United States Department of Agriculture

Climate Change Vulnerability and Adaptation in the Northern Rocky Mountains

Part 2

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Forest Service

Rocky Mountain Research Station

General Technical Report
RMRS-GTR-374

March 2018

Halofsky, Jessica E.; Peterson, David L.; Dante-Wood, S. Karen; Hoang, Linh; Ho, Joanne J.; Joyce, Linda A., eds. 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. Part 2. pp. 275–475.

Abstract

The Northern Rockies Adaptation Partnership (NRAP) identified climate change issues relevant to resource management in the Northern Rockies (USA) region, and developed solutions intended to minimize negative effects of climate change and facilitate transition of diverse ecosystems to a warmer climate. The NRAP region covers 183 million acres, spanning northern Idaho, Montana, northwestern Wyoming, North Dakota, and northern South Dakota, and includes 15 national forests and 3 national parks across the U.S. Forest Service Northern Region and adjacent Greater Yellowstone Area. U.S. Forest Service scientists, resource managers, and stakeholders worked together over 2 years to conduct a state-of-science climate change vulnerability assessment and develop adaptation options for national forests and national parks in the Northern Rockies region. The vulnerability assessment emphasized key resource areas—water, fisheries, wildlife, forest and rangeland vegetation and disturbance, recreation, cultural heritage, and ecosystem services—regarded as the most important for local ecosystems and communities. Resource managers used the assessment to develop a detailed list of ways to address climate change vulnerabilities through management actions. The large number of adaptation strategies and tactics, many of which are a component of current management practice, provide a pathway for slowing the rate of deleterious change in resource conditions.

***Keywords**:* adaptation, climate change, ecological disturbance, climate-smart resource management, Northern Rocky Mountains, vulnerability assessment

Front cover: Top left, Twin Lakes Campground, Beaverhead-Deerlodge National Forest; top right, Holland Lake, Flathead National Forest; bottom left, Horse Prairie Guard Station, Beaverhead-Deerlodge National Forest; bottom right, Rock Creek, Lolo National Forest (photos, Eric Henderson, used with permission).

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Summary

The Northern Rockies Adaptation Partnership (NRAP) is a science-management partnership consisting of 15 national forests in the Northern Region of the Forest Service, U.S. Department of Agriculture (USFS); 3 national parks; the USFS Pacific Northwest and Rocky Mountain Research Stations; the University of Washington; and numerous other organizations and stakeholders. These organizations worked together over a period of 2 years to identify climate change issues relevant to resource management in the Northern Rocky Mountains (USA) and to find solutions that can minimize negative effects of climate change and facilitate transition of diverse ecosystems to a warmer climate. The NRAP provided education, conducted a climate change vulnerability assessment, and developed adaptation options for national forests and national parks that manage more than 28 million acres in northern Idaho, Montana, northwestern Wyoming, North Dakota, and northern South Dakota.

Global climate models project that the Earth's current warming trend will continue throughout the 21st century in the Northern Rockies. Compared to observed historical temperature, average warming across the five NRAP subregions is projected to be about 4 to 5 °F by 2050, depending on greenhouse gas emissions. Precipitation may increase slightly in the winter, although the magnitude is uncertain.

Climatic extremes are difficult to project, but they will probably be more common, driving biophysical changes in terrestrial and aquatic ecosystems. Droughts of increasing frequency and magnitude are expected in the future, promoting an increase in wildfires, insect outbreaks, and nonnative species. These periodic disturbances, will rapidly alter productivity and structure of vegetation, potentially altering the distribution and abundance of dominant plant species and animal habitat.

Highlights of the vulnerability assessment and adaptation options for the Northern Rockies include the following:

Water resources and infrastructure

- Effects: Decreasing snowpack and declining summer flows will alter timing and availability of water supply, affecting agricultural, municipal, and public uses in and downstream from national forests, and affecting other forest uses such as livestock, wildlife, recreation, firefighting, road maintenance, and instream fishery flows. Declining summer low flows will affect water availability during late summer, the period of peak demand (e.g., for irrigation and power supply). Increased magnitude of peak streamflows will damage roads near perennial streams, ranging from minor erosion to extensive damage, thus affecting public safety, access for resource management, water quality, and aquatic habitat. Bridges, campgrounds, and national forest facilities near streams and floodplains will be especially vulnerable, reducing access by the public.

- Adaptation options: Primary adaptation strategies to address changing hydrology in the Northern Rockies include restoring the function of watersheds, connecting floodplains, reducing drainage efficiency, maximizing valley storage, and reducing hazardous fuels. Tactics include adding wood to streams, restoring beaver populations, modifying livestock management, and reducing surface fuels and forest stand densities. Primary strategies for

infrastructure include increasing the resilience of stream crossings, culverts, and bridges to higher peakflows and facilitating response to higher peakflows by reducing the road system and disconnecting roads from streams. Tactics include completing geospatial databases of infrastructure (and drainage) components, installing higher capacity culverts, and decommissioning roads or converting them to alternative uses. It will be important to map aquifers and alluvial deposits, improve monitoring to provide feedback on water dynamics, and understand the physical and legal availability of water for aquifer recharge. Erosion potential to protect water quality can be addressed by reducing hazardous fuels in dry forests, reducing nonfire disturbances, and using road management practices that prevent erosion.

Fisheries

- Effects: Decreased snowpack will shift the timing of peakflows, decrease summer low flows, and in combination with higher air temperature, increase stream temperatures, all of which will reduce the vigor of cold-water fish species. Abundance and distribution of cutthroat trout and especially bull trout will be greatly reduced, although effects will differ by location as a function of both stream temperature and competition from nonnative fish species. Increased wildfire will add sediment to streams, increase peakflows and channel scouring, and raise stream temperature by removing vegetation.
- Adaptation options: Primary strategies to address climate change threats to coldwater fish species include maintaining or restoring functionality of channels and floodplains to retain (hence, to cool) water and buffer against future changes, decreasing fragmentation of stream networks so aquatic organisms can reach similar habitats, and developing wildfire use plans that address sediment inputs and road failures. Adaptation tactics include using watershed analysis to develop integrated actions for vegetation and hydrology, protecting groundwater and springs, restoring riparian areas and beaver populations to maintain summer baseflows, reconnecting and increasing off-channel habitat and refugia, identifying and improving stream crossings that impede fish movement, decreasing road connectivity, and revegetating burned areas to store sediment and maintain channel geomorphology. Removing nonnative fish species and reducing their access to cold water habitat reduces competition with native fish species.

Forest vegetation

- Effects: Increasing air temperature, through its influence on soil moisture, is expected to cause gradual changes in the abundance and distribution of tree, shrub, and grass species throughout the Northern Rockies, with more drought-tolerant species becoming more competitive. The earliest changes will be at ecotones between lifeforms (e.g., upper and lower treelines). Ecological disturbance, including wildfire and insect outbreaks, will be the primary facilitator of vegetation change, and future forest landscapes may be dominated by younger age classes and smaller trees. High elevation forests will be especially vulnerable if disturbance frequency increases significantly. Increased abundance and distribution of nonnative plant species, as well as the legacy of past land uses, create additional stress for regeneration of native forest species.
- Adaptation options: Most strategies for conserving native tree, shrub, and grassland systems focus on increasing resilience to chronic low soil moisture (especially extreme drought and low snowpack), and to more frequent and extensive ecological disturbance (wildfire, insects, nonnative species). These strategies generally include managing landscapes to reduce the severity and patch size of disturbances, encouraging fire to play a more natural role, and protecting refugia where fire-sensitive species can persist. Increasing species, genetic, and landscape diversity (spatial pattern, structure) is an important “hedge your bets” strategy that will reduce the risk of major forest loss. Adaptation tactics include using silvicultural prescriptions (especially stand density management) and fuels treatments to reduce fuel continuity, reducing populations of nonnative species, potentially using multiple genotypes in reforestation, and revising grazing policies and practices. Rare and disjunct species and communities (e.g., whitebark pine, quaking aspen) require adaptation strategies and tactics focused on encouraging regeneration, preventing damage from disturbance, and establishing refugia.

Rangeland vegetation

- Effects: A longer growing season is expected to increase net primary productivity of many rangeland types, especially those dominated by grasses, although responses will depend on local climate and soil conditions. Elevated atmospheric carbon dioxide may increase water use efficiency and productivity of some species. In many cases, increasing wildfire frequency and extent will be particularly damaging for big sagebrush and other shrub species that are readily killed by fire. The widespread occurrence of cheatgrass and other nonnative species facilitates frequent fire through annual fuel accumulation. In montane grasslands, wildfire may kill Douglas-fir and other species that have recently established in rangelands through fire exclusion. Shrub species that sprout following fire may be very resilient to increased disturbance, but may be outcompeted by more drought-tolerant species over time.

- Adaptation options: Adaptation strategies for rangeland vegetation focus on increasing resilience of rangeland ecosystems, primarily through control and prevention of invasion by nonnative species. Ecologically based management of nonnative plants focuses on strategies to repair damaged ecological processes that facilitate invasion, and seeding of desired native species can be done where seed availability and dispersal of these species are low. Proactive management to prevent establishment of nonnative species is also critical (early detection-rapid response), including tactics such as weed-free policies, education of employees and the public, and collaboration among multiple agencies to control weeds. Livestock grazing can also be managed through the development of site-specific indicators that inform livestock movement guides and allow for maintenance and enhancement of plant health.

Wildlife

- Effects: Few data exist on the direct effects of climatic variability and change on most animal species. Therefore, projected climate change effects must be inferred from what is known about habitat characteristics and the autecology of each species. Habitat for mammals that depend on high-elevation, snowy environments, whether predators (Canada lynx, fisher, wolverine) or prey (snowshoe hare), is expected to deteriorate relatively soon if snowpack continues to decrease. Species that are highly dependent on a narrow range of habitat (pygmy rabbit, Brewer's sparrow, greater sage-grouse) will be especially vulnerable if that habitat decreases from increased disturbance (e.g., sagebrush mortality from wildfire). Species that are mobile or respond well to increased disturbance and habitat patchiness (deer, elk) will probably be resilient to a warmer climate in most locations. Some amphibian species (Columbia spotted frog, western toad) may be affected by pathogens (e.g., amphibian chytrid fungus) that are favored by a warmer climate.

- Adaptation options: Adaptation strategies for wildlife are focused on maintaining adequate habitat and healthy wildlife populations, and increasing knowledge of the needs and climate sensitivities of species. Connectivity is an important conservation strategy for most species in the Northern Rockies. Maintaining healthy American beaver populations will provide riparian habitat structure and foraging opportunities for multiple species. Quaking aspen habitat, which is also important for several species, can be enhanced by allowing wildfire, protecting aspen from grazing, and reducing conifer encroachment. Restoration of more-open stands of ponderosa pine and mixed-conifer forest through reduction of stand densities will benefit species such as fisher and flammulated owl. Excluding fire and reducing nonnative species will maintain sagebrush habitats that are required by several bird and mammal species.

Recreation

- Effects: Recreation has a significant economic impact throughout the Northern Rockies. A warmer climate will generally improve opportunities for warm weather activities (hiking, camping, sightseeing) because it will create a longer time during which these activities are possible, especially in the spring and fall "shoulder seasons." However, it will reduce opportunities for snow-based, winter activities (downhill skiing, cross-country skiing, snowmobiling) because snowpack is expected to decline significantly in the future. Recreationists will probably seek more water-based activities in lakes and rivers as refuge from hotter summer weather. Higher temperatures may have both positive and negative effects on wildlife-based activities (hunting, fishing, birding) and gathering of forest products (e.g., berries, mushrooms), depending on how target habitats and species are affected.

- Adaptation options: Recreationists are expected to be highly adaptable to a warmer climate by shifting to different activities and different locations, behavior that is already observed from year to year. For example, downhill skiers may switch to ski areas that have more reliable snow, cross-country skiers will travel to higher elevations, and larger ski areas on Federal lands may expand to multi-season operation. Water-based recreationists may adapt to climate change by choosing different sites that are less susceptible to changes in water levels. Hunters may need to adapt by altering the timing and location of hunts. Federal management of recreation is currently not very flexible with respect to altered temporal and spatial patterns of recreation. This can be at least partially resolved by assessing expected use patterns in a warmer climate, modifying opening times of facilities, and deploying seasonal employees responsible for recreational facilities earlier in the year.

Ecosystem services

Ecosystem services are increasingly valued on Federal lands, beyond just their economic value. Climate change effects will vary greatly within different subregions of the Northern Rockies, with some ecosystem services being affected in the short term and others in the long term. Of the many ecosystem services provided in the Northern Rockies, eight are considered here, most of which are relevant to other resource categories included in the assessment.

- Although annual *water quantity* (or water yield or water supply) is not expected to change significantly, timing of water availability is likely to shift, and summer flows may decline. These changes may result in some communities experiencing summer water shortages, although reservoir storage can provide some capacity. Rural agricultural communities will be disproportionately affected by climate change if water does become limiting.

- *Water quality* will decrease in some locations if wildfires and floods increase, adding sediment to rivers and reservoirs. Agriculture is currently the major source of impairment, affecting riparian systems, aquatic habitat, water temperatures, and fecal coliform. Climate change is expected to amplify these effects. Hazardous fuels treatments, riparian restoration, and upgrading of hydrologic infrastructure can build resilience to disturbances that damage water quality.
- *Wood products* are a relatively small component of the Northern Rockies economy, and economic forces will probably have the biggest impacts in the future. As wildfires and insect outbreaks become more common, wood supply could become less reliable, but overall effects will generally be small except in small towns that depend on a steady timber supply.
- *Minerals* and mineral extraction are important economic drivers in eastern Montana and western North Dakota. The biggest effects on this industry will be economic factors and factors related to how it connects to other ecosystem services, particularly water quality. Wildfires and floods can put mineral extraction infrastructure at risk in some watersheds.
- *Forage for livestock* is expected to increase in productive grasslands as a result of a longer growing season and in some cases elevated carbon dioxide. Therefore, ranching and grazing may benefit from climate change. Primary effects on grazing include loss of rural population, spread of nonnative grasses, and fragmentation of rangelands.
- *Viewsheds and air quality* will be negatively affected by increasing wildfires and longer pollen seasons. A growing percentage of the Northern Rockies population will be in demographic groups at risk for respiratory and other medical problems on days with poor air quality. Treatments of hazardous fuels can help build resilience to disturbances that degrade air quality.
- *Regulation of soil erosion* will be decreased by agricultural expansion, spread of nonnative plants, and increased frequency of wildfire and floods. Increased capital investments may be needed for water treatment plants if water quality declines significantly. Climate-smart practices in agriculture and road construction can reduce some negative effects.
- *Carbon sequestration* will be increasingly difficult if wildfires, insect outbreaks, and perhaps plant disease increase as expected, especially in the western part of the Northern Rockies. At the same time, managing forests for carbon sequestration is likely to become more important in response to national policies on carbon emissions. Hazardous fuels treatments can help build resilience to disturbances that rapidly oxidize carbon and emit it to the atmosphere.

Cultural resources

- Disturbances such as wildfires, floods, and soil erosion place cultural and heritage values at risk. Damage to cultural and historic sites is irreversible, making protection a key management focus. Climate-induced changes in terrestrial and aquatic habitats affect abundance of culturally valued plants and animals (especially fish), affecting the ability of Native American tribes to exercise their treaty rights. Effects on cultural resources are amplified by external social forces that include a growing regional population, vandalism, and loss of traditional practices in a globalizing culture.

Conclusions

The NRAP facilitated the largest climate change adaptation effort on public lands to date. This collaboration included participants from Federal agencies and stakeholder organizations interested in a broad range of resource issues. It achieved specific goals of national climate change strategies for the USFS and National Park Service, providing a scientific foundation for resource management and planning in the Northern Rockies. The large number of adaptation strategies and tactics, many of which are a component of current management practice, provide a pathway for slowing the rate of deleterious change in resource conditions. Rapid implementation of adaptation—in land management plans, National Environmental Policy Act documents, project plans, and restoration—will help maintain functionality of terrestrial and aquatic ecosystems in the Northern Rockies, as well as build the organizational capacity of Federal agencies to incorporate climate change in their mission of sustainable resource management. Long-term monitoring will help detect potential climate change effects on natural resources, and evaluate the effectiveness of adaptation options that have been implemented.

Contents—Part 2

Chapter 7: Effects of Climate Change on Rangeland Vegetation in the Northern Rockies Region

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Introduction

Rangelands are dominated by grass, forb, or shrub species, but are usually not modified by using agronomic improvements such as fertilization or irrigation (Lund 2007; Reeves and Mitchell 2011) as these lands would normally be considered pastures. Rangeland includes grassland, shrubland, and desert ecosystems, alpine areas, and some woodlands (box 7.1). This chapter addresses the potential effects of climate change on rangeland vegetation in the Forest Service, U.S. Department of Agriculture (USFS) Northern Region and the Greater Yellowstone Area (GYA), hereafter called the Northern Rockies region. Within the Northern Rockies region, rangelands occupy more than 65 million acres (Reeves and Mitchell 2011). Ecosystem services derived from these rangelands include forage for millions of domestic and wild ungulates, greater sage-grouse (*Centrocercus urophasianus*) habitat, and numerous recreational opportunities (see Chapter 10).

The sustainability of goods and services is threatened by land-use change, such as residential development, energy development, and invasion by nonnative plant species (see Chapter 11). These threats, expressed against the backdrop of climate change, pose unique challenges for managers in the Northern Rockies region. The effects of climate change on rangelands have received less attention than effects on forests, but similar to forests, past and future human land-use activities may exceed climate change effects, at least in the short term (Peilke et al. 2002). Interactions among land-use change, management, and climate change are not well understood and are difficult to forecast. Therefore, this analysis of potential climate change effects on rangelands does not explicitly include estimates of future land-use change or management, and instead focuses on estimated regeneration success, response to disturbance (especially fire), and life history traits.

Relative to forests, rangelands usually occur in more arid environments, either due to edaphic (e.g., some montane grasslands, subalpine shrublands, and fell-fields) or climatic factors. These arid conditions present challenges for studying the effects of climate change because some rangelands will be less resilient to changes in environmental

Box 7.1—Rangeland Definitions used by Different Federal Agencies

<u>U.S. Forest Service</u>

Land primarily composed of grasses, forbs, or shrubs. This includes lands vegetated naturally or artificially to provide a plant cover managed like native vegetation and does not meet the definition of pasture. The area must be at least 1.0 acre in size and 120.0 feet wide (USDA FS 2010).

<u>Bureau of Land Management</u>

Land on which the indigenous vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs, or shrubs and is managed as a natural ecosystem. If plants are introduced, they are managed similarly. Rangelands include natural grasslands, savannas, shrublands, many deserts, tundra, alpine communities, marshes, and wet meadows (Society for Range Management 1998).

<u>Natural Resources Conservation Service</u>

A land cover/use category that includes land on which the climax or potential plant cover is composed principally of native grasses, grass-like plants, forbs or shrubs suitable for grazing and browsing, and introduced forage species that are managed like rangeland. This would include areas where introduced hardy and persistent grasses, such as crested wheatgrass, are planted and practices such as deferred grazing, burning, chaining, and rotational grazing, are used with little or no chemicals/fertilizer being applied. Grasslands, savannas, many wetlands, some deserts, and tundra are considered to be rangeland. Certain low forb and shrub communities, such as mesquite, chaparral, mountain shrub, and pinyon-juniper, are also included as rangeland (USDA 2009).

influences such as fire regimes and periodicity of precipitation. Understanding resistance and resilience for rangelands is important for estimating possible effects of climate change. In broad terms, resilience refers to the capacity of ecosystems to regain structure, processes, and functioning in response to disturbance (Allen et al. 2005; Holling 1973), whereas resistance describes capacity to retain these community attributes in response to disturbance (Folke et al. 2004). These concepts are especially critical when considering establishment of nonnative plants and interactions between climate change stressors (Chambers et al. 2014). In the Northern Rockies region, areas with higher precipitation and cooler temperatures generally result in greater resources and more favorable conditions for plant growth and reproduction (Alexander et al. 1993; Dahlgren et al. 1997). These concepts are demonstrated in fig. 7.1, which indicates that management for ecosystem services derived from rangelands will be relatively more effective in more mesic rangelands.

In this chapter we explore potential effects of climate change on selected rangeland habitats. The evaluation of risk was qualitatively and synthetically determined by using a combination of workshop output, literature (where available), and the judgment of the authors and two reviewers. It is meant to represent our best guess as to the relative vulnerability of each system to estimated perturbations brought forth by expected changes in climate across the Northern Rockies region.

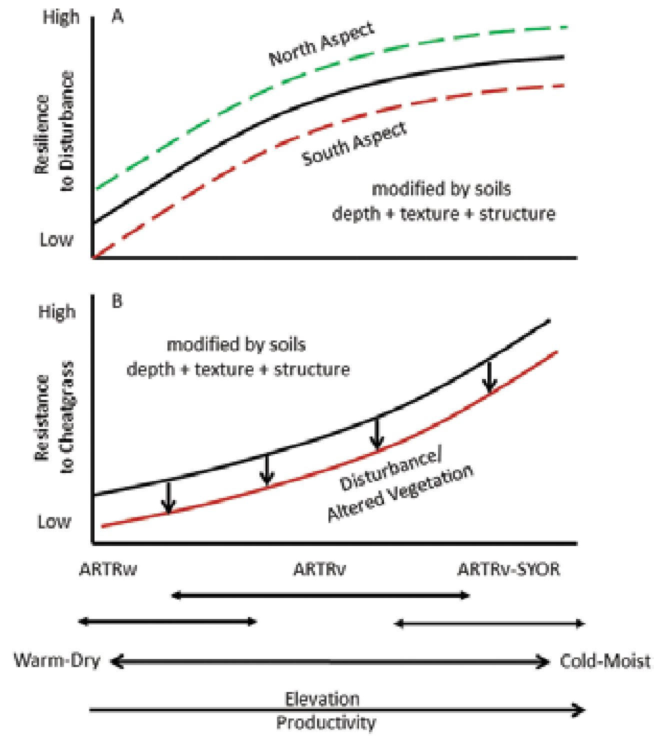

Figure 7.1—Resilience to disturbance (a) and resistance to cheatgrass (b) over a typical temperature/precipitation gradient in the cold desert. Dominant ecological sites occur along a continuum that includes Wyoming big sagebrush on warm and dry sites, to mountain big sagebrush on cool and moist sites, to mountain big sagebrush and root-sprouting shrubs on cold and moist sites. Resilience increases along the temperature/precipitation gradient and is influenced by site characteristics like aspect. Resistance also increases along the temperature/precipitation gradient and is affected by disturbances and management treatments that alter vegetation structure and composition and increase resource availability. ARTRw = Wyoming big sagebrush (Artemisia tridentata ssp. wyomingensis); ARTRv = mountain big sagebrush (A. tridentata ssp. vaseyana); SYOR = mountain snowberry (Symphoricarpos oreophilus) (modified from Chambers et al. 2014).

Vegetation Classes

The rangeland assessment focuses largely on groupings of vegetation types but also references individual species where information and data suggest inferences can be made for species. We identified rangeland vegetation to be included in the vulnerability assessment by first reviewing the extent of rangelands within the conterminous United States (Reeves and Mitchell 2011). The National Resources Inventory definition (box 7.1) of rangelands was used to identify rangelands within the Northern Rockies region. The list of U.S. Ecological Systems designated as rangelands that were retained for evaluation is found in table 7.1. The great complexity of rangeland vegetation combined with a paucity of studies on climate change effects suggests that a grouping of individual vegetation types into classes would be useful. The resulting groups to be analyzed are the northern Great Plains, montane shrubs, montane grasslands (referred to as “western grasslands”), and sagebrush systems. It is important for the reader to understand that multiple vegetation types make up each of the four broad classes of vegetation. In the case of sagebrush systems, however, four groups (big sagebrushes, short sagebrushes, sprouting sagebrushes, and mountain sagebrush) were subsequently further permuted by individual types (table 7.1).

The northern Great Plains has a broad geographic expanse and mixture of both cool-season (C3) and warm-season (C4) species. Montane shrubs are species important for browsing by native ungulates. The relatively rare montane grasslands have a unique position on the landscape, dominance of cool-season species, and specific types of habitats they provide in juxtaposition to forest vegetation.

Sagebrush systems (dominated by species in the genus *Artemisia*) provide critical wildlife habitat, including for the imperiled greater sage-grouse, and are a ubiquitous and iconic species in much of the western United States. In addition, sagebrush systems, especially those dominated by big sagebrushes, have been more widely studied, at least partially as a result of recent research on sage-grouse habitat. Therefore, the vulnerability of some sagebrush species is supported by a richer body of information than for other vegetation. But this does not mean that all sagebrush types have been studied equally in the context of climate change.

Table 7.1—Aproximate area of U.S. Ecological Systems identified as rangelands within the NRAP assessment region. Sagebrush systems were further subdivided into mountain, low, and big or sprouters. These distinct species were grouped into the "big or sprouters" category only for developing map legends because, using the mid-level Ecological Systems mapping approach, without external data, it would be difficult to differentiate each unique cover type dominated by the various *Artemisia* spp. across the landscape.

