky, J.E.; Peterson, D.L.; Hoang, L., eds. Climate change vulnerability and adaptation in the Northern Rocky Mountains region. Gen. Tech. Rep. RMRS-GTR-374. Fort Collins, CO: U.S. Department of Agriculture, Rocky Mountain Research Station.

Hay, M.J.; McConnell, K.E. 1979. An analysis of participation in nonconsumptive wildlife recreation. Land Economics. 55: 460–471.

Hesseln, H.; Loomis, J.B.; González-Cabán, A. 2004. The effects of fire on recreation demand in Montana. Western Journal of Applied Forestry. 19: 47–53.

Hesseln, H.; Loomis, J.B.; González-Cabán, A.; [et al.]. 2003. Wildfire effects on hiking and biking demand in New Mexico: A travel cost study. Journal of Environmental Management. 69: 359–368.

Idaho State Parks and Recreation [ISPAR]. 2013. Day use visitation. Boise, ID: Idaho State Parks and Recreation. http://parksandrecreation.idaho.gov/sites/default/files/uploads/documents/Visitation%20Statistics/2013%20Day%20Use%20-%202014-01-15.pdf [Accessed March 4, 2016].

Irland, L.C.; Adams, D.; Alig, R.; [et al.]. 2001. Assessing socioeconomic impacts of climate change on U.S. forests, wood-product markets, and forest recreation. BioScience. 51: 753–764.

Jones, R.; Travers, C.; Rodgers, C.; [et al.]. 2013. Climate change impacts on freshwater recreational fishing in the United States. Mitigation and Adaptation Strategies for Global Change. 18: 731–758.

Klos, P.Z.; Link, T.E.; Abatzoglou, J.T. 2014. Extent of the rain-snow transition zone in the western U.S. under historic and projected climate. Geophysical Research Letters. 41: 4560–4568.

Leaver, J. 2014. The state of Utah's tourism, travel and recreation industry. Utah Economic and Business Review. 3: 1–15

Leung, Y–F.; Smith, J.W.; Miller, A. 2015. Statistical report of state park operations: 2013–2014—Annual information exchange for the period July 1, 2013 through June 30, 2014. Raleigh, NC: North Carolina State University, Department of Parks, Recreation and Tourism Management.

Loomis, J. 1995. Four models for determining environmental quality effects on recreational demand and regional economics. Ecological Economics. 12: 55–65.

Loomis, J.; Crespi, J. 2004. Estimated effects of climate change on selected outdoor recreation activities in the United States. In: Mendelsohn, R.; Neumann, J., eds. The impact of climate change on the United States economy, Cambridge, UK: Cambridge University Press: 289–314.

Loomis, J.; González-Cabán, A.; Englin, J. 2001. Testing for differential effects of forest fires on hiking and mountain biking demand and benefits. Journal of Agricultural and Resource Economics. 26: 508–522.

Loomis, J.B.; Richardson, R.B. 2006. An external validity test of intended behavior: Comparing revealed preference and intended visitation in response to climate change. Journal of Environmental Planning and Management. 49: 621–630.

Matzarakis, A.; de Freitas, C.R. 2001. Proceedings of the first international workshop on climate, tourism, and recreation. Milwaukee, WI: International Society of Biometeorology, University of Wisconsin-Milwaukee.

Mendelsohn, R.; Markowski, M. 2004. The impact of climate change on outdoor recreation. In: Mendelsohn, R.; Neumann, J., eds. The impact of climate change on the United States economy, Cambridge, United Kingdom: Cambridge University Press: 267–288.

Miller, J.R.; Hay, M.J. 1981. Determinants of hunter participation: Duck hunting in the Mississippi flyway. American Journal of Agricultural Economics. 63: 401–412.

Milon, J.W.; Clemmons, R. 1991. Hunters' demand for species variety. Land Economics. 67: 401–412.

Morey, E.R.; Breffle, W.S.; Rowe, R.D.; [et al.]. 2002. Estimating recreational trout fishing damages in Montana's Clark Fork River basin: Summary of a natural resource damage assessment. Journal of Environmental Management. 66: 159–170.

Morris, S.; Walls, M. 2009. Climate change and outdoor recreation resources. Backgrounder Rep. Washington, DC: Resources for the Future.

Mote, P.W.; Casson, J.; Hamlet, A.; [et al.]. 2008. Sensitivity of Northwest ski areas to warming. In McGurk, B., ed. Proceedings of the 75th Western Snow Conference, April 16–19, 2007, Kailua-Kona, Hawaii. Soda Springs, CA: Western Snow Conference: 63–67.

National Park Service [NPS]. 2006. Management policies. Chapter 8. Washington, DC: National Park Service. http://www.nps.gov/applications/npspolicy/index.cfm [Accessed March 4, 2016].

National Park Service [NPS]. 2014. National Park Service visitor use statistics, park reports, 5-year visitation summary, 2010-2014. https://irma.nps.gov/Stats/Reports/Park. [Accessed June 26, 2015].

Penrod, E. 2015. It's not just Utah Lake: Toxic algae plagues 20 waterways, including drinking water sources. The Salt Lake Tribune, August 7, 2015.

Pitts, H.M.; Thacher, J.A.; Champ, P.A.; [et al.]. 2012. A hedonic price analysis of the outfitter market for trout fishing in the Rocky Mountain West. Human Dimensions of Wildlife. 17: 446–462.

Rausch, M.; Boxall, P.C.; Verbyla, A.P. 2010. The development of fire-induced damage functions for forest recreation activity in Alberta, Canada. International Journal of Wildland Fire. 19: 63–74.

Richardson, R.B.; Loomis, J.B. 2004. Adaptive recreation planning and climate change: A contingent visitation approach. Ecological Economics. 50: 83–99.

Scott, D.; McBoyle, G. 2007. Climate change adaptation in the ski industry. Mitigation and Adaptation Strategies for Global Change. 12: 1411–1431.

Scott, D.; Dawson, J.; Jones, B. 2008. Climate change vulnerability of the U.S. Northeast winter recreation-tourism sector. Mitigation and Adaptation Strategies for Global Change. 13: 577–596.

Scott, D.; Jones, B.; Konopek, J. 2007. Implications of climate and environmental change for nature-based tourism in the Canadian Rocky Mountains: A case study of Waterton Lakes National Park. Tourism Management. 28: 570–579.

Shaw, D.; Loomis, J. 2008. Frameworks for analyzing the economic effects of climate change on outdoor recreation and selected estimates. Climate Research. 36: 259–269.

Smith, J.W.; Moore, R.L. 2013. Social-psychological factors influencing recreation demand: Evidence from two recreational rivers. Environment and Behavior. 45: 821–850.

Smith, J.W.; Seekamp, E.; McCreary, A.; [et al.]. 2016. Shifting demand for winter outdoor recreation along the North Shore of Lake Superior under variable rates of climate change: A finite-mixture modeling approach. Ecological Economics. 123: 1–13.

Starbuck, C.M.; Berrens, R.P.; McKee, M. 2006. Simulating changes in forest recreation demand and associated economic impacts due to fire and fuels management activities. Forest Policy Economics. 8: 52–66.

Stratus Consulting. 2009. Climate change in Park City: An assessment of climate, snowpack, and economic impacts. Report prepared for The Park City Foundation. Boulder, CO: Stratus Consulting, Inc. http://www.parkcitymountain.com/site/mountain-info/learn/environment [Accessed March 23, 2015].

Thompson Coon, J.; Boddy, K.; Stein, K.; [et al.]. 2011. Does participating in physical activity in outdoor natural environments have a greater effect on physical and mental wellbeing than physical activity indoors? A systematic review. Environmental Science and Technology. 45: 1761–1772.

USDA Forest Service [USDA FS]. 1990. ROS primer and field guide. Washington, DC: U.S. Department of Agriculture, Forest Service, Recreation staff.

USDA Forest Service [USDA FS]. 2010. Connecting people with America's great outdoors: A framework for sustainable recreation. Washington, DC: U.S. Department of Agriculture, Forest Service. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5346549.pdf [Accessed March 24, 2015].

USDA Forest Service [USDA FS]. 2012a. Future of America's forest and rangelands: Forest Service 2010 Resources Planning Act assessment. Gen. Tech. Rep. WO-87. Washington, DC: U.S. Department of Agriculture, Forest Service, Research and Development.

USDA Forest Service [USDA FS]. 2012b. National Forest System land management planning, 36 CFR Part 219, RIN 0596-AD02. Federal Register. 77: 21162–21276.

USDA Forest Service [USDA FS]. 2016. Future of America's forests and rangelands: Update to the Forest Service 2010 Resources Planning Act assessment. Gen. Tech. Rep. WO-94. Washington, DC: U.S. Department of Agriculture, Forest Service, Research and Development.

USDA Forest Service [USDA FS]. [n.d.]. Calculations of national visitor use monitoring survey data, round 2 (Custer, Bridger-Teton, Gallatin, Shoshone National Forests) and round 3 (Beaverhead-Deerlodge, Caribou-Targhee National Forests). Washington, DC: U.S. Department of Agriculture, Forest Service. http://www.fs.fed.us/recreation/programs/nvum/ [Accessed March 24, 2015].

USDOI Fish and Wildlife Service [USFWS]. 2013. 2011 National survey of fishing, hunting, and wildlife-associated recreation–Idaho. Rep. FHW/11-ID. Washington, DC: U.S. Department of the Interior, U.S. Fish and Wildlife Service.

Wobus, C., Small, E.E., Hosterman, H.; [et al.]. 2017. Projected climate change impacts on skiing and snowmobiling: A case study of the United States. Global Environmental Change. 45: 1–14.

Yen, S.T.; Adamowicz, W.L. 1994. Participation, trip frequency and site choice: A multinomial-Poisson hurdle model of recreation demand. Canadian Journal of Agricultural Economics. 42: 65–76.

Yoder, J.K.; Ohler, A.M.; Chouinard, H.H. 2014. What floats your boat? Preference revelation from lotteries over complex goods. Journal of Environmental Economics and Management. 67: 412–430.

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:

Potential magnitude of climate change effects

- For those watersheds determined to be sensitive
  - Moderate magnitude by 2040
  - High magnitude by 2080

Likelihood of climate change effects

- For those watersheds determined to be sensitive
  - Moderate likelihood by 2040
  - High likelihood by 2080

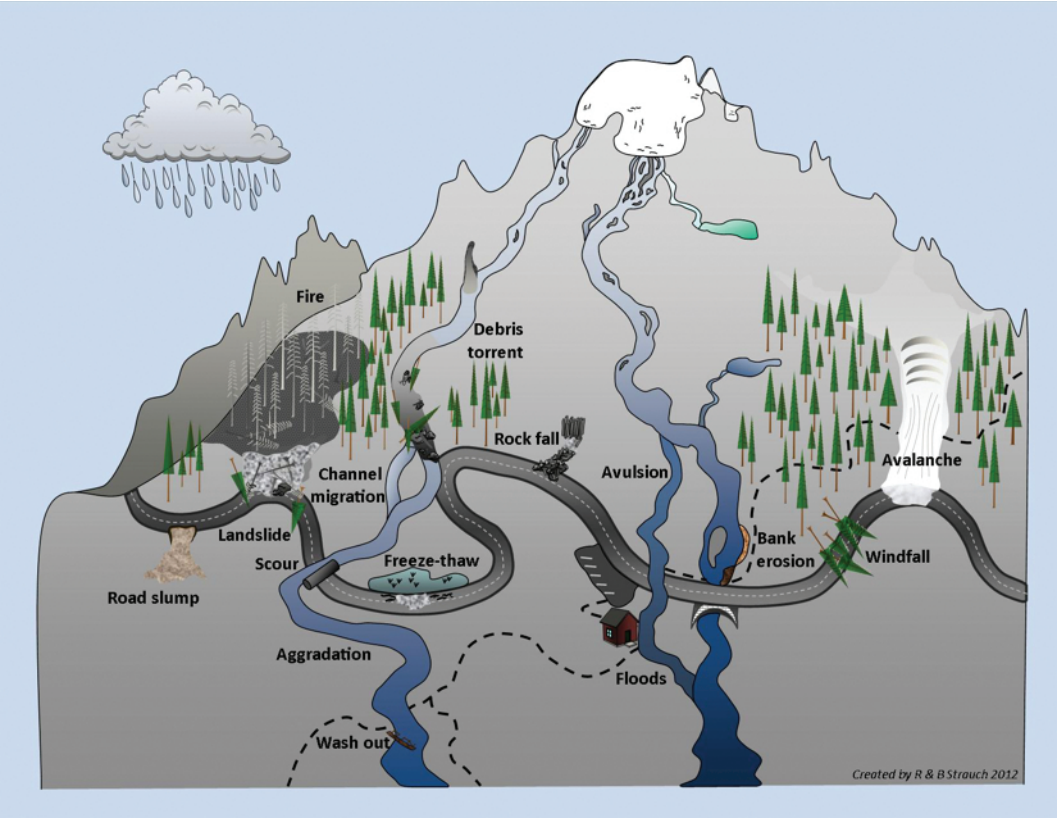


Figure 11.1—Schematic depicting the many geomorphic, hydrological, and weather-related disturbances that can damage roads and other infrastructure (from Strauch et al. 2014).

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.

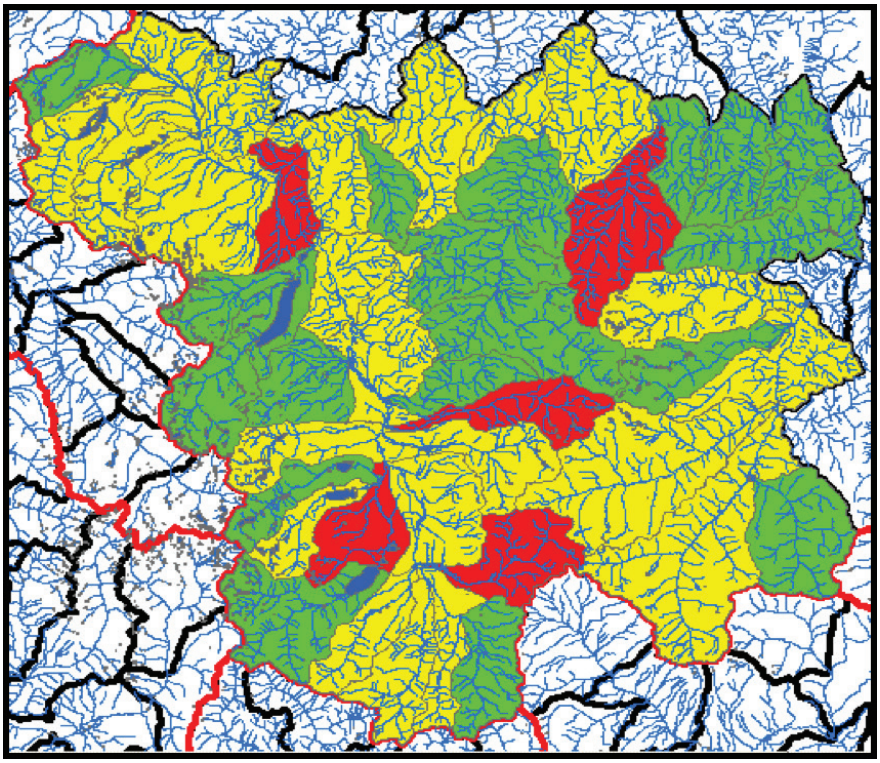


Figure 11.2—An example of using the presence of infrastructure as an indicator of vulnerability. This map shows the amount of infrastructure in Sawtooth National Recreation Area in Idaho by subwatersheds (Hydrologic Unit Code 6). Red-shaded subwatersheds have high amounts of infrastructure; yellow, moderate amounts; and green, low amounts (from Furniss et al. [2013]).

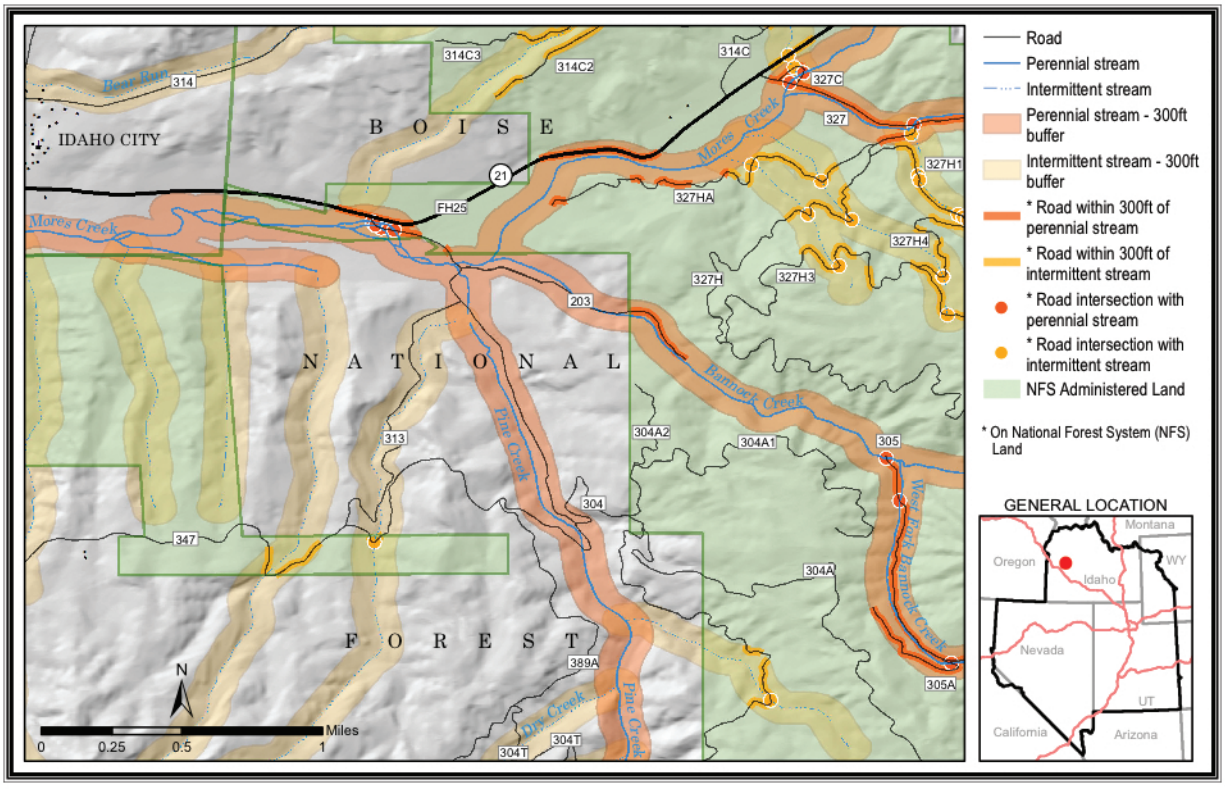


Figure 11.3—Map of an area from Upper Morse Creek and adjacent watersheds in Boise National Forest, Idaho, depicting 300-foot buffers around streams (map created by Teresa Rhoades, U.S. Forest Service). Mapping buffers around streams can be used to identify current roads that are potentially at risk 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).

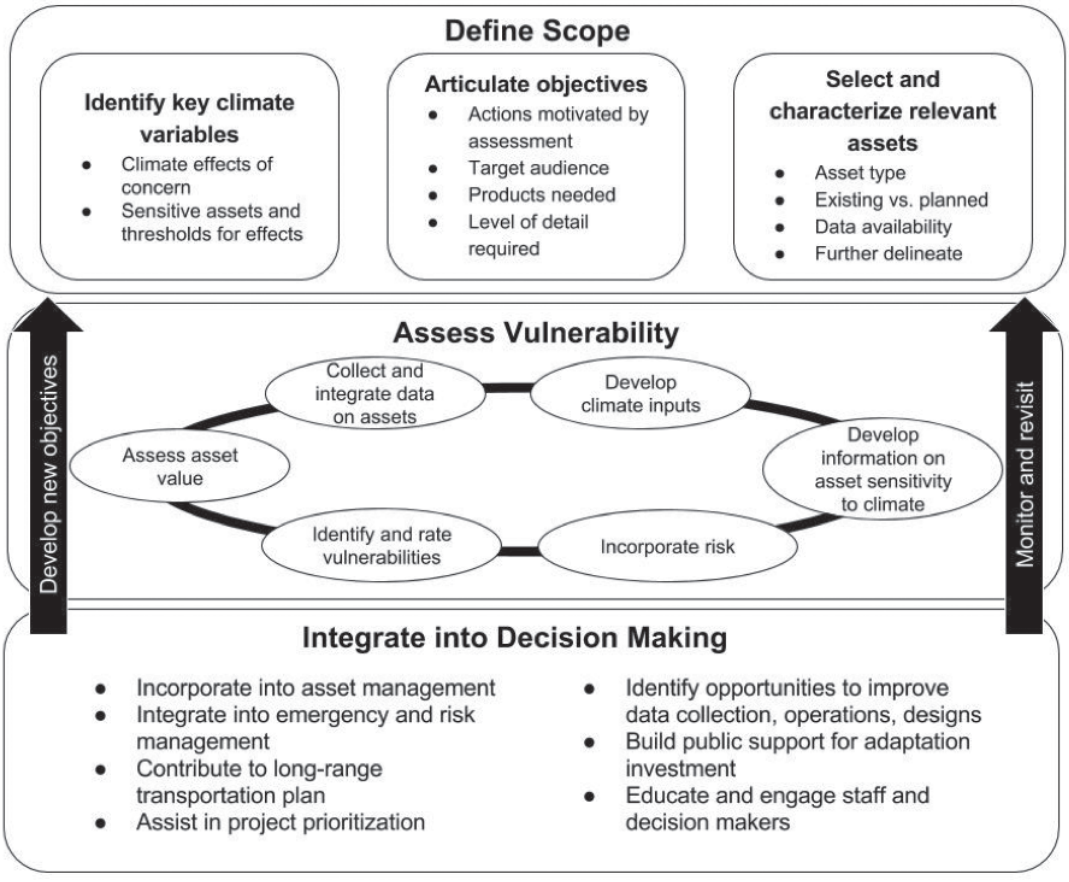


Figure 11.5—A framework for assessing the effects of climate change and extreme weather vulnerability on infrastructure. This framework can be used for both high-level planning and on-the-ground project implementation. This structured approach ensures thoroughness and consistency in designing and maintaining infrastructure in a changing climate (modified from Federal Highway Administration [FHWA] 2012).

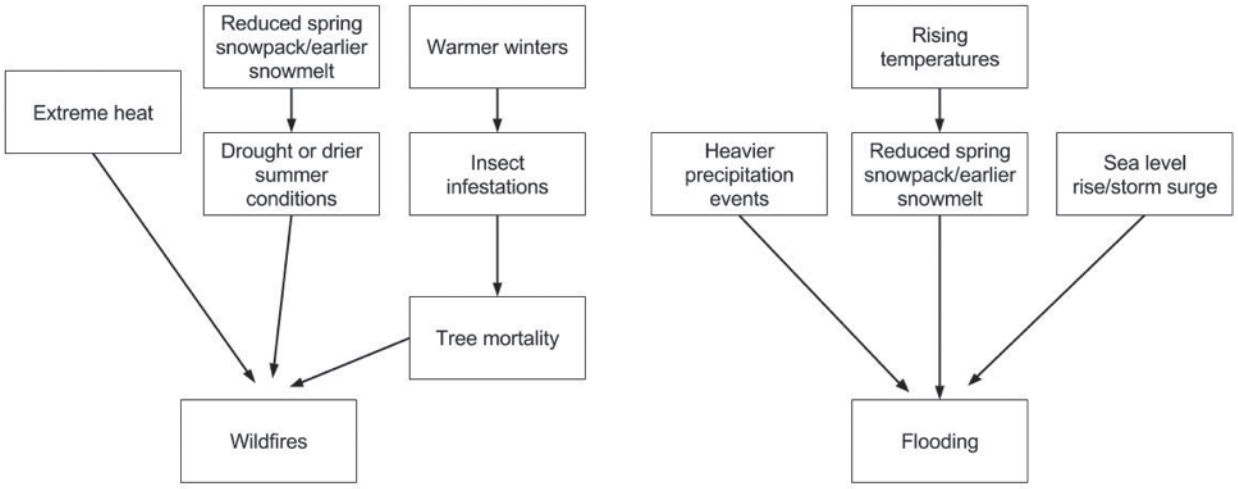


Figure 11.6—Conceptual framework of changes in climate- and weather-related stressors to flooding, wildfires, and tree mortality (modified from USDA FS n.d.).

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	Operational maintenance level					
	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
	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

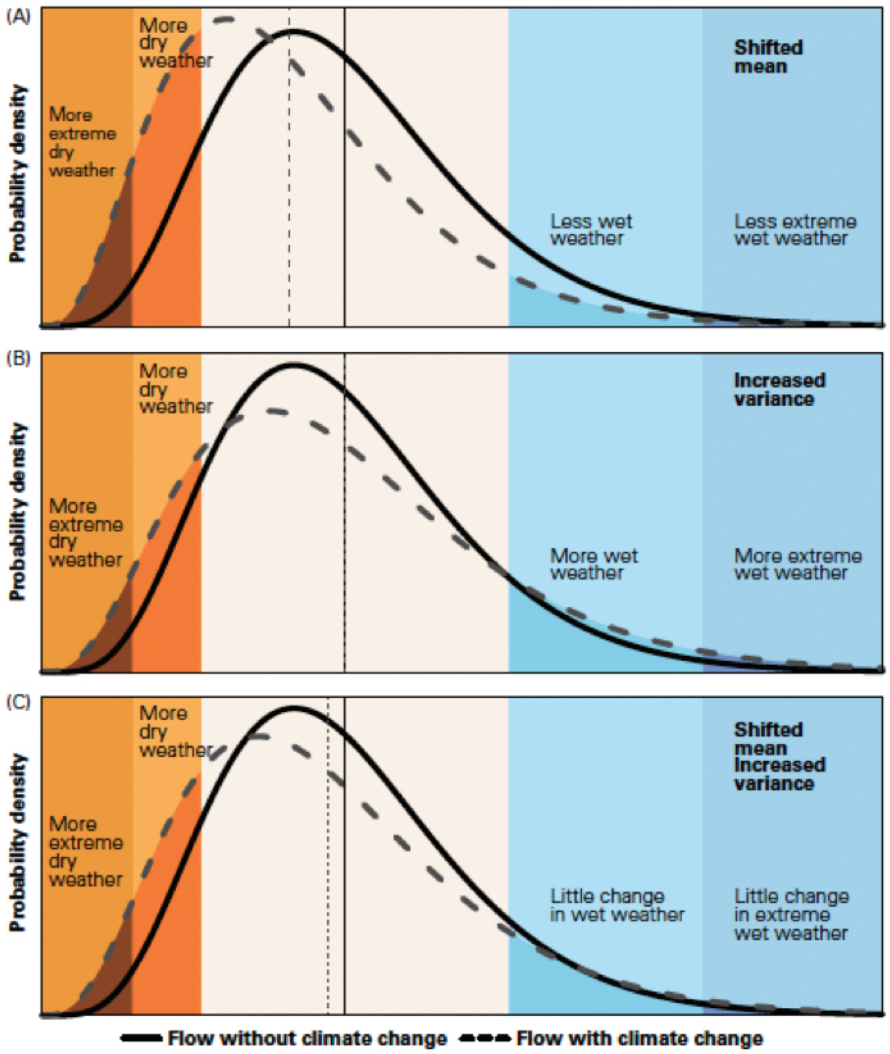


Figure 11.7—Conceptual diagram of how hydrological flow can be affected by both a change in the mean and change in the variance of climate and weather. Climate change is expected to increase the frequency and magnitude of peakflows and flooding in winter (from Field et al. 2012).

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.

References

Baum, R.; Harp, E.; Highland, L. 2007. Landslide hazards in the Seattle, Washington, area. Fact Sheet 2007-3005. Denver, CO: U.S. Geological Survey. http://pubs.usgs.gov/fs/2007/3005/pdf/FS07-3005_508.pdf [Accessed September 4, 2016].

Benda, L.; Miller, D.; Andras, K.; [et al.]. 2007. NetMap: A new tool in support of watershed science and resource management. Forest Science. 53: 206–219.

Bisson, P.A.; Cleaves, D.A.; Everest, F.H.; [et al.]. 1999. Roads analysis: Informing decisions about managing the National Forest transportation system. Misc. Rep. FS-643. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Black, T.A.; Cissel, R.M.; Luce, C.H. 2012. The geomorphic road analysis and inventory package (GRAIP). Volume 1: Data collection method. Gen. Tech. Rep. RMRS-GTR-280WWW. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Chatwin, S.C.; Howes, D.E.; Schwab, J.W.; [et al.]. 1994. A guide for management of landslide-prone terrain in the Pacific Northwest. Land Manage. Handbk. 18. 2nd ed. Victoria, BC, Canada: Ministry of Forests, Research Program.

Cissel, R.M.; Black, T.A.; Schreuders, K.A.T.; [et al.]. 2012. The geomorphic road analysis and inventory package (GRAIP). Volume 2: Office procedures. Gen. Tech. Rep. RMRS-GTR-281WWW. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Clifton, C.F.; Day, K.T.; Dello, K.; [et al.]. 2017. Climate change and hydrology in the Blue Mountains. In: Halofsky, J.E.; Peterson, D.L., eds. Climate change vulnerability and adaptation in the Blue Mountains region. Gen. Tech. Rep. PNW-GTR-939. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Croke, J.; Hairsine, P. 2006. Sediment delivery in managed forest: A review. Environmental Reviews. 14: 59–87.

Crozier, M.J. 1986. Landslides: Causes, consequences, and environment. Dover, NH: Croom Helm Limited.

Federal Highway Administration [FHWA]. 2012. Climate change and extreme weather vulnerability handbook. Washington, DC: U.S. Department of Transportation, Federal Highway Administration. http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications/vulnerability_assessment_framework [Accessed September 4, 2016].

Federal Highway Administration [FHWA]. [n.d.]. Emergency relief for Federally owned roads (ERFO). Washington, DC: U.S. Department of Transportation, Federal Highway Administration, Office of Federal Lands Highway. https://flh.fhwa.dot.gov/programs/erfo [Accessed September 3, 2016].

Field, C.B.; Barros, V.; Stoecker, T.F., eds. 2012. Managing the risks of extreme events and disasters to advance climate change adaptation: Special report of the Intergovernmental Panel on Climate Change. A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change. New York, NY: Cambridge University Press.

Flanagan, S.; Furniss, M.J. 1997. Field indicators of inlet controlled road-stream crossing capacity. San Dimas, CA: U.S. Department of Agriculture, Forest Service, San Dimas Technology and Development Center.

Flanagan, D.C.; Nearing, M.A., eds. 1995. USDA–Water Erosion Prediction Project: Hillslope profile and watershed model documentation. NSERL Rep. No. 10. Lafayette, IN: U.S. Department of Agriculture, National Soil Erosion Research Laboratory.

Flanagan, S.A.; Furniss, M.J.; Ledwith, T.S.; [et al.]. 1998. Methods for inventory and environmental risk assessment of road drainage crossings. Res. Pap. 9877-1809-SDTDC. San Dimas, CA: US Department of Agriculture, Forest Service, San Dimas Technology and Development Center.

Furniss, M.J.; Flanagan, S.; McFadin, B. 2000. Hydrologically-connected roads: An indicator of the influence of roads on chronic sedimentation, surface water hydrology, and exposure to toxic chemicals. Stream Notes. July 2000: 1–2.

Furniss, M.J.; Roby, K.B.; Cenderelli, D.; [et al.]. 2013. Assessing the vulnerability of watersheds to climate change: Results of national forest watershed vulnerability pilot assessments. Gen. Tech. Rep. PNW-GTR-884. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Gillespie, N.; Unthank, A.; Campbell, L.; [et al.]. 2014. Flood effects on road-stream crossing infrastructure: Economic and ecological benefits of stream simulation designs. Fisheries. 39: 62–76.

Goode, J.R.; Luce, C.H.; Buffington, J.M. 2012. Enhanced sediment delivery in a changing climate in semi-arid mountain basins: Implications for water resource management and aquatic habitat in the northern Rocky Mountains. Geomorphology. 139–140: 1–15.

Gucinski, H.; Furniss, M.J.; Ziemer, R.R.; [et al.]. 2001. Forest roads: A synthesis of scientific information. Gen. Tech. Rep. PNW- GTR-509. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Halofsky, J.E; Shelmerdine, W.S.; Stoddard, R.; [et al.]. 2011. Climate change, hydrology, and road management at Olympic National Forest and Olympic National Park. In: Halofsky, J.E; Peterson, D.L.; O'Halloran, K.A.; Hoffman, C.H. Adapting to climate change at Olympic National Forest and Olympic National Park. Gen. Tech. Rep. PNW-GTR-844. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 21–42.

Hamlet, A.F.; Elsner, M.M.; Mauger, G.S.; [et al.]. 2013. An overview of the Columbia Basin climate change scenarios project: Approach, methods, and summary of key results. Atmosphere-Ocean. 51: 392–415.

Hand, M.S.; Lawson, M. 2018. Effects of climate change on recreation. In: Halofsky, J.E.; Peterson, D.L.; Dante-Wood, S.K., eds. Climate change vulnerability and adaptation in the northern Rocky Mountains. Gen. Tech. Rep. RMRS-GTR-374. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Huntington, T.G. 2006. Evidence for intensification of the global water cycle: Review and synthesis. Journal of Hydrology. 319.1: 83–95.