Rangeland vegetation types	Ecological system	Area	Sagebrush grouping
		Acres	
Northern Great Plains (C3/C4 mix)	Central Tallgrass Prairie	479,899	NA
	Northwestern Great Plains Mixedgrass Prairie	37,818,629	NA
	Western Great Plains Sand Prairie	2,285,234	NA
	Western Great Plains Shortgrass Prairie	39,543	NA
	Western Great Plains Tallgrass Prairie	7,763	NA
	North-Central Interior Sand and Gravel Tallgrass Prairie	209,599	NA
	Northern Tallgrass Prairie	367,864	NA
	Great Plains Prairie Pothole	262,813	NA
Total		**41,471,344**	**NA**
Montane shrubs	Northern Rocky Mountain Montane-Foothill Deciduous Shrubland	1,257,671	NA
	Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland and Shrubland	175,887	NA
	Rocky Mountain Lower Montane-Foothill Shrubland	4,602	NA
Total		**1,438,160**	**NA**
			NA
Montane grasslands (C3)	Columbia Plateau Steppe and Grassland	1,257,642	NA
	Columbia Basin Palouse Prairie	2,692,161	NA
	Columbia Basin Foothill and Canyon Dry Grassland	58,773	NA
	Inter-Mountain Basins Semi-Desert Grassland	42,311	NA
	Northern Rocky Mountain Lower Montane-Foothill-Valley Grassland	14,419	NA
	Northern Rocky Mountain Subalpine-Upper Montane Grassland	5,957	NA
Total		**4,071,263**	**NA**
Sagebrush systems	*Artemisia tridentata* ssp. *vaseyana* Shrubland Alliance	2,931,640	Mountain
	Inter-Mountain Basins Big Sagebrush Steppe	9,656,339	Big or sprouter
	Inter-Mountain Basins Big Sagebrush Shrubland	2,451,624	Big or sprouter
	Inter-Mountain Basins Montane Sagebrush Steppe	1,993,178	Big or sprouter
	Columbia Plateau Low Sagebrush Steppe	156,012	Low
	Wyoming Basins Dwarf Sagebrush Shrubland and Steppe	49,723	Low
	Inter-Mountain Basins Semi-Desert Shrub-Steppe	41,572	Big or sprouter
	Great Basin Xeric Mixed Sagebrush Shrubland	17,970	Low
	Columbia Plateau Scabland Shrubland	14,529	Big or sprouter
Total		**17,312,587**	
All rangelands total		**64,293,354**	

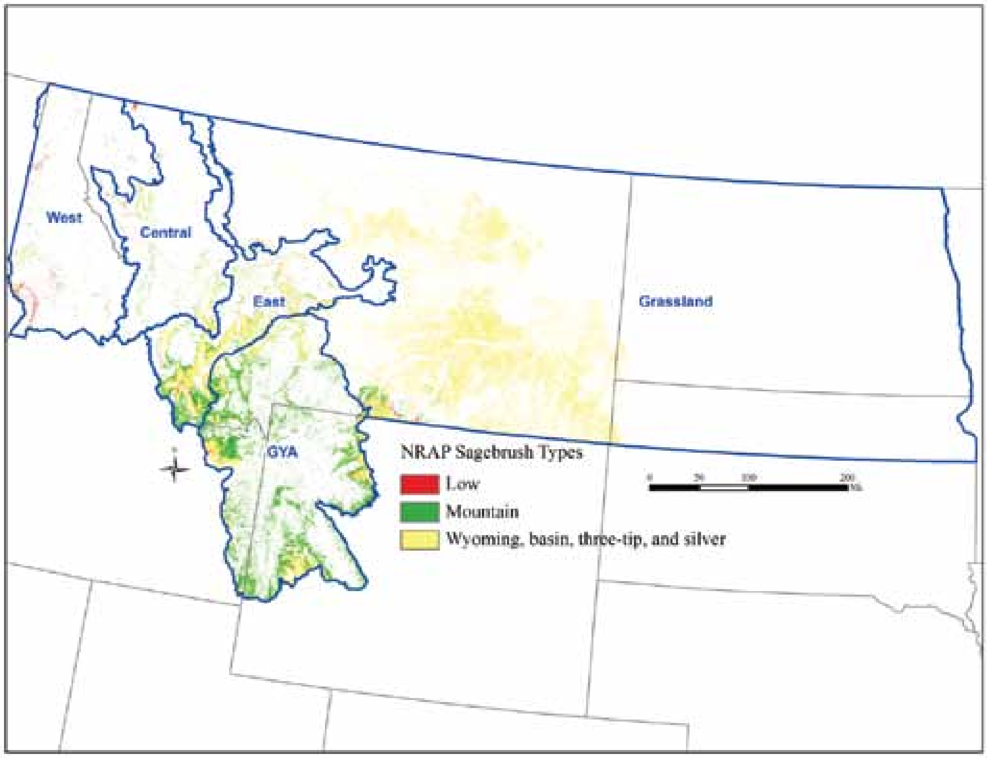

Figure 7.2—Estimated distribution of various sagebrush vegetation classes in the Northern Rockies.

To reflect the disparate amount of study on climate change effects on sagebrush species, four sagebrush types were delineated for the Northern Rockies for this study (fig. 7.2, sagebrush types):

- Big sagebrushes: Wyoming big sagebrush (*A. tridentata* spp. *wyomingensis*) and basin big sagebush (*A. tridentata* ssp. *tridentata*)
- Low sagebrushes: low sagebrush (*A. arbuscula*) and black sagebrush (*A. nova*)
- Sprouting sagebrushes: silver sagebrush (*A. cana*) and threetip sagebrush (*A. tripartita*)
- Mountain big sagebrush (*A. tridentata* ssp. *vaseyana*)

Figure 7.2 does not represent an exact accounting of these four vegetation classes but suggests an estimated distribution where each grouping is usually found. In addition, when Ecological Systems are mapped at this level, it is not possible to differentiate the distribution of silver and threetip sagebrush as they are often disjunctively commingled with other types. As a result, only three categories are mapped; within the largest category, the big sagebrushes and sprouting sagebrushes are all represented in one estimated distribution.

The Wyoming and basin big sagebrush types were aggregated because they have similar life histories, stature, and areal coverage in the Northern Rockies region, and represent critical habitats for many species of birds and wild and domestic ungulates. Despite similar life history traits, basin big sagebrush occupies sites with deeper soils (often on alluvial fans). These conditions tend to increase available moisture with higher coverage by perennial bunchgrasses, suggesting these sites may be more resilient and resistant to various threats (Chambers et al. 2007). Similarly, the low sagebrushes were chosen for the unique habitats they represent (especially black sagebrush) and similar life histories. Both silver sagebrush and threetip sagebrush can resprout after fire, making them unique in that regard among the sagebrush species, with the exception of periodic sprouting by some variants of mountain big sagebrush.

Finally, mountain big sagebrush was chosen for its (usually) distinct positioning on the landscape, in addition to being the most mesic of sagebrush communities in the Northern Rockies region. Communities dominated by Wyoming big sagebrush are by far the most common and occupy the greatest area (table 7.2), whereas the low sagebrush type occupies the least. However, although basin and Wyoming big sagebrush are common throughout the Northern Region, mountain big sagebrush communities occupy the greatest extent on lands managed by the USFS. Although the communities dominated by the *Artemisia* species listed here were subdivided for evaluating possible effects of climate change, four species (basin big, Wyoming big, threetip, and silver) were grouped for mapping purposes as the "big or sprouter" category (table 7.1) because differentiating them across the landscape was impractical.

Vegetation Productivity in Response to Climate Change

Although the current extent of rangeland in the Northern Rockies region can be accurately described, uncertainty in

Table 7.2—Area of rangeland vegetation classes evaluated in each NRAP subregion.

Subregion	Rangeland vegetation classes	Area	Proportion
		Acres	*Percent*
Western Rockies	Montane grasslands	596,837	34.4
	Montane shrubs	298,153	35.7
	Sagebrush systems	358,086	29.9
Total		**1,253,076**	
Central Rockies	Montane grasslands	845,539	43.6
	Montane shrubs	173,980	18.6
	Sagebrush systems	507,391	37.8
Total		**1,526,909**	
Eastern Rockies	Montane grasslands	735,758	13.5
	Montane shrubs	328,306	12.5
	Northern Great Plains (C3/C4 mix)	221,193	5.9
	Sagebrush systems	2,572,138	68.2
Total		**3,857,395**	
Grassland	Montane grasslands	1,343,858	1.8
	Montane shrubs	266,233	0.7
	Northern Great Plains (C3/C4 mix)	41,204,297	80.6
	Sagebrush systems	8,586,897	16.8
Total		**51,401,285**	
Greater Yellowstone Area	Montane grasslands	549,271	6.1
	Montane shrubs	371,488	8.5
	Northern Great Plains (C3/C4 mix)	45,848	0.7
	Sagebrush systems	5,288,075	84.7
Total		**6,254,682**	
All subregions total		**128,586,695**	

the underlying global climate models (GCMs) used to estimate climate change effects (see Chapter 3), and uncertainty in models of physiological response, make it difficult to confidently project the effects of climate change on rangelands. Our understanding of the potential effects of climate change in the region can be improved if comparisons of impacts are made with other areas.

The primary inference about climate change effects on rangeland vegetation nationally is one of increasing temperature, lower soil moisture, changing phenology, and decreasing annual production. However, projected temperatures exhibit far less variability among scenarios and GCMs than precipitation. Therefore, areas where projections suggest that temperature rather than precipitation is a dominant driver may be more reliable. Figure 7.3 suggests that, relative to much of the rest of the United States, the Northern Rockies region could experience an increase in annual net primary productivity (NPP). In addition, the modeled overall increases in productivity appear to be more consistent in the region compared with other areas because there is less disagreement among the three emissions scenarios evaluated (Nakićenović et al. 2000; Reeves et al. 2014).

Changing climate regimes will also influence phenology in unexpected ways. For example, in tallgrass prairie (a rare type in the Northern Rockies region), a 7.2 °F increase in ambient temperature caused earlier anthesis among spring-blooming species and later anthesis in fall-blooming species (Sherry et al. 2007), implying that climate change will influence vegetation in complex ways (Suttle et al. 2007; Walther 2010). In addition, effects of climate change may be greater at higher elevations (Beniston et al. 1997) (fig. 7.3), a logical projection for the Northern Rockies region, where

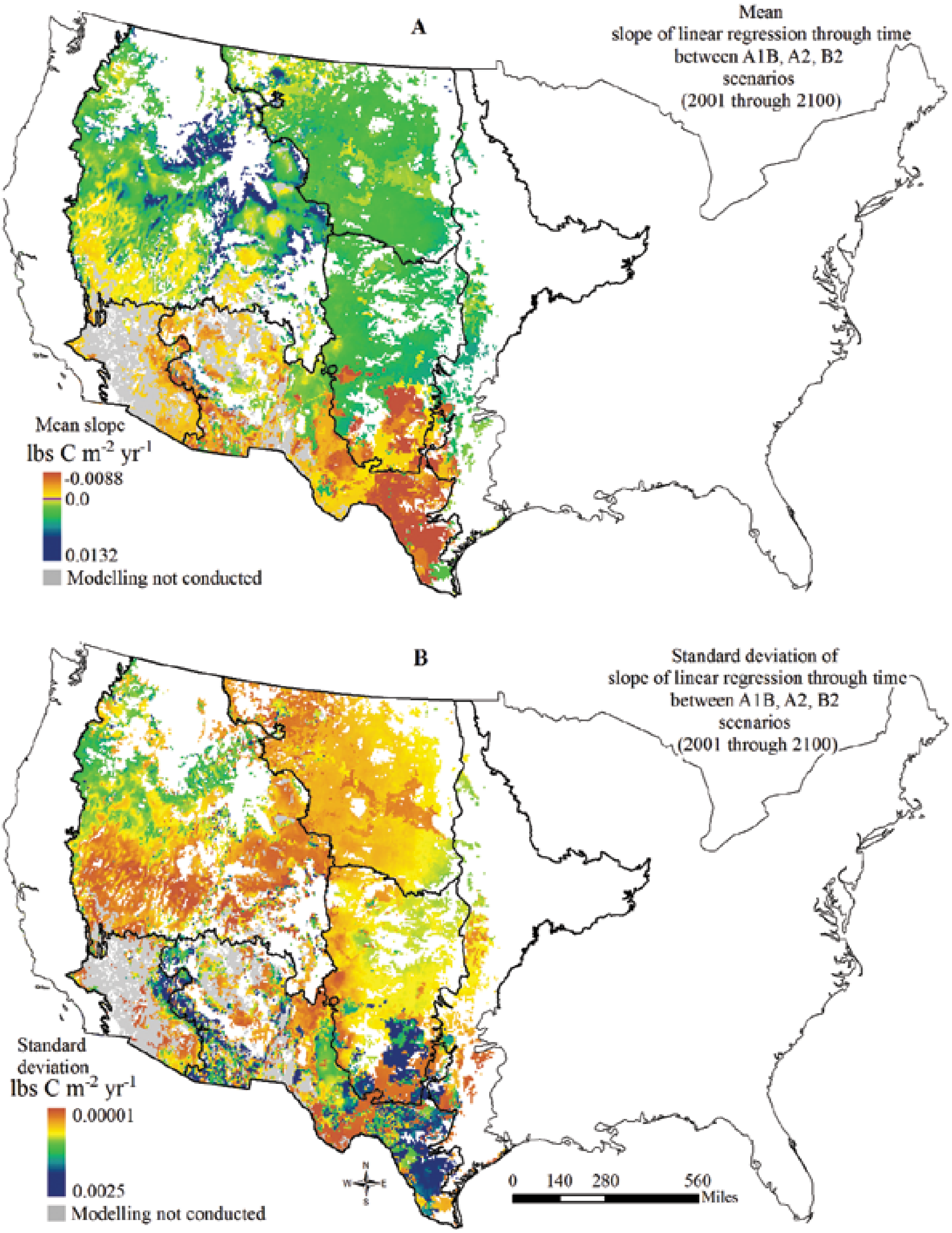

Figure 7.3—Mean slope of linear regression of the net primary productivity trend for the B2, A1B, and A2 emission scenarios (models averaged here include: GCGM2, HadCM3, CSIRO, MK2, MIROC3.2) (a) and standard deviation of the mean slope of linear regression of the net primary productivity trend for the same scenarios (b) (from Reeves et al. 2014).

the primary factor limiting plant growth at high elevations is growing season length and cold temperatures.

The modeled overall effect of projected climate change in the Northern Rockies region is apparently increased growing season length and increased NPP, which may be especially pronounced at higher elevations. Removal of growth limitations could result in significant changes in vegetation at higher elevations, such as the Greater Yellowstone Area subregion. Higher NPP may seem counterintuitive because increased temperatures suggest greater moisture stress and therefore potentially less favorable growing conditions. Indeed, if all other factors besides temperature remained constant in the future, then vegetation might undergo significant reductions in productivity from increased evaporative demand and reduced soil moisture. Conversely, some high-elevation areas may experience increased production with increasing temperatures (Reeves et al. 2014), especially relatively mesic areas supporting mountain sagebrush.

Increased atmospheric carbon dioxide (CO_2) concentrations may modify ecophysiological growth processes in rangeland vegetation. Carbon dioxide enrichment can enhance water use efficiency through reduced water lost through stomata (see Chapter 6), but the response is not consistent across all vegetation. For example, in tallgrass prairie, Owensby et al. (1999) found that elevated CO_2 could increase productivity of aboveground and belowground biomass, but response depended on water stress. These findings are consistent with results from Reeves et al. (2014) and suggest that desiccation effects of increased temperature can be offset to some extent by CO_2 enrichment via reduced transpirational demand (Leakey 2009; Morgan et al. 2004b, 2011; Woodward and Kelly 2008) and higher water use efficiency (Bachelet et al. 2001; Christensen et al. 2004; Morgan et al. 2008, 2011; Polley et al. 2003).

Recent experimental research on the northern Great Plains is particularly relevant to the managers in the Grassland subregion where northern mixed-grass prairie dominates. The Prairie Heating and CO_2 Enrichment (PHACE) study reported an increase of aboveground productivity by an average of 33 percent over 3 years (Morgan et al. 2011), which substantiates estimates by Reeves et al. (2014) of a 28-percent increase in productivity for the northern Great Plains by 2100.

As a footnote to the preceding discussion, it is important to note that all models are a simplification of reality, and interpretation of model results needs to consider uncertainty, inputs, and model assumptions. Models cited here have increasing disparity as time progresses, especially in more arid regions where changing precipitation amounts and patterns may be the primary driver of change.

Management Concerns

The primary management and ecological concerns identified as affecting rangelands in the Northern Rockies region include uncharacteristic fire regimes, improper grazing, and invasive species. Uncharacteristic fire regimes, which are based on the historical fire regime, threaten some rangeland habitats, especially sagebrush steppe, across much of the western United States, including the Northern Rockies region. The overall concern over uncharacteristic fire regimes is perhaps smaller than for other regions such as the Great Basin. On one end of the spectrum, the shortened fire return intervals of many sagebrush habitats suggest that "too much" fire currently affects the landscape relative to historical fire regimes. It is widely documented that increasing dominance of invasive annual grasses has created a positive feedback cycle characterized by frequent fire followed by increased dominance of annual grasses, which further create fuel conditions that facilitate combustion (Chambers et al. 2007). These conditions are exacerbated by wetter and warmer winters, which are projected throughout the region in the future.

On the other end of the spectrum, fire exclusion has led to decreased fire return intervals, which may be responsible for Douglas-fir (*Pseudotsuga menziesii*) encroachment into montane grasslands (Arno and Gruell 1986), and into higher elevation sagebrush habitats, especially those dominated by mountain big sagebrush (Heyerdahl et al. 2006) (fig. 7.4). Overall, the invasive species of greatest concern in sagebrush communities throughout Northern Rockies rangelands is cheatgrass (*Bromus tectorum*), although Japanese brome (*B. japonicus*) and leafy spurge (*Eurphorbia esula*) are also concerns in the northern Great Plains. Recent range expansion of cheatgrass is particularly prominent in the western half of the Northern Rockies region and can be somewhat explained by genetic variation leading to increased survival and persistence in otherwise marginal habitats (Merrill et al. 2012; Ramakrishnan et al. 2006). This rapid range

Figure 7.4—Conifer encroachment, predominantly ponderosa pine into a montane grassland, including the ubiquitous graminoid rough fescue (photo: Mary Manning, USDA Forest Service).

expansion may be enhanced by elevated atmospheric CO_2 concentrations and increased soil disturbance (Chambers et al. 2014). Improper grazing, a term referring to the mis-management of grazing that produces detrimental effects on vegetation or soil resources, can exacerbate these conditions (see chapter 6). Generally, however, U.S. rangelands are not improperly grazed (Reeves and Bagget 2014; Reeves and Mitchell 2011) to the point of degradation; improper grazing is not the normal condition across rangelands in the Northern Region. Where improper grazing does occur, it can accelerate the annual grass invasion/fire cycle, especially in some sagebrush types, the northern Great Plains, and montane grasslands.

Broad-Scale Vulnerability of Rangelands to Climate Change

Determining the vulnerability of rangeland vegetation is a difficult task. Uncertainty exists in the projections of future climatic conditions as well as in expected effects of vegetation. Given the lack of studies focused on manipulated climate on vegetation performance, we are limited to past observations, some published scientific studies, and our collective best judgment. Despite the paucity of relevant studies and the uncertainty of projected climates, a few elements of climate change are increasingly recognized as potential outcomes. In this section, we briefly discuss some overarching expected climatic conditions against which we estimate likely outcomes for vegetation in each of the four identified vegetation classes.

Projected temperature increases (Intergovernmental Panel on Climate Change [IPCC] 2014; see also Capter 3) are expected to increase evaporative demand (e.g., potential evapotranspiration) (Klos et al. 2014) and pose the greatest overall temperature stress of all the estimated future climate outcomes (Polley et al. 2013). Projected changes in precipitation patterns and increasing potential evapotranspiration could encourage more frequent and intense fires from the effects of early-season plant growth combined with the desiccating effects of warmer, drier summers (Morgan et al. 2008). Collectively, these changes may result in considerably drier soils, particularly in the summer months when plants are phenologically active (Bradford et al. 2014; Polley et al. 2013). However, winter precipitation is projected to increase by 10 to 20 percent in the Northern Rockies region (IPCC 2014; Shafer et al. 2014; see also Chapter 3), which may compensate for increasing severity and frequency of droughts. In addition, rising CO_2 levels may offset water loss due to higher evaporative demand by increasing stomatal closure and water use efficiency.

Warmer winters and decreasing snowpack may also be significant factors affecting rangeland vegetation classes (discussed next). Minimum temperatures are expected to increase more than maximum temperatures, providing longer frost-free periods. Warmer, wetter winters would favor early-season plant species and tap-rooted species that are able to reach accumulated early growing season soil water (Polley et al. 2013). These conditions are projected to significantly increase annual area burned and fire intensity (Westerling et al. 2006).

Northern Great Plains, Dominated by Mixtures of Cool-Season and Warm-Season Grasses

Eastern grasslands are expansive across the northern Great Plains, extending from the foothill grasslands along the east slope of the northern and central Rocky Mountains in Montana to the Red River basin in eastern North Dakota. Annual precipitation increases from west to east and ecological provinces change from dry temperate steppe to humid temperate prairie parkland along this gradient (Cleland et al. 2007). Grasslands are the predominant potential vegetation type, occupying about 80 percent of the northern Great Plains landscape. Küchler (1975) divides the potential natural vegetation of this area into shortgrass prairie, northern mixed grass prairie, and tallgrass prairie, reflecting the changing precipitation regime. The shortgrass prairie borders the foothill grasslands and extends to eastern Montana. The typical grassland vegetation types are characterized by grama (*Bouteloua* spp.)/needlegrass (*Stipa* spp.)/wheatgrass (*Pseudoroegneria* spp.) and a mix of C3 and C4 plant species. The northern mixed grass prairie borders the shortgrass prairie in eastern Montana and extends to eastern North Dakota. Typical grassland vegetation types are characterized by wheatgrass/needlegrass in the west and wheatgrass/bluestem (*Andropogon* spp.)/needlegrass to the east, including a mix of C3 and C4 plant species. The tallgrass prairie borders the northern mixed grass prairie in eastern North Dakota and South Dakota and borders the eastern hardwood forest to the east. The typical grassland vegetation types are characterized by bluestem and a dominance of C4 grasses, although C3 grass species are present.

Frequent fire was a major factor in maintaining grassland dominance, particularly in the eastern Great Plains. Settlement in the late 19th and early 20th centuries altered fire regimes by reducing fire frequency and changing the seasonality of fire. The predominant land use and land cover changed from grasslands to crop agriculture and domestic livestock production, affecting the continuity of fuels and fire spread. Reduced fire coupled with increased CO_2 has encouraged woody plant encroachment, primarily in the eastern Great Plains (Morgan et al. 2008).

Other stressors include increased presence and abundance of competitive invasive grass and forb species. These species reduce plant diversity of native grasslands and alter grassland structure. Noxious weeds such as leafy spurge (*Euphorbia esula*) are abundant in places, and other invasive nonnative species include Kentucky bluegrass (*Poa pratensis*), Japanese brome, and cheatgrass. In addition, energy development and the associated infrastructure fragments local grassland patterns where it occurs. Roads and traffic increase opportunities for introduction and spread of invasive species.

Soil water availability and water stress are principal driving factors in semiarid grasslands, influencing plant species distribution, plant community composition and structure, productivity, and associated social and economic systems of the northern Great Plains. Soil water availability is influenced by complex interactions among temperature, precipitation, topography, soil properties, and ambient CO_2 (Ghannoum 2009; Morgan et al. 2011). These physical factors interacting with plant species physiological mechanisms, particularly those of C3 and C4 plants, will influence how grasslands will respond to climate change and elevated atmospheric CO_2 levels (Bachman et al. 2010; Chen et al. 1996; Ghannoum 2009; Morgan et al. 2011).

Available soil water is unevenly distributed across landscapes and is a function of landform, topography, and soil properties. Soil moisture loss through evapotranspiration is influenced by slope, aspect, and solar loading at the ground surface, and water holding capacity is influenced by soil properties. These characteristics in the northern plains may modify the effects of climate change and enhanced CO_2 locally. Landscape patterns of available soil water may result in uneven patterns of vegetation change and productivity under changing temperature and moisture regimes and elevated CO_2 levels. The desiccating effect of higher temperature and increased evaporative demand (Morgan et al. 2011) is expected to offset the benefit of higher precipitation, resulting in lower soil water content and increased drought throughout most of the Great Plains (Morgan et al. 2008). Elevated CO_2 may counter the effects of higher temperatures and evaporative demand by improving water use efficiency of plants (Morgan et al. 2011).

Rising CO_2 and temperature combined with increased winter precipitation may favor some herbaceous forbs, legumes, and woody plants (Morgan et al. 2008). Plant productivity is expected to increase with projected changes in temperature and moisture combined with elevated CO_2 (Morgan et al. 2008). Forage quality may decline as a result of less available forms of soil nitrogen and changes in plant species and functional groups (Morgan et al. 2008). A major shift in functional groups from C3 to C4 plants is possible but uncertain; warmer temperature and longer growing seasons favor C4 grasses, but the effects of higher CO_2 on water-use efficiency may benefit C3 grasses. Most invasive species are C3 plants, so they may become more problematic with the benefits of increased CO_2 (Morgan et al. 2008).

The adaptive capacity of Great Plains grasslands during the drought of the 1930s and 1950s was documented for the central plains (Weaver 1968). There was a shift in C4 grasses, in which big bluestem (*Andropogon gerardii*) and little bluestem (*Schizachyrium scoparium*) were replaced by the shortgrass species blue grama (*Bouteloua gracili*) and buffalograss (*B. dactyloides*). Shifts from tallgrass prairie to mixed grass prairie were also documented with an increase in the C3 plants western wheatgrass and needlegrass. This shift was later reversed during the higher precipitation period of the 1940s, indicating historical adaptive capacity of Great Plains grasslands to the effects of long-term drought. These shifts were also affected by grazing condition of the grasslands before the drought.