Intergovernmental Panel on Climate Change (IPCC). 2007. Summary for policymakers. In: Parry, M.L.; Canziani, O.F.; Palutikof, J.P.; [et al.], eds. Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press: 7–22.

Joyce, L.; Abers, J.; McNulty, S.; [et al.]. 2001. Potential consequences of climate variability and change for the forests of the United States. In: Melillo, J.; Janetos, A.; Karl, T., chairs. Climate change impacts on the United States: The potential consequences of climate variability and change. Cambridge, UK: Cambridge University Press: 489–524.

Keller, G.; Ketcheson, G. 2015. Storm damage risk reduction guide for low-volume roads. Tech. Rep. 1277-1814. San Dimas, CA: U.S. Department of Agriculture, Forest Service, San Dimas Technology and Development Center.

Kim, S.K.; Hong, W.P.; Kim, Y.M. 1991. Prediction of rainfall-triggered landslides in Korea. Landslides. 2: 989–994.

Louter, D. 2006. Windshield wilderness: Cars, roads, and nature in Washington's national parks. Seattle, WA: University of Washington Press.

Luce, C.H. 2018. Effects of climate change on snowpack, glaciers, and water resources in the Northern Rockies. In: Halofsky, J.E.; Peterson, D.L.; Dante-Wood, S.K., eds. Climate change vulnerability and adaptation in the northern Rocky Mountains. Gen. Tech. Rep. RMRS-GTR-374. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Luce, C.H.; Rieman, B.E.; Dunham, J.B.; [et al.]. 2001. Incorporating aquatic ecology into decisions on prioritization of road decommissioning. Water Resources Impact. 3: 8–14.

MacArthur, J.; Mote, P.; Ideker, J.; [et al.]. 2012. Climate change impact assessment for surface transportation in the Pacific Northwest and Alaska. Res. Rep. WA-RD 772. Olympia, WA: State of Washington, Department of Transportation, Office of Research and Library Services. OTREC-RR-12-01. Salem, OR: Oregon Transportation Research and Education Consortium.

Martin, Y.E. 2007. Wildfire disturbance and shallow landsliding in coastal British Columbia over millennial time scales: A numerical modeling study. Catena. 69: 206–219.

McCabe, G.J.; Clark, M.P.; Hay, L.E. 2007. Rain-on-snow events in the western United States. Bulletin of the American Meteorological Society. 88: 319–328.

Meyer, R.S.; Nicholls, D.L.; Patterson, T.M.; White R.E. 2013. Energy efficiency in U.S. Forest Service facilities: A multiregion review. Gen. Tech. Rep. PNW-GTR-886. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Mickelson, K.E.B. 2009. Impacts of regional climate change on the Pacific Northwest white water recreation industry. Master's thesis. Seattle, WA: University of Washington.

Montgomery, D.R. 1994. Road surface drainage, channel initiation, and slope instability. Water Resources Research. 30: 1925–1932.

Montgomery, D.R.; Schmidt, K.M.; Greenberg, H.M.; [et al.]. 2000. Forest clearing and regional landsliding. Geology. 28: 311–314.

Morris, D.; Walls, M. 2009. Climate change and outdoor recreation resources for the future: Background. Washington, DC: Resources for the Future. http://www.rff.org/RFF/Documents/RFF-BCK-ORRG_ClimateChange.pdf [Accessed September 4, 2016].

Murray, V.; Ebi, K.L. 2012. IPCC special report on managing the risks of extreme events and disasters to advance climate change adaptation (SREX). Journal of Epidemiology and Community Health. 66: 759–760.

Muzik, I. 2002. A first-order analysis of the climate change effect on flood frequencies in a subalpine watershed by means of a hydrological rainfall–runoff model. Journal of Hydrology. 267: 65–73.

Natural Resource Manager-Infra [INFRA]. n.d. Infrastructure corporate database (not accessible to public). Washington, DC: USDA Forest Service. [Accessed April 13, 2017].

Neary, D.G.; Ryan, K.C.; DeBano, L.F., eds. 2005. Rev. 2008. Wildland fire in ecosystems: Effects of fire on soils and water. Gen. Tech. Rep. RMRS-GTR-42-vol.4. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Nelson, N.; Cissel, R.; Black, T.; [et al.]. 2014. GRAIP roads assessment: Upper East Fork Weiser River and Boulder Creek, Payette National Forest. Boise, ID: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Ojima, D.S., Iverson, L.R.; Sohngen, B.L.; [et al.]. 2014. Risk assessment. In: Peterson, D.L.; Vose, J.M.; Patel-Weynand, T., eds. Climate change and United States forests. Dordrecht, The Netherlands: Springer: 233–244.

Olsen, J.R. 2015. Adapting infrastructure and civil engineering practice to a changing climate. Reston, VA: American Society of Civil Engineers, Committee on Adaptation to a Changing Climate.

Peterson, D.L.; Millar, C.I.; Joyce, L.A.; [et al.]. 2011. Responding to climate change in national forests: A guidebook for developing adaptation options. Gen. Tech. Rep. PNW-GTR-855. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Peterson, D.L.; Vose, J.M.; Patel-Weynand, T., eds. 2014. Climate change and United States forests. Dordrecht, The Netherlands: Springer.

Potyondy, J.P.; Geier, T.W. 2011. Watershed condition classification technical guide. FS-978. Washington, DC: United States Department of Agriculture, Forest Service.

Rice, J.; Tredennick, A.; Joyce, L.A. 2012. Climate change on the Shoshone National Forest, Wyoming: A synthesis of past climate, climate projections, and ecosystem implications. Gen. Tech. Rep. RMRS-GTR-274. Fort Collins, CO; U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Ritter, M.A.; Skog, K.; Bergman, R. 2011. Science supporting the economic and environmental benefits of using wood and wood products in green building construction. Gen. Tech. Rep. FPL-GTR-206. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Lab.

Safeeq, M.; Grant, G.E.; Lewis, S.L.; [et al.]. 2014. A hydrogeologic framework for characterizing summer streamflow sensitivity to climate warming in the Pacific Northwest, USA. Hydrology and Earth System Sciences. 18: 3693–3710.

Salathé, E.P.; Hamlet, A.F.; Mass, C.F.; [et al.]. 2014. Estimates of twenty-first-century flood risk in the Pacific Northwest based on regional climate model simulations. Journal of Hydrometeorology. 15: 1881–1899.

Schmidt, K.M.; Roering, J.J.; Stock, J.D.; [et al.]. 2001. The variability of root cohesion as an influence on shallow landslide susceptibility in the Oregon Coast Range. Canadian Geotechnical Journal. 38: 995–1024.

Schuster, R.L.; Highland, L.M. 2003. Impact of landslides and innovative landslide-mitigation measures on the natural environment. In: Lee, C.F.; Tham, L.G., eds. Proceedings of the International Conference on Slope Engineering. Hong Kong, China: University of Hong Kong: 64–74.

Strauch, R.L.; Raymond, C.L.; Hamlet, A.F. 2014. Climate change, hydrology, and access in the North Cascade Range. In: Raymond, C.L.; Peterson, D.L.; Rochefort, R.M., eds. Climate change vulnerability and adaptation in the North Cascades region. Gen. Tech. Rep. PNW-GTR-892. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 45–112.

Stream Simulation Working Group. 2008. Stream simulation: An ecological approach to providing passage for aquatic organisms at road-stream crossings. 7700–Transportation Mgmt. 0877 1801–SDTDC. San Dimas, CA: U.S. Department of Agriculture, Forest Service, National Technology and Development Program.

Swanson, F.J.; Dyrness, C.T. 1975. Impact of clear-cutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon. Geology. 3: 393–396.

Swanston, D.N. 1971. Principal mass movement processes influences by logging, road building and fire. In: Krygier, J.T.; Hall, J.D., eds., Forest land uses and stream environment: Proceedings of a symposium. Corvallis, OR: Oregon State University, School of Forestry and Department of Fisheries and Wildlife: 29–40.

Swanston, D.N. 1976. Erosion processes and control methods in North America. In: Proceedings: 16. IUFRO World Congress, Div. I: Forest environment and silviculture. Aas, Norway: Norwegian IUFRO Congress Committee: 251–275.

Trombulak, S.C.; Frissell, C.A. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology. 14: 18–30.

USDA Forest Service [USDA FS]. 2012. National best management practices for water quality management on National Forest System lands. Volume 1: National core BMP technical guide. FS-990a. Washington, DC: U.S. Department of Agriculture, Forest Service.

USDA Forest Service [USDA FS]. 2014. National visitor use monitoring program. Washington, DC: U.S. Department of Agriculture, Forest Service, Recreation, Heritage & Wilderness Resources. http://www.fs.fed.us/recreation/programs/nvum [Accessed September 4, 2016].

USDA Forest Service [USDA FS]. [n.d.]. U.S. Forest Service climate change and transportation resiliency guidebook: Assessing and addressing climate change impacts on U.S. Forest Service transportation assets. Washington, DC: U.S. Department of Agriculture, Forest Service.

USDA Forest Service [USDA FS]. [In press]. National best management practices for water quality management on National Forest System lands. Volume 2: National core BMP monitoring technical guide. FS-990b. Washington, DC: U.S. Department of Agriculture, Forest Service.

Vose, J.M.; Clark, J.S.; Luce, C.H.; [et al.], eds. 2016. Effects of drought on forests and rangelands in the United States: A comprehensive science synthesis. Gen. Tech. Rep. WO-93b. Washington, DC: U.S. Department of Agriculture, Forest Service.

Vose, J.; Peterson, D.L.; Patel-Weynand, T., eds. 2012. Effects of climatic variability and change on forest ecosystems: A comprehensive science synthesis for the U.S. forest sector. Gen. Tech. Rep. PNW-GTR-870. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Walker, L.; Figliozzi, M.; Haire, A.; [et al.]. 2011. Identifying surface transportation vulnerabilities and risk assessment opportunities under climate change: Case study in Portland, Oregon. Transportation Research Record: Journal of the Transportation Research Board. 2244: 41–49.

Chapter 12: Effects of Climate Change on Cultural Resources

Tom H. Flanigan, Charmaine Thompson, and William G. Reed

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

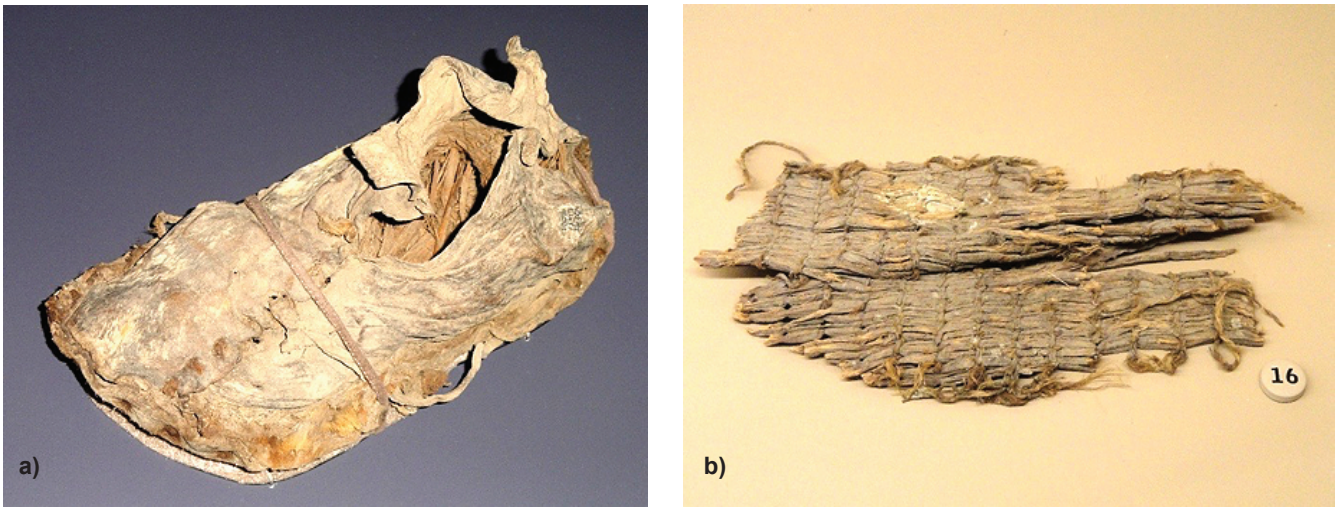


Figure 12.1—Artifacts made of organic materials: (a) Moccasin made of hide and sinew, Hogup Cave, Utah, 420 AD; (b) twined mat, 1225–1275 AD, Promontory Cave I, Utah. Artifacts made of organic materials are typically well preserved only when buried in caves or other shelters. Fluctuations in moisture 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.

References

Adams, J. 1993. Toward understanding the technological development of manos and metates. Kiva. 58: 331–344.

Allen, M.; Baker, S.A. 2000. Of earth, stone, and corn: The Anasazi and their Puebloan descendants. Museum of Peoples and Cultures Popular Series 2. Provo, UT: Brigham Young University, Museum of Peoples and Cultures.

Ambrose, S.E. 2001. Nothing like it in the world: The men who built the Transcontinental Railroad 1863–1869. New York, NY: Simon and Schuster.

Arrington, L. 1993. Great Basin kingdom: An economic history of the Latter-day Saints 1830–1900. Salt Lake City, UT: University of Utah Press.

Beck, C.; Jones, G. 1997. The terminal Pleistocene/early Holocene archaeology of the Great Basin. Journal of World Prehistory. 11: 161–236.

Brown, R. 1979. Hard-rock miners: The Intermountain West, 1860–1920. 1st ed. College Station, TX: Texas A&M University Press.

Coltrain, J.; Leavitt, S. 2002. Climate and diet in Fremont prehistory: Economic variability and abandonment of maize agriculture in the Great Salt Lake basin. American Antiquity. 67: 453–485.

Fernández-Shaw, C. 1999. The Hispanic presence in North America from 1492 to today. Updated ed. New York, NY: Facts On File.

Fisichelli, N.A.; Schuurman, G.W.; Monahan, W.B.; [et al.]. 2015. Protected area tourism in a changing climate: Will visitation at US National Parks warm up or overheat? PloS ONE. 10.6: e0128226.

Hamilton, M.C. 1995. Nineteenth-century Mormon architecture and city planning. New York, NY: Oxford University Press.

Intergovernmental Panel on Climate Change [IPCC]. 2014. Climate change 2014—Impacts, adaptation and vulnerability: Regional aspects. Cambridge, UK: Cambridge University Press.

Jennings, J.; Norbeck, E. 1955. Great Basin prehistory: A review. American Antiquity. 21: 1–11.

Kloor, K. 2007. The vanishing Fremont. Science. 318: 1540–1543.

Lee, C.M. 2012. Withering snow and ice in the mid-latitudes: A new archaeological and paleobiological record for the Rocky Mountain region. Arctic. 65: 165–177.

Lekson, S. 2008. The idea of the kiva in Anasazi archaeology. Kiva. 74: 203–225.

Leone, M. 1973. Archaeology as the science of technology: Mormon town plans and fences. In: Redman, C., ed., Research and theory in current archaeology. New York, NY: John Wiley and Sons: 125–150.

Logan, J.; Powell, J. 2001. Ghost forests, global warming, and the mountain pine beetle (Coleoptera: Scolytidae). American Entomologist. 47: 160–173.

Lyneis, M. 1992. The Main Ridge community at Lost City: Virgin Anasazi architecture, ceramics, and burials. University of Utah Anthropological Paper 117. Salt Lake City, UT: University of Utah Press.

Madsen, D.; Metcalf, M.D. 2000. Intermountain archaeology. University of Utah Anthropological Papers No. 122. Salt Lake City, UT: University of Utah Press.

Mallea-Olaetxe, J. 2008. Speaking through aspens: Basque tree carvings in Nevada and California. Reno, NV: University of Nevada Press.

Mayewski, P.A.; White, F. 2002. The ice chronicles*:* The quest to understand global climate change. Hanover, NH: University of New Hampshire Press.

McKenzie, D.; Gedalof, Z.; Peterson, D.L.; [et al.]. 2004. Climatic change, wildfire, and conservation. Conservation Biology. 18: 890–902.

McKenzie, D.; Littell, J.S. 2017. Climate change and the eco-hydrology of fire: Will area burned increase in a warming western USA? Ecological Applications. 27: 26–36.

Melnick, R.Z. 2009. Climate change and landscape preservation: A twenty-first century conundrum. APT Bulletin: Journal of Preservation Technology. 40: 3–4, 34–43.

Meltzer, D.J. 1990. Human responses to Middle Holocene (Altithermal) climates on the North American Great Plains. Quaternary Research. 52: 404–416.

Merritt, C. 2016. Wooden beds for wooden heads: Railroad tie cutting in the Uinta Mountains, 1867–1938. Utah Historical Quarterly Volume 84, Number 2.

Morgan, M.; Rockman, M.; Smith, C.; [et al.]. 2016. Climate change impacts on cultural resources. Washington, DC: National Park Service. https://www.nps.gov/subjects/climatechange/upload/NPS-Climate-Impacts-Cultural-Resources-Guide_v7-2016.pdf [Accessed January 2, 2017].

National Park Service [NPS]. 1994. Protecting cultural landscapes: Planning, treatment and management of historic landscapes. Preservation Brief 36. Washington, DC: U.S Department of the Interior, National Park Service. https://www.nps.gov/tps/how-to-preserve/briefs/36-cultural-landscapes.htm [Accessed November 16, 2016].

National Park Service [NPS]. 2011. Cultural resources, partnerships and science directorate. Washington, DC: U.S. Department of the Interior, National Park Service. http://www.nps.gov/history/tribes/aboutus.htm [Accessed December 1, 2016].

National Park Service [NPS]. 2015a. Archaeology program–Antiquities Act 1906–2006. Washington, DC: U.S. Department of the Interior, National Park Service. http://www.nps.gov/archeology/sites/antiquities/about.htm [Accessed December 1, 2016].

National Park Service [NPS]. 2015b. Coastal adaptation strategies: Case studies. Washington, DC: U.S. Department of the Interior, National Park Service. https://www.nps.gov/subjects/climatechange/upload/2015-11-25-FINAL-CAS-Case-Studies-LoRes.pdf [Accessed June 6, 2017].

National Park Service [NPS]. 2015c. Glacier National Park: What are cultural resources? Washington, DC: U.S. Department of the Interior, National Park Service. http://gnpculturalresourceguide.info/files/resources/What%20Are%20Cultural%20ResourcesFinal.pdf [Accessed December 1, 2016].

National Park Service [NPS]. 2017. Cultural resources impacts table. Washington, DC: U.S. Department of the Interior, National Park Service. https://www.nps.gov/subjects/climatechange/culturalimpactstable.htm [Accessed June 22, 2017].

National Research Council. 2002. Abrupt climate change: Inevitable surprises. Washington, DC: National Academy Press, Committee on Abrupt Climate Change. 244 p.

Paul, R. 1963. Mining frontiers of the Far West, 1848–1880. New York, NY: Holt, Rinehart and Winston.

Rhode, D.; Goebel, T.; Graf, K.; [et al.]. 2005. Latest Pleistocene-early Holocene human occupation and paleoenvironmental change in the Bonneville Basin, Utah-Nevada. Field Guides. 6: 211–230.

Rockman, M. 2014. A national strategic vision for climate change and archaeology. National Park Service archaeology webinar, January 15, 2014. Washington, DC: U.S. Department of the Interior, National Park Service. https://www.nps.gov/training/npsarcheology/html/index.cfm [Accessed January 2, 2017].

Rockman, M. 2015. An NPS framework for addressing climate change with cultural resources. The George Wright Forum. 32: 37–50.

Rockman, M.; Morgan, M.; Ziaja, S.; [et al.]. 2016. Cultural resources climate change strategy. Washington, DC: U.S. Department of the Interior, National Park Service, Cultural Resources, Partnerships, and Science and Climate Change Response Program.

Ruddiman, W.F. 2007. Earth's climate: Past and future, New York, NY: W.H. Freeman.

Ryan, K.C.; Jones, A.T.; Koerner, C.L.; [et al.], tech. eds. 2012. Wildland fire in ecosystems: Effects of fire on cultural resources and archaeology. Gen. Tech. Rep. RMRS-GTR-42-Vol. 3. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Schlanger, S. 1991. On manos, metates, and the history of site occupations. American Antiquity. 56: 460–474.

Simms, S. 1989. The structure of the Bustos wickiup site, Eastern Nevada. Journal of California and Great Basin Anthropology. 11: 2–34.

Smith, B. 2011. The subsistence economies of indigenous North American societies: A handbook. Washington, DC: Smithsonian Institution Scholarly Press.

South, S. 1977. Method and theory in historical archaeology. New York, NY: Academic Press.

Straka, T. 2006. Tom Straka on Chris Kreider›s "Ward charcoal ovens" and Nevada's Carbonari. Environmental History. 11: 344–349.

Tomback, D.F.; Arno, S.F.; Keane, R.E., eds. 2001. Whitebark pine communities: Ecology and restoration. Washington, DC: Island Press.

United Nations Educational, Scientific, and Cultural Organization [UNESCO]. 2007. Climate change and world heritage: Report on predicting and managing the impacts of climate change on world heritage and strategy to assist states parties to implement appropriate management responses. World Heritage Report 22. Paris, France: United Nations Educational, Scientific, and Cultural Organization, World Heritage Centre.

Voss, B.L.; Allen, R. 2008. Overseas Chinese archaeology: Historical foundations, current reflections, and new directions. Historical Archaeology. 32: 5–28.

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

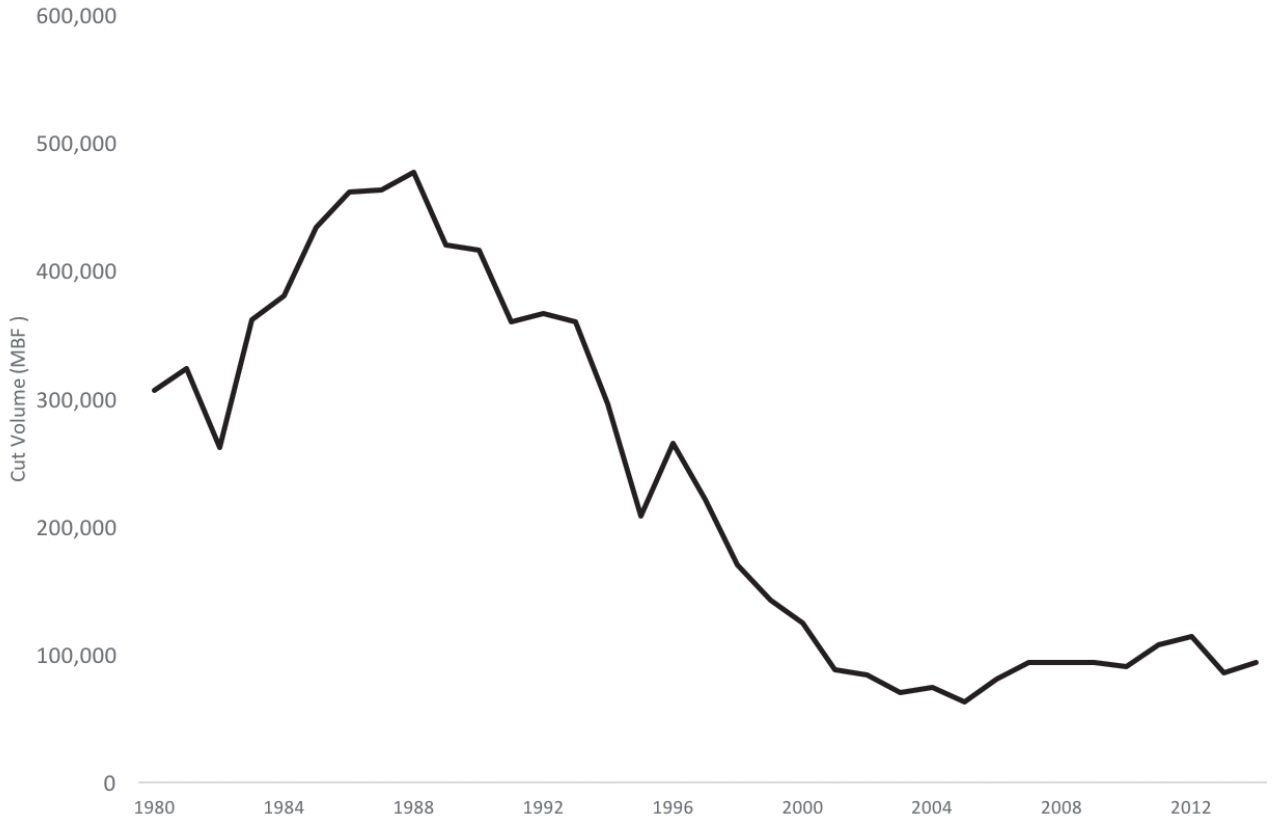


Figure 13.1—Timber volume harvested in national forests in the U.S. Forest Service Intermountain Region (1980–2014) (USDA FS 2016a). Small sales (<$300) contribute substantial percentages of cut volume and value, and are included here. Nonconvertible forest products (e.g., Christmas trees, boughs) are not included.

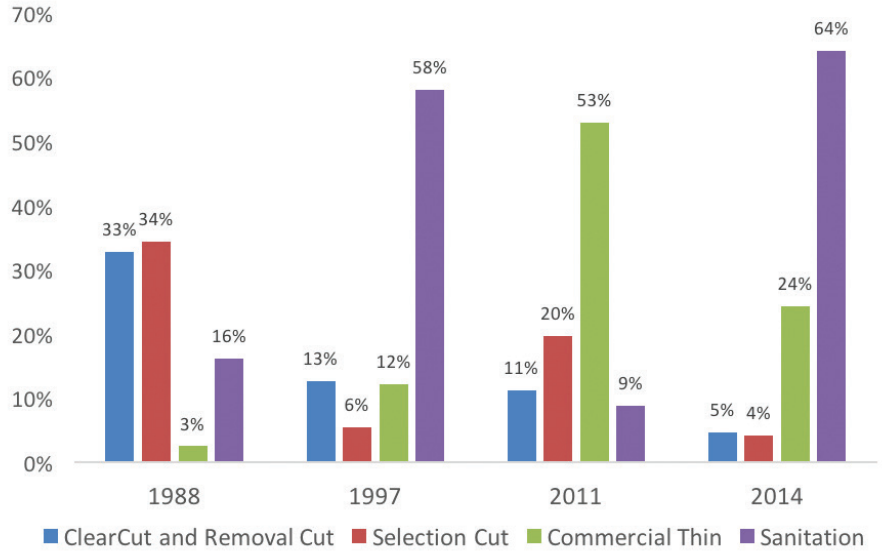


Figure 13.2—Changes in harvest type in national forests in the U.S. Forest Service Intermountain Region (percentage of all commercial harvest acres) (USDA FS 2015). Includes harvests where commercial sales occurred, as compiled by Forest Service TRACS (through 2004) and FACTS (after 2004) systems.

(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

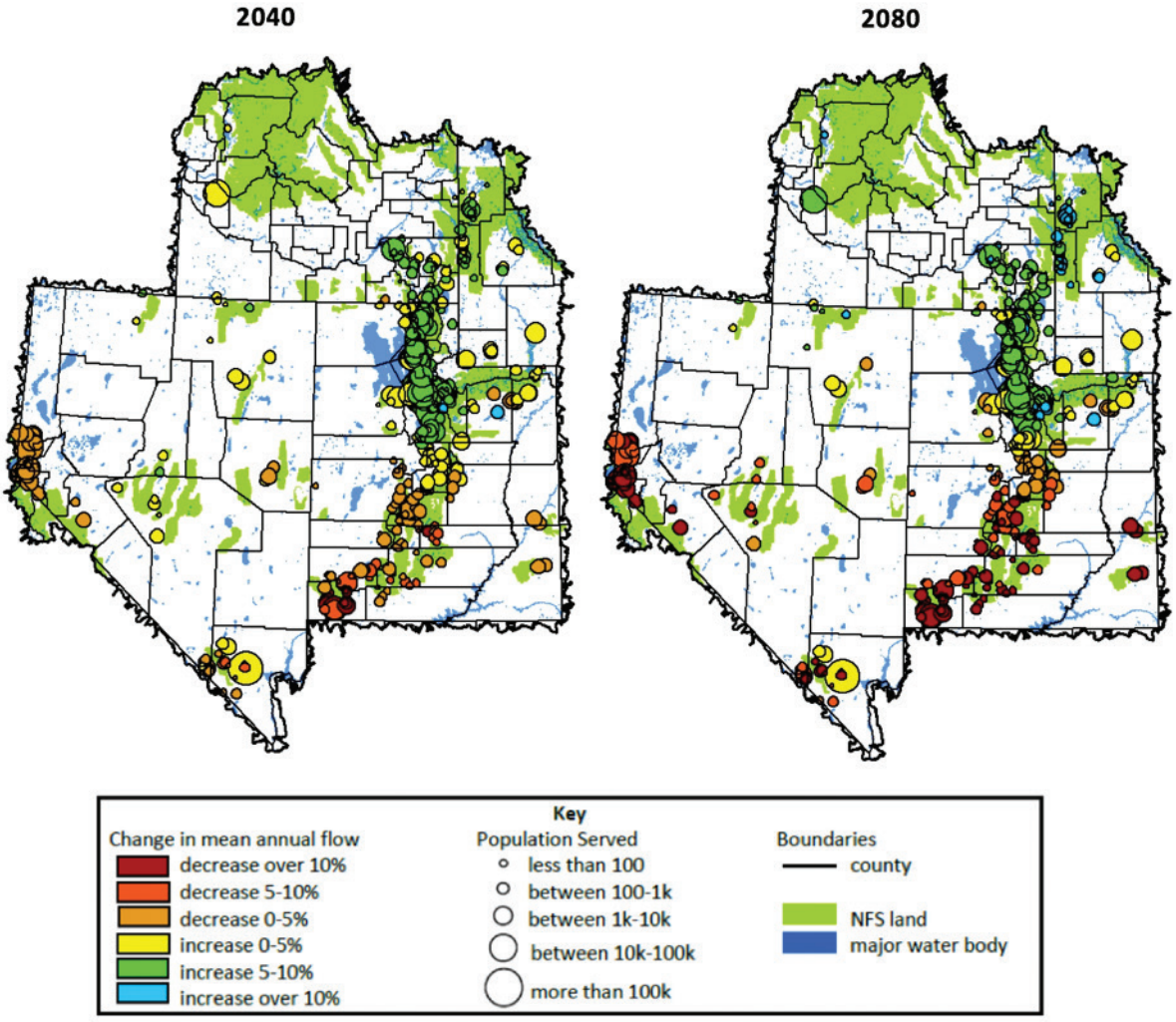


Figure 13.3—Projected changes in mean annual flow for municipal water systems. The center of each circle is the central location of each drinking water system relative to intake locations.

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.

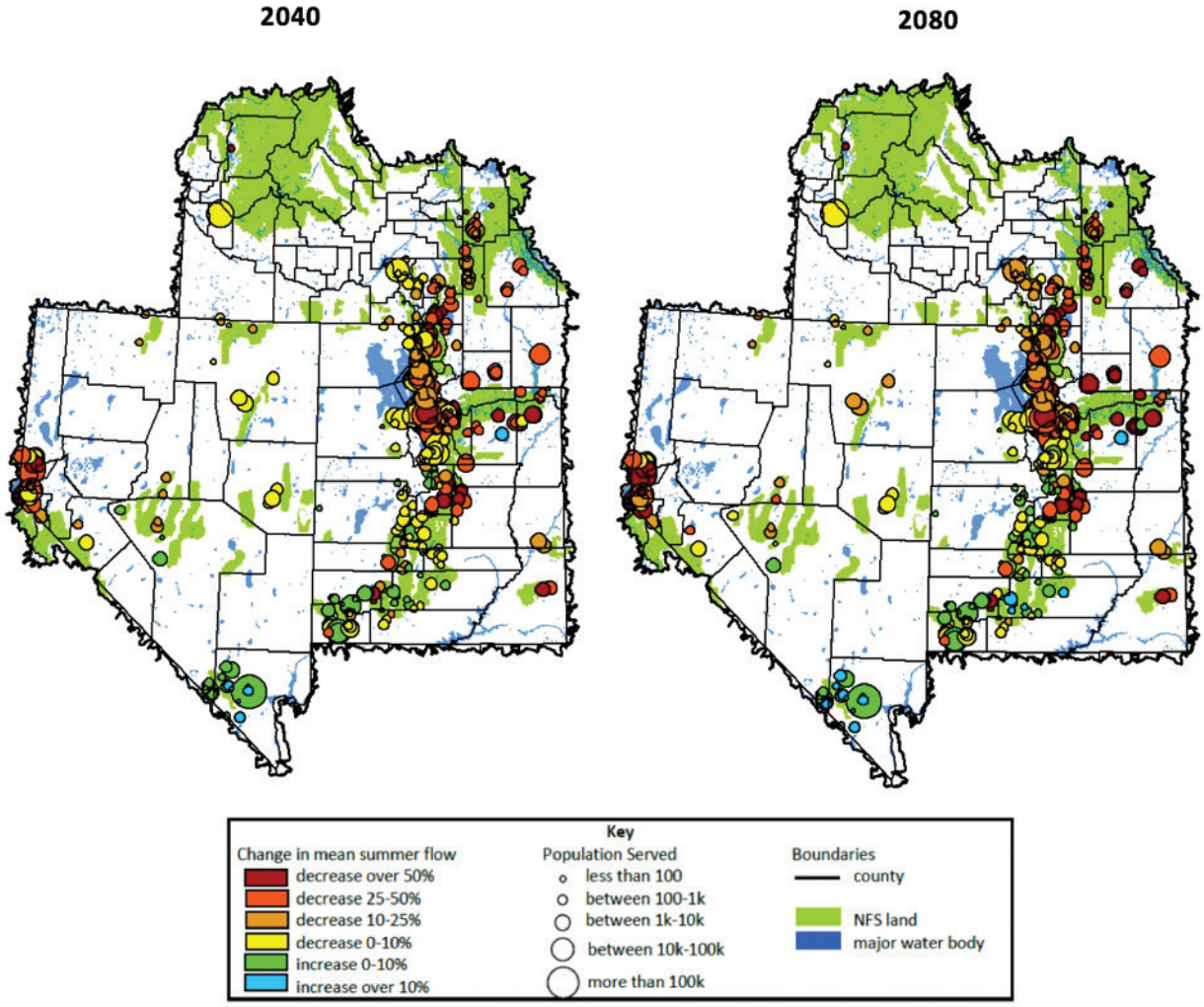


Figure 13.4—Projected changes in mean summer flow for municipal water systems. The center of each circle is the central location of each drinking water system relative to intake locations.