Risk Assessment

Magnitude of effects: Moderate magnitude for change from temperate grassland to subtropical grassland by 2050 under no fire suppression. Change toward increased woody vegetation by 2050 with fire suppression. High magnitude for change from temperate grassland to subtropical grassland by 2100. Moderate magnitude for change toward woody vegetation by 2100.

Likelihood of effects: Moderate likelihood for change from temperate grassland to subtropical grassland by 2050 with no fire suppression, and moderate likelihood for change to increased woody vegetation by 2050 with fire suppression. The response of C3 and C4 species to the combined effects of higher temperature and elevated CO_2 is uncertain.

Communities Dominated by Montane Shrubs

Montane shrubs are typically associated with montane and subalpine forests, and occur as large patches within forested landscapes. Species such as Rocky Mountain maple (*Acer glabrum*), oceanspray (*Holidiscus discolor*), tobacco brush (*Ceanothus velutintis* var. *velutinus*), Sitka alder (*Alnus viridus* subsp. *sinuata*), thimbleberry (*Rubus parviflorus*), chokecherry *(Prunus virginiana*), serviceberry (*Amelanchier alnifolia*), currant (*Ribes* spp.), snowberry (*Symphoricarpos albus*), Scouler willow (*Salix scouleriana*), and mountain ash (*Sorbus scopulina*) are common.

Montane shrubs persist on sites where regular disturbance kills the top of plants. This, along with full sunlight and adequate soil moisture, stimulates regrowth from the root crown, rhizomes, and roots. Stressors include fire exclusion and conifer establishment, browsing by both native and domestic wildlife, and insects and disease. Loss of topsoil following frequent, hot fires, can lead to loss of these species over time (Larsen 1925; Wellner 1970). Mesic shrubs are well adapted to frequent fire, and under the right conditions can expand and outcompete regenerating conifers. However, with declining snowpack and warmer temperatures, fires may be hotter and sites may be drier, causing variable amounts of mortality, depending on site conditions.

Mesic shrubs are well adapted to frequent fire (Smith and Fisher 1997) and sprout vigorously after fire, enabling them to quickly regain dominance on the site. As sites become drier and fires become more frequent and severe, however, there may be a shift away from mesic species to more xeric species such as rubber rabbitbrush (*Ericameria nauseosa*), green rabbitbrush (*Chrysothamnus viscidiflorus*), and spineless horsebrush (*Tetradymia canescens*). Nonnative invasive plant species may also expand into these communities, particularly following fire (Bradley 2008;

D'Antonio and Vitousek 1992). With warmer temperatures and drier soils, some mesic shrub species (e.g., Sitka alder and Rocky Mountain maple) may shift their distribution up in elevation or to cooler, moister sites (e.g., northeast-facing depressions).

Risk Assessment

Magnitude of effects: Moderate
Likelihood of effects: High

Montane Grasslands

Montane grasslands are associated with mountainous portions of the Northern Rockies region including the Palouse prairie and canyon grasslands of northern and central Idaho. Montane grasslands occur in intermountain valleys, foothills, and mountain slopes from low to relatively high elevation. They are dominated by C3 grasses, along with a large number of forbs and upland sedges. Shrubs and trees may occur with low cover. Dominant species include bluebunch wheatgrass (*Pseudoroegneria spicata*), rough fescue (*Festuca campestris*), Idaho fescue (*F. idahoensis*), Sandberg bluegrass (*Poa secunda*), needle-and-thread (*Hesperostipa comata*), western wheatgrass (*Pascopyrum smithii*), prairie junegrass (*Koeleria macrantha*), western needlegrass (*Achnatherum nelsonii*), and Richardson's needlegrass *(A. richardsonii*).

Many low-elevation grasslands have been converted to agricultural use or are grazed by domestic livestock. They have also been subjected to extensive human use and land use conversion. Those grasslands that remain, particularly at lower elevations, are typically highly disturbed, fragmented, and frequently occupied by many nonnative invasive plant species. Prolonged improper livestock grazing, native ungulate herbivory, and nonnative invasive plants are the primary stressors in these grasslands (Finch 2012). Loss of topsoil can occur if vegetation cover and density decline and bare ground increases. Lack of fire is also a chronic stressor because conifers from lower montane forests can become established in some areas, and can increase in density and cover with fire exclusion (Arno and Gruell 1986; Heyerdahl et al. 2006). As conifer density and cover increase with fire exclusion, grass cover declines because most grassland species are shade-intolerant (Arno and Gruell 1983). If fires become hotter and more frequent, however, there is an increased risk of mortality of native species and invasion by nonnative plant species. But invasive plants may not always establish and dominate a site (Ortega et al. 2012; Pearson et al., in review) under these conditions. If spring and winter precipitation increase, some expect exotic annual grasses, particularly cheatgrass, which germinates in the winter/early spring, to establish and set seed earlier than native perennial grasses (Finch 2012). This would create an uncharacteristic, continuous fine fuel load that is combustible by early summer and capable of burning native perennial grasses often before they have matured and set seed (Bradley 2008; Chambers et al. 2007). Other nonnative species, such as spotted knapweed (*Centaurea melitensis*), Dalmatian toadflax (*Linaria dalmatica*), butter-and-eggs (*Linaria vulgaris*), and sulphur cinquefoil (*Potentilla recta*) respond favorably after fire and can increase in cover and density.

Nonnative invasive plant species will probably expand, particularly in the lower elevation grassland communities, because resistance to invasion may decrease as these communities become warmer and drier (Chambers et al. 2014). Greater disturbance is likely to increase the rate and magnitude of infestation (Bradley 2008). In addition, drier site conditions coupled with ungulate effects (grazing, browsing, hoof damage) and the associated increases in surface soil erosion may increase bare ground (Washington-Allen et al. 2010). Low-elevation grasslands may shift in dominance towards more drought-tolerant species. Some model output, such as MC2 (Bachelet et al. 2001) (see Chapter 6), suggests that C3 grasslands will decline and C4 grasslands will expand based solely on temperature trends. However, elevated CO_2 favors C3 grasses and enhances biomass production, whereas warming favors C4 grasses due to increased water use efficiency (Morgan et al. 2004a, 2007). Although C3 grasses dominate western montane grasslands, a warmer and drier climate may allow C4 grasses (primarily northern Great Plains species) to expand westward into montane grasslands. In general, it is likely that with increased warming and more frequent fires, grasslands will become a more dominant landscape component as shrublands and lower montane conifer forests are burned more frequently and unable to regenerate. Increasing fire would also lead to the expansion of invasive species into grasslands (Bradley 2008; D'Antonio and Vitousek 1992).

Risk Assessment

Magnitude of effects: High
Likelihood of effects: High

Sagebrush Systems

Communities Dominated by Wyoming Big Sagebrush and Basin Big Sagebrush

The current distribution of Wyoming big sagebrush ecosystems in the Northern Rockies region is generally patchy throughout most of Montana with more spatially consistent cover in the Eastern Rockies and Grassland subregions (Comer et al. 2002). As previously mentioned, the distribution of basin big sagebrush habitats is generally restricted to deeper soils, often including alluvial fans. Stressors to both Wyoming and basin big sagebrush communities include prolonged improper livestock grazing, native ungulate herbivory, and nonnative invasive plants. Loss of topsoil can occur if vegetation cover and density decline and bare ground increases, primarily caused by ungulate impacts (e.g., grazing and mechanical/hoof damage). In contrast with mountain and basin big sagebrush habitats, Wyoming big sagebrush habitats spatially coincide with oil and gas development, which is prominent on the eastern edge of its distribution. The Grassland and Greater Yellowstone Area subregions contain the largest extent of these two big sagebrushes, although the Western Rockies subregion may contain the largest amount of basin big sagebrush.

Big sagebrush ecosystems have decreased in spatial extent in the 20th century (Bradley 2010; Knick et al. 2003; Manier et al. 2013; Noss et al. 1995) because of oil and gas development (Doherty et al. 2008; Walston et al. 2009), removal of big sagebrushes to increase livestock forage (Shane et al. 1983), plant pathogens and insect pests (Haws et al. 1990; Nelson et al. 1990), improper grazing (Davies et al. 2011), invasive species (D'Antonio and Vitousek 1992; Davies 2011), and changes in disturbance regimes (Baker 2011; Balch et al. 2013). Oil and gas development, along with urbanization and land conversion for agriculture and livestock grazing, lead not only to habitat loss, but to fragmented habitat patches (Naugle et al. 2011), resulting in barriers to plant dispersal, avoidance by greater sage-grouse, and loss of obligate and facultative wildlife species (Rowland et al. 2006). In addition to habitat destruction of big sagebrush ecosystems, several stressors can cause big sagebrush dieback and reduce its biomass and density, including insect pests (Haws et al. 1990), plant pathogens (Cárdenas et al. 1997; Nelson et al. 1990), and frost damage (Hanson et al. 1982). Improper use by domestic livestock alters the structure and composition of big sagebrush ecosystems through the loss of palatable components of the plant community (i.e., perennial grasses and forbs), along with reducing or increasing big sagebrush cover (Anderson and Holte 1981; Brotherson and Brotherson 1981), and increasing the probability of nonnative annual grass invasion (Cooper et al. 2007; Davies et al. 2011; Knapp and Soulé 1996). Cheatgrass has reduced the spatial distribution and habitat quality of sagebrush ecosystems throughout much of the western United States (Balch et al. 2013; Brooks et al. 2004).

Invasion by cheatgrass will pose an even greater threat to big sagebrush ecosystems in the future because of projected increases in its biomass production and in fire frequency due to rising temperature and CO_2 levels (Westerling et al. 2006; Ziska et al. 2005). Although less studied, field brome (*Bromus arvensis*) can also negatively affect big sagebrush plant communities because it can colonize readily after stand-replacing fires that eliminate big sagebrushes (Cooper et al. 2007).

Several life history traits of big sagebrushes make them sensitive to direct and indirect effects of climate change. Amount and timing of precipitation control seeding establishment at low elevation, whereas minimum temperature and snow depth control germination and survival at high elevations (Nelson et al. 2014; Poore et al. 2009; Schlaepfer et al. 2014a). Drought events are projected to increase in the western United States in the future (IPCC 2014), although the likelihood of increased drought in the Northern Rockies Region is uncertain (see Chapter 3). Big sagebrush ecosystems remain vulnerable to drought, which may affect germination and survival of seedlings because soil water content primarily controls seedling survival (Schlaepfer et al. 2014a). Big sagebrush seedling survival may be highest in intermediate temperature and precipitation regimes (Schlaepfer et al. 2014b). Even after seedling establishment, drought and increased summer temperature can affect survival and growth of adult plants because growth is positively correlated with winter precipitation and winter snow depth (Poore et al. 2009). Thus, if drought events increase in frequency and severity in the Northern Rockies region, big sagebrush biomass and the abundance and diversity of perennial grasses and forbs may decrease.

It is uncertain if big sagebrush species can move in concert with shifting temperature and precipitation regimes and disperse to available habitat patches and colonize them. Most big sagebrush seeds (50–60 percent) are not viable in the seedbank after 2 years, with few viable seed in the upper soil (Wijayratne and Pyke 2009, 2012). Furthermore, big sagebrushes are poor dispersers (Schlaepfer et al. 2014a; Young and Evans 1989) and seed production is episodic (Young et al. 1989). Even if big sagebrush seeds successfully disperse and germinate in response to a changing climate, probabilities of seedling establishment and adult survivorship are uncertain because big sagebrushes are poor competitors relative to associated herbaceous species (Schlaepfer et al. 2014a).

Big sagebrushes are sensitive to fire and cannot resprout (Shultz 2006). Recovery from seed dispersal can take 50 to 150 years (Baker 2006, 2011), so postfire recovery may become a problem in the future, if the frequency and intensity of fires increase as projected (Abatzoglou and Kolden 2011; Westerling et al. 2006). Regeneration of big sagebrushes postfire is strongly linked to winter precipitation (Nelson et al. 2014), which is expected to increase by 10 to 20 percent in the Northern Rockies region by 2100 (IPCC 2014; Shafer et al. 2014). Although more frequent fire may result in larger losses of big sagebrush habitat in the future, recovery of big sagebrushes may be less impeded. It is also possible that much of this increased precipitation will come as rainfall (Klos et al. 2014), which could, in turn, promote herbaceous growth that might suppress sagebrush recovery in some instances.

Climate change will result in shifts in the distribution of conditions suitable to support big sagebrushes and hence the spatial configuration of big sagebrush habitat, with direct and indirect effects on sagebrush-dependent species (e.g., greater sage-grouse). Several studies using species distribution modeling (SDM) have projected that big sagebrushes will move northward and up in elevation in response to increased winter temperatures and summer drought associated with climate change (Schlaepfer et al. 2012; Shafer et al. 2001). Although big sagebrush species may expand northward and upslope, their habitat is predicted to contract significantly due to increased soil moisture stress, primarily at southern latitudes and lower elevations (fig. 7.5).

The probability of big sagebrush regeneration has been projected to increase at the leading edge of their range (i.e., northern range limit) under future climatic conditions, suggesting potential northward range expansion with climate

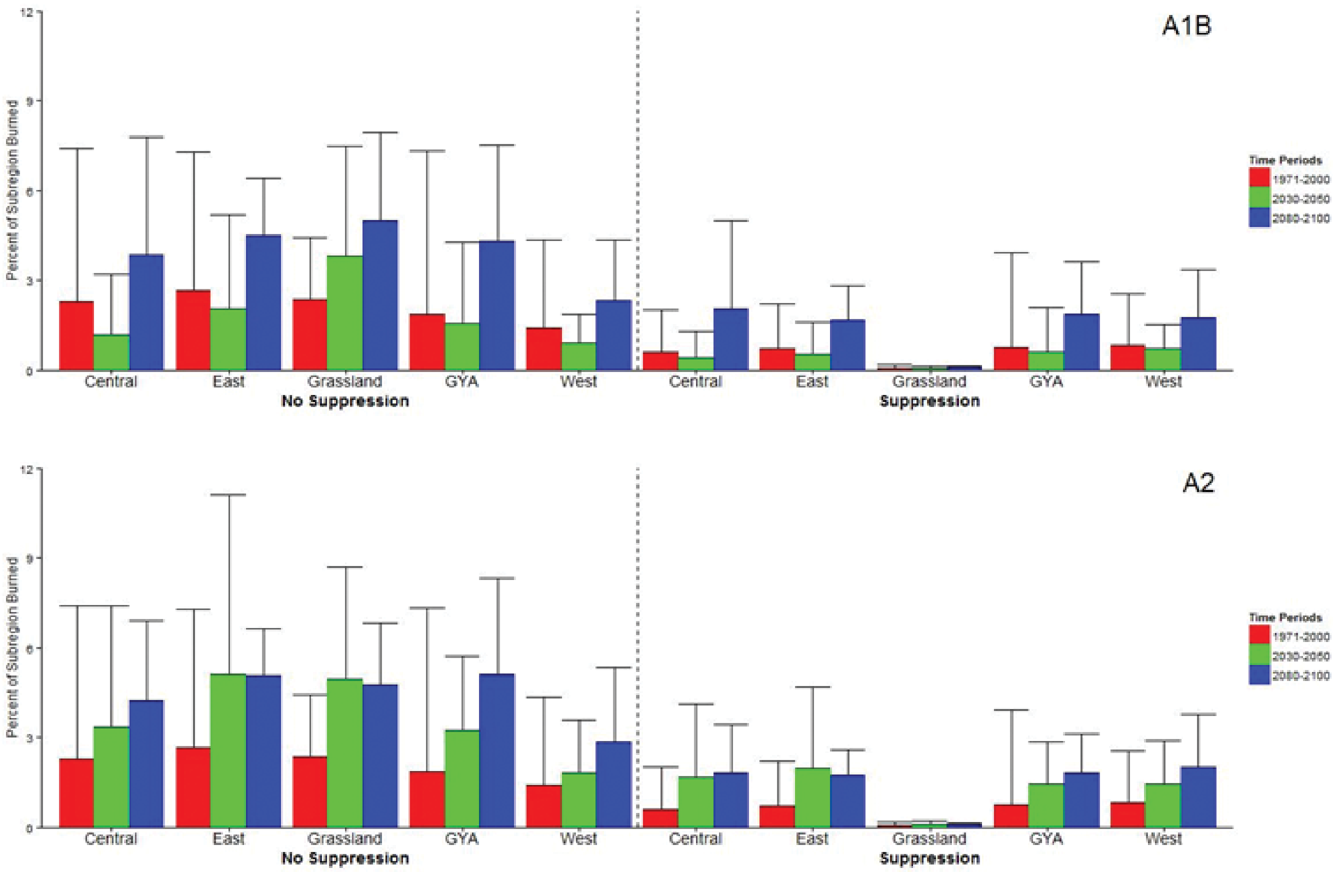

Figure 7.5—Mean and standard deviation of percent of subregions burned across three time spans (historic, 2030–2050, 2080–2100) and without/with fire suppression.

change (Schlaepfer et al. 2015). This is in part due to changes in habitat suitability because soil water conditions at the leading edge will be similar to current soil water patterns in big sagebrush systems. Habitat suitability for big sagebrush species is predicted to increase primarily in northeastern and north-central Montana (Schlaepfer et al. 2015; Schrag et al. 2011) (fig. 7.5). In contrast, habitat suitability is predicted to decrease in parts of the Western Rockies and northwestern Greater Yellowstone Area subregions (fig. 7.5), primarily from summer drought (Schlaepfer et al. 2012; Schlaepfer et al, in review). However, expansion of big sagebrush species out of unsuitable habitat and into suitable habitat is contingent on the ability of the species to disperse to available habitat patches and compete with other species.

In addition to changes in big sagebrush distribution, shifts in community composition and productivity are expected with climate change. Because of the uncertainty about length and severity of drought events in the future, the projected shifts in community composition and productivity in big sagebrush ecosystems in response to climate change remain uncertain. If drought events do increase in the Northern Rockies region, native herbaceous plant diversity and cover may be reduced. In contrast, in nondrought years, warming temperatures and increased levels of CO_2 may lead to increased biomass production (Reeves et al. 2014), more frequent fires, and increases in herbaceous biomass at the expense of fire-intolerant shrubs, such as big sagebrush species.

Paleoecological studies have shown that species move individualistically and at different rates in response to climate change, resulting in novel combinations of species (Delcourt and Delcourt 1981). Even species in the same functional group (e.g., grasses) may respond differentially to climate change (Anderson and Inouye 2001). Thus, big sagebrush plant communities are unlikely to migrate as a unit in response to altered temperature and precipitation. The response of individual species to climate change will depend on both physiological tolerances and competitive ability.

Shifts in disturbance regimes (e.g., fire, insects, pathogens) associated with climate change may affect big sagebrush ecosystems in the future. Disturbances affect vegetation directly by killing individuals and removing aboveground biomass, and indirectly by altering soil conditions. Climate change and disturbance may have additive effects on soil water balance in big sagebrush ecosystems, decreasing soil water content (Bradford et al. 2014) and resulting in diminished growth and regeneration (Poore et al. 2009). Increased disturbance frequency could reduce the spatial extent of big sagebrush in the future, despite increased habitat suitability and regeneration potential, because big sagebrush is incapable of resprouting after disturbance (Shultz 2006). As with other vegetation types, there is great uncertainty and variability regarding estimates of fire return intervals of stands dominated by big sagebrush species. For example, in the Northern Rockies, Lesica et al. (2007) suggest that fire return intervals for Wyoming big sagebrush are longer than for basin big sagebrush and mountain big sagebrush, and range from 50 to 150 years, whereas Baker (2011, 2013) and Bukowski and Baker (2013) estimate ranges of 200 to about 350 years.

The long fire return intervals to which Wyoming big sagebrush is adapted are related to its very slow postfire recovery, as low as 2 percent recovery 23 years after fire (Lesica et al. 2007). The slow recovery of these systems is partly due to slow growth rates and harsher environmental conditions in many sites in the Northern Rockies region. Basin big sagebrush canopy cover development and growth are faster than for Wyoming big sagebrush (Booth et al. 1990; Lesica et al. 2007; McArthur and Welch 1982). Invasive annual grasses such as cheatgrass may exacerbate slow growth.

Big sagebrush ecosystems have some capacity to adapt to climate change. Big sagebrush species occur over a large geographic area with high diversity in topography, soils, and climate, suggesting that these species can withstand a relatively broad range of ecological conditions and may tolerate shifting climates. Various subspecies of big sagebrush often hybridize and have a high level of polyploidy, providing them with the capacity to undergo selection and adapt to shifting climatic regimes relatively quickly (e.g., Poore et al. 2009).

Although lower soil water availability may pose a threat to big sagebrush ecosystems, long periods of sustained drought would be needed to cause mortality (Kolb and Sperry 1999). Even though big sagebrush habitat suitability is projected to change across space (e.g., decreasing suitability in northwestern Wyoming and across much of western Montana), big sagebrush species may still persist in relatively “unsuitable” habitat for some time, perhaps in a degraded state.

Risk Assessment

Magnitude of effects: Highly variable. In northwestern Wyoming and western Montana, the effects of climate change are likely to be low to moderate. Lower water availability may cause declines in big sagebrush growth and regeneration, facilitating some habitat contraction. However, big sagebrush species may expand northward into northern and eastern Montana, as habitat suitability increases in future decades. Despite this generalization, it is also possible that an increase in fire activity will decrease the extent of big sagebrush communities in many locations.

Likelihood of effects: Variable. Some contraction in big sagebrush habitat may occur in northwestern Wyoming and western Montana, particularly at lower elevations, because of increased temperature and evapotranspiration. However, if big sagebrush can successfully exploit changing climatic conditions, the total area covered by big sagebrush species in the Northern Rockies region may increase by the end of the 21st century. Potential expansion may be tempered by faster rates of loss if the cheatgrass-fire cycle tracks new habitats in the northeastern part of the region. It is conceivable that drier sites, such as those with sandy soils, may lose the ability to regenerate sagebrush, whereas more mesic sites might still be able to regenerate.

Communities Dominated by Low Sagebrushes (Black and Low Sagebrush)

The current distribution of low sagebrush ecosystems in the Northern Rockies region is restricted to about 1 percent of the total sagebrush habitat as indicated in the LANDFIRE existing vegetation type (EVT) database. The western portion of the Northern Rockies region contains 50 percent of the low sagebrush habitat, but limited patches are also found in the Eastern Rockies subregion and in the Greater Yellowstone Area subregion, especially on the western edge. Most of these sites support low sagebrush but not black sagebrush. Low sagebrush sites are characterized as relatively low-production areas over shallow, claypan soils that restrict drainage and root growth. Low sagebrush is found on altitudinal gradients from 2,300 feet to more than 11,500 feet (Beetle and Johnson 1982), and it is generally found between 6,000 and 9,000 feet in Montana and Idaho. In contrast, black sagebrush is considerably more restricted in ecological amplitude and is found on shallow, dry, infertile soils. Current stressors are predominantly improper use by livestock and invasion by nonnative species.

Despite growing across a broad range of elevations, low and black sagebrush are less common than other sagebrush species. Thus, it is reasonable to assume that as climates change, ranges could be further restricted, resulting in small islands being isolated, although this is more likely for black sagebrush because of its poor competitive ability (West and Mooney 1972). Both species depend heavily on seeding for reproduction (Wright et al. 1979) and recovery from disturbance. In addition, several traits make low sagebrush species sensitive to climate change. There is high mortality in the first year of growth (Shaw and Monsen 1990). Establishment is probably greatest when a thin layer of soil covers the seeds, and if erosion increases from drought-induced reductions of plant cover, the already thin soils may not provide suitable seedbeds for germination. Seed development and establishment are best in years with ample precipitation, and if unfavorable conditions for seeding persist following disturbance, it is reasonable to assume that low sagebrush species may disappear from some stands, especially if annual grass invasion occurs concomitantly with unfavorable growth conditions.

Climate change will result in shifts in the distribution of conditions suitable to support low sagebrush species and hence the spatial configuration of low sagebrush habitats. Both low and black sagebrush are intolerant of fire and do not resprout. Therefore, increased fire activity will have negative consequences for both species. Fire return intervals vary considerably among communities dominated by low sagebrush species. Estimates of fire return intervals for xeric sagebrush communities of the Great Basin range from 35 to more than 100 years (Brown 2000; Riegel et al. 2006), but intervals of 100 to 200 years for low-productivity black sagebrush communities have been reported. Especially for black sagebrush, which usually occupies quite unproductive sites with small buildup of fuels, these fire return intervals may be overestimated (Baker 2013). Within the boundaries and on the periphery of the Greater Yellowstone Area subregion, MC2 results indicate that the proportion of landscape burned will increase substantially in the future (fig. 7.6), allowing a higher likelihood of ignition and flaming fronts to reach some low sagebrush communities. The extent to which these sites will carry fire depends on herbaceous production and probably on magnitude of invasion by annual grasses (especially cheatgrass). In summary, climate change may influence low sagebrush systems by reducing seedling establishment in unfavorable years. In addition, projected increased fire activity will decrease the abundance of low sagebrush relative to other species, especially if nonnative annual grasses, such as medusahead (*Taeniatherum caput-medusae*) and cheatgrass, become more prevalent.

Relative to other sagebrush species, low and black sagebrush have limited adaptive capacity. Black sagebrush hybridizes with silver sagebrush, and sprouting is thought to be a heritable trait in crosses between nonsprouting and sprouting sagebrushes (McArthur 1994). In the Northern Rockies region, however, it is unlikely that silver sagebrush will exhibit a significant presence in areas that support low sagebrush; the distribution of these species is usually disjunctive, so the possibility of inheriting sprouting traits is unlikely. In addition, the relatively low productivity characterizing low sagebrush sites may also limit adaptive capacity, especially if other risk factors are present.

Risk Assessment

Magnitude of effects: High. The resilience of many of these areas is low given the thin and argillic soil properties characterizing these sites. The magnitude of effects is likely to increase if other perturbations such as improper recreational or grazing schemes are present. The low adaptive capacity of this sagebrush type, intolerance of fires, and low rate of reproduction act in concert to increase the magnitude of effects.

Likelihood of effects: Moderate to high. Models suggest increased production at higher elevations (Reeves et al. 2014), increasing the likelihood of fires carrying through otherwise relatively unburnable landscapes. The problem of increased flammability will increase, especially if invasive

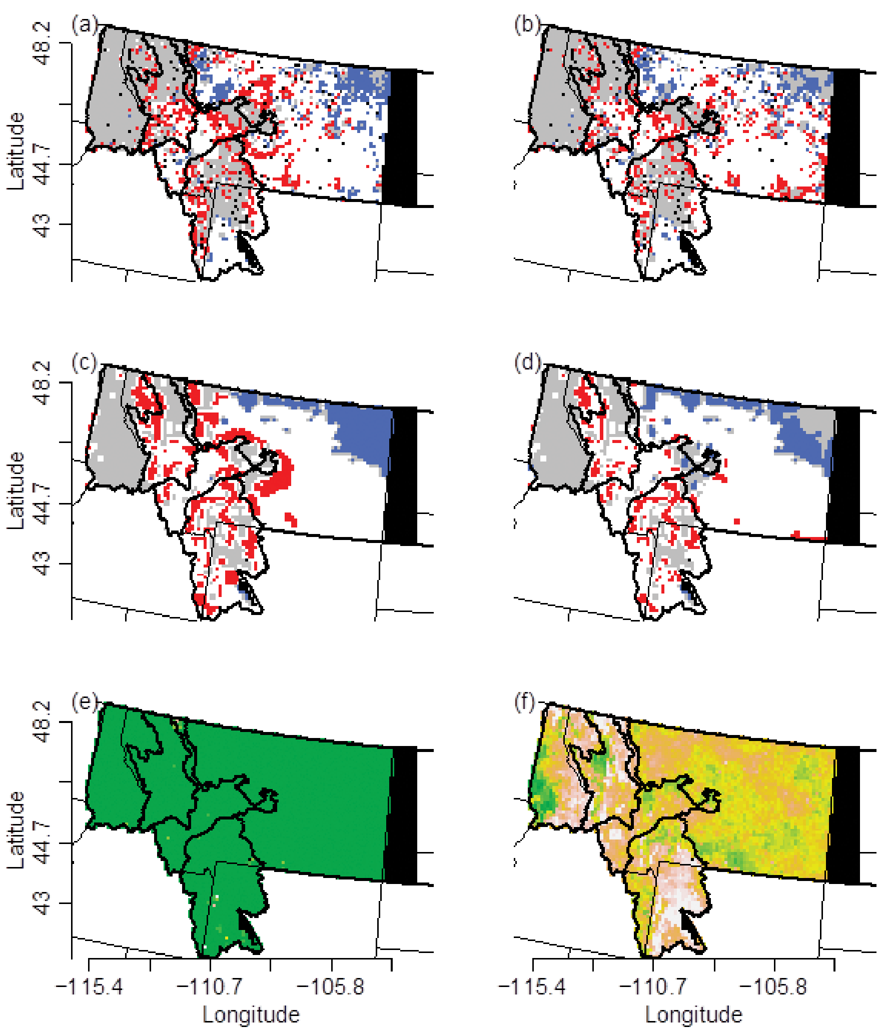

Figure 7.6—Change in big sagebrush habitat suitability (a–d) based on species distribution models using climate (c)-(d) or ecohydrology (a)-(b), along with germination (e) and seedling survival potential (f) for NR (outlined in bold). Projected change in big sagebrush habitat suitability is between 1970–1999 climate and future A2 scenario (a)-(c) and B1 scenario (b)-(d) 2070–2099 emission scenarios. Red cells indicate areas of decrease in big sagebrush habitat suitability, blue cells indicate areas of increase, white cells indicate stable areas, and gray cells indicate absence of big sagebrush. Maps of germination (e) and seedling survival (f) represent current conditions and are summarized as fraction of years with successes: red (0, no years with success), tan (>0), green (1, every year with success). Black cells indicate data not available (data source: Schlaepfer et al. 2012).

annual grasses exhibit a significant presence on short sagebrush sites in the future.

Shrublands Dominated by Sprouting Sagebrush Species (Threetip and Silver Sagebrush)

Significant areas of threetip and silver sagebrush shrublands have been converted to agricultural lands. Those that remain are often used for domestic livestock grazing because of the palatable herbaceous undergrowth in this sagebrush type. Those that have had chronic improper grazing typically have a large amount of bare ground, low vigor of native herbaceous species, and as a result, nonnative plant species present in varying amounts. Prolonged improper livestock grazing, native ungulate herbivory, and nonnative invasive plants are the primary stressors. Loss of topsoil can occur if vegetation cover and density decline and bare ground increases, primarily caused by ungulate impacts (e.g., grazing and mechanical/hoof damage) (Sheatch and Carlson 1998; Washington-Allen et al. 2010).

Both species can sprout from the root crown following top kill (primarily from fire) (Bunting et al. 1987), but this trait depends on site conditions and fire severity. Silver sagebrush is a vigorous sprouter (Rupp et al. 1997), whereas threetip sagebrush is less successful as a sprouter, and its response varies with site characteristics (Akinsoji 1988; Bunting et al. 1987). Both species occur on mesic sites; threetip sagebrush is often associated with mountain big sagebrush communities, and silver sagebrush typically occupies moist riparian benches or moist toe slopes. Although these species will sprout, increased fire frequency and severity (particularly in threetip communities) may cause a shift in community composition to dominance by fire-adapted herbaceous species or nonnative species. Other fire-adapted shrub species may increase, particularly following fire. In addition, if spring and winter precipitation increase, exotic annual grasses may establish and set seed earlier than the native perennial grasses, particularly in lower elevation communities (Bradley 2008; D'Antonio and Vitousek 1992). This creates an uncharacteristic, continuous fine fuel load that can burn by late spring/early summer, burning sagebrush and native grasses often before they have matured and set seed (Chambers and Pellant 2008). Other nonnative invasive species respond favorably after fire, and, if present, will increase in cover and density.

Historical fire return intervals for both species are relatively short and research shows that threetip sagebrush cover can return to preburn levels 30 to 40 years after fire (Barrington et al. 1988; Neuenschwander n.d.). Lesica et al. (2007) found that after a fire in southwestern Montana, threetip sagebrush cover did not increase by resprouting, but instead established from seed. These generalizations will vary considerably depending on site conditions and postfire management. All three subspecies of silver sagebrush sprout after fire, and along with threetip, also typically occur on more mesic sites. With a warmer and drier climate, not only may frequent high-severity burns cause initial mortality, but sites may not be as favorable for postfire vegetation regeneration (from sprouting, regrowth, or seed). Invasive species are likely either to expand into these communities after fire or to increase in abundance in altered conditions that are less favorable to the native plant community.

Understory composition in both communities may possibly shift to more-xeric grassland species (e.g., bluebunch wheatgrass, needle-and-thread grass [*Hesperostipa comata*]), which are better adapted to warmer and drier conditions. Both of these sagebrush species may shift landscape position to sites with more moisture and cooler temperature (e.g., higher elevation, lower landscape position, and northeast aspects).

Risk Assessment

Magnitude of effects: Moderate
Likelihood of effects: High

Mountain Big Sagebrush Shrublands

Some areas of mountain big sagebrush shrublands have been converted to agricultural lands, and those that remain are used for domestic livestock grazing, primarily because of the palatable herbaceous undergrowth. Those that have had chronic improper grazing typically have high bare ground and low vigor of native herbaceous species; as a result, nonnative plant species are present in varying amounts. Prolonged improper livestock grazing, native ungulate herbivory, and invasive nonnative plants are the primary stressors. Loss of topsoil can occur if vegetation cover and density decline and bare ground increases due to improper grazing and other impacts, primarily caused by ungulates (e.g., grazing and mechanical/hoof damage). Lack of fire is also a chronic stressor, facilitating establishment of conifers, which increase in density and cover over time (Arno and Gruell 1986; Heyerdahl et al. 2006) while grass cover declines (Arno and Gruell 1983).

Mountain big sagebrush is killed by fire. If fire severity and frequency increase, there will be a shift in community composition to dominance by fire-adapted shrub and herbaceous species and possibly nonnative species. Fire-adapted shrub species may increase in abundance following fire (Fischer and Clayton 1983; Smith and Fischer 1997). In addition, if spring and winter precipitation increase, establishment of nonnative annual grasses (particularly cheatgrass, which germinates in winter/early spring) may be facilitated, although this is less likely in cooler, moister mountain big sagebrush communities than in lower elevation Wyoming and basin big sagebrush communities. With a warmer, drier climate, however, the conditions may be conducive to cheatgrass establishment. An abundance of cheatgrass creates an uncharacteristic, continuous fine fuel load that can burn by late spring/early summer, burning sagebrush and native perennial grasses often before they have matured and set seed (Chambers et al. 2007; Pellant 1990; Whisenant 1990), especially in the

Great Basin. However, other research in the northern edge of the Great Basin indicates that some sagebrush communities may be less susceptible to cheatgrass invasion following fire, at least under the current climate (Lavin et al. 2013; Seefeldt et al. 2007). Other nonnative species respond favorably after fire and, if present, will increase in cover and density.

Historically, the fire return intervals were relatively short but variable—a few decades (Lesica et al. 2007) to more than 100 years (Baker 2013)—compared to Wyoming big sagebrush habitat (more than 100 years) (Heyerdahl et al. 2006; Lesica et al. 2005, 2007). Mountain big sagebrush regenerates from seeds shed from nearby unburned plants. It will fully recover between 15 and 40 years after fire (Bunting et al. 1987), depending on site characteristics and fire severity. In a warmer and drier climate, frequent high-severity burns (facilitated by cheatgrass) may not cause initial mortality and create unfavorable conditions for postfire regeneration (from sprouting, regrowth, or seed). There is no viable sagebrush seedbank; if fires burn large areas and there are no live, seed-bearing sagebrush nearby, there may be a type conversion to grassland. In addition, invasive nonnative species are likely either to expand into these areas after fire, or to increase in abundance due to altered conditions that no longer favor the native plant community (Bradley 2008; D'Antonio and Vitousek 1992).

Mountain big sagebrush is not fire adapted, and may decline in cover and density or be extirpated in response to warmer temperatures and increased fire frequency and severity. Over time, especially if fine fuels such as senesced cheatgrass are present, more frequent fires may eliminate mountain big sagebrush from a community (Chambers and Pellant 2008; D'Antonio and Vitousek 1992; Whisenant 1990). However, because mountain big sagebrush occurs at higher elevations, typically on more productive cooler, mesic sites, these communities are typically less invaded by nonnative species. If these sites become warmer and drier, however, herbaceous understory composition could shift to more xeric species that are better adapted, and bare ground may increase (Chambers et al. 2014). As a result, invasive species, particularly cheatgrass, could expand into and establish dominance in these altered communities.

The distribution of mountain big sagebrush possibly may shift to cooler and moister sites (e.g., higher elevation, northeast-facing snow-filled depressions). With climate change, it may be able to persist only in sites with higher moisture and deeper soils than the surrounding landscape. Understory composition may shift to more-xeric grassland species, that are more tolerant of warmer, drier conditions.

Risk Assessment

Magnitude of effects: Moderate
Likelihood of effects: Moderate

Adapting Rangeland Vegetation Management to Climate Change in the Northern Rockies Region

Rangeland vegetation in the Northern Rockies Region is likely to be affected by changing fire regimes, increased drought, and increased establishment of invasive species in a changing climate. Effects of climate change will also compound existing stressors on rangeland ecosystems caused by human activities. Thus, adaptation strategies and tactics for rangeland vegetation focused on increasing the resilience of rangeland ecosystems, primarily through invasive species control and prevention (table 7.3).

To control invasive species in rangelands, managers stressed the importance of using ecologically based invasive plant management (EBIPM) (Krueger-Mangold et al. 2006; Sheley et al. 2006). The EBIPM framework focuses on strategies to repair damaged ecological processes that facilitate invasion (James et al. 2010). For example, prescribed fire treatments can be used where fire regimes have been altered, and seeding of desired natives can be done where seed availability and dispersal of natives is low.

Another adaptation strategy is to increase proactive management actions to prevent establishment of invasive species. Early detection, rapid response (EDRR) for new invasions was the most frequently suggested tactic to prevent invasive species establishment. Other tactics include implementing weed-free policies, conducting outreach to educate employees and the public about invasive species (e.g., teach people to clean their boots), and developing weed management areas that are collaboratively managed by multiple agencies, nongovernmental organizations, and the public.

In addition to invasive species control and prevention, grazing management will be important in maintaining and increasing resilience of rangelands to climate change. Climate changes will lead to altered availability of forage, requiring some reconsideration of grazing strategies. For example, reducing grazing in July and August may encourage growth of desired perennials in degraded systems. Livestock grazing can also be managed through the development of site-specific within-season triggers and end point indicators that would inform livestock movement guides and allow for the maintenance and enhancement of plant health.

A changing climate has led to a decline of pollinators in some communities (Potts et al. 2010) and may lead to phenological mismatches between pollinators and host plants (Forrest 2015). Pollinator declines may negatively affect the health of grasslands in the Northern Rockies, and encouraging native pollinators may be key to sustaining these ecosystems. Tools to promote native pollinators include revegetation with native species, appropriate herbicide and insecticide use, and education. Implementing long-term monitoring of pollinators can help to identify where treatments can be prioritized.

Table 7.3—Adaptation options that address climate change effects on rangelands in the Northern Rockies.

Sensitivity to climatic variability and change: Increased susceptibility of vegetation communities (e.g., grasslands) to invasive species.			
Adaptation strategy/approach: Increase proactive management actions in order to prevent invasive species.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Conduct ecologically based invasive plant management; implement prescriptive grazing, fire, herbicide and re-seeding.	Develop weed management areas and coordinate with multiple agencies, non-governmental organizations, and the public.	Apply early detection rapid response (EDRR) and inventory and mapping.
Where can tactics be applied?	Prioritize small/new invasions by most critical species; work back to road corridors and developed areas.	Recreation high use areas (roads); administrative areas	All lands
	Specific tactic – D	**Specific tactic – E**	**Specific tactic – F**
Tactic	Use best invasive management practices to address vectors; emphasize invasive species education (e.g., teach people how to clean their equipment, boots).	Remove conifers with mechanical treatments, prescribed fire, and harvest.	Conduct integrated weed management (i.e., spraying, chemical, biological, mechanical, manual control, targeted grazing).
Where can tactics be applied?	Forest/grassland/region level	Encroached communities	Recreation high-use areas (roads), administrative areas

Table 7.3(cont.)—Adaptation options that address climate change effects on rangelands in the Northern Rockies.

Sensitivity to climatic variability and change: Increased temperature and drought will cause more and larger wildfires, leading to mortality of sagebrush and grasslands and increased dominance of fire-adapted herbaceous and non-native species.			
Adaptation strategy/approach: Maintain intact ecosystems, and increase resilience and resistance of native sagebrush-grass ecosystems.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Inventory intact areas with high native cover (i.e., weed-free areas).	Employ preventative measures to reduce the spread and introduction of invasive species into intact/weed free plant communities.	Manage priority invasive species on priority acres.
Where can tactics be applied?	On all land	Areas that are currently weed free	In priority areas
	Specific tactic – D	**Specific tactic – E**	**Specific tactic – F**
Tactic	Restore to minimize or reverse adverse effects.	Manage fire for resource benefits.	Promote the occurrence and growth of native species.
Where can tactics be applied?	Degraded non-forest vegetation communities	Priority areas based on current condition and potential response to fire	Sagebrush-dominated areas where native species have significant populations and nonnatives are not dominant
	Specific tactic – G	**Specific tactic – H**	**Specific tactic – I**
Tactic	Determine and implement proper grazing; conduct adaptive management that recognizes climate changes will lead to different availability of range; use rest and rotation practices; reduce grazing in July and August to encourage perennial growth.	Manage livestock grazing through planning efforts that serve as livestock movement guides (within-season triggers) and allow for the maintenance and/or enhancement of plant health (end-point indicators).	Use targeted grazing to address contemporary vegetation management challenges (e.g., control invasive nonnative and noxious weeds and undesirable species, and reduce fire risk).
Where can tactics be applied?	On all grazed lands	On all grazed lands	Priority areas based on current condition and potential response to treatment

Table 7.3(cont.)—Adaptation options that address climate change effects on rangelands in the Northern Rockies.

Sensitivity to climatic variability and change: Phenological mismatch between pollinators and host plants.			
Adaptation strategy/approach: Maintain and restore natural grassland habitat to ensure pollination.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Encourage native pollinators; provide other habitats for pollinators (nesting cover, feeding cover, brooding cover).	Restore and enhance habitat (using tools such as grazing, fire, herbicide application, reseeding).	Implement long-term monitoring of pollinators (e.g., research, tech transfer, education, citizen science projects, and monitor existing populations).
Where can tactics be applied?	Throughout current range of grasslands	Use ecological site descriptions to identify priority areas for restoration or enhancement.	Look at native and nonnative ecosystems, overlap in these ecosystems, and the types of pollinators present.
Sensitivity to climatic variability and change: Loss of topsoil and invasion of weeds in montane shrublands.			
Adaptation strategy/approach: Maintain and increase montane shrublands.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Educate fuels specialists, forest ecologists, wildlife biologists and silviculturists on ecology and disturbances affecting shrublands; effects of repeated burns; shifting mosaics (creating a balance of types across landscapes); and weeds (identification, awareness, reporting).	Maintain adequate shrub cover, vigor, and species richness, and avoid bare ground; create different age classes and compositions of shrubfields (shifting mosaic); no action is a viable alternative dependent on system; tools include removal of timber products, targeted grazing, prescribed burning, and mastication/slashing.	Apply early detection rapid response (EDRR), and use ecologically based invasive plant management (EBIPM); tools include biocontrol, herbicides, timing burning prescriptions (to avoid annual brome expansion), and targeted grazing.
Where can tactics be applied?	Throughout and across jurisdictional boundaries	Throughout and across jurisdictional boundaries	Throughout and across jurisdictional boundaries

In montane shrublands, existing stressors include fire exclusion and conifer establishment, browsing by both native and domestic ungulates, and insects and disease. Characteristic species can be lost in these systems with loss of topsoil following frequent, hot fires. Warmer temperatures and drier conditions with climate change may lead to an increase in high-severity fires. Adaptation tactics include implementing fuel reduction projects such as brush cutting, slashing, mastication, and targeted browsing; reestablishing appropriate fire regimes may prove beneficial in maintaining these shrublands and increasing their resilience. To control invasive vegetation, EDRR and EBIPM can be applied, along with maintenance of adequate shrub cover, vigor, and species richness. Educating specialists on ecology and disturbances affecting shrublands, effects of repeated burns, reforestation needs, and reporting on weeds will also help to maintain these systems.

More specific details on adaptation strategies and tactics that address climate change effects on rangeland vegetation in each Northern Rockies Adaptation Partnership subregion are in Appendix 7A.

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Appendix 7A—Adaptation Options for Nonforest Vegetation in the Northern Rockies.

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 Northern Rockies Adaptation Partnership. Tables are organized by sub-region within the Northern Rockies. See Chapter 7 for summary tables and discussion of adaptation options for nonforest vegetation.

Table 7A.1—Adaptation options that address climate change effects on nonforest vegetation in the Central Rockies subregion.

Sensitivity to climatic variability and change: Increased susceptibility of vegetation communities (e.g., grasslands) to invasive species. Effects of climate change on grasslands will be amplified by management actions.

Adaptation strategy/approach: Increase proactive management actions in order to prevent invasive species

Strategy objective: Reduce stressors/threats, engage coordination, increase knowledge

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**	**Specific tactic – D**
Tactic	Conduct integrated weed management (i.e., spraying, chemical, biological, mechanical, manual control, education, targeted grazing).	Develop weed management areas and coordinate with multiple agencies, non-governmental organizations, and public.	Apply early detection rapid response (EDRR) and inventory and mapping.	Update weed risk assessment (WRA) to enhance integrated weed management.
Tactic effectiveness (risks)	High	High (if properly implemented)	High	Moderate
Implementation urgency	Near term	Near term	Near term	Mid term
Where can tactics be applied? (geographic)	Recreation high use areas (roads), administrative areas; Lolo Creek (Missoula District for sheep/goat grazing)	Recreation high use areas (roads); administrative areas	Wilderness protected areas	Multi-scale effort
Opportunities for implementation	Coordinate with multiple agencies, non-governmental organizations, public; opportunity to graze in newly acquired lands (sheep/goats)	Coordinate with multiple agencies, non-governmental organizations, public	Coordinate with multiple agencies, non-governmental organizations, public, employees	Coordinate with Federal and State agencies
Cost	Expensive	Inexpensive/moderately expensive (depends on implementation scale)	Inexpensive/moderately expensive	Moderately expensive
Barriers to implementation	Management support; conflict between bighorn sheep and domestic	Community support; social economic barriers (e.g., education, trust, holdouts)	Lack of acceptance that it is a priority	Time, lack of prioritization

Table 7A.2—Adaptation options that address climate change effects on nonforest vegetation in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Increased temperature and drought will cause more and larger wildfires, leading to mortality of sagebrush and grasslands and increased dominance of fire-adapted herbaceous and non-native species.

Adaptation strategy/approach: Maintain intact ecosystems, and increase resilience and resistance of native sagebrush-grass ecosystems**.**

Strategy objective: Promote resilience, reduce stressors/threats, engage coordination, and increase knowledge.

	Specific tactic – A	Specific tactic – B	Specific tactic – C	Specific tactic – D
Tactic	Inventory intact/high native cover/weed free areas.	Employ preventative measures to reduce the spread and introduction of invasive species into intact/weed free plant communities.	Survey for new invasive species.	Manage priority invasive species on priority acres.
Tactic effectiveness (risks)	High	Moderate to high	High	Moderate
Implementation urgency	Near term	Near term	Near term	Near term
Where can tactics be applied? (geographic)	On all lands (where access can be granted)	Areas that are currently weed free	On all lands (where access can be granted)	On priority acres
Opportunities for implementation	Work with agencies, counties, State, non-profit and private land owners to share and incorporate current and future inventory data	Work with agencies, counties, State, non-profit and private land owners to partner in weed prevention strategies and practices	Work with agencies, counties, State, non-profit and private land owners to share and incorporate current and future survey data, technology	Work with agencies, counties, State, non-profit and private land owners to collaborate on invasive species management activities
Cost	Moderately expensive	Inexpensive to moderately expensive	Moderately expensive	Inexpensive to moderately expensive
Barriers to implementation	Some to major barriers: staff capacity; budgets; priorities	Some to major barriers: public and internal awareness and perception; funding	Some to major barriers: staff capacity; budgets; priorities	Some to major barriers: budget; plant identification and phenology; capacity

Table 7A.2 (cont.)—Adaptation options that address climate change effects on nonforest vegetation in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Increased temperature and drought will cause more and larger wildfires, leading to mortality of sagebrush and grasslands and increased dominance of fire-adapted herbaceous and nonnative species.

Adaptation strategy/approach: Maintain intact ecosystems, and increase resilience and resistance of native sagebrush-grass ecosystems**.**

Strategy objective: Promote resilience, reduce stressors/threats, engage coordination, and increase knowledge.

	Specific tactic – E	**Specific tactic – F**	**Specific tactic – G**	**Specific tactic – H**
Tactic	Restore to minimize or reverse adverse effects.	Manage conifer encroachment.	Manage fire for resource benefits.	Promote the occurrence and growth of early-season natives.
Tactic effectiveness (risks)	Moderate to high	Low to high	Moderate to high	Moderate
Implementation urgency	Near term	Near term	Near term	Short term
Where can tactics be applied? (geographic)	Degraded non-forest vegetation communities	Priority areas based on current condition and potential response to treatment	Priority areas based on current condition and potential response to fire	Sagebrush-dominated areas where native species have significant populations and non-natives are not dominant
Opportunities for implementation	Collaborate with partners on the design and implementation of restoration activities	Collaborate with partners on conifer encroachment management activities	Collaborate with agencies, counties, state, non-profit and private land owners on fire management	Coordinate with range permittees
Cost	Inexpensive to expensive	Inexpensive to moderately expensive	Inexpensive to moderately expensive	Moderately expensive, depending on work needed
Barriers to implementation	Some to major barriers: awareness and recognition of need	Some to major barriers: litigation; burn windows; awareness and recognition of need	Some to major barriers**:** Recognition of need; public and internal perception and risk aversion	Some barriers: Some public opposition

Table 7A.2 (cont.)—Adaptation options that address climate change effects on nonforest vegetation in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Increased temperature and drought will cause more and larger wildfires, leading to mortality of sagebrush and grasslands and increased dominance of fire-adapted herbaceous and nonnative species.

Adaptation strategy/approach: Maintain intact ecosystems, and increase resilience and resistance of native sagebrush-grass ecosystems**.**

Strategy objective: Promote resilience, reduce stressors/threats, engage coordination, and increase knowledge.