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

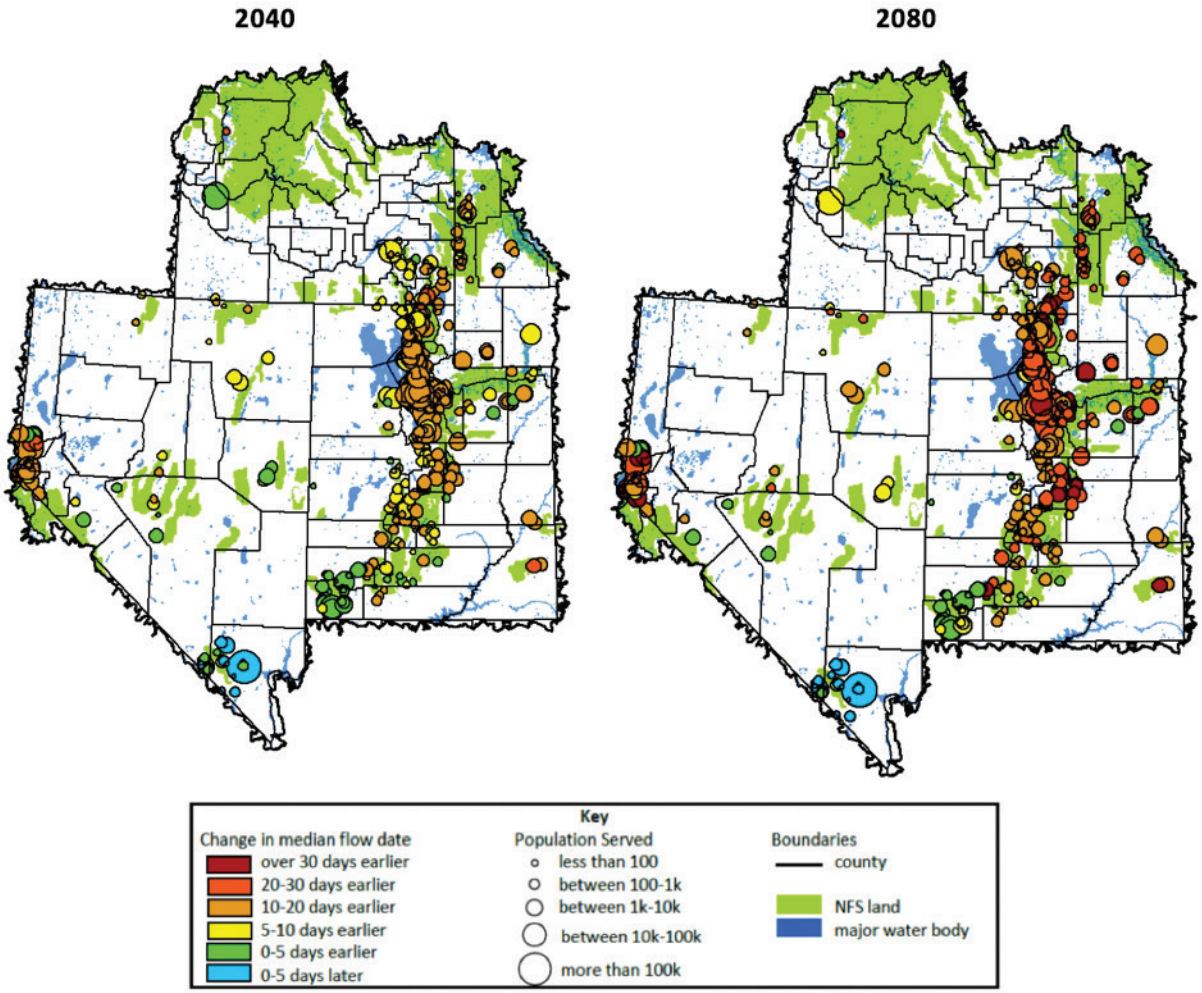


Figure 13.5—Projected changes in runoff timing (median flow date) for municipal water systems. The center of each circle is the central location of each drinking water system relative to intake locations.

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

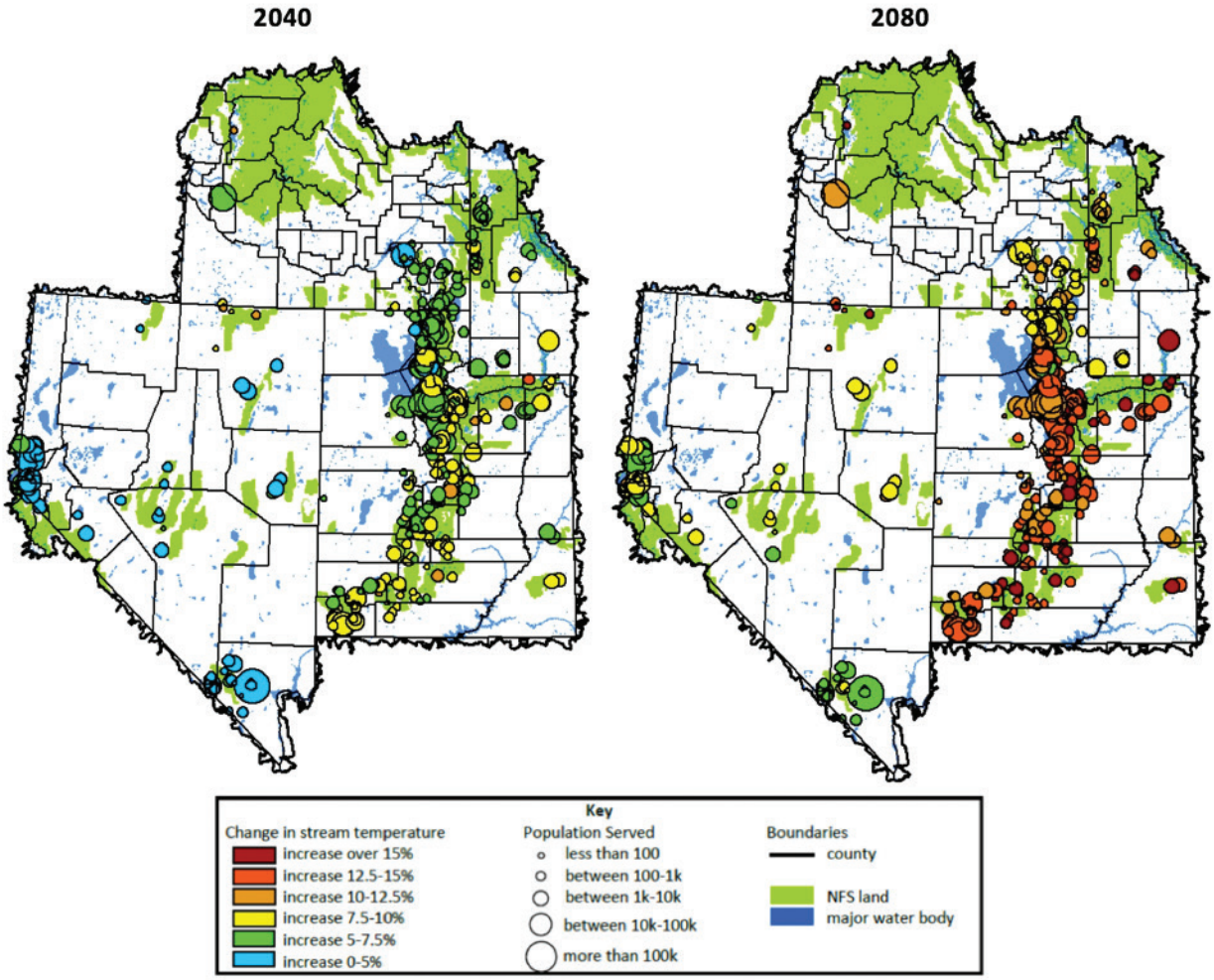


Figure 13.6—Projected changes in stream temperature for municipal water systems. The center of each circle is the central location of each drinking water system relative to intake locations.

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

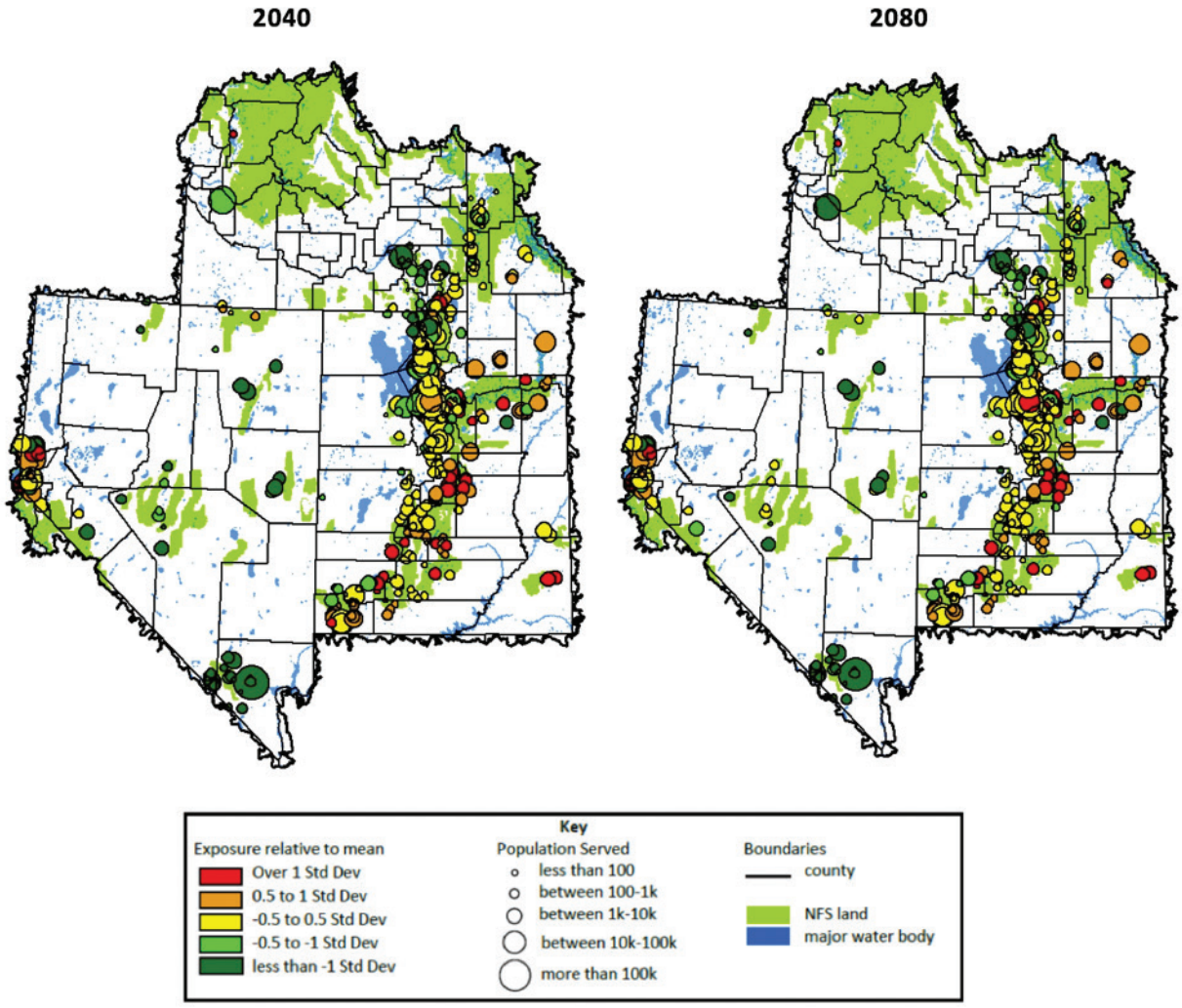


Figure 13.7—Municipal water system exposure. This is a standardized measure of the projected changes in mean annual flow, mean summer flow, runoff timing, and water temperature. Lower annual flow, lower summer flow, earlier median flow date, and higher temperature correspond with greater exposure. Each 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).

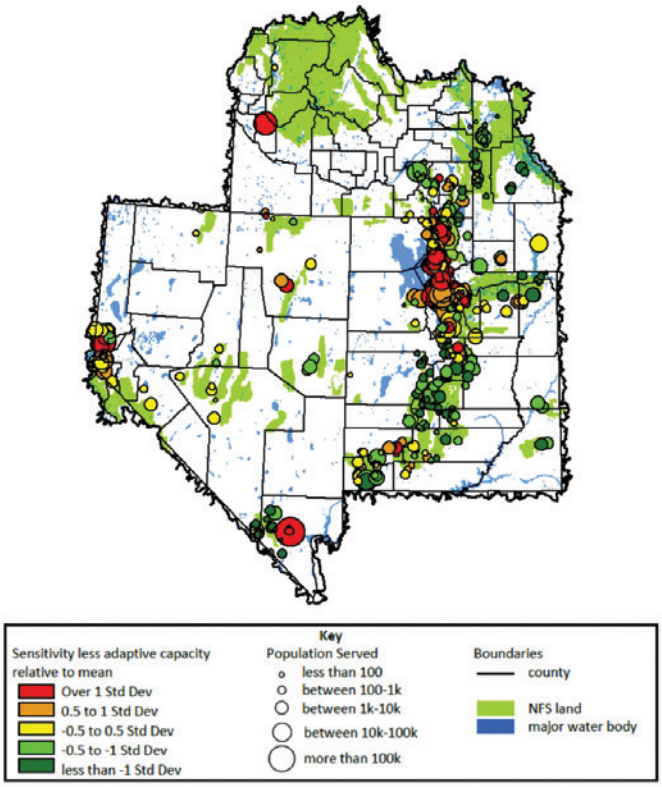


Figure 13.8—Municipal water system sensitivity less adaptive capacity. This is a standardized measure of sensitivity for each municipal system that also takes into account adaptive capacity. The measure is derived using factor analysis with the variables described in table 13.9. The center of each circle 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,