	Specific tactic – I	**Specific tactic – J**	**Specific tactic – K**	**Specific tactic – L**
Tactic	Reduce grazing in July and August to encourage perennial growth.	Manage livestock grazing through planning efforts that serve as livestock movement guides (within-season triggers) and allow for the maintenance and/or enhancement of plant health (end-point indicators).	Use targeted grazing to address contemporary vegetation management challenges (e.g., control invasive exotic and noxious weeds and undesirable species, reduce fire risk).	Identify and manage (e.g., close, obliterate, re-route) non-system/user created routes (roads and trails).
Tactic effectiveness (risks)	Moderate	Low to moderate	Low to moderate	Low to high
Implementation urgency	Mid term	Near term	Near to mid term	Near term
Where can tactics be applied? (geographic)	Areas with high probability of recovery, primarily moist sites	On all grazed lands	Priority areas based on current condition and potential response to treatment	On priority areas
Opportunities for implementation	Coordinate with range permittees	Livestock managers	Livestock managers	Partner with National Forest Foundation, NGOs
Cost	Inexpensive	Inexpensive to moderately expensive	Inexpensive to moderately expensive	Inexpensive to moderately expensive
Barriers to implementation	Opposition by some permittees	Commitment by managers; compliance by livestock managers; staff capacity	Public perception, National Environmental Policy Act; litigation; logistics and access	Awareness; detection; budget; perception of need (internal and external);

Table 7A.3—Adaptation options that address climate change effects on nonforest vegetation in the Grassland subregion.

Sensitivity to climatic variability and change: Phenological mismatch between pollinators and host plants.		
Adaptation strategy/approach: Maintain and restore natural habitat to ensure pollination.		
Strategy objective: Promote resilience, reduce stressors/threat.		
	Specific tactic – A	**Specific tactic – B**
Tactic	Restore and enhance habitat (using tools such as grazing, fire, herbicide application, reseeding).	Implement long term monitoring of pollinators (e.g., research, tech transfer, education, citizen science projects, and monitor existing populations).
Tactic effectiveness (risks)	Depends on the combination of tools	Not applicable
Implementation urgency	Near term	Near term
Where can tactics be applied? (geographic)	Use ecological site descriptions to identify priority areas for restoration or enhancement	Look at native and non-native ecosystems, overlap in these ecosystems and the types of pollinators present
Opportunities for implementation	Take advantage of other restoration activities; public involvement	Search for existing information; engage with Natural Resources Conservation Service, Agricultural Research Service, state extensions, North Dakota Department of Agriculture for education on pollinators and agricultural practices; opportunity for citizen science projects to detect broad trends
Cost	Cost varies by tool; shared cost with other restoration projects	Inexpensive with partnerships (i.e., citizen science projects)
Barriers to implementation	Some of the restoration tools may adversely impact the habitat.	

Table 7A.4—Adaptation options that address climate change effects on nonforest vegetation in the Grassland subregion.

Sensitivity to climatic variability and change: Encroachment of native species into grasslands (i.e., willow [*Salix*], sumac [*Rhus*], juniper [*Juniperus*], snowberries [*Gaultheria*], ponderosa pine [*Pinus ponderosa*]).

Adaptation strategy/approach: Restore natural disturbance regimes in grasslands.

Strategy objective: Promote resilience, reduce stressors/threats

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Conduct prescribed fires.	Conduct mechanical treatments (chainsaws, mowing, mastication, logging, lop and scatter, haying, grazing).	Use herbicide (use appropriate delivery method).
Tactic effectiveness (risks)	Moderate	Moderate/high	High
Implementation urgency			
Where can tactics be applied? (geographic)	Use ecological site descriptions to determine where to apply prescribed fire		
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 7A.5—Adaptation options that address climate change effects on nonforest vegetation in the Grassland subregion.

Sensitivity to climatic variability and change: Encroachment of nonnative species into grasslands (i.e., leafy spurge [*Euphorbia esula*], knapweed [*Centaurea*], sulphur cinquefoil [*Potentilla recta*], Canada thistle [*Cirsium arvense*], Russian olive [*Elaeagnus angustifolia*], hounds tongue [*Cynoglossum officinale*], redtop [*Agrostis stolonifera*], cattail [*Typha*], reed canary grass [*Phalaris arundinacea*], paleyellow iris [*Iris pseudacorus*], Japanese brome [*Bromus japonicus*], Kentucky bluegrass [*Poa pratensis*], smooth brome [*Bromus inermis*], crested wheatgrass [*Agropyron cristatum*], cheatgrass [*Bromus tectorum*], sweet clover [*Melilotus*], absinth wormwood [*Artemisia absinthium*], black henbane [*Hyoscyamus niger*], buckthorn [*Rhamnus*]).

Adaptation strategy/approach: Maintain and increase resilience of native grassland communities.

Strategy objective: Promote resilience.

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactic	Use ecological site descriptions to prioritize areas for treatment *(would not apply to all the species listed above)*.	Apply biological control.	Implement prescriptive grazing, fire, herbicide and re-seeding (timing, duration, frequency, kind and class of livestock).
Tactic effectiveness (risks)	Moderate/high	Low-high	Moderate/high
Implementation urgency	Near term	Dependent on research	Near term
Where can tactics be applied? (geographic)	Forest/grassland/subregion level	Where it is likely to be effective and not have unintended consequences	Forest/grassland/sub region level
Opportunities for implementation	Interagency weed working groups	Interagency weed working groups	Interagency weed working groups; US Fish and Wildlife Service; interagency fire program; ranchers
Cost	Varies	Varies by agent	Moderately expensive/ expensive
Barriers to implementation	Lack of knowledge; funding and training	Uncertainty and unintended consequences of using biological control in a changing climate	Social perceptions (e.g., grazing, fire, herbicide use)

Table 7A.5 (cont.)—Adaptation options that address climate change effects on nonforest vegetation in the Grasslands subregion.

Sensitivity to climatic variability and change: Encroachment of non-native species into grasslands.

Adaptation strategy/approach: Maintain and increase resilience of native grassland communities.

Strategy objective: Promote resilience.

	Specific tactic – D	**Specific tactic – E**	**Specific tactic – F**	**Specific tactic – G**
Tactic	Apply early detection rapid response.	Use best invasive management practices to address vectors; emphasize invasive species education (e.g., teach people how to clean their equipment, boots).	Conduct internal and external education and outreach.	Maintain and increase agency, State and county cooperation on invasive weeds.
Tactic effectiveness (risks)	High	High	High	High
Implementation urgency	Near term	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Wherever new invasions are	Forest/grassland/region level	Forest/grassland/region level	Forest/grassland/region level
Opportunities for implementation	Interagency weed working groups	Interagency weed working groups; field technicians	Interagency weed working groups; field technicians	Interagency weed working groups
Cost	Inexpensive	Inexpensive	Inexpensive	Inexpensive
Barriers to implementation	Plant identification skills	Plant identification skills; turnover of local population	Plant identification skills; turnover of local population	Coordinated action (need mechanism to ensure continued coordination)

Table 7A.6—Adaptation options that address climate change effects on nonforest vegetation in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Increase in fire frequency and intervals, invasive species, herbivory, and species shift (C4)

Adaptation strategy/approach: Increase resilience of C3 grassland communities to the above sensitivities, and maintain C3 grassland communities on the landscape.

Strategy objective: Promote resilience, reduce stressors/threats.

	Specific tactic – A	Specific tactic – B	Specific tactic – C	Specific tactic – D
Tactic	Allow natural and prescribed fire.	Conduct ecologically based invasive plant management; use herbivory (goats), biocontrol, wildfire, and seeding (e.g., smooth brome).	Conduct inventory of data, including maps and risk assessments; use Early Detection Rapid Response (EDRR) and weed-free policies regarding stock; conduct inventory and monitoring.	Remove conifers with mechanical treatments, prescribed fire, and harvest.
Tactic effectiveness (risks)	Moderate	Moderate	High	High
Implementation urgency	Mid term	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Expand beyond wildland urban interface; apply in areas with healthy vegetation	Prioritize small/new invasions by most critical species; work back to road corridors and developed areas	EDRR for all new findings	Encroached communities
Opportunities for implementation	Implement projects per forest management plan	Effective at local levels; not at landscape scale	Effective at local levels; not at landscape scale	Small watershed or landscape of 1000–1500 acres
Cost	Cost varies by project size and complexity	Moderately expensive	Inexpensive	Moderately expensive
Barriers to implementation	Some barriers: Community acceptance; litigation; risk aversion; lack of non-WUI funding	Major barriers: Community acceptance; capacity; need to scale up to be effective; perceived lack of urgency	Some barriers: Lack of champions; workforce availability; perceived lack of urgency	Some barriers: Staffing; litigation; availability of burn windows; fiscal year limitations; risk aversion

Table 7A.7—Adaptation options that address climate change effects on nonforest vegetation in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Increase in fire severity and frequency, invasive species, and herbivory.

Adaptation strategy/approach: Increase resilience of mountain sagebrush community to the above sensitivities, and maintain sagebrush communities on the landscape.

Strategy objective: Maintain current trend. Promote resilience. Reduce stressors/threats.

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactic	Strategically place fuels treatments (thinning, mulching, limited suppression) across the landscape.	Conduct ecologically based invasive plant management (EBIPM); use herbivory (goats), biocontrol, wildfire, and seeding.	Conduct inventory of data, including maps and risk assessments; use Early Detection Rapid Response (EDRR) and weed-free policies regarding stock; conduct inventory and monitoring.
Tactic effectiveness (risks)	Moderate	Moderate	High
Implementation urgency	Near term/mid term	Near term	Near term
Where can tactics be applied? (geographic)	Expand beyond wildland urban interface; apply in areas with existing healthy vegetation	Prioritize small/new invasions by most critical species; work back to road corridors and developed areas	EDRR for all new findings
Opportunities for implementation	Implement projects per forest management plan; be opportunistic when wildfire does strike (crew availability; community acceptance)	Public Lands Day and other volunteer projects; partner with wildlife and other stakeholder groups for habitat improvement	Public Lands Day and other volunteer projects; partner with wildlife and other stakeholder groups for habitat improvement (Trout Unlimited, friends group).
Cost	Moderately expensive; cost varies by project size and complexity	Moderately expensive	Inexpensive
Barriers to implementation	Some barriers: political; community acceptance; litigation; risk aversion; lack of non-wildland urban interface funding	Major barriers: community acceptance; availability of workforce; need to scale up to be effective; perceived lack of urgency	Some barriers: lack of champions; workforce availability; perceived lack of urgency

Table 7A.7 (cont.)—Adaptation options that address climate change effects on nonforest vegetation in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Increase in fire severity and frequency, invasive species, and herbivory.		
Adaptation strategy/approach: Increase resilience of mountain sagebrush community to the above sensitivities, and maintain sagebrush communities on the landscape.		
Strategy objective: Maintain current trend. Promote resilience. Reduce stressors/threats.		
	Specific tactic – D	**Specific tactic – E**
Tactic	Determine and implement proper grazing; conduct adaptive management that recognizes climate changes will lead to different availability of range; use rest and rotation practices.	Remove conifers with mechanical treatments, prescribed fire, and harvest.
Tactic effectiveness (risks)	High	High
Implementation urgency	Moderate	Near term
Where can tactics be applied? (geographic)	Everywhere	Encroached communities
Opportunities for implementation	Coordinate with range permittees; cultivate management support.	Coordinate with fuels and habitat objectives for interagency and partnership work and funding; commercial harvest
Cost	Inexpensive	Moderately expensive
Barriers to implementation	Some barriers: Lack of stakeholder support (real or perceived); lack of trust; noncompliance; perceived lack of urgency	Some barriers: Staffing levels; litigation; uncertain availability of burn windows due to climate change; fiscal year limitations; challenges with interagency and/or non-Federal implementation and coordinated planning efforts; risk aversion

Table 7A.8—Adaptation options that address climate change effects on nonforest vegetation in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Increase in fire severity and frequency, invasive species, and herbivory.		
Adaptation strategy/approach: Increase resilience of Wyoming sagebrush community to the above sensitivities.		
Strategy objective: Maintain sagebrush communities on the landscape; **c**reate and maintain a healthy and diverse plant community.		
	Specific tactic – A	**Specific tactic – B**
Tactic	Strategically place fuels treatments (thinning, mulch, limited suppression) across the landscape.	Conduct ecologically based invasive plant management (EBIPM); use herbivory (goats), biocontrol, wildfire, and seeding.
Tactic effectiveness (risks)	Moderate	Moderate (unless strict adherence to EBIPM, then high)
Implementation urgency	Near term/Mid term	Near term
Where can tactics be applied? (geographic)	Anywhere we can; expand beyond wildland urban interface; apply tactic in areas with existing healthy intact vegetation; avoid degraded areas	Prioritize small/new invasions by most critical species; work back to road corridors and developed areas in non-wilderness.
Opportunities for implementation	Implement projects per forest management plan; be opportunistic when wildfire does strike (crew availability; community acceptance)	Public Lands Day and other volunteer projects; partner with wildlife and other stakeholder groups for habitat improvement (Trout Unlimited, friends groups)
Cost	Moderately expensive; cost varies by project size and complexity	Moderately expensive
Barriers to implementation	Some barriers: Political; community acceptance; management and community tolerance; litigation; risk aversion; lack of non-wildland urban interface funding	Major barriers: Community acceptance; availability of workforce; methodology; public perception; technology; need to scale up to be effective; perceived lack of urgency

Table 7A.8 (cont.)—Adaptation options that address climate change effects on nonforest vegetation in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Increase in fire severity and frequency, invasive species, and herbivory.		
Adaptation strategy/approach: Increase resilience of Wyoming sagebrush community to the above sensitivities.		
Strategy objective: Maintain sagebrush communities on the landscape; **c**reate and maintain a healthy and diverse plant community.		
	Specific tactic – C	**Specific tactic – D**
Tactic	Conduct inventory of data, including maps and risk assessments; use Early Detection Rapid Response (EDRR) and weed-free policies regarding stock; conduct inventory and monitoring.	Determine and implement proper grazing; conduct adaptive management that recognizes climate changes will lead to different availability of range; use rest and rotation practices.
Tactic effectiveness (risks)	High	High
Implementation urgency	Near term	Moderate
Where can tactics be applied? (geographic)	EDRR for all new findings	Everywhere
Opportunities for implementation	Public Lands Day and other volunteer projects; partner with wildlife and other stakeholder groups for habitat improvement (Trout Unlimited, friends groups)	Coordinate with range permittees; cultivate management support.
Cost	Inexpensive	Inexpensive
Barriers to implementation	Some barriers: Lack of champions; workforce availability; perceived lack of urgency	Some barriers: Lack of stakeholder support (real or perceived); lack of trust; noncompliance; perceived lack of urgency

Table 7A.9—Adaptation options that address climate change effects on nonforest vegetation in the Western Rockies subregion.

Sensitivity to climatic variability and change: Increase in fires, warmer drier conditions, and invasive species, and decline in pollinators. With warmer wetter conditions, conifers are establishing in balds and snow belts because of changes in precipitation from snow to rain.

Adaptation strategy/approach: Maintain healthy and intact grasslands.

Strategy objective: Maintain and increase resilience from perturbation and resistance to invasive species; reduce weed invasion; increased knowledge of the ecology of grasslands.

	Specific tactic – A	**Specific tactic – B**
Tactic	Maintain or restore adequate native plant cover, vigor, and species richness; ensure ecologically significant remnant populations of endemics are maintained; tools include appropriate grazing management, focused herbicide use, re-vegetation (with locally adapted and site specific species, forbs and graminoids), appropriate fire management, appropriate travel management, maintaining public land management of ecologically significant remnant plant communities (e.g., rough fescue, Palouse prairie), and conservation easements.	Encourage native pollinators; provide other habitats for pollinators (nesting cover, feeding cover, brooding cover); tools include re-vegetation (with native species), appropriate herbicide and insecticide use, and education for public and within agency.
Tactic effectiveness (risks)	Low/moderate/high	Moderate/high
Implementation urgency	Near term/ongoing	Near term/ongoing
Where can tactics be applied? (geographic)	Throughout current range of grasslands; management activities are species specific	Throughout
Opportunities for implementation	Acquiring remnant populations (partners: The Nature Conservancy (TNC), working with tribes, private landowners, land trusts); conservation easements (TNC, local land trusts)	Xerces Society; native plant societies; local garden clubs; local conservation groups; Idaho Master Naturalists; youth organizations (high schools, 4H)
Cost	Inexpensive/moderately expensive	Inexpensive/ moderately expensive
Barriers to implementation	Multiple land ownership and fragmentation; lack of scientific knowledge; reduced budgets for inventory and monitoring	Farm Bill language; introduction of nonnative pollinators; use of insecticides; multiple ownerships

Table 7A.9 (cont.)—Adaptation options that address climate change effects on nonforest vegetation in the Western Rockies subregion.

Sensitivity to climatic variability and change: Increase in fires, warmer drier conditions, and invasive species, and decline in pollinators. With warmer wetter conditions, conifers are establishing in balds and snow belts because of changes in precipitation from snow to rain.

Adaptation strategy/approach: Maintain healthy and intact grasslands.

Strategy objective: Maintain and increase resilience from perturbation and resistance to invasive species; reduce weed invasion; increased knowledge of the ecology of grasslands.

	Specific tactic – C	**Specific tactic - D**
Tactic	Step 1 - Identify and map soil types (locate molisols); Step 2 - Prioritize restoration based on Step 1; sites that were historically maintained have now shifted to conifer savannas; identify sites that were fire maintained versus snow maintained.	Step 1 - Map risk areas for severe drought, and conduct snow melt risk analysis; Step 2 - Establish targeted areas for monitoring based on step 1 (re-visit and monitor established plots); Step 3 - Work with geneticists to isolate frost and drought hardiness, early emergence; Step 4 - Use seed sources with those traits (Step 3) to help vegetate specific sites that were identified in Step 1.
Tactic effectiveness (risks)	Step 1/2 moderate	High
Implementation urgency	Near term	Step 1 – near term; Step 2 – ongoing dependent on prioritization of areas
Where can tactics be applied? (geographic)	In identified and mapped areas	In identified risk areas
Opportunities for implementation	Partnerships with Natural Resources Conservation Service (NRCS)	Heritage Program (for monitoring); partner with NRCS, National Oceanic and Atmospheric Administration (snow melt data), Rocky Mountain Research Station; local cooperators to help with seed accessions and Forest Service nursery
Cost	Moderately expensive	Moderately expensive
Barriers to implementation	Funding; time and personnel intensive; Requires finer-scale knowledge to be effective; higher priorities (mindset)	Funding; time and personnel intensive; higher priorities? (mindset); sequential process

Table 7A.10—Adaptation options that address climate change effects on nonforest vegetation in the Western Rockies subregion.

Sensitivity to climatic variability and change: Loss of topsoil and invasion of weeds.

Adaptation strategy/approach: Maintain and increase montane shrublands.

Strategy objective: Maintain and increase resilience from perturbation and resistance to invasive species; reduce weed invasion; increased knowledge of the ecology of shrublands.

	Specific tactic – A	**Specific tactic – B**
Tactic	Implement fuel reduction projects (i.e., reduce conifer encroachment, brush cutting, slashing/ mastication without burning, targeted browsing); if burning is used, design prescriptions according to requirements of desired shrub species (soil moisture requirements, desired end result conditions).	Maintain adequate shrub cover, vigor, and species richness, and avoid bare ground; create different age classes and compositions of shrubfields (shifting mosaic); no action is a viable alternative dependent on system; tools include removal of timber products, targeted grazing, prescribed burning, and mastication/slashing.
Tactic effectiveness (risks)	Moderate (unintended consequences, higher priorities)	Moderate/high
Implementation urgency	Near term/ongoing	Near term/ongoing
Where can tactics be applied? (geographic)	Throughout; critical areas for restoration	Throughout and across jurisdictional boundaries
Opportunities for implementation	Partners – Rocky Mountain Elk Foundation, sportsmen associations, Idaho Fish and Game, Bureau of Land Management, Idaho Forest Landowner association; forest harvests open up new shrublands	Partners – Rocky Mountain Elk Foundation, sportsmen associations, Idaho Fish and Game, BLM, Idaho Forest Landowner association, Turkey Federation
Cost	Inexpensive/moderately expensive (depends on scale)	Inexpensive/moderately expensive (depends on scale)
Barriers to implementation	Current forest management policies about allowing shrubfields to be maintained rather than reforestation; mindset of current land managers (tradition)	Mindset of current land managers (tradition); lack of equipment; availability of target livestock; road access; inaccessibility (slope); multi-resource objectives

Table 7A.10 (cont.)—Adaptation options that address climate change effects on nonforest vegetation in the Western Rockies subregion.

Sensitivity to climatic variability and change: Loss of topsoil and invasion of weeds.

Adaptation strategy/approach: Maintain and increase montane shrublands.

Strategy objective: Maintain and increase resilience from perturbation and resistance to invasive species; reduce weed invasion; increased knowledge of the ecology of shrublands.

	Specific Tactic – C	**Specific tactic - D**
Tactic	Apply early detection rapid response (EDRR), and use ecologically based invasive plant management (EBIPM); tools include biocontrol, herbicides, timing burning prescriptions (to avoid annual brome expansion, and targeted grazing.	Educate fuels specialists, forest ecologists, wildlife biologists and silviculturists on ecology and disturbances affecting shrublands; effects of repeated burns; shifting mosaics (creating a balance of types across landscapes); and weeds (identification, awareness, reporting).
Tactic effectiveness (risks)	Low/moderate	Moderate
Implementation urgency	Near term/ongoing	Near term/ongoing
Where can tactics be applied? (geographic)	Throughout and across jurisdictional boundaries	Throughout and across land management jurisdictions
Opportunities for implementation	Coordinate with private landowners; cooperative weed management areas; partner with Bonneville Power, tribes, private groups such as backcountry horsemen, National Forest Foundation; use volunteer cooperators (for surveys and monitoring)	Revise Forest Service manual; brownbag lunch – weed webinar; educational products such as flyers, posters; ross training and/or internal training for line officers
Cost	Inexpensive/moderately expensive (depends on scale)	Moderately expensive
Barriers to implementation	Multiple jurisdictions; National Environmental Policy Act – not being able to adapt to new chemicals; logistically inaccessible (backpack or on horse); public mindset of using chemicals; budgets are prohibitive.	Tie implementation to performance for achieving objectives (misuse of herbicides, treating non-target native plants); need line officer support; mindset of current land managers (tradition); public mindset of using chemicals

Chapter 8: Effects of Climate Change on Ecological Disturbance in the Northern Rockies Region

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Introduction

This chapter describes the ecology of important disturbance regimes in the Forest Service, U.S. Department of Agriculture (USFS) Northern Region and the Greater Yellowstone Area, hereafter called the Northern Rockies 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*—insect, disease, fire, weather, even human activity—and the effects of that agent on the landscape (table 8.1). More specifically, a disturbance regime is the cumulative effect of multiple disturbance events over space and time (Keane 2013). Disturbances disrupt an ecosystem, community, or population structure and change elements of the biological environment, physical environment, or both (White and Pickett 1985). The resulting 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 biological diversity in the form of shifting, heterogeneous mosaics of diverse communities and habitats across a landscape (McKinney and Drake 1998), and biodiversity is generally highest when disturbance is neither too rare nor too frequent on the landscape (Grime 1973).

A changing climate may already be altering characteristics of disturbance agents, events, and regimes, with additional effects expected in the future (Dale et al. 2001). Climate changes 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 (*Dendroctonus* spp.) outbreaks and wildfires, can result in highly visible, rapidly occurring, and persistent changes in landscape composition and structure. Understanding how altered disturbance patterns and multiple disturbance interactions might result in novel and emergent landscape behaviors is critical for addressing climate change impacts and for designing land management strategies that are appropriate for future climates (Keane et al. 2015).

We summarize five disturbance types present in the Northern Rockies region that are sensitive to a changing climate. Wildfires, bark beetles, white pine blister rust (*Cronartium ribicola*), other forest diseases, and nonnative plant invasions acting individually or synergistically can transform landscape patterns and ecological functions. This chapter provides background that can help managers understand the important role of disturbances on Northern Rockies landscapes, and anticipate how, when, where, and why climate changes may alter the characteristics of disturbance regimes.

Wildfire

Overview

Wildland fire is ubiquitous throughout forest ecosystems of the Northern Rockies and was historically the most important and extensive landscape disturbance in the region (Hejl et al. 1995). Wildfire emerged as a dominant process in North America after the end of the last glacial period, about 16,500 to 13,000 years B.P., commensurate with rapid climate changes and increased tree cover (Marlon et al. 2009). In the Northern Rockies region, many forest types are fire-prone and fire adapted, meaning that fire is an integral and predictable part of their maintenance and ecological functioning. Wildfire, as well as other disturbances such as insect outbreaks, disease, drought, invasive species, and storms, is part of the ecological history of most forest ecosystems, influencing vegetation age and structure, plant species composition, productivity, carbon (C) storage, water yield, nutrient retention, and wildlife habitat (Agee 1993).

Climate and fuels are the two most important factors controlling patterns of fire in forest ecosystems. Climate controls the frequency of weather conditions that promote fire, whereas the amount and arrangement of fuels influence fire intensity and spread. Climate influences fuels on

Table 8.1—Characteristics used to describe disturbance regimes.[a]

Disturbance characteristic	Description	Example
Agent	Factor causing the disturbance	Mountain pine beetle is the agent that kills trees
Source, cause	Origin of the agent	Lightning is a source for wildland fire
Frequency	How often the disturbance occurs or its return time	Years since last fire or beetle outbreak (scale dependent)
Intensity	A description of the magnitude of the disturbance agent	Mountain pine beetle population levels; wildland fire heat output
Severity	The level of impact of the disturbance on the environment	Percent mountain pine beetle tree mortality; fuel consumption in wildland fires
Size	Spatial extent of the disturbance	Mountain pine beetles can kill trees in small patches or across entire landscapes
Pattern	Patch size distribution of disturbance effects; spatial heterogeneity of disturbance effects	Fire can burn large regions but weather and fuels can influence fire intensity and therefore the patchwork of tree mortality
Seasonality	Time of year at which a disturbance occurs	Species phenology can influence wildland fire effects; spring burns can be more damaging to growing plants than fall burns on dormant plants
Duration	Length of time that disturbances occur	Mountain pine beetle outbreaks usually last for 3–8 years; fires can burn for a day or for an entire summer
Interactions	Disturbances interact with each other, climate, vegetation, and other landscape characteristics	Mountain pine beetles can create fuel complexes that facilitate or exclude wildland fire
Variability	Spatial and temporal variability of the above factors	Highly variable weather and mountain pine beetle mortality can cause highly variable burn conditions resulting in patchy burns of small to large sizes

[a] From Keane (2013).

longer time scales by shaping species composition and productivity (Dale et al. 2001; Marlon et al. 2008; Power et al. 2008), and large-scale climatic patterns such as the El Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) are important drivers of forest productivity and susceptibility to disturbance (Collins et al. 2006; Kitzberger et al. 2007). Current and past land use, including timber harvest, forest clearing, fire suppression, and fire exclusion through grazing have affected the amount and structure of fuels in the United States (Allen et al. 2002; Falk et al. 2011; Pausas and Keeley 2014).

Disturbance effects can overwhelm the direct effects of climate changes on ecosystems. As described in other chapters in this publication, climate changes influence forests directly; for example, it has been suggested that drought and heat stress 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 climate changes on forest ecosystems will be caused by altered disturbances, often occurring with increased frequency and severity. The warmer, drier conditions expected with climate change are likely to increase fire frequency, fire season length, and cumulative area burned in the coming decades in the western United States (Flannigan et al. 2006; McKenzie et al. 2004). Climate changes may also increase the frequency or magnitude of extreme weather events that affect fire behavior (Kurz et al. 2008b; Lubchenco and Karl 2012). Although shifts in vegetation composition and distribution caused by climate alone may occur over decades or centuries, wildfires can temporarily or persistently reorganize landscapes over a period of days (Overpeck et al. 1990; Seidl et al. 2011).

The role of fire in ecosystems and its interactions with dominant vegetation is termed a “fire regime” (Agee 1993). Fire regimes are 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 (table 8.2). These characteristics vary across vegetation types 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). Ecosystems in the Northern Rockies have been subject to a range of historical fire regimes, including (1) frequent (1–35 years), low- or mixed-severity fires that replaced less than 25 percent of the dominant overstory vegetation; (2) moderate-frequency (35–200 years), mixed-severity fires that replaced up to 75 percent of the overstory; and (3) infrequent (200+ years), high-severity fires that replaced greater than 75 percent of

Table 8.2— Risk assessment for fire regime changes.[a]

Fire regime component	Predicted direction of change	Main driver(s) of change	Projected duration of change	Likelihood of change
Ignitions	Unknown	Changes in lightning frequency and anthropogenic ignitions	Unknown	Unknown
Area burned	Increase	Increased fire season length, decreased fuel moistures, increased extreme fire conditions	Until a sufficient proportion of the landscape has been exposed to fire, thus decreasing fuel loads and increasing structural and species heterogeneity	High
Fire frequency	Increase	Increased ignitions, increased fuel loads, decreased fuel moistures, increased fire season length	In forested systems until a sufficient proportion of the landscape has been exposed to fire, reducing fuel loads and continuity; in grass- and shrubland systems, until global climate stabilizes	Moderate
Average fire size	Increase	Increased fire season length, decreased fuel moistures, increased extreme fire conditions	Until a sufficient proportion of the landscape has been exposed to fire, thus increasing the likelihood that previous fires will restrict growth of current year fires	High
Fire season length	Increase	Increased temperatures, decreased precipitation, decreased winter snowpack, decreased runoff	Until the global climate system stabilizes; predicted to increase as climate changes become more severe	High
Fire severity	Increase	Decreased fuel moistures, increased extreme fire conditions	In dry forest types, until fires decrease surface fuel loads; in mesic forests, if increased fire frequency decreases fuel loads	Moderate

[a] Developed using expert opinion and information from literature as summarized in this chapter.

the dominant overstory vegetation (fig. 8.1). More-detailed information on fire regimes specific to individual vegetation species and vegetation types can be found in Chapter 6 of this volume.

Wildland fire behavior is influenced by variability in environmental conditions including vegetation type and distribution, climate, weather, and topography. Despite major human influences on western U.S. wildfires since Euro-American settlement, climate is generally considered to be the primary control on fire regimes in the region, influencing vegetation production and condition as well as the physical environment (Marlon et al. 2012). Where rates of vegetation production outpace decomposition, sufficient biomass is available to support fires, although higher elevation regions with abundant fuels do not always have sufficiently dry conditions to sustain a fire. In these systems, short-duration drying episodes generally do not create dry enough conditions to sustain a fire, but 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 in the Northern Rockies region, during which time there are ample sources of ignition from lightning strikes and humans. Therefore, the active fire 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 (Littell et al. 2009).

At annual time scales, weather is the best predictor of fire characteristics such as area burned and fire size. Correlations between weather and annual area burned by fire or the number of large fires are similar for both pre-20th-century fires and fires that have occurred during the past few decades. Fire-weather relationships have been constructed for forested ecosystems of the Pacific Northwest (Hessl et al. 2004; Heyerdahl et al. 2002, 2008a) and Northern Rockies (Heyerdahl et al. 2008b; Littell et al. 2009; Westerling et al. 2003, 2006), based on tree-ring and fire-scar records and independently reconstructed climate, or observations of fire

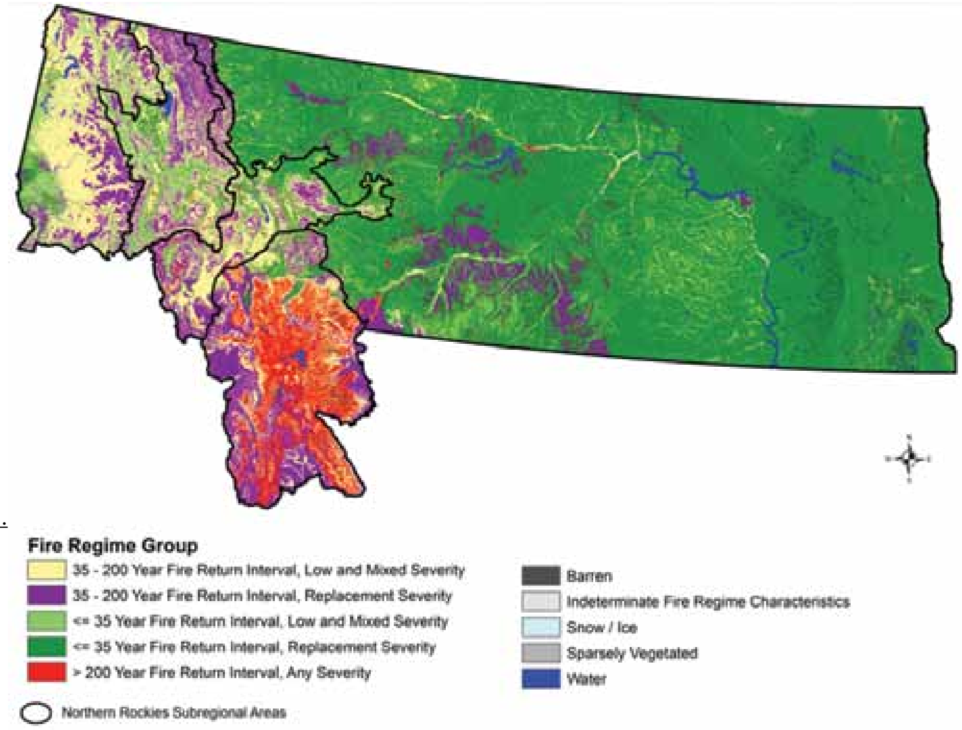

Figure 8.1—Fire regime groups for the Northern Rockies, LANDFIRE mapping program. The fire regime group layer characterizes the presumed historical fire regimes within landscapes based on interactions among vegetation dynamics, fire spread, fire effects, and spatial context (see http://www.landfire.gov/NationalProductDescriptions12.php).

events and weather in the seasons leading up to and during the fire where records are available. Regionally, widespread fire years are correlated with drought (Heyerdahl et al. 2008b; Morgan et al. 2008), and these regionally synchronous fires have generally occurred in the Northern Rockies (Idaho and western Montana) during years with relatively warm spring-summers and warm-dry summers (Heyerdahl et al. 2008a; Morgan et al. 2008).

In nonforested systems in the eastern Northern Rockies, precipitation amount, at both short (weeks to months) (Littell et al. 2009) and long (decades to centuries) (Brown et al. 2005) time scales is the dominant control on fire. During the fire season, the amount and timing of precipitation largely determine availability and combustibility 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). In contrast to the grasslands of the southwestern United States, antecedent precipitation has not been found to be a significant driver of large fires in the northern grasslands; rather, 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).

Humans are also important drivers of wildfire, via altered ignition patterns associated with land clearing and land cover change, agriculture, introduction of exotic species, and fire management (fuels treatments and fire suppression/exclusion). Grazing and the introduction of nonnative species have altered ecological processes that affect fire, including fuel loading and continuity, forest composition and structure, nutrient cycling, soils, and hydrology (Marlon et al. 2009; Swetnam et al. 1999). For many sagebrush ecosystems of low to moderate productivity, fire intervals are 10 to 20 times shorter today than what is estimated for pre-20th-century conditions (Peters and Bunting 1994; Whisenant 1990; see also Chapter 7), because of the spread and dominance of the nonnative annual cheatgrass (*Bromus tectorum*). Dry forests, shrublands, and grasslands in the region exist in a state of "fire deficit" as the result of fire exclusion, leading to less frequent wildfire, higher stand densities, higher fuel quantities, and higher fuel continuity. This has increased the potential for crown fires in forests with a history of low-severity fire regimes (Agee 1998; Peterson et al. 2005) and in some forests with mixed-severity regimes (Taylor and Skinner 2003).

Wildfire Shapes Landscape Patterns

The composition and structure of forests in the Northern Rockies is determined by climate, elevation, topographic position, and history of fire. In general, fire regimes vary along environmental gradients, with fire frequency decreasing and fire severity increasing with elevation (although aspect and slope position can influence fire patterns). For example, low-severity fires are typical in many ponderosa pine (*Pinus ponderosa*) forests at low elevations. Historically, fires here 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 rare (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. Conversely, high-severity fires occurring at intervals of more than 300 years are typical in subalpine forests and tend to result in high mortality of mature trees ("stand replacement") because

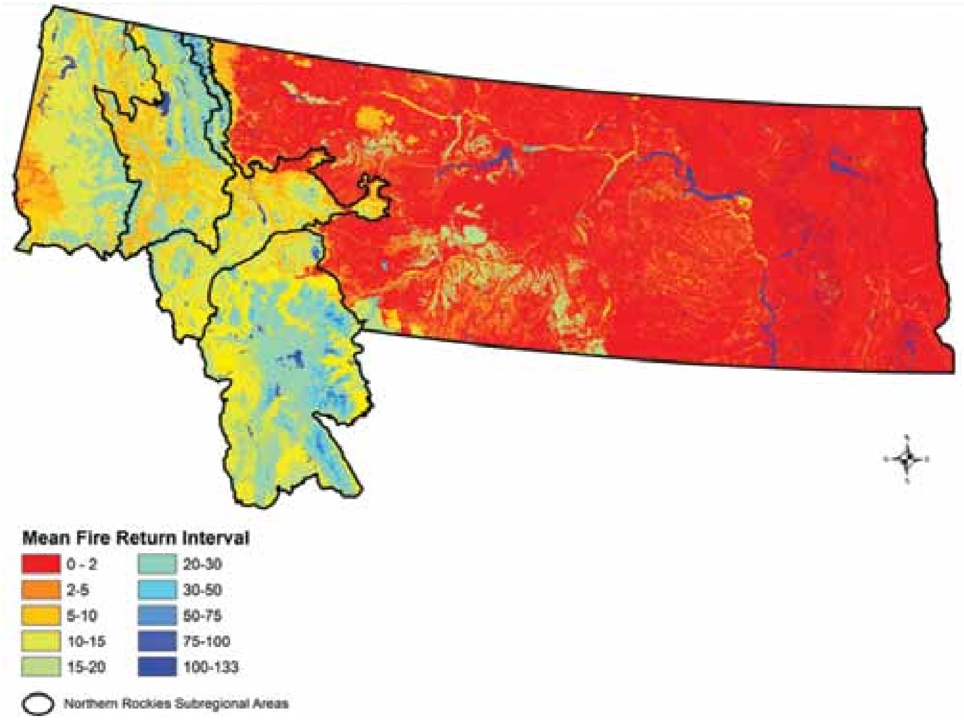

Figure 8.2—Mean fire return interval for the Northern Rockies, LANDFIRE mapping program. The mean fire return interval layer quantifies the average period between fires under the presumed historical fire regime (see http://www.landfire.gov/NationalProductDescriptions13.php for more information).

long intervals between fires result in dense, multi-storied forest structures that are susceptible to crown fires (Agee 1998) (fig. 8.2).

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. 8.3). 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 not altered fire regimes (Romme and Despain 1989; Schoennagel et al. 2004). For example, large, stand-replacing fires occasionally occurred in lodgepole pine (*Pinus contorta* var. *latifolia*) forests in Yellowstone National Park (Romme 1982), and many (but not all) lodgepole pine trees can regenerate prolifically when heating from fires releases seed from serotinous cones (Schoennagel et al. 2003).

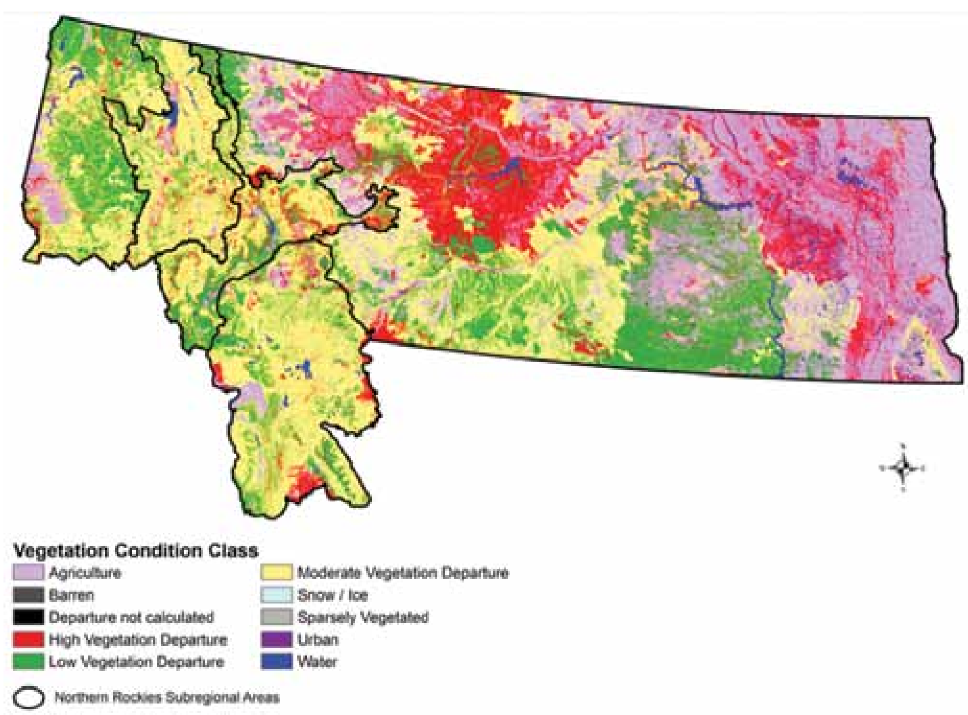

Figure 8.3—Vegetation condition class for the Northern Rockies, LANDFIRE mapping program. The vegetation condition class layer quantifies the amount that current vegetation has departed from the simulated historical vegetation reference conditions (see http://www.landfire.gov/NationalProductDescriptions10.php).

Wildfires and Forest Carbon Sequestration

Concerns about projected changes in global climate have raised an expectation that forests can help mitigate climate changes via management for increased carbon sequestration and storage (Sommers et al. 2014). Forests contain large reservoirs of carbon in soils (~45 percent of total storage), aboveground and belowground live biomass (~42 percent), dead wood (~8 percent), and litter (~5 percent) (Pan et al. 2011). The carbon sequestration potential of Earth's forests is about 33 percent of global emissions from fossil fuels and land use (Denman 2007), and North American forests currently offset about 13 percent of annual continental fossil fuel emissions (Pacala et al. 2007). The potential for forests 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 (Loehman et al. 2014).

Carbon typically accumulates in woody biomass and soils for decades to centuries until a disturbance event such as wildfire releases this stored carbon into the atmosphere (Goward et al. 2008). Wildfire in forested ecosystems is one of the primary disturbances that regulate patterns of carbon storage and release (Kasischke et al. 2000). The amount and rate of carbon release from a wildfire depend on the extent and severity of the fire, as well as pre-disturbance site conditions and productivity (Bigler et al. 2005; Dale et al. 2001; Falk et al. 2007). For example, high-severity fires typical of mid-to-upper elevation forests in the Northern Rockies 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 carbon is stored in woody biomass as forests regrow. Low-severity fires such as those that occur in low-elevation dry forest types typically release less carbon per fire event (although total emissions are dependent on area burned) at more frequent intervals than with stand-replacing regimes, and favor long-lived and fire-resistant (or tolerant) forest species that typically survive multiple fire events (Ritchie et al. 2007). Carbon losses from wildland fire are balanced by carbon capture from forest regrowth across unmanaged fire regimes and over multiple decades, unless a lasting shift in dominant plant lifeform occurs or fire return intervals change (Kashian et al. 2006; Wiedinmyer and Neff 2007).

There are several important ideas to consider when managing forests and fires for carbon resources. First, as stated above, unless structural or functional ecosystem shifts occur, net carbon balance in disturbance-adapted systems at steady state is zero when assessed over long time periods and at large spatial scales. Under these conditions, although a fire may result in a temporary loss of stored carbon from a forest to the atmosphere (i.e., the forest temporarily becomes a carbon source), this effect is transitory and balanced by carbon accumulation as the forest regrows. The time required for the postfire environment to shift from carbon source to sink varies among forest types and climates. For example, in simulations of effects of stand-scale fuels treatments on carbon-fire relationships in Northern Rockies forests, post-fire carbon recovery occurred in 10 to 50 years, depending on vegetation type and whether stands were treated before fire to reduce woody fuels (Reinhardt and Holsinger 2010).

Second, quantifying or projecting wildland fire emissions is difficult because their amount and character vary greatly from fire to fire, depending on biomass carbon densities, quantity and condition of consumed fuels, combustion efficiency, and weather (Loehman et al. 2014). Emissions measured for an individual fire event may not be characteristic of large-scale emissions potential, because of complex ecological patterning and spatial heterogeneity of burn severity within fire perimeters. Although long intervals between wildfires can allow carbon to accumulate for years to centuries, disturbance-prone forests will eventually lose stored carbon to the atmosphere, regardless of management strategies designed to limit or prevent disturbance events.

Third, wildfire confers many important ecological benefits not measurable in carbon units (e.g., nutrient release and redistribution, stimulation of plant growth, increased productivity in soil systems from decomposition of burned material, initiation of vegetation succession and forest regeneration, increased availability of resources for surviving trees). Thus, it will be important to develop accounting methods that can assess ecological benefits in carbon-equivalent units so that they can be weighed against carbon losses from disturbance.

Finally, climate changes in combination with other ecosystem stressors may be sufficient to cause structural or functional changes in ecosystems and thus alter carbon dynamics of landscapes. For example, if climate changes increase wildfire frequency, extent, or severity in forested ecosystems, forests will likely lose carbon to the atmosphere that will not be rapidly replaced by new growth. This will cause forests to act as carbon sources for a period of time until disturbance regimes and biomass stabilize. Future landscapes could have the potential to store less, or more, carbon than under current climate and disturbance regimes.

Potential Future Wildfire Regimes and Wildfire Occurrence

Potential climate-driven changes to regional fire regimes in the mid-to-late 21st century include longer fire seasons and increases in fire frequency, annual area burned, number of high fire danger days, and fire severity as compared with modern fire patterns (Bachelet et al. 2003; Brown et al. 2004; Dillon et al. 2011; Krawchuk et al. 2009; Rocca et al. 2014; Westerling et al. 2006) (figs. 8.4, 8.5). In particular, lengthening of the fire season (the period of the year when fires can burn) will allow for more ignitions, greater likelihood of fire spread, and a longer burning duration. A longer burning window combined with regionally dry fuels will promote larger fires and increased annual area burned relative to modern recorded fire activity. Earlier onset of

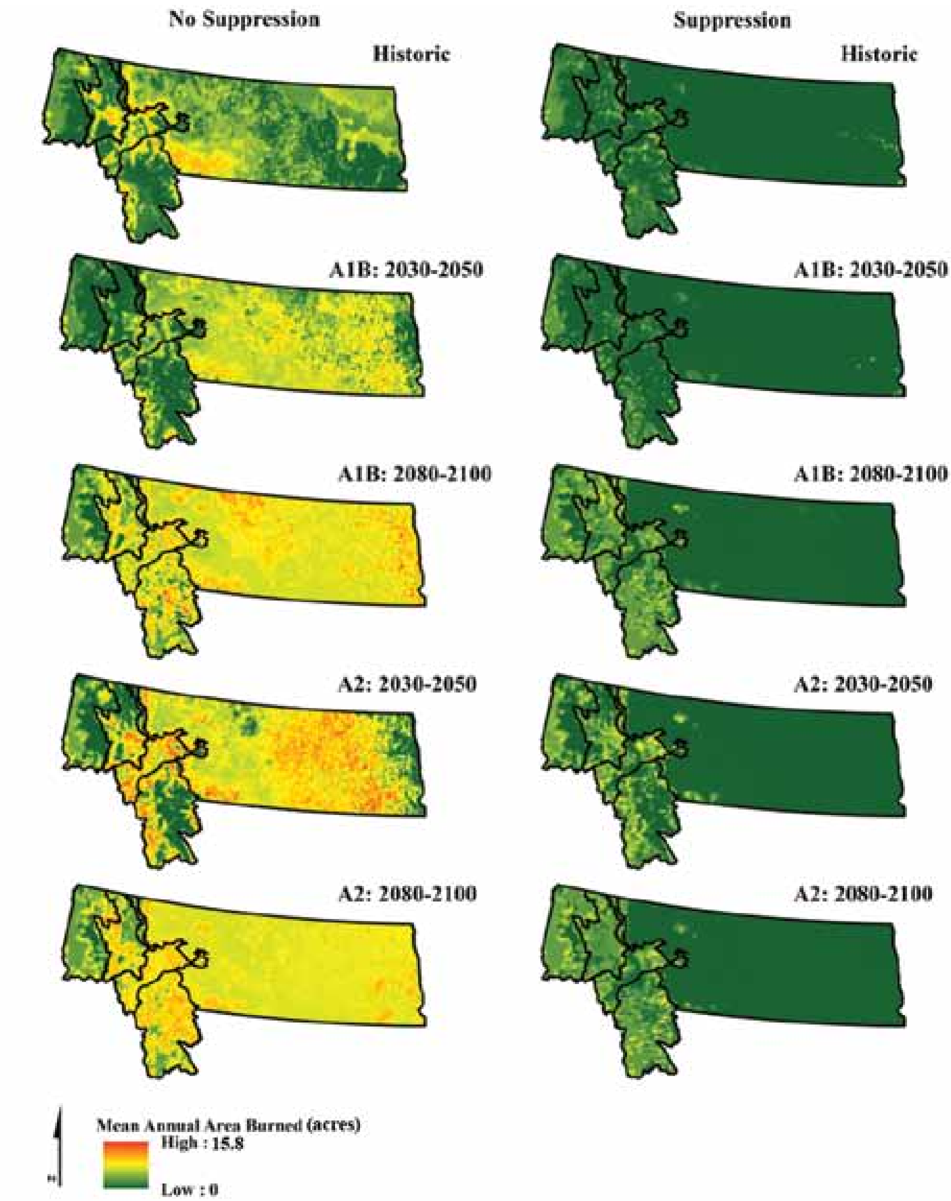

Figure 8.4—Changes in mean annual area burned (acres) for current levels of fire suppression and no fire suppression, A1B (moderate) and A2 (high) emission scenarios, and for the time periods 2030–2050 and 2080–2100, as projected by the MC2 dynamic global vegetation model.

snowmelt will reduce fuel moisture during fire season, making a larger portion of the landscape flammable for longer periods of time (McKenzie et al. 2004; Miller et al. 2011). This shift may be especially pronounced in mid- to high-elevation forested systems where fuels are abundant.

Earlier snowmelt, higher summer temperatures, longer fire season, and expanded vulnerable area of high elevation forests have produced observed increased wildfire activity compared to the mid-20th century, particularly in the Northern Rockies region (Westerling et al. 2006). Annual area burned by Western wildfires in the 20th century was greater in years with low precipitation, high drought severity, and high temperatures (Littell et al. 2009). Wildfire activity in the western United States is expected to increase if climates become warmer and drier in the future. Among western U.S. forests, mid-elevation forests of the Northern Rockies are projected to have a high risk of climate-induced increase in fire (Westerling et al. 2006), and increases in the area burned by fire are likely in lower and middle elevations of mountainous areas (Littell et al. 2009). However, in areas that are fuel limited, fires may become more infrequent where there is insufficient moisture for fine fuel accumulation (Littell et al. 2009).