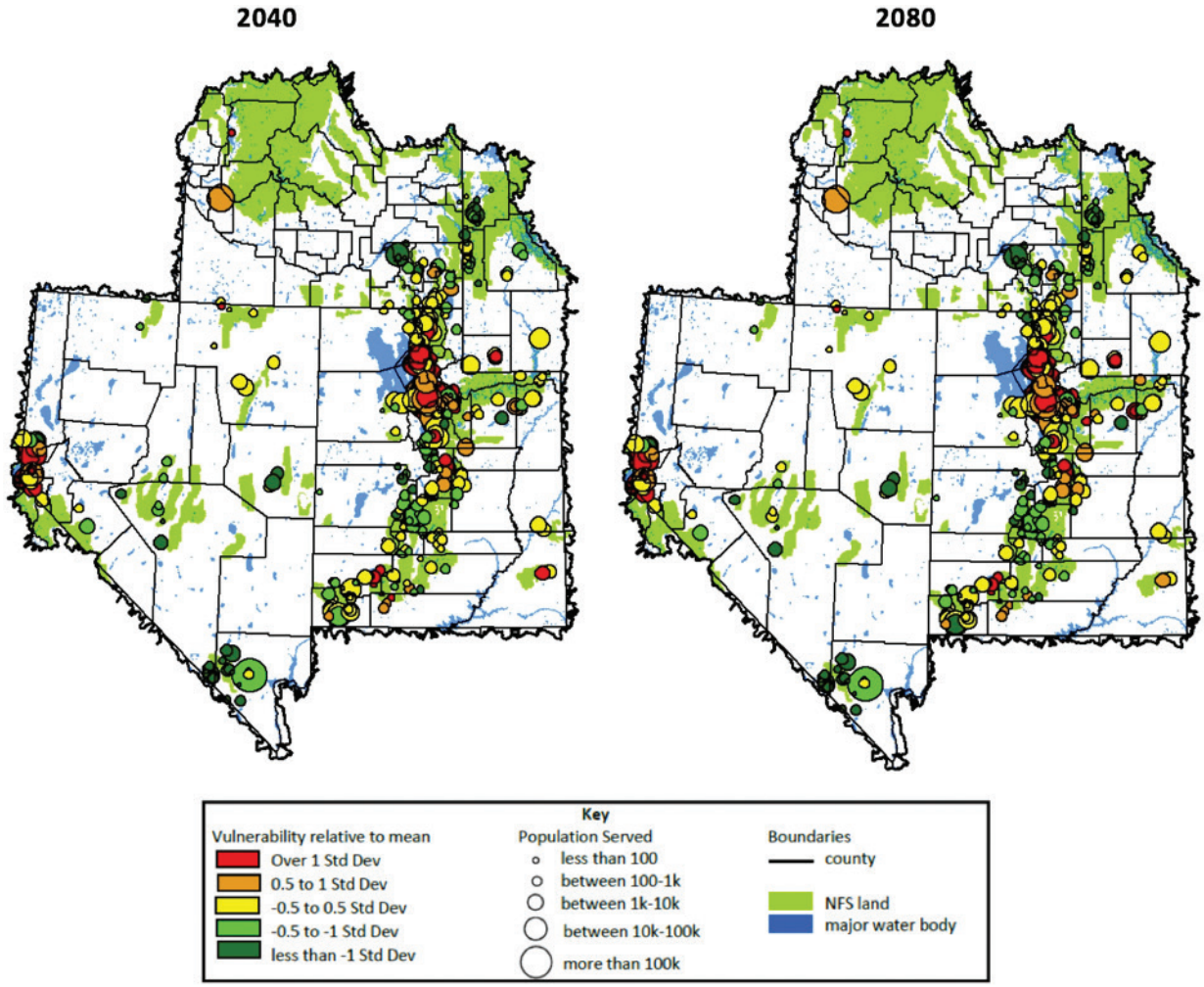


Figure 13.9—Municipal water system vulnerability. This is the final vulnerability measure for each water system. The measure is derived by summing the standardized measures of exposure and sensitivity less adaptive capacity for each system. The center of each circle is the central location of each drinking 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

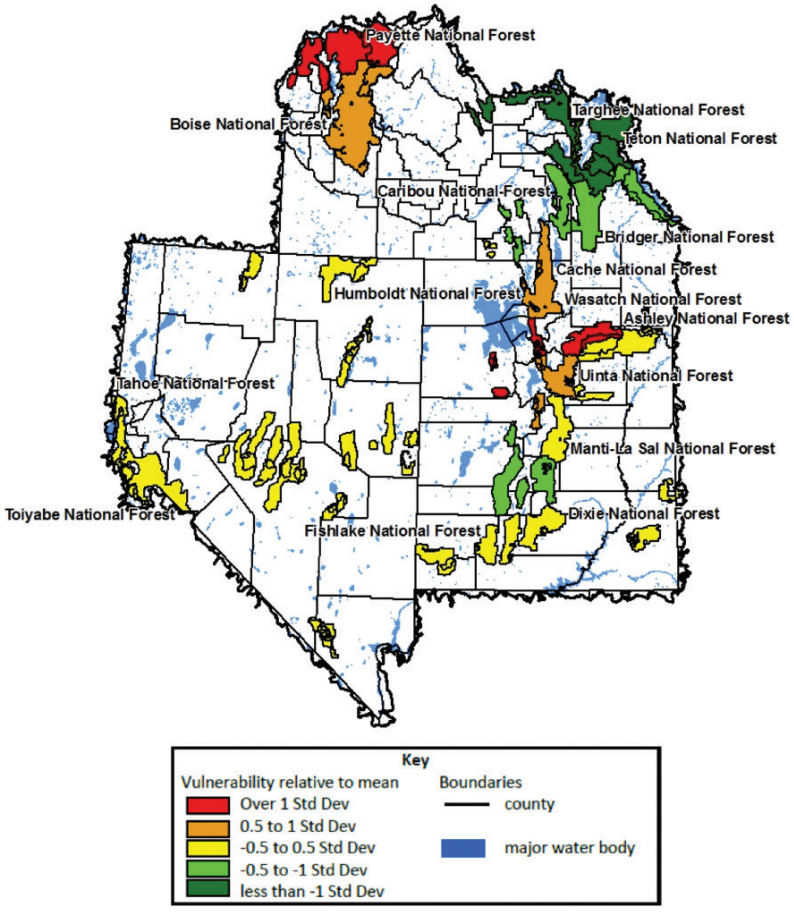


Figure 13.10—Water system vulnerability by national forest. Average vulnerability measure for each municipal water system is aggregated to the national forest level. Only water systems within one subwatershed (Hydrologic Unit Code 12) of national forest lands are included. Due to similarity after aggregation, this represents both 2040 and 2080 projections.

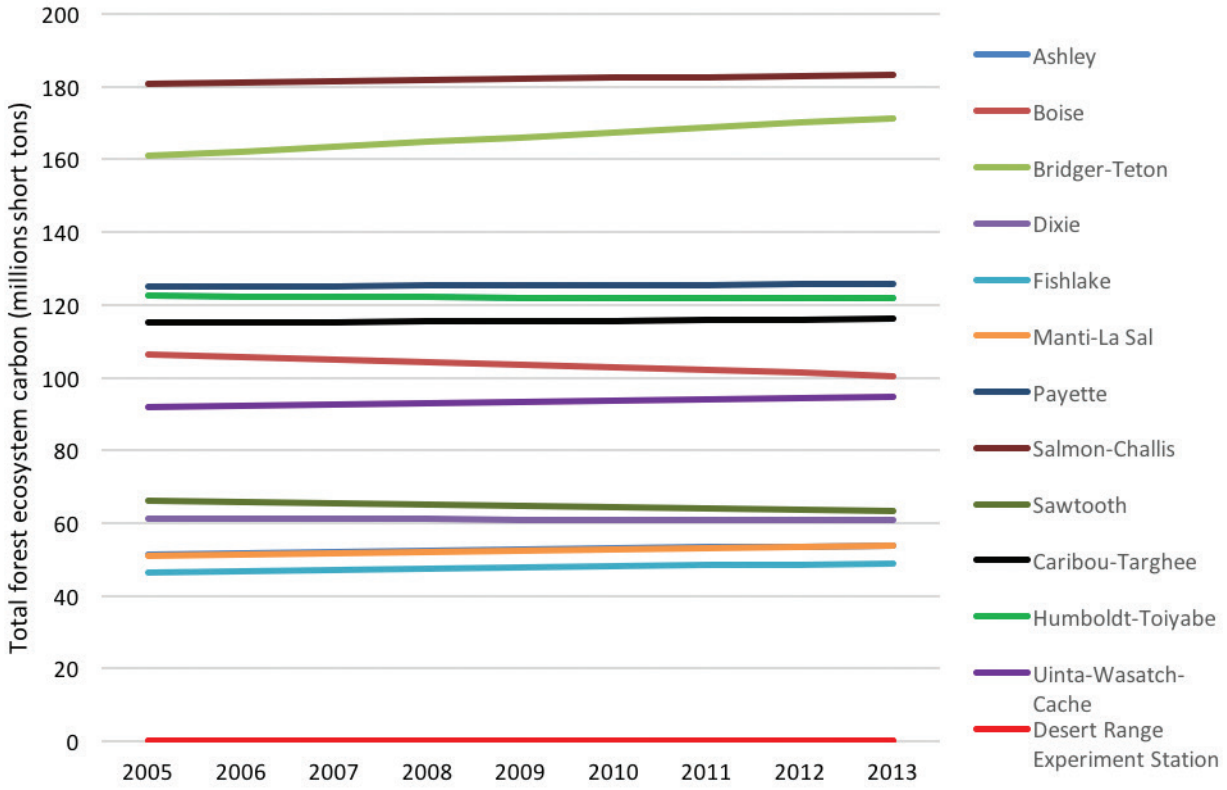


Figure 13.11—Total forest ecosystem carbon for national forests in the U.S. Forest Service Intermountain Region (2005–2013) (from O'Connell et al. [2016]).

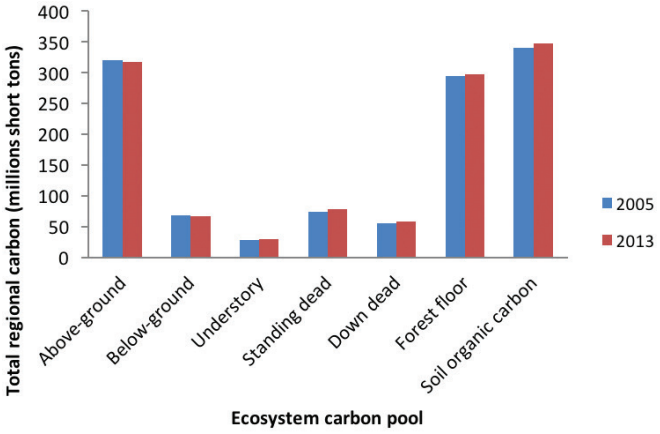


Figure 13.12—Carbon stocks in the seven forest ecosystem pools in national forest lands of the U.S. Forest Service Intermountain Region (2005 and 2013) (from O'Connell et al. [2016]).

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

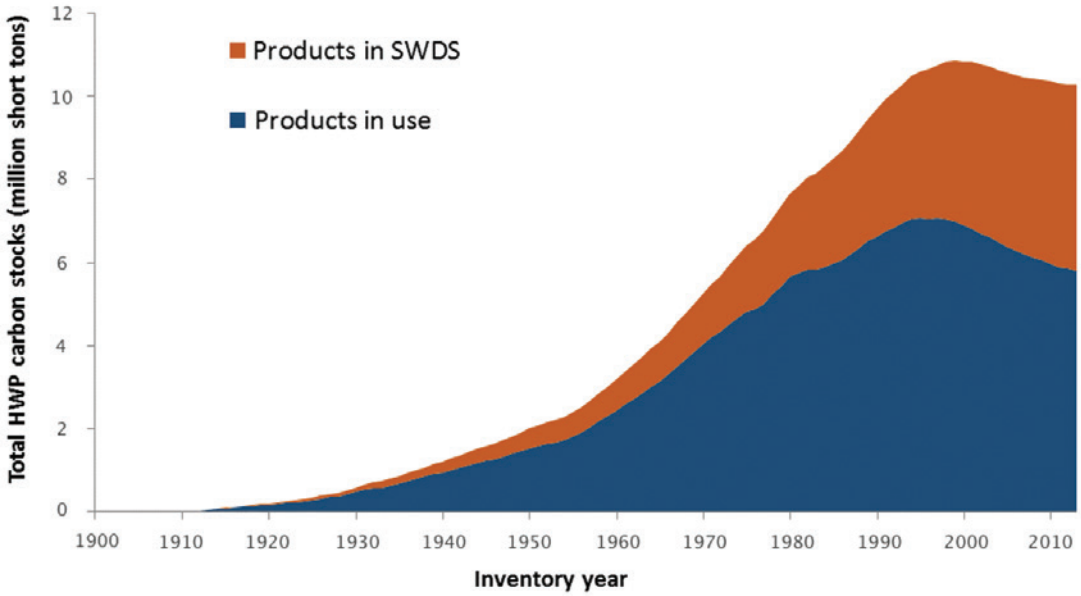


Figure 13.13—Cumulative total carbon stored in harvested wood products (HWP) manufactured from U.S. Forest Service Intermountain Region timber. Carbon in HWP includes products that are still in use and carbon stored at solid waste disposal sites (from Stockmann et al. [2014]).

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 overwintering 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).

References

Bureau of Business and Economic Research [BBER]. 2016. Forest Industries Data Collection System (FIDACS). Unpublished dataset. Missoula, MT: Bureau of Business and Economic Research, Forest Industry Research Program.

Beschta, R.L.; Donahue, D.L.; DellaSala, D.A.; [et al.]. 2013. Adapting to climate change on western public lands: Addressing the ecological effects of domestic, wild and feral ungulates. Environmental Management. 51: 474–491.

Bureau of Land Management [BLM]. 2013. Central basin and range rapid ecoregional assessment examination of findings. https://www.blm.gov/style/medialib/blm/wo/Communications_Directorate/public_affairs/landscape_approach/documents1.Par.86060.File.tmp/CBR_1_ReportBody.pdf [Accessed December 1, 2016].

Bureau of Land Management [BLM] 2014. Public land statistics 2014. https://www.blm.gov/public_land_statistics/ [Accessed October 10, 2016].

Bureau of Land Management [BLM]. 2015a. National seed strategy for rehabilitation and restoration. BLM/WO/GI-15/012+7400. Washington, DC.

Bureau of Land Management [BLM] 2015b. Pollinator-friendly best management practices for federal lands. https://www.fs.fed.us/wildflowers/pollinators/BMPs/documents/PollinatorFriendlyBMPsFederalLands05152015.pdf [Accessed June 30, 2017].

Cameron, S.A.; Lozier, J.D.; Strange, J.P.; [et al.]. 2011. Patterns of widespread decline in North American bumble bees. Proceedings of the National Academy of Sciences, U.S.A. 108: 662–667.

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.

Campbell, J.L.; Harmon, M.E.; Mitchell, S.R. 2012. Can fuel-reduction treatments really increase forest carbon storage in the western U.S. by reducing future fire emissions? Frontiers in Ecology and the Environment. 10: 83–90.

Cohen, W.B.; Yang, Z.; Stehman, S.V.; [et al.]. 2016. Forest disturbance across the conterminous United States from 1985–2012: The emerging dominance of forest decline. Forest Ecology and Management. 360: 242–252.

Dore, S.; Kolb, T.E.; Montes-Helu, M.; [et al.]. 2010. Carbon and water fluxes from ponderosa pine forests disturbed by wildfire and thinning. Ecological Applications. 20: 663–683.

Dullinger, S.; Gattringer, A.; Thuiller, W.; [et al.]. 2012. Extinction debt of high-mountain plants under twenty-first-century climate change. Nature Climate Change. 2: 619–622.

Dullinger, S.; Hülber, K. 2011. Experimental evaluation of seed limitation in alpine snowbed plants. PLoS One. 6: e21537.

Finkral, A.J.; Evans, A.M. 2008. The effects of a thinning treatment on carbon stocks in a northern Arizona ponderosa pine forest. Forest Ecology and Management. 255: 2743–2750.

Great Basin Native Plant Project [GBNPP]. [n.d.]. http://www.greatbasinnpp.org/ [Accessed January 12, 2017].

Grixti, J.C.; Wong, L.T.; Cameron, S.A.; Favret, C. 2009. Decline of bumble bees (*Bombus*) in the North American Midwest. Biological Conservation. 142: 75–84.

Hatfield, R.; Jepsen, S.; Mader, E.; [et al.]. 2012. Conserving bumble bees: Guidelines for creating and managing habitat for America's declining pollinators. The Xerces Society for Invertebrate Conservation.

Headwaters Economics. 2016a. Economic Profile System [EPS]. http://headwatersecoomics.org/tools/economic-profile-system/about/ [Accessed August 15, 2016].

Headwaters Economics. 2016b. Forest products cut and sold from the National Forests and Grasslands. As compiled and cited in Headwaters Economics Report "U.S. Forest Service cut and sold reports for all convertible products by region, state, and National Forest, 1980 to 2014". http://headwaterseconomics.org/county-payments/history-context/commercial-activities-national-forests/ [Accessed August 6, 2016].

Heath, L.S.; Smith, J.E.; Woodall, C.W.; [et al.]. 2011. Carbon stocks on forestland of the United States, with emphasis on USDA Forest Service ownership. Ecosphere. 2: 1–21.

Hegland, S.J.; Nielsen, A.; Lázaro, A.; [et al.]. 2009. How does climate warming affect plant-pollinator interactions? Ecology Letters. 12: 184–195.

Holechek, J. 2001. Western ranching at the crossroads. Rangelands. 23: 17–21.

Janowiak, M.; Connelly, W.J.; Dante-Wood, K.; [et al.]. 2017. Considering forest and grassland carbon in land management. Gen. Tech. Rep. WO-95. Washington, DC: U.S. Department of Agriculture, Forest Service. 68 p.

Jepsen, S.; Schweitzer, D.F.; Young, B.; [et al.]. 2015. Understanding and conserving the western North American monarch population. Portland, OR: Xerces Society for Invertebrate Conservation.