The potential effects of climate change on wildfire area have been assessed by using statistical and ecological process models for the western United States (McKenzie et al. 2004; Spracklen et al. 2009), Pacific Northwest (Littell et al. 2010), Northern Rockies (Holsinger et al. 2014; Loehman et al. 2011a,b; Rocca et al. 2014), and the Greater Yellowstone Area (Westerling et al. 2011). For a mean temperature increase of 4 ºF, the annual area burned by wildfires is expected to increase by a factor of 1.4 to 5 for most western States (McKenzie et al. 2004), ultimately leading to greater damage, growth reductions, and mortality in forest ecosystems. The effects of future climate on fire severity (i.e., the proportion of overstory mortality) are less certain because

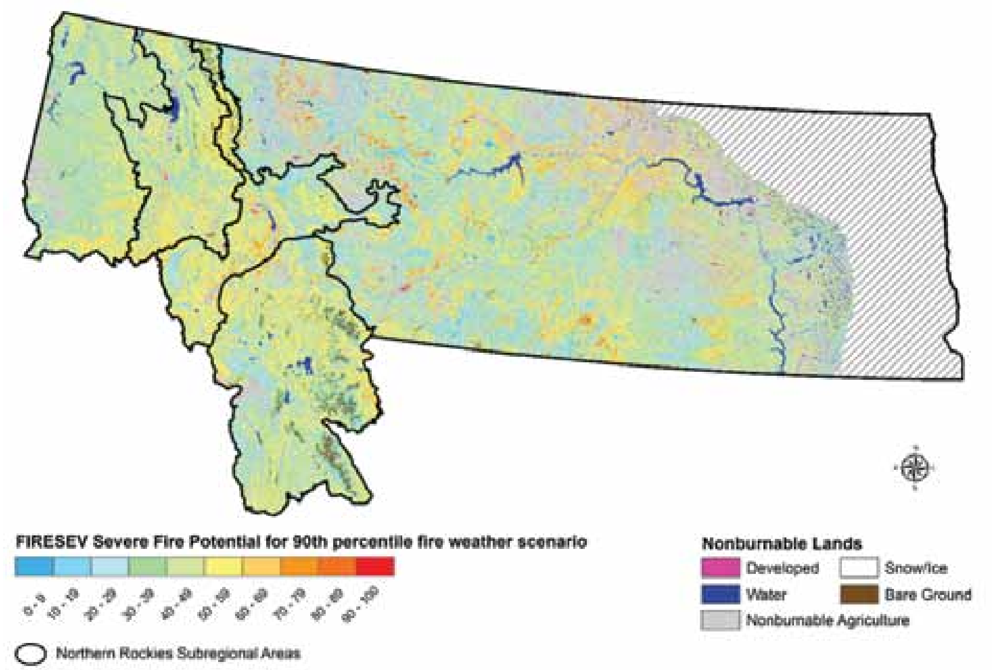

Figure 8.5—Severe fire potential (probability) for 90th percentile fire weather scenario, with non-burnable areas added in from the LANDFIRE 2008 Fire Behavior Fuel Model layer (data source: Dillon et al. 2011).

severity may be more sensitive than area burned to arrangement and availability of fuels. The risk posed by future fire activity in a changing climate can be assessed by its likely effects on human and ecological systems. At the wildland-urban interface, higher population and forest density have created forest conditions that are likely to experience more area burned and possibly higher fire severity than in the historical record (Dillon et al. 2011) (figs. 8.4, 8.5).

Although fire size in historical sagebrush landscapes is poorly understood, it is generally accepted that recent large fires have been fueled by woodland encroachment and higher fine fuel loads from weed invasions (e.g., cheatgrass). These changes in fire regime and vegetation-fuel structure affect large areas in the semiarid western United States and cascade through all trophic levels. Effects are particularly harmful on landscapes where postfire recovery is slow. The trend for larger, more damaging fires in sagebrush ecosystems is expected to continue until aberrations in fuel conditions that drive fire are corrected (Keane et al. 2008).

Interactions with Other Disturbance Processes

Wildland fires and insect outbreaks are the two primary natural disturbance processes in conifer forests of western North America (Hicke et al. 2012; Jenkins et al. 2012). The interaction of wildland fire and bark beetles has been studied since the early 20th century (Evenden and Gibson 1940; Miller and Patterson 1927; Weaver 1943), with research primarily focused on the potential for increased fire hazard following outbreaks. Multiple studies have cited changes in fire behavior, extent, and severity resulting from bark beetle-caused mortality in pine forests (see Hicke et al. 2012 for a summary). Drought and increased temperatures are key drivers of both wildland fires and bark beetle outbreaks. Climate change may be a causal factor in recent increases in annual area burned by wildfires (Littell et al. 2009) and area affected by bark beetle outbreaks (Bentz et al. 2010). Projections of warmer temperatures and increased drought stress suggest that the total area susceptible to or affected by beetle outbreaks and large or severe fires may increase in the coming decades (Williams et al. 2013). Acting independently or synchronously in space and time, wildland fires and bark beetle outbreaks can substantially influence forest structure, composition, and function; abruptly reorganize landscapes; and alter biogeochemical processes such as carbon cycling, water supply, and nutrient cycles (Edburg et al. 2012; Falk 2013; Fettig et al. 2013; Hansen 2014; Kurz et al. 2008a).

Unknowns and Uncertainties

Projections of future climate are somewhat uncertain because the ultimate magnitude of climate change and the severity of its impacts depend strongly on the actions that human societies take to respond to these risks (National Research Council 2010). Global climate models and their downscaled products may not accurately represent climate and weather at the regional and local scales that influence fire occurrence and behavior. For example, although associations between fire and quasi-periodic patterns such as ENSO and PDO have been identified, there is incomplete understanding of how these will respond to climate warming (McKenzie et al. 2004). In addition, precipitation trends are highly variable, and projections of future precipitation reflect both uncertainty and high variation (Intergovernmental Panel on Climate Change [IPCC] 2007, 2012; Littell et al. 2011). Lightning, an important ignition source for wildland fires, may increase in the future, thus increasing the potential for fire activity. For example, recent projections suggest that lightning strikes in the continental United States may increase by about 50 percent over the 20th century as the result of global warming-induced increase in updraft speeds and atmospheric water content (Romps et al. 2014). However, others have concluded that confidence in projections of increased thunderstorms and severe local weather events is low (Seneviratne et al. 2012).

Thus, the influence of climate changes on future fire patterns is not precisely known. Long-term changes in climate are unlikely to produce simple linear responses in global fire regimes (e.g., warmer temperatures do not always lead to increased fire frequency) because fire activity is influenced by precipitation, which is not projected accurately by climate models (Grissino-Mayer and Swetnam (2000). Other research suggests that increases in burned area can be expected in a warming climate, 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). In addition, climate drivers interact with legacies of human land use and local vegetation and fuel conditions at large spatial scales, making linear climate-fire predictions difficult. Specifically, decades-long fire exclusion and timber harvesting in some forests of the western United States have resulted in densely stocked stands and heavy down woody fuels accumulation that have probably contributed to the anomalous size and intensity of recent fires (Grissino-Mayer and Swetnam 2000; Naficy et al. 2010).

Bark Beetles

Overview

Bark beetles (Coleoptera: Curculionidae, Scolytinae) make up a large subfamily of insects, although less than 1 percent of the more than 6,000 species found worldwide cause significant economic impacts. In the Northern Rockies region, bark beetles of economic concern feed in the phloem of living conifers and can have extreme population amplifications over short time periods, the hallmark of outbreak species. Larval feeding, in addition to colonization by beetle-introduced fungi, typically results in death of the tree, and new host material is therefore required for each beetle generation. Historically, pulses of bark beetle-caused tree mortality have been extensive across the northern portion of the Rocky Mountain region. Between 1999 and 2013, bark beetle-caused tree mortality had substantial impacts in the Northern Rockies across an average of 1.4 million acres each year (fig. 8.6). Mountain pine beetle (*Dendroctonus ponderosae*, hereafter referred to as MPB) caused the majority of tree mortality (82 percent of acres with mortality detected) with a cumulative impact across 8.7 million acres during this time period (fig. 8.7). Across western North America between 1997 and 2010, bark beetle-caused tree mortality resulted in a transfer of carbon that exceeded that of fire-caused tree mortality (Hicke et al. 2013).

Both bark beetle populations and their host trees are being influenced by a warmer climate. Many bark beetle life history traits that affect population success are temperature-dependent (Bentz and Jönsson 2015), and warming temperatures associated with climate change have directly influenced bark beetle-caused tree mortality in some areas of western North America (Safranyik et al. 2010; Weed et al. 2015b). Warming climate will also influence host tree distribution across the Northern Rockies region, and tree vigor, which affects susceptibility to bark beetle attack (Chapman et al. 2012; Hart et al. 2013).

Bark Beetles in the Northern Rockies

Bark beetles are relative specialists, feeding on a single tree species or several species within a single genus. In the Northern Rockies region, multiple tree species are affected by different bark beetle species (table 8.3). Populations of several beetle species, and MPB in particular, began building in 1999, with high populations continuing in some areas through 2013 (USDA FS n.d.) (figs. 8.6, 8.7). Trend analysis indicates that most subwatersheds have declining populations, although some specific locations had increases in 2012 and 2013

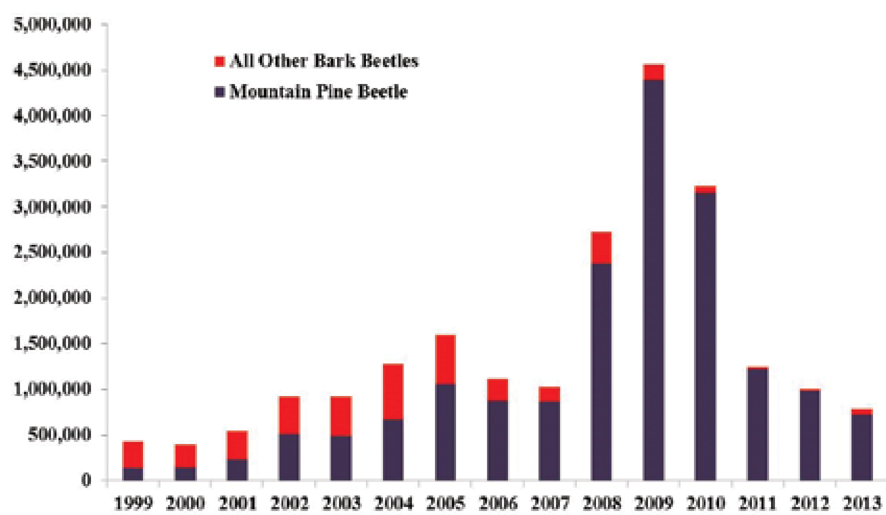

Figure 8.6—Area (acres) affected by bark beetles in the U.S. Forest Service Northern Region. Data based on Forest Health Protection aerial detections surveys.

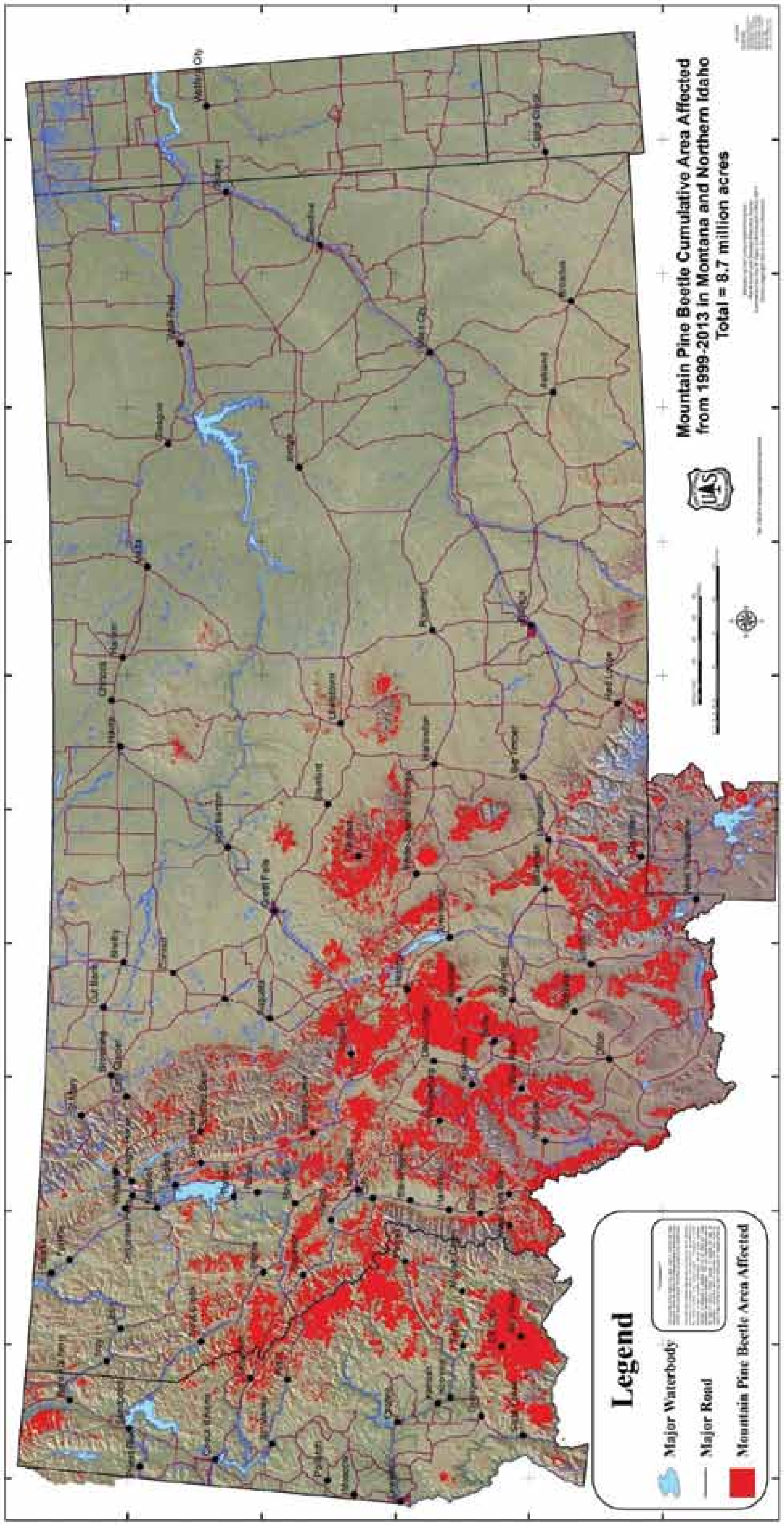

Figure 8.7—Cumulative area affected by mountain pine beetle between 1999 and 2013 in the Northern Rockies. Data based on Forest Health Protection aerial detection surveys.

Table 8.3—Bark beetle species that cause economic impacts in the Northern Rockies.

Bark beetle species		
Common name	**Scientific name**	**Host tree species**
Western pine beetle	*Dendroctonus brevicomis*	Ponderosa pine
Mountain pine beetle	*D. ponderosae*	Limber pine, lodgepole pine, ponderosa pine, western white pine, whitebark pine
Douglas-fir beetle	*D. pseudotsugae*	Douglas-fir
Spruce beetle	*D. rufipennis*	Engelmann spruce
Pine engraver beetle	*Ips* spp.	Lodgepole pine, ponderosa pine, western white pine
Fir engraver	*Scolytus ventralis*	Grand fir

(Egan 2014; Egan et al. 2013). Based on 2012 vegetation characteristics, susceptibility of Northern Rockies watersheds to future MPB outbreaks is spatially variable with many areas projected to lose more than 25 percent of total basal area (Krist et al. 2014).

Drivers of Bark Beetle Outbreaks

Bark beetle population outbreaks require forests with extensive host trees of suitable size and age (Fettig et al. 2013). For most irruptive species, preferred hosts are large, mature trees that provide a large amount of phloem resource for a developing brood. Large landscapes of these mature stands provide ideal conditions for years of bark beetle population growth.

Although suitable host trees are critical to outbreak development, beetle populations can exist for years at low levels until release is triggered by inciting factors. These triggers allow for rapid population growth that utilizes plentiful host trees. Triggers have been difficult to quantify but include factors that make food more readily available and that increase survival and reproduction of the beetles. Stand conditions (Fettig et al. 2013), drought (Chapman et al. 2012; Hart et al. 2013), and pathogens (Goheen and Hansen 1993) can make it easier for low levels of beetles to overwhelm and kill trees. Similarly, large areas of host trees recently killed by fire, wind, or avalanche provide pulses of accessible food, and have resulted in outbreaks of some species such as Douglas-fir beetle (*Dendroctonus pseudotsugae*) and spruce beetle (*D. rufipennis*) (Hebertson and Jenkins 2007; Shore et al. 1999), as well as secondary beetles including *Ips* species and fir engraver (*Scolytus ventralis*) (Livingston 1979). Weather favorable to beetle reproduction and survival also influences population fluctuations, and can both initiate and sustain outbreaks (Bentz et al. 2011; Powell and Bentz 2009; Régnière and Bentz 2007).

Given a susceptible forest, climate and weather directly drive bark beetle outbreaks by affecting beetle growth and survival through temperature-dependent life history traits. For example, the process of mass attack needed to successfully overcome tree defenses requires synchronous emergence of adults, a process mediated by temperature (Bentz et al. 1991). Diapause and development rate thresholds help in this synchrony (Bentz and Jönsson 2015; Hansen et al. 2001, 2011; Ryan 1959; Safranyik et al. 1990). These strategies also reduce the likelihood that life stages most sensitive to cold (eggs and pupae) are not present during winter. Development rates and thresholds also dictate life cycle timing, an important determinant of the number of generations per year.

The western pine beetle (*D. brevicomis*) and *Ips* species can be bivoltine (two generations in one year) in the Northern Rockies (Kegley et al. 1997; Livingston 1991), although multivoltine in more southern parts of their range. Other bark beetle species need at least 1 year to complete a generation (univoltine), and at higher elevations, where temperatures are cooler, 2 to 3 years may be required for a complete life cycle. Warm temperatures in the summer and spring extend the time that temperatures are above development thresholds, thereby allowing a reduction in generation time (Bentz et al. 2014; Hansen et al. 2001). Shorter generation times can lead to increased population growth, causing increased tree mortality. Winter temperature also influences bark beetle population success. Larvae cold-harden to survive subfreezing temperatures (Bentz and Mullins 1999; Miller and Werner 1987), although extreme fluctuations in temperature in spring and fall, in addition to long durations of temperatures below –31 °F, can cause extensive larval mortality (Evenden and Gibson 1940; Régnière and Bentz 2007; Safranyik and Linton 1991).

Bark Beetle Outbreaks Shape Landscape Patterns

Bark beetle disturbances play a significant role in successional pathways and biogeochemical cycles in Northern Rockies forests (DeRose and Long 2007; Edburg et al. 2012; Hansen 2014). At low population levels, bark beetles act locally as thinning agents, producing forest gaps that promote regeneration and the release and subsequent growth of neighboring host and nonhost trees, often producing uneven-aged stands (Mitchell and Preisler 1998). At outbreak population levels, tree mortality can approach 80 percent across landscapes of homogeneous host species and age, changing age-class distributions and overstory and understory species compositions. For example, in seral lodgepole pine forests, removal of the largest trees by MPB can hasten succession by climax species when fire is absent (Hagle et al. 2000; Roe and Amman 1970). Bark beetle disturbance can have long-term effects on forest structure and composition (Pelz and Smith 2012), and future landscape patterns in some forest types will be driven by tree mortality caused by large outbreaks of beetles.

Potential Future Bark Beetle Regimes and Occurrence

Climate change will have indirect and direct effects on bark beetle population outbreaks (table 8.4). Indirectly, changing temperature and precipitation regimes will influence the suitability and spatial distribution of host trees. Community associates important to bark beetle population success, including fungi, predators, and competitors, will also be affected by changing climate and thereby indirectly affect beetle population outbreaks. Direct effects will also occur as changing temperature regimes either promote or disrupt bark beetle temperature-dependent life history strategies that evolved through local adaptation for increased beetle population fitness and survival. Future bark beetle-caused tree mortality will therefore depend not only on the spatial distribution of live host trees and heterogeneity of future landscapes (see Chapter 6), but also on the ability of beetle populations and their associates to adapt to changing conditions when existing phenotypic plasticity is surpassed.

Projected changes in temperature and precipitation, in addition to a potential increase in extreme events such as windstorms, will significantly influence the spatial and temporal distribution of suitable host trees across future landscapes. For example, host tree defenses can be weakened by reduced water availability (Chapman et al. 2012; Gaylord et al. 2013; Hart et al. 2013). Increasing temperature is also associated with changing hydrologic regimes (see Chapter 4), including altered interseasonal timing of soil water availability facilitated by snowpacks that have progressively melted earlier in recent decades, and changes in the distribution of precipitation falling as rain versus snow (Regonda et al. 2005). These factors, along with other potential climate changes, may exacerbate physiological drought stress in host trees, which could indirectly benefit bark beetles that colonize stressed hosts in the late spring or summer (Raffa et al. 2008). Similarly, increased wind events could provide a reservoir of stressed trees used by some bark beetle species to surpass the endemic-epidemic threshold. Species currently considered secondary (i.e., those that infest stressed trees) could become primary tree killers as their favored habitat increases.

Warming temperatures will also directly influence bark beetle population success, although the effects will depend on the beetle species, as well as the seasonal timing, amount, and variability of thermal input. For example, across MPB habitats in the western United States from 1960 to 2011, minimum temperatures increased 6.5 °F. This increase in minimum temperature resulted in an increase in MPB survival and subsequent beetle-caused tree mortality in many areas of the Northern Rockies (Weed et al. 2015a). As climate continues to change, however, extreme within-year variability in winter warming could be detrimental to insect survival. Bark beetles produce supercooling compounds as temperatures decrease and catabolize compounds as temperatures warm. 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 species overwinter at the base of tree boles, gaining protection from predators and excessive cold temperatures when insulated beneath snow. Reduced snow levels in a warming climate could therefore add to increased overwinter mortality.

Warming at other times of the year could similarly have both positive and negative effects on bark beetle populations. Phenological flexibility allows some species to shift voltinism pathways, developing on a semivoltine (one generation every 2 years) life cycle in cool years, and a univoltine life cycle in warm years (Bentz et al. 2014; Hansen et al. 2001). Warming temperatures could also cause species that are

Table 8.4—Risk assessment for mountain pine beetle outbreaks.[a]

Elevation	Direction of change	Main driver(s) of change	Projected duration of change	Likelihood of change
<3,300 ft	Increase if host trees available	Temperature–caused shift to bivoltinism[b]	Increasing risk through 2100	High
3,300–6600 ft	Decrease	Temperature-caused disruption of seasonality	Decreasing risk through 2100	High
6,600–10,000 ft	Increase initially, then decrease	Initially temperature-caused shift from semivoltine[c] to unvioltine[d], then disruption of seasonality	Decreasing risk through 2100	High
>10,000 ft	Increase	Temperature-caused shift from semivoltine to univoltine	Increasing risk through 2100	High

[a] Developed using model simulations and expert opinion and information from literature as summarized in this chapter.
[b] Two generations in one year.
[c] One generation in two years.
[d] One generation in one year.

currently bivoltine (e.g., western pine beetle, *Ips* species) to become multivoltine. These types of voltinism shifts can lead to rapid increases in beetle populations and subsequent tree mortality. Some thermal regimes allow these life cycle shifts yet maintain seasonal flights. However, other thermal regimes that result in voltinism shifts could also disrupt seasonality. For example, warm summers could accelerate development, resulting in reduced generation time, but could also result in cold-sensitive life stages entering winter. Existing developmental thresholds and diapause strategies that serve synchrony currently reduce the likelihood of this happening. As existing phenotypic plasticity is surpassed, rapid warming without adaptation could lead to lower overall population fitness in some areas as a result of poor seasonal timing (Régnière et al. 2015).

Expected Effects of Climate Change

Although many bark beetle species in the Northern Rockies region can cause economic impact, the influence of climate change on population outbreaks has been most studied in MPB. It is clear that multiple aspects of climate change can positively influence MPB, including increasing winter temperature (Régnière and Bentz 2007; Weed et al. 2015b) and reduced precipitation (Chapman et al. 2012). But changing thermal regimes can have both positive and negative effects on MPB population growth through phenological synchrony and generation timing. Acknowledging potential other climate effects, here we describe expected direct effects of climate change using a temperature-dependent mechanistic demographic model of MPB population growth that is based on phenological synchrony (Powell and Bentz 2009). The effect of future temperatures on univoltine population growth rate relative to historical conditions is projected. Although current climates apparently prevent MPB from successfully completing two generations in a single year (Bentz and Powell 2015; Bentz et al. 2014), we also evaluated if future thermal regimes would promote bivoltinism. The model was driven with downscaled temperatures from two global climate models (GCMs: CanEMS2, CCSM4) and two emissions scenarios (Representative Concentration Pathways RCP 4.5 and RCP 8.5) based on the multivariate adaptive constructed analogs approach (University of Idaho n.d.). Although indirect effects of climate clearly affect host tree vigor, stand composition, and distribution across a landscape, these effects are currently not included in our demographic model. We report our model results, however, in conjunction with hazard categories developed by Krist et al. (2014) based on stand conditions conducive to MPB population growth (table 8.5). Model output was considered only for locations where pines currently grow. Model projections are presented in figures 8.8 and 8.9, and tables 8.4 and 8.5, and are summarized next. See Bentz et al. (2016) for spatial displays (for the CanEMS2 GCM).