Kent, L.L.Y.; Shive, K.L.; Strom, B.A.; [et al.]. 2015. Interactions of fuel treatments, wildfire severity, and carbon dynamics in dry conifer forests. Forest Ecology and Management. 349: 66–72.

Koch, J.; Strange, J.; Williams, P. 2012. Bumble bees of the western United States. Pollinator partnership. http://www.fs.fed.us/wildflowers/pollinators/documents/BumbleBeeGuideWestern2012.pdf [Accessed September 8, 2017].

Mader, E.; Shepherd, M.; Vaughan, M.; [et al.]. 2011. Attracting native pollinators: Protecting North America's bees and butterflies. The Xerces Society Guide. North Adams, MA: Storey Publishing. http://www.xerces.org/announcing-the-publication-of-attracting-native-pollinators [Accessed January 17, 2017].

Mathews, K.H.; Ingram, K.; Lewandrowski, J.; Dunmore, J. 2002. Public lands and western communities. Agricultural Outlook AGO-292. Washington, DC: U.S. Department of Agriculture, Economic Research Service.

McGinty, E.L.; Baldwin, B.; Banner, R. 2009. A review of livestock grazing and range management in Utah. State of Utah Governor's Public Lands Policy Coordination Office, State of Utah Control No. 080720, Utah State University Control No. 080300.

Meigs, G.W.; Donato, D.C.; Campbell, J.L.; [et al.]. 2009. Forest fire impacts on carbon uptake, storage, and emission: the role of burn severity in the Eastern Cascades, Oregon. Ecosystems. 12: 1246–1267.

Millar, C.I.; Stephenson, N.L. 2015. Temperate forest health in an era of emerging megadisturbance. Science. 349: 823–826.

Moore, S.K.; Trainer, V.L.; Mantua N.; Parker, M.S.; [et al.]. 2008. Impacts of climate variability and future climate change on harmful algal blooms and human health. Environmental Health. 7: Suppl 2.

Nardone, A.; Ronchi, B.; Lacetera, N.; [et al.]. 2010. Effects of climate changes on animal production and sustainability of livestock systems. Livestock Science. 130: 57–69.

National Park Service [NPS]. 2014. A call to action: Preparing for a second century of stewardship and engagement. https://www.nps.gov/CalltoAction/PDF/C2A_2014.pdf [Accessed June 30, 2017].

National Research Council [NRC]. 2007. Committee on the Status of Pollinators in North America. Status of pollinators in North America. Washington, DC: National Academies Press.

Nickerson, C.; Ebel, R.; Borchers, A.; Carriazo, F. 2011. Major uses of land in the United States, 2007, EIB-89. Washington, DC: U.S. Department of Agriculture, Economic Research Service.

O'Connell, B.M.; Conkling, B.L.; Wilson, A.M.; [et al.]. 2016. The Forest Inventory and Analysis database: Database description and user guide version 6.1.1 for phase 2. U.S. Department of Agriculture, Forest Service. http://www.fia.fs.fed.us/library/database-documentation [Accessed January 17, 2017].

Pan, Y.; Birdsey, R.; Hom, J.; [et al.]. 2009. Separating effects of changes in atmospheric composition, climate and land-use on carbon sequestration of U.S. mid-Atlantic temperate forests. Forest Ecology and Management. 259: 151–164.

Pan, Y.; Birdsey, R.A.; Fang, J.; [et al.]. 2011. A large and persistent carbon sink in the world's forests. Science. 333: 988–993.

Pelten, E.; Jepsen, S.; Schultz, C.; [et al.]. 2016. State of the monarch butterfly overwintering sites in California. Portland, OR: Xerces Society for Invertebrate Conservation.

Pettis, J.; Delaplane, S. 2010. Coordinated responses to honey bee decline in the U.S.A. Apidologie. 41: 256–263.

Pollinator Health Task Force, The White House. 2015. The national strategy to promote the health of honey bees and other pollinators. https://www.whitehouse.gov/sites/default/files/microsites/ostp/Pollinator%20Health%20Strategy%202015.pdf [Accessed December 12, 2016].

Resnik, J.; Wallace, G.N.; Brunson, M.; Mitchell J. 2006. Open spaces, working places: Local government programs can slow loss of rangelands—But only if urban and ranching interests can find ways to work together. Rangelands. 28: 4–9.

Restaino, J.C.; Peterson, D.L. 2013. Wildfire and fuel treatment effects on forest carbon dynamics in the western United States. Forest Ecology and Management. 303: 46–60.

Roberson, E.L. 2013. Guidance on estimating nonmarket environmental values, instruction memorandum. No. 2013-131, Change 1. https://www.blm.gov/wo/st/en/info/regulations/Instruction_Memos_and_Bulletins/national_instruction/2013/IM_2013-131__Ch1.print.html [Accessed January 17, 2017].

Seitz, N; Traynor, K.S.; Steinhauer, N.; [et al.]. 2015. A national survey of managed honey bee 2014–2015 annual colony losses in the U.S.A. Journal of Apicultural Research. 54: 292–304.

Skog, K.E. 2008. Sequestration of carbon in harvested wood products for the United States. Forest Products Journal. 58: 56–72.

Sorensen, C.D.; Finkral, A.J.; Kolb, T.E.; Huang, C.H. 2011. Short- and long-term effects of thinning and prescribed fire on carbon stocks in ponderosa pine stands in northern Arizona. Forest Ecology and Management. 261: 460–472.

Stevens-Rumann, C.; Shive, K.; Fulé, P.; Sieg, C.H. 2013. Pre-wildfire fuel reduction treatments result in more resilient forest structure a decade after wildfire. International Journal of Wildland Fire. 22: 1108–1117.

Stockmann, K.; Anderson, N.; Young, J.; [et al.]. 2014. Estimates of carbon stored in harvested wood products from United States Forest Service Intermountain Region, 1911-2012. Unpublished report. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Forestry Sciences Laboratory. 28 p.

Traynor, K.S.; Rennich, K.; Forsgren, E.; [et al.]. 2016. Multiyear survey targeting disease incidence in U.S. honey bees. Apidologie. 47: 325–347.

U.S. Department of Agriculture [USDA]. 2012. Census of agriculture. https://www.agcensus.usda.gov/ [Accessed October 10, 2016].

U.S. Department of Agriculture, Forest Service [USDA FS]. 2011. Watershed Condition Framework. 2011. Watershed Condition Classification [shapefile]. https://www.fs.fed.us/biology/watershed/condition_framework.html [Accessed December 2, 2016].

U.S. Department of Agriculture, Forest Service [USDA FS]. 2012a. 2012 planning rule. Washington, DC: U.S. Department of Agriculture, Forest Service. Federal Register. 77(68). 115 p. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5362536.pdf [Accessed February 9, 2017].

U.S. Department of Agriculture, Forest Service [USDA FS]. 2012b. Native plant materials policy: A strategic framework. FS-1006. Washington, DC.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2014. Initial review of livestock grazing effects on select ecosystems of the Dixie, Fishlake and Manti-La Sal National Forests. 28 p. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprd3810252.docx [Accessed October 19, 2017].

U.S. Department of Agriculture, Forest Service [USDA FS]. 2015a. Baseline estimates of carbon stocks in forests and harvested wood products for National Forest system units; Intermountain Region. 42 p.

U.S. Department of Agriculture, Forest Service [USDA FS] 2015b. Grazing statistical summary report 2015. https://www.fs.fed.us/rangeland-management/reports/index.shtml [Accessed October 10, 2016].

U.S. Department of Agriculture, Forest Service [USDA FS] 2015c. Harvest trends on National Forest System lands: 1984 to present. Washington, DC.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2015d. Pollinator-friendly best management practices (BMPs) for federal lands. http://www.fs.fed.us/wildflowers/pollinators/BMPs/documents/PollinatorFriendlyBMPsFederalLandsDRAFT05152015.pdf [Accessed December 13, 2016].

U.S. Department of Agriculture, Forest Service [USDA FS] 2016a. Forest products cut and sold from the National Forests and Grasslands. http://www.fs.fed.us/forestmanagement/products/cut-sold/index.shtml [Accessed December 12, 2016].

U.S. Department of Agriculture, Forest Service [USDA FS] 2016b. Future of America's forests and rangelands: Update to the Forest Service 2010 Resources Planning Act Assessment. Gen. Tech. Rep. WO-94. Washington, DC.

U.S. Department of Agriculture, Forest Service [USDA]. 2017. Economic impact, contribution, efficiency and economic services analysis—Applications for forest planning. Washington, DC: U.S. Department of Agriculture, Forest Service, Ecosystem Management Coordination. http://www.fs.fed.us/emc/economics/applications.shtml [Accessed November 16, 2017].

U.S. Department of Agriculture, Forest Service [USDA FS]. [n.d.]. Forest Inventory and Analysis National Program, FIA library: Database documentation.

U.S. Department of Commerce. 2014. Census Bureau, County Business Patterns, Washington, DC. http://www.census.gov/programs-surveys/cbp/data.html. [Accessed October 5, 2016].

U.S. Fish and Wildlife Service [USFWS]. 2009. Managing invasive plants: Concepts, principles, and practices. https://www.fws.gov/invasives/stafftrainingmodule/methods/grazing/introduction.html [Accessed January 10, 2017].

van Engelsdorp, D.; Hayes, J., Jr.; Underwood, R.M.; [et al.]. 2010. A survey of honey bee colony losses in the United States, fall 2008 to spring 2009. Journal of Apicultural Research. 49: 7–14.

van Engelsdorp, D.; Meixner, M.D. 2010. A historical review of managed honey bee populations in Europe and the United States and the factors that may affect them. Journal of Invertebrate Pathology. 103: S80–S95.

Vaughan, D; Mackes, K. 2015. Characteristics of Colorado forestry contractors and their role in current forest health issues. Forest Products Journal. 65: 217–225.

Wear, D.N.; Coulston, J.W. 2015. From sink to source: Regional variation in U.S. forest carbon futures. Scientific Reports. 5: 16518.

Westbrooks, R.G. 1998. Invasive plants: Changing the landscape of America. U.S. Government Documents. Salt Lake City, UT: Utah Regional Depository.

The White House, Office of the Press Secretary. 2014. The presidential memorandum—creating a strategy to promote the health of honey bees and other pollinators. https://www.whitehouse.gov/the-press-office/2014/06/20/presidential-memorandum-creating-federal-strategy-promote-health-honey-b [Accessed December 2, 2016].

Wiedinmyer, C.; Neff, J.C. 2007. Estimates of CO_2 from fires in the United States: Implications for carbon management. Carbon Balance and Management. 2: 10.

Woodall, C.; Smith, J.; Nichols, M. 2013. Data sources and estimation/modeling procedures for the National Forest System carbon stock and stock change estimates derived from the U.S. National Greenhouse Gas Inventory. http://www.fs.fed.us/climatechange/documents/NFSCarbonMethodology.pdf [Accessed December 13, 2016].

Chapter 14: Adapting to the Effects of Climate Change

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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.

References

Adams, H.D.; Luce, C.H.; Breshears, D.D.; [et al.]. 2011. Ecohydrological consequences of drought- and infestation-triggered tree die-off: Insights and hypotheses. Ecohydrology. 5: 145–159.

Bagne, K.E.; Finch, D.M. 2013. Vulnerability of species to climate change in the Southwest: Threatened, endangered, and at-risk species at Fort Huachuca, Arizona. Gen. Tech. Rep. RMRS-GTR-302. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 183 p.

Bagne, K.E.; Friggens, M.M.; Coe, S.J.; Finch, D.M. 2014. The importance of assessing climate change vulnerability to address species conservation. Journal of Fish and Wildlife Management. 5: 450–462.

Bates, C.G.; Henry, A.J. 1928. Forest and streamflow experiment at Wagon Wheel Gap, Colorado. Final Report upon completion of the second phase of the experiment. Monthly Weather Review Supplement 30. 79 p.

Beechie, T.; Imaki, H.; Greene, J.; [et al.]. 2013. Restoring salmon habitat for a changing climate. River Research and Applications. 29: 939–960.

Black, T.A.; Cissel, R.M.; Luce, C. 2012. The geomorphic roads analysis and inventory package (GRAIP) Volume 1: Data collection method. RMRS-GTR-280. Boise, ID: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 115 p.

Broad, K.; Pfaff, A.; Taddei, R.; [et al.]. 2007. Climate, stream flow prediction and water management in northeast Brazil: Societal trends and forecast value. Climatic Change. 84: 217–239.

Brown, A.; Zhang, L.; McMahon, T.; [et al.]. 2005. A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. Journal of Hydrology. 310: 28–61.

Chmura, D.J.; Anderson, P.D.; Howe, G.T. 2011. Forest responses to climate change in the northwestern United States: Ecophysiological foundations for adaptive management. Forest Ecology and Management. 261: 1121–1142.

Churchill, D.J.; Larson, A.J.; Dahlgreen, M.C.; [et al.]. 2013. Restoring forest resilience: From reference spatial patterns to silvicultural prescriptions and monitoring. Forest Ecology and Management. 291: 442–457.

Clark, R.N.; Stankey, G.H. 1979. The Recreation Opportunity Spectrum: A framework for planning, management, and research. Gen. Tech. Rep. PNW-GTR-098. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 32 p.

Creutzburg, M.K.; Halofsky, J.E.; Halofsky, J.S.; Christopher, T.A. 2015. Climate change and land management in the rangelands of central Oregon. Environmental Management. 55: 43–55.

Davies, K.W.; Johnson, D.D. 2011. Are we “missing the boat” on preventing the spread of invasive plants in rangelands? Invasive Plant Science and Management. 4: 166–171.

Davis, C.M. 2017. Effects of climate change on cultural resources in the Northern Rockies. In: Halofsky, J.E.; Peterson, D.L., eds. Climate Change and Rocky Mountain Ecosystems. Advances in Global Change Research, Volume 63. Cham, Switzerland: Springer International Publishing: 209–219.

DeRose, R.J.; Mock, K.E.; Long, J.N. 2014. Cytotype differences in radial increment provide novel insight into aspen reproductive ecology and stand dynamics. Canadian Journal of Forest Research. 45: 1–8.

Dymond, C.C.; Sinclair, T.; Spittlehouse, D.L.; Raymer, B. 2014. Diversifying managed forests to increase resilience. Canadian Journal of Forest Research. 44: 1196–1205.

Fagan, W.F.; Bewick, S.; Cantrell, S.; [et al.]. 2014. Phenologically-explicit models for studying plant-pollinator interactions under climate change. Theoretical Ecology. 7: 289–297.

Fausch, K.D.; Rieman, B.E.; Dunham, J.B.; [et al.]. 2009. Invasion versus isolation: Trade-offs in managing native salmonids with barriers to upstream movement. Conservation Biology. 23: 859–870.

Federal Register. 2009. Executive Order 13514 of October 5, 2009—Federal leadership in environmental, energy, and economic performance. Washington, DC: Executive Office of the President. 74(194): 52117-52127. https://www.gpo.gov/fdsys/pkg/FR-2009-10-08/pdf/E9-24518.pdf [Accessed January 23, 2018].

Federal Register. 2013. Executive Order 13653 of November 1, 2013—Preparing the United States for the impacts of climate change. Washington, DC: Executive Office of the President. 78(215): 66819-66824. https://www.gpo.gov/fdsys/pkg/FR-2013-11-06/pdf/2013-26785.pdf [Accessed January 23, 2018].

Guardiola-Claramonte, M.; Troch, P.; Breshears, D.; [et al.]. 2011. Streamflow response in semi-arid basins following drought-induced tree die-off: Indirect climate impact on hydrology. Journal of Hydrology. 406: 225–233.

Halofsky, J.E.; Peterson, D.L. 2016. Climate change vulnerabilities and adaptation options for forest vegetation management in the northwestern USA. Atmosphere. 7: 46.

Halofsky, J.E.; Peterson, D.L.; Marcinkowski, K.W. 2015. Climate change adaptation in United States federal natural resource science and management agencies: A synthesis. Washington, DC: U.S. Global Change Research Program. http://www.globalchange.gov/sites/globalchange/files/ASIWG_Synthesis_4.28.15_final.pdf [Accessed November 11, 2016].

Halofsky, J.E.; Shelmerdine, W.S.; Stoddard, R.; [et al.]. 2011. Climate change, hydrology, and road management at Olympic National Forest and Olympic National Park. In: Halofsky, J.E.; Peterson, D.L.; O'Halloran, K.A.; Hawkins Hoffman, C., eds. Adapting to climate change at Olympic National Forest and Olympic National Park. Gen. Tech. Rep. PNW-GTR-844. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 21–42.

Hand, M.S.; Lawson, M. 2017. Effects of climate change on recreation in the Northern Rockies. In: Halofsky, J.E.; Peterson, D.L., eds. Climate change and Rocky Mountain ecosystems. Advances in Global Change Research, Volume 63. Cham, Switzerland: Springer International Publishing: 169–188.

Heller, N.E.; Zavaleta, E.S. 2009. Biodiversity management in the face of climate change: A review of 22 years of recommendations. Biological Conservation. 142: 14–32.

Hellmann, J.J.; Byers, J.E.; Bierwagen, B.G.; Dukes, J.S. 2008. Five potential consequences of climate change for invasive species. Conservation Biology. 22: 534–543.

Higgins, C.L.; Wilde, G.R. 2005. The role of salinity in structuring fish assemblages in a prairie stream system. Hydrobiologia. 549: 197–203.

Independent Science Advisory Board [ISAB]. 2007. Climate change impacts on Columbia River basin fish and wildlife. ISAB Climate Change Rep. ISAB 2007-2. Portland, OR: Northwest Power and Conservation Council.

Isaak, D.J.; Wollrab, S.; Horan, D.; Chandler, G. 2012. Climate change effects on stream and river temperatures across the northwest U.S. from 1980–2009 and implications for salmonid fishes. Climatic Change. 113: 499–524.

Isaak, D.J.; Young, M.K. Luce, C.H.; [et al.]. 2016. Slow climate velocities of mountain streams portend their role as refugia for cold-water biodiversity. Proceedings of the National Academy of Sciences. 113: 4374–4379.

Janowiak, M.K.; Swanston, C.W.; Nagel, L.M.; [et al.]. 2014. A practical approach for translating climate change adaptation principles into forest management actions. Journal of Forestry. 112: 424–433.

Jones, J.A.; Post, D.A. 2004. Seasonal and successional streamflow response to forest cutting and regrowth in the northwest and eastern United States. Water Resources Research. 40, W05203, doi:10.1029/2003WR002952.

Keane, R.E.; Mahalovich, M.F.; Bollenbacher, B.L.; [et al.]. 2017. Effects of climate change on forest vegetation in the Northern Rockies. In: Halofsky, J.E.; Peterson, D.L., eds. Climate Change and Rocky Mountain Ecosystems. Advances in Global Change Research, Volume 63. Cham, Switzerland: Springer International Publishing: 59–95.

Lesch, W.; Scott, D.F. 1997. The response in water yield to the thinning of *Pinus radiata, Pinus patula* and *Eucalyptus grandis* plantations. Forest Ecology and Management. 99: 295–307.

Littell, J.S.; McKenzie, D.; Peterson, D.L.; Westerling, A.L. 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916-2003. Ecological Applications. 19: 1003–1021.

Luce, C.H.; Abatzoglou, J.T.; Holden, Z.A. 2013. The missing mountain water: slower westerlies decrease orographic precipitation. Science. 266: 776–779.

Luce, C.H.; Black, T.A. 1999. Sediment production from forest roads in western Oregon. Water Resources Research. 35: 2561–2570.

Luce, C.H.; Holden, Z.A. 2009. Declining annual streamflow distributions in the Pacific Northwest United States, 1948-2006. Geophysical Research Letters. 36: L16401.

Luce, C.H.; Lopez-Burgos, V.; Holden, Z. 2014. Sensitivity of snowpack storage to precipitation and temperature using spatial and temporal analog models. Water Resources Research. 50: 9447–9462.

Luce, C.H.; Morgan, P.; Dwire, K.; [et al.]. 2012. Climate change, forests, fire, water, and fish: Building resilient landscapes, streams, and managers. Gen. Tech. Rep. RMRS-GTR-290. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 207 p.

Malmsheimer, R.W.; Heffernan, P.; Brink, S.; [et al.]. 2008. Forest management solutions for mitigating climate change in the United States. Journal of Forestry. 106: 115–173.

Mantua, N.J.; Raymond, C.L. 2014. Climate change, fish, and aquatic habitat in the North Cascade Range. In: Raymond, C.L.; Peterson, D.L.; Rochefort, R.M., eds. Climate change vulnerability and adaptation in the North Cascades region, Washington. Gen. Tech. Rep. PNW-GTR-892. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 235–270.

Mawdsley, J.R.; O'Malley, R.; Ojima, D.S. 2009. A review of climate-change adaptation strategies for wildlife management and biodiversity conservation. Conservation Biology. 23: 1080–1089.

Mendelsohn, R.; Markowski, M. 2004. The impact of climate change on outdoor recreation. In: Mendelsohn, R.; Neumann, J., eds. The impact of climate change on the United States economy. Cambridge, United Kingdom: Cambridge University Press: 267–288.

Millar, C.I.; Stephenson, N.L.; Stephens, S.L. 2007. Climate change and forests of the future: Managing in the face of uncertainty. Ecological Applications. 17: 2145–2151.

Morelli, T.L.; Daly, C.; Dobrowski, S.Z.; [et al.]. 2016. Managing climate change refugia for climate adaptation. PloS One. 11: e0159909.

Morgan, M.; Rockman, M.; Smith, C.; Meadow, A. 2016. Climate change impacts on cultural resources. Washington, DC: National Park Service, Cultural Resources Partnerships and Science.

Noble, I.R.; Huq, S.; Anokhin, Y.A.; [et al.]. 2014. Adaptation needs and options. In: Field, C.B.; Barros, V.R.; Dokken, D.J., eds. Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY: Cambridge University Press: 833–868.

Peterson, D.L.; Halofsky, J.E. 2017. Adapting to the effects of climate change on natural resources in the Blue Mountains, USA. Climate Services. https://doi.org/10.1016/j.cliser.2017.06.005.

Peterson, D.L.; Halofsky, J.E.; Johnson, M.C. 2011a. Managing and adapting to changing fire regimes in a warmer climate. In: McKenzie, D.; Miller, C.; Falk, D., eds. The landscape ecology of fire. New York: Springer: 249–267.

Peterson, D.L.; Millar, C.I.; Joyce, L.A.; [et al.]. 2011b. Responding to climate change on National Forests: A guidebook for developing adaptation options. Gen. Tech. Rep. PNW-GTR-855. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 109 p.

Peterson, D.P.; Wenger, S.J.; Rieman, B.E.; Isaak, D.J. 2013. Linking climate change and fish conservation efforts using spatially explicit decision support models. Fisheries. 38: 111–125.

Polley, H.W.; Briske, D.D.; Morgan, J.A.; [et al.]. 2013. Climate change and North American rangelands: Trends, projections, and implications. Rangeland Ecology and Management. 66: 493–511.

Pollock, M.M.; Beechie, T.J.; Wheaton, J.M.; [et al.]. 2014. Using beaver dams to restore incised stream ecosystems. Bioscience. 64: 279–290.

Pollock, M.M.; Lewallen, G.; Woodruff, K.; [et al.], eds. 2015. The beaver restoration guidebook: Working with beaver to restore streams, wetlands, and floodplains. Version 1.02. Portland, OR: U.S. Fish and Wildlife Service. 189 p. https://www.fws.gov/oregonfwo/Documents/BeaverRestGBv.1.02.pdf [Accessed August 2, 2016].

Rahel, F.J.; Olden, J.D. 2008. Assessing the effects of climate change on aquatic invasive species. Conservation Biology. 22: 521–533.

Reeves, M.C.; Manning, M.E.; DiBenedetto, J.P.; [et al.]. 2017. Effects of climate change on rangeland vegetation in the Northern Rockies. In: Halofsky, J.E.; Peterson, D.L., eds. Climate change and Rocky Mountain ecosystems. Advances in Global Change Research, Volume 63. Cham, Switzerland: Springer International Publishing: 97–114.

Reeves, M.; Moreno, A.; Bagne, K.; Running, S.W. 2014. Estimating the effects of climate change on net primary production of U.S. rangelands. Climatic Change. 126: 429–442.

Rieman, B.E.; Isaak, D.J. 2010. Climate change, aquatic ecosystems, and fishes in the Rocky Mountain West: Implications and alternatives for management. Gen. Tech. Rep. GTR-RMRS-250. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Rockman, M. 2015. An NPS framework for addressing climate change with cultural resources. The George Wright Forum. 32: 37–50.

Rogers, P.C.; Mittanck, C.M. 2014. Herbivory strains resilience in drought-prone aspen landscapes of the western United States. Journal of Vegetation Science. 25: 457–469.

Sankey, T.; Donald, J.; McVay, J.; [et al.]. 2015. Multi-scale analysis of snow dynamics at the southern margin of the North American continental snow distribution. Remote Sensing of Environment. 169: 307–319.

Schoennagel, T.L.; Veblen, T.T.; Romme, W.H. 2004. The interaction of fire, fuels, and climate across Rocky Mountain landscapes. Bioscience. 54: 651–672.

Scott, D.; Jones, B.; Konopek, J. 2007. Implications of climate and environmental change for nature-based tourism in the Canadian Rocky Mountains: A case study of Waterton Lakes National Park. Tourism Management. 28: 570–579.

Scott, D.; McBoyle, G. 2007. Climate change adaptation in the ski industry. Mitigation and Adaptation Strategies for Global Change. 12: 1411–1431.

Spies, T.A.; Giesen, T.W.; Swanson, F.J.; [et al.]. 2010. Climate change adaptation strategies for federal forests of the Pacific Northwest, USA: Ecological, policy, and socio-economic perspectives. Landscape Ecology. 25: 1185–1199.

Spittlehouse, D.L.; Stewart, R.B. 2003. Adaptation to climate change in forest management. British Columbia Journal of Ecosystems and Management. 4: 1–11.

Stine, P.; Hessburg, P.; Spies, T.; [et al.]. 2014. The ecology and management of moist mixed-conifer forests in eastern Oregon and Washington: A synthesis of the relevant biophysical science and implications for future land management. Gen. Tech. Rep. PNW-GTR-897. Portland, OR: U.S. Department of Agriculture. Forest Service, Pacific Northwest Research Station. 254 p.

Strauch, R.L.; Raymond, C.L.; Rochefort, R.M.; [et al.]. 2015. Adapting transportation to climate change on federal lands in Washington State, USA. Climatic Change. 130: 185–199.

Swanston, C.; Janowiak, M., eds. 2012. Forest adaptation resources: Climate change tools and approaches for land managers. Gen. Tech. Rep. NRS-GTR-87. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 121 p.

Swanston, C.W.; Janowiak, M.K.; Brandt, L.A.; [et al.]. 2016. Forest adaptation resources: Climate change tools and approaches for land managers, 2nd ed. Gen. Tech. Rep. NRS-GTR-87-2. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 161 p.

Thomsen, P.; Kielgast, J.O.S.; Iversen, L.L.; [et al.]. 2012. Monitoring endangered freshwater biodiversity using environmental DNA. Molecular Ecology. 21: 2565–2573.

Troendle, C.; King, R. 1987. The effect of partial and clearcutting on streamflow at Deadhorse Creek, Colorado. Journal of Hydrology. 90: 145–157.

Troendle, C.A.; MacDonald, L.; Luce, C.H.; Larsen, I.J. 2010. Fuel management and water yield. In: Elliot, W.J.; Miller, I.S.; Audin, L., eds. Cumulative watershed effects of fuel management in the western United States. Gen. Tech. Rep. RMRS-GTR-231. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 124–148.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2012. 2012 planning rule. Washington, DC: U.S. Department of Agriculture, Forest Service. Federal Register. 77(68). 115 p. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5362536.pdf [Accessed February 9, 2017].

U.S. Environmental Protection Agency [USEPA]. 2014. Best practices for continuous monitoring of temperature and flow in wadeable streams. EPA/600/R-13/170F. Washington, DC: Global Change Research Program, National Center for Environmental Assessment.

Vose, J.M.; Clark, J.S.; Luce, C.H.; Patel-Weynand, T., eds. 2016. Effects of drought on forests and rangelands in the United States: A comprehensive science synthesis. Gen. Tech. Report WO-93b. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 289 p.

Vose, J.M.; Ford, C.R.; Laseter, S.; [et al.]. 2012. Can forest watershed management mitigate climate change effects on water resources? In: Webb, A.A.; Bonell, M.; Bren, L.; [et al.], eds. Revisiting experimental catchment studies in forest hydrology. IAHS Publ. 353. Wallingford, Oxfordshire, UK: IAHS Press: 12–25.

Water Resources and Climate Change Workgroup. 2016. Looking forward: priorities for managing freshwater resources in a changing climate. https://acwi.gov/climate_wkg/iwrcc/2016_nap_final_20161129.pdf [Accessed February 28, 2017].

Williams, J.E.; Neville, H.M.; Haak, A.L.; [et al.]. 2015. Climate change adaptation and restoration of Western trout streams: Opportunities and strategies. Fisheries. 40: 304–317.

Wilm, H. 1944. The effect of timber cutting in a lodgepole-pine forest on the storage and melting of snow. Transactions of the American Geophysical Union. 25: 153–155.

Wilm, H.; Dunford, E. 1948. Effect of timber cutting on water available for streamflow from a lodgepole pine forest, Tech. Bull. 968. Washington, DC: U.S. Department of Agriculture, Forest Service. 43 p.

Wood, A.W.; Hopson, T.; Newman, A.; [et al.]. 2015. Quantifying streamflow forecast skill elasticity to initial condition and climate prediction skill. Journal of Hydrometeorology. 17: 651–668.

Wood, A.W.; Lettenmaier, D.P. 2006. A test bed for new seasonal hydrologic forecasting approaches in the western United States. Bulletin of the American Meteorological Society. 87: 1699.

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.

References

Halofsky, J.E.; Peterson, D.L., eds. 2017. Climate change vulnerability and adaptation in the Blue Mountains. Gen. Tech. Rep. PNW-GTR-939. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Halofsky, J.E.; Peterson, D.L.; Dante-Wood, S.K.; [et al.]. 2018. Climate change vulnerability and adaptation in the Northern Rocky Mountains. Gen. Tech. Rep. RMRS-GTR-374. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Halofsky, J.E.; Peterson, D.L.; Ho, J.J., eds. [In press]. Vulnerability of natural resources to climate change in the South Central Oregon region. PNW-GTR-XXX. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Halofsky, J.E.; Peterson, D.L.; O'Halloran, K.A.; [et al.]. 2011. Adapting to climate change at Olympic National Forest and Olympic National Park. Gen. Tech. Rep. PNW-GTR-844. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Morelli, T.L.; Yeh, Y.; Smith, N.; [et al.]. 2012. Climate project screening tool: An aid for climate adaptation. Res. Pap. PSW-RP-263. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 29 p.

National Park Service [NPS]. 2010. National Park Service climate change response strategy. Fort Collins, CO: U.S. Department of the Interior, National Park Service, Climate Change Response Program. 28 p. http://www.nps.gov/orgs/ccrp/upload/NPS_CCRS.pdf [Accessed February 9, 2017].

Peterson, D.L.; Millar, C.I.; Joyce, L.A.; [et al.]. 2011. Responding to climate change in national forests: A guidebook for developing adaptation options. Gen. Tech. Rep. PNW-GTR-855. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Raymond, C.L.; Peterson, D.L.; Rochefort, R.M., eds. 2014. Climate change vulnerability and adaptation in the North Cascades region. Gen. Tech. Rep. PNW-GTR-892. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

USDA Forest Service [USDA FS]. 2010a. National roadmap for responding to climate change. Washington, DC: U.S. Department of Agriculture, Forest Service. http://www.fs.fed.us/climatechange/pdf/roadmap.pdf [Accessed February 9, 2017].

USDA Forest Service [USDA FS]. 2010b. A performance scorecard for implementing the Forest Service climate change strategy. Washington, DC: U.S. Department of Agriculture, Forest Service. http://www.fs.fed.us/climatechange/pdf/performance_scorecard_final.pdf [Accessed February 9, 2017].

USDA Forest Service [USDA FS]. 2010c. Strategic plan 2010–2015 FY. Washington, DC: U.S. Department of Agriculture, Forest Service. http://www.ocfo.usda.gov/usdasp/sp2010/sp2010.pdf [Accessed February 9, 2017].

USDA Forest Service [USDA FS]. 2012. 2012 planning rule. Washington, DC: U.S. Department of Agriculture, Forest Service. Federal Register. 77(68). 115 p. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5362536.pdf [Accessed February 9, 2017].

USDA Forest Service [USDA FS]. 2015. USDA Forest Service Strategic Plan: FY 2015–2020. Washington, DC: U.S. Department of Agriculture, Forest Service. 53 p. https://www.fs.fed.us/sites/default/files/strategic-plan%5B2%5D-6_17_15_revised.pdf?utm_medium=email&utm_source=govdelivery [Accessed June 26, 2017].

USDA Forest Service [USFS FS]. 2016. USDA Forest Service Intermountain Region Strategic Framework: FY 2017–2020. Washington, DC: U.S. Department of Agriculture, Forest Service. 18 p. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd530247.pdf?utm_medium=email&utm_source=govdelivery [Accessed June 26, 2017].

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