Table 8.5—Pine and mountain pine beetle (MPB) metrics by elevation category. Pine forests <6,600 ft have relatively low current hazard for MPB and low univoltine growth potential, although bivoltine potential is moderate. Pine forests >6,600 ft have relatively high current stand hazard conditions for MPB and relatively high univoltine growth potential, although bivoltine potential is zero.

	<3,300 ft	3,300–6,600 ft	6,600–10,000 ft	>10,000 ft
Current stand density pine (trees per acre [standard deviation])[a]	46.4 (58.7)	142 (206)	471 (434)	223 (223)
Proportion of area (percent) [b] rated as:				
Low hazard	97	69	30	18
Moderate hazard	2	13	14	13
High hazard	1	18	56	68
MPB potential for population success (2015–2025), based on simulation with CanEMS2 GCM, emission scenario RCP-45				
Univoltine population growth rate (R)	0.00	0.44	1.62	0.65
Bivoltine (percent of points within elevation category projected to have a thermal regime supporting bivoltinism for >50 percent of years between 2015 and 2025)	24	5	0	0
MPB potential for population success (2015–2025), based on simulation with CanEMS2 GCM, emission scenario RCP-85				
Univoltine population growth rate (R)	0.04	0.86	2.0	1.05
Bivoltine (as above)	35	7	0	0

[a] From Blackard et al. (2009).
[b] Current MPB hazard based on host stand conditions (from Krist et al. 2014).

The proportion of areas with thermal requirements for MPB bivoltinism has historically been low in the Northern Rockies region (figs. 8.8, 8.9). Stands at elevations less than 3,300 feet currently have relatively few pines and low hazard to MPB, and population growth of univoltine populations was historically very low. This is most likely because it was too warm, and adult emergence synchrony was disrupted. Growth rate is projected to decrease further in current (2000–2009) and future climates relative to historical periods (fig. 8.8). However, the proportion of simulation points at less than 3,300 feet with thermal regimes that allow for bivoltinism is projected to increase through 2100, particularly when the RCP 8.5 scenario temperature projections are used (fig. 8.8). The availability of pines at less than 3,300 feet in future climates may be restricted.

- Pine stands at 3,300 to 6,600 feet were also projected to have lower univoltine population growth rates in current and future climates than historically, and some small proportion of stands will have increasing probability of bivoltinism (fig. 8.8).
- The highest density of pine currently occurs at 6,600 to 10,000 feet, the elevation range also associated with most (56 percent) of the high-hazard stands (table 8.5). These stands are predicted to have higher univoltine population growth rates than historically, through 2030–2050. Thermal regimes for bivoltinism are unlikely at this elevation (fig. 8.8).
- Population growth rates were historically very low in stands above 10,000 feet until 2000–2009; rates are projected to increase through 2100 (fig. 8.8). These stands historically were too cool for bivoltinism and are projected to remain too cool in future climates.
- Pine forests below 6,600 feet currently have low stand hazard for MPB and low univoltine growth potential in the near future (2015–2025), although bivoltine potential is moderate. Pine forests above 6,600 feet have high current stand hazard for MPB and high univoltine growth potential between 2015 and 2025, although bivoltine potential is zero. Pine stands above 6,600 feet, particularly between 6,600 and 10,000 feet, have the highest risk of MPB-caused tree mortality in the near future.
- The Grassland subregion contains a small amount of "Great Plains ponderosa pine," and historically temperatures were too warm for univoltine MPB population success (fig. 8.9). A high proportion of locations in these areas is projected to become thermally suitable for bivoltinism (fig. 8.9), although pine occurrence in future climates may be limited.
- In the Western Rockies, Central Rockies, and Eastern Rockies subregions, univoltine population growth is projected to decrease beginning in the 2000–2009 period, although a small proportion of locations at the lowest elevations will become thermally suitable for bivoltinism by 2080–2100.
- In the Greater Yellowstone Area subregion, univoltine population growth remains relatively high until the 2080–2100 time period (fig. 8.9) with a small proportion of locations at the lowest elevations with the potential to become bivoltine at that time (fig. 8.9).

Interactions with Other Disturbance Processes

Bark beetle-caused tree mortality is influenced by and can influence fire, although the relationships are complex and dynamic (Hicke et al. 2012; Jenkins et al. 2014). In fact, any disturbance that influences the distribution and vigor of host trees will influence bark beetle outbreaks. Moreover, the pattern of bark beetle-killed trees across a landscape will have cascading effects on a myriad of abiotic and biotic processes such as fire, wildlife habitat, and vegetation succession and dynamics (Saab et al. 2014). During non-outbreak years, many bark beetle species survive in trees infected with root diseases. The amount of root disease in trees stressed by climate change may increase, which in turn can result in higher populations of bark beetles causing increased tree mortality (see *Root Disease* section).

Unknowns and Uncertainties

It is important to acknowledge sources of uncertainty in models that describe relationships among climate, bark beetle populations, and their host trees, in addition to uncertainties with projections of future climate. Mechanistic-based phenology models are good tools for projecting beetle population response in a changing climate (Bentz and Jönsson 2015). This type of model incorporates the important role of seasonality and allows for emergent population processes when driven by climate change projections. However, data are lacking on temperature-dependent relationships of most bark beetle species in the Northern Rockies, hindering development of conceptual and empirical models. Moreover, one of the greatest sources of uncertainty is the lack of understanding of potential adaptations in bark beetle developmental traits to a rapidly changing climate. With few exceptions (Addison et al. 2013, 2014), little is also known about climatic effects on the wide array of bark beetle community associates including fungi, bacteria, parasites, and predators.

Host trees will also respond to climate change, and responses will have cascading effects on bark beetle populations. Further investigation, especially in water-limited systems, is needed to increase quantitative understanding of how climate-induced changes in trees influence bark beetle population success at different spatial scales. Due to this limited understanding, predictive models that incorporate the integrated effects of climate and bark beetle disturbances on vegetation pathways are lacking, constraining our ability to make projections for future forests (Anderegg et al. 2015).

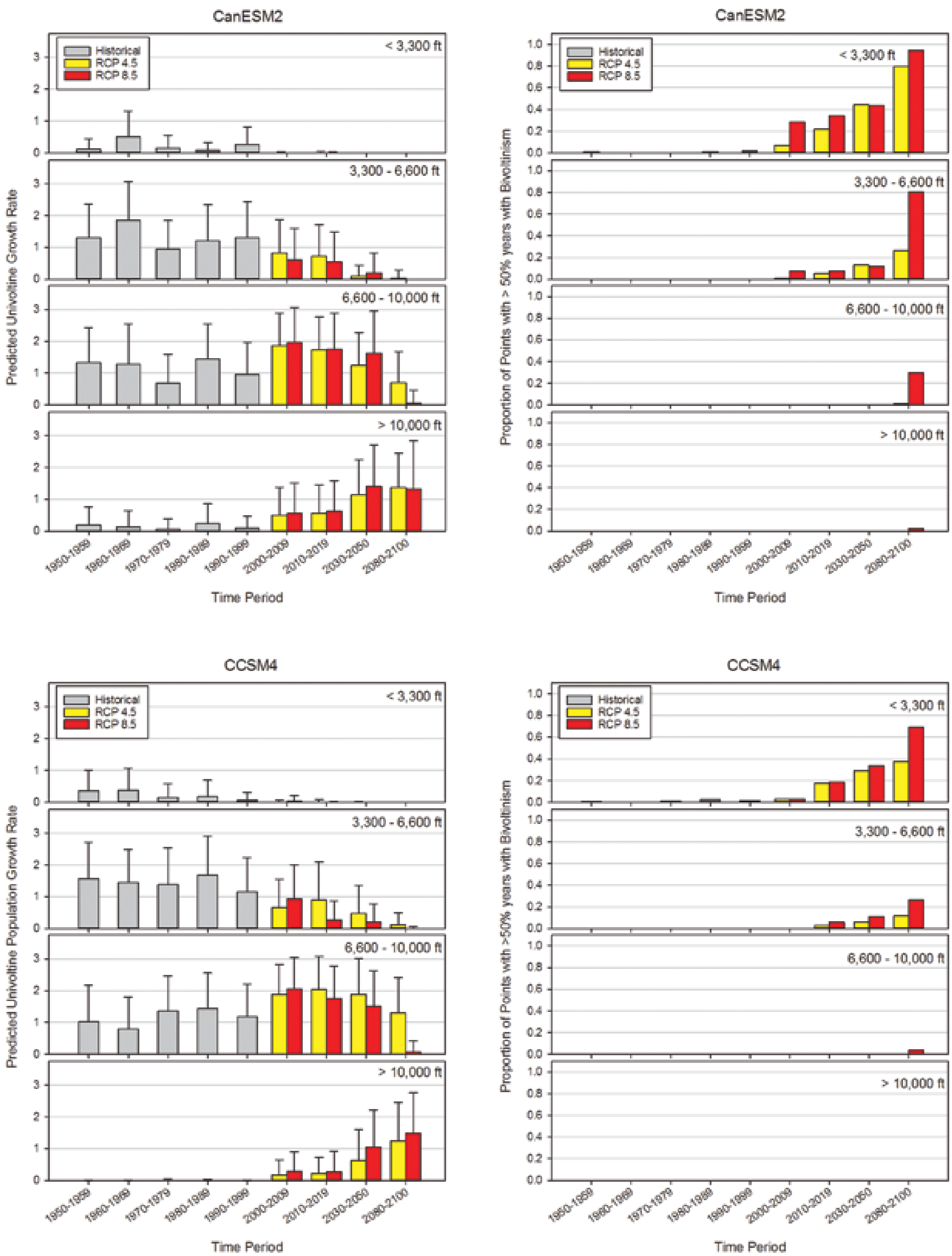

Figure 8.8—Left panel: projected mountain pine beetle (MPB) population growth rate (mean, standard deviation) of univoltine populations (one generation per year) over decades (historical) and 20-year periods (projected) from 1950 to 2100. Shown are the mean and standard deviation among locations of decadal (historic) and 2-decadal (projected) growth rates. Right panel: proportion of simulation points in which bivoltinism (two generations in one year) is projected for more than 50 percent of years in each time period. Projections are based on a temperature-dependent model of MPB development and population growth (Powell and Bentz 2009) using temperatures from the CanESM2 and CCSM4 GCMs and two emission scenarios (Representative Concentration Pathways [RCP] 4.5 and 8.5). Model output is shown by elevation category (in feet). Simulation points are geographic locations of downscaled temperatures where pines occur (sample size = 17,616).

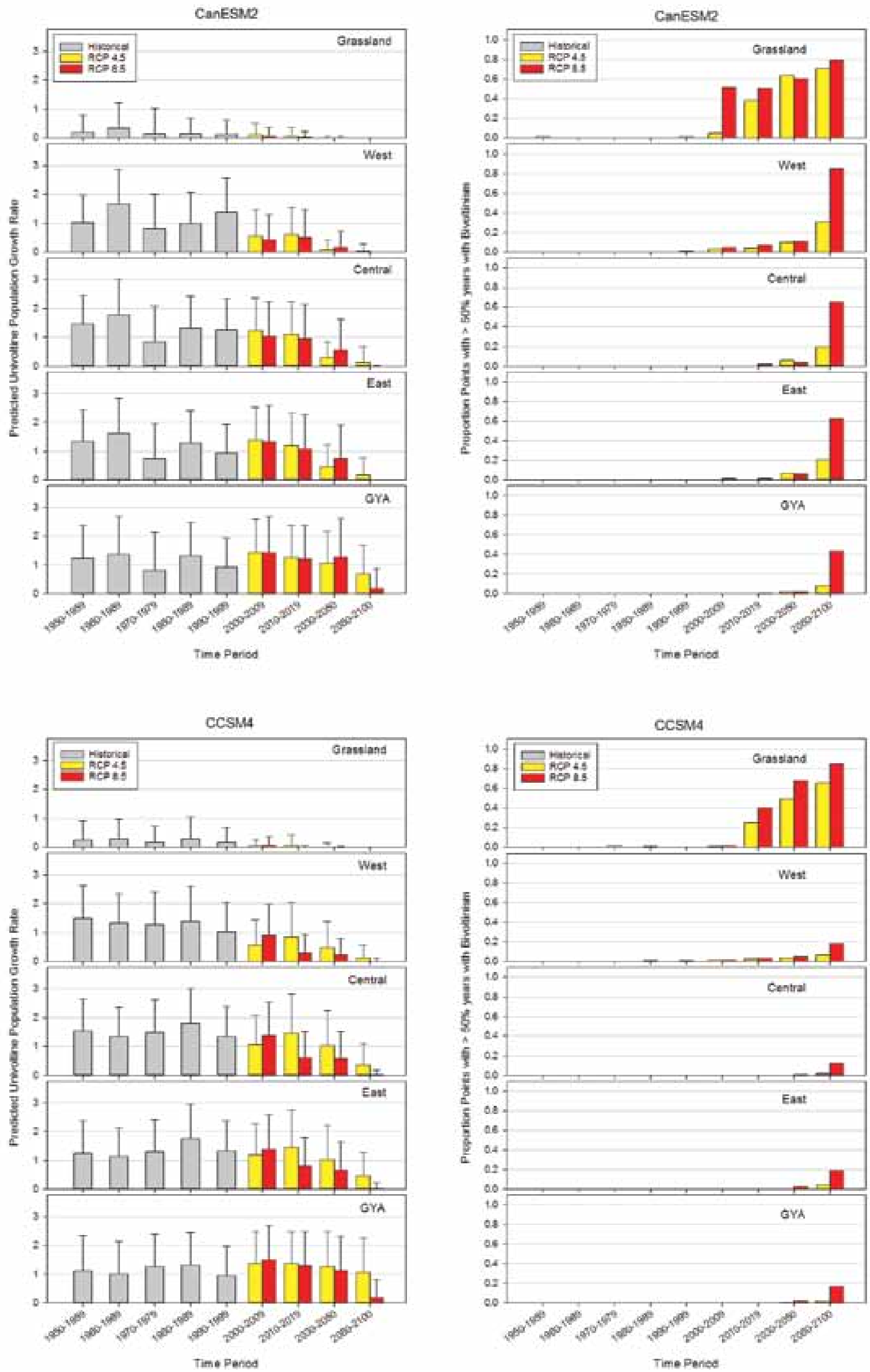

Figure 8.9—Left panel: Projected mountain pine beetle (MPB) population growth rate (mean, standard deviation) of univoltine populations (one generation per year) over decades (historical) and 20 year periods (projected) from 1950 to 2100. Shown are the mean and standard deviation among locations of decadal (historic) and 2-decadal (projected) growth rates. Right panel: proportion of simulation points where bivoltinism (i.e., two generations in one year) is projected for more than 50 percent of years in each time period. Predictions are based on a temperature-dependent model of MPB development and population growth (Powell and Bentz 2009) using temperatures from the CanESM2 and CCSM4 GCMs and two emission scenarios (RCP 4.5, RCP 8.5). Model output is shown by Northern Rockies Adaptation Partners (NRAP) subregion. Simulation points are geographic locations of downscaled temperatures where pines occur (sample size = 17,616).

White Pine Blister Rust

Overview

White pine blister rust (*Cronartium ribicola,* hereafter referred to as WPBR) is a nonnative fungus that was inadvertently introduced to western North America from Europe around 1910 (Bingham 1983; Tomback and Achuff 2011). The WPBR fungus infects only five-needle pine species, and all nine North American white pine species are susceptible. Three white pines occur in the Northern Region: western white pine (*Pinus monticola*), whitebark pine (*Pinus albicaulis*), and limber pine (*Pinus flexilis*). WPBR has been found across most of the ranges of these three pines in the Northern Region, and it has caused greater than 90-percent mortality in western white pine. WPBR presence in whitebark and limber pine is variable, but highest in the warmer, moister parts of their ranges (Tomback and Achuff 2010).

The life cycle of WPBR requires two hosts, with two spore-producing stages on white pine and three separate spore-producing stages on three potential alternate hosts: *Ribes*, *Pedicularis,* and *Castilleja* species. Pine infection begins when basidiospores produced on *Ribes* leaves in late summer are wind dispersed to nearby pines. The basidiospores germinate on pine needles and fungal hyphae grow through the stomata into the cell tissues, needles, and stem (Patton and Johnson 1970).

Cankers form on white pine branches and main stems as the phloem is first invaded by hyphae and then becomes disrupted by blister-like structures that are filled with powdery yellow aeciospores (Hudgins et al. 2005). As tree branches and stems are girdled, branches and tops die back to the canker. Continued downward growth of the persistent cankers and poor competitive ability then kill infected trees. Depending on where the canker occurs, cone production often decreases or is prevented well before tree death.

The released aeciospores infect *Ribes* and the other alternate host species (Schwandt et al. 2013). This can occur at long distances from infected pines, as aeciospores are hardy and can disperse as much as 60 miles (Frank et al. 2008). At most locations and for most alternate hosts, infected leaves produce urediniospores that spread only short distances from leaf to leaf or plant to plant (Newcomb 2003). These recurrent infections keep rust alive through the growing season until conditions are suitable for pine infection. For most alternate hosts, leaf infections produce hair-like structures (teliospores) that produce basidiospores in fall or when night temperatures are cool; other hosts with less vigorous leaf infections may produce teliospores directly. Locations where synergistic pairs of alternate hosts occur—one that readily spreads urediniospores, and one that produces pine-infecting basidiospores—are especially favorable for pine infection (Zambino 2010).

Basidiospores have a narrow weather window for production, dispersal, and successful infection of pine needles: they infect best in periods of high humidity (>98 percent) with moderate temperatures (between 60 and 68 ^{o}F) (Bega 1960). Conditions for infection are determined by temperature, with a 48-hour optimum for infection at 64 ^{o}F, though up to 5 days may be required at 39 ^{o}F (McDonald et al. 1981). Temperatures exceeding 77 ^{o}F are lethal for teliospores. Basidiospores are short-lived and most often cause infections within a few feet of *Ribes* plants, but they can be carried long distances or upslope on moist air masses, lofted in thermals over bodies of water, or carried downslope on cold air currents to infect trees at the interfaces with temperature inversions (Van Arsdel et al. 2005; Zambino 2010).

The time required for WPBR to kill its host varies by species, distance of infection from bole (Schwandt et al. 2013), and bole circumference. Typically WPBR kills western white pine in 5 to 10 years, and whitebark pines (*P. albicaulis*) after 20 years (Hoff and Hagle 1990). WPBR-caused tree mortality greatly affects stand structure and species composition, but the most serious impact of WPBR is the long-term impact on white pine regeneration capacity, with direct mortality of rust-susceptible seedlings and saplings and the loss of cone and seed production following branch dieback and top kill. Native pine populations show some heritable resistance to WPBR, but the frequency of resistance is low and variable (Zambino and McDonald 2004). Studies in the 1970s of natural stands that originated in the late 1920s estimated that fewer than 1 in 10,000 trees lacked cankers (were rust-resistant) (Hoff et al. 1980). But resistance may have increased in the 35 years since this

Table 8.6—Risk assessment for white pine blister rust.[a]

	Direction of change	Main driver(s) of change	Predicted duration of change	Likelihood of change
Infection frequency and severity	Little to moderate Increase	Possibility of increased wave years in high elevation ecosystems	Until a sufficient proportion of the landscape has populations of rust-resistant pine trees, there will always be high infections regardless of climate	Low

[a] Developed using expert opinion and information from literature as summarized in this chapter.

report, as a result of additional rounds of regeneration under natural selection (Klopfenstein et al. 2009; McDonald et al. 2004, 2005; Zambino and McDonald 2005).

Effects of Climate Change on White Pine Blister Rust

Climate changes may cause WPBR infections to occur earlier and with greater incidence in pine stands (table 8.6). Specific weather conditions required for basidiospore germination and infection of pine needles may occur more frequently and for longer periods in the future (Koteen 1999). "Wave" years are projected to increase in the future for whitebark pine (Keane et al. in press); these years have hot and humid weather conditions throughout most of the growing season that facilitate infections on pine and alternate hosts, followed by moist but cooler weather events for teliospore and basidiospore production and pine infection. For most temperate pine forests (western white and limber pine), however, Sturrock et al. (2011) speculate that wave years will actually decrease because of hotter, drier projected climates. Further, Helfer (2014) suggests that warmer temperatures could negatively affect rusts and that higher concentrations of atmospheric carbon dioxide (CO_2) could cause declines in rust populations. He also states that the highly variable and extreme weather projected in the future will aid in WPBR spore dispersal, resulting in expansion of its range and higher spore loads on existing pines.

The highly variable and novel climatic conditions projected in the future may serve to accelerate mutations of WPBR to create populations that may overcome the native rust resistance in five-needle pines (Simberloff 2000). Alternatively, changing climates may lead to suitable climates for WPBR variants that are in locations other than North America. Most rust infection and mortality occur regardless of tree condition and vigor, so it is doubtful that any direct responses of the tree or the *Ribes* hosts to future climates, such as increased growth, will enhance or degrade the ability of the host to ward off infections. However, climate-mediated changes in host regeneration dynamics could restrict or expand host ranges (Helfer 2014). As a result, this could alter WPBR range. Some predict higher leaf biomass for the two host species with warmer, enriched CO_2 environments, and more leaves could provide additional germination surfaces and a higher chance for rust infection on both hosts.

Distribution and frequency of synergistic alternate host species combinations (Zambino 2010) could also change. In higher elevation areas, new climates (i.e., warming temperatures along with high precipitation) may facilitate the expansion of *Ribes* into areas that were historically too cold and snowy to support certain hosts. On the other hand, in low-elevation upland areas where *Ribes* is currently abundant, drought may cause decline of the host. Moreover, drought may cause extended and extensive stomatal closure in the pines, thus preventing hyphae entry. The shifting of mosaics of the *Ribes* host populations into new higher elevation areas, driven by drought in lower elevations, may spread WPBR into areas where it has not yet occurred.

Interactions with Other Disturbance Processes

The interaction of fungal pathogens and their hosts with other disturbances may be a key factor in future WPBR infections (Ayres and Lombardero 2000). The interactive effects of wildland fire on WPBR are probably most important, but they are mostly minor and primarily indirect under future climates. The exception is the possibility that smoke may kill rust spores produced at the time of the fire (Hoffman et al. 2013).

White Pine Blister Rust and Wildland Fire

Fire indirectly affects WPBR by changing the size, distribution, and abundance of its hosts. Most five-needle pines of the western United States are somewhat fire-adapted with thick bark, high canopies, and deep roots (Ryan and Reinhardt 1988). Mixed- and high-severity fires are currently common in most forests where WPBR is present (Arno et al. 2000; Murray 2007) and are projected to increase in size, frequency, and intensity (Westerling et al. 2011). Increases in fires and burned areas can create favorable conditions for pine regeneration because most five-needle pine seeds are dispersed by rodents and birds and are thus better adapted to spread into postfire landscapes than seeds of their tree competitors (Lanner 1989; Morgan et al. 1994). *Ribes* populations may increase after fire through regeneration by seed and sprouting from roots and rhizomes. Therefore, fire will often favor *Ribes* regeneration over other species not adapted to fire. However, re-burns soon after an initial fire can eliminate regenerating *Ribes* individuals before they can develop a seedbank for the next forest regeneration cycle (Zambino 2010).

Severe fires that kill rust-resistant pine trees may ensure continued high rust mortality in the future because it dampens the rate of rust-resistant adaptations (Keane et al. 2012). However, where rust-resistant five-needle pines survive fire they can provide the seeds for populating future landscapes that are resilient to both rust infection and fire mortality. Fire exclusion generally increases competition stress (Heward et al. 2013), weakening pine trees. Stress from competition does not increase rust infection (Parker et al. 2006), but may facilitate mortality in pines trees under stress after being girdled by blister rust.

Trees infected with WPBR are weakened, and may be more susceptible to fire-caused damage and mortality (Stephens and Finney 2002). Ladder fuels of trees attacked or killed by WPBR may increase crowning owing to abundant pitch, which can extend from base to rust bole cankers, and from dead red crowns of girdled trees. As branches and tops of white pines die back, they add dead foliage and wood to the fuelbed, which may increase fire intensity and fire-caused tree mortality. In contrast, western white pine needles gradually added to the fuel bed are more similar to normal needle shed, and are quickly degraded in moist, productive environments. Mortality from WPBR often results in the elimination or 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; Reinhardt et al. 2010). Many shade-tolerant competitors are also more susceptible to fire damage, resulting in higher postfire tree mortality in rust-infected landscapes.

White Pine Blister Rust and Mountain Pine Beetle

Interactions between native MPB populations and WPBR are rarely studied because they are difficult to quantify over time. In their endemic phase, MPB populations may weaken pines and facilitate infection by WPBR, but these interactions are strongly governed by climate and biophysical environment (Tomback and Achuff 2011). However, the ubiquitous presence of WPBR spores and the resistance to the disease in pine species ensure that most five-needle pines at many sites will eventually become infected and die from WPBR, regardless of MPB endemic levels (Hoff et al. 2001). More importantly, MPB influences WPBR through regulation of the tree species that are host to both disturbance agents and killing of host trees that are resistant to the rust (Campbell and Antos 2000). For example, although whitebark pine stands in the Greater Yellowstone Area show little WPBR-related mortality, levels of MPB-related mortality are high (Kendall and Keane 2001; Macfarlane et al. 2013). Many stands of healthy five-needle pines in Yellowstone have been subjected to a major MPB outbreak over the last decade as a result of high densities of large diameter trees coupled with prolonged warm, dry conditions. These outbreaks resulted in substantial mortality of rust-resistant whitebark pine trees (Logan et al. 2008).

Effects of WPBR on MPB infestations are also highly variable and subtle. Archibald et al. (2013) found less MPB activity in trees that had high WPBR damage, whereas Bockino and Tinker (2012) found that whitebark pine selected as hosts for MPB had significantly higher WPBR infection, but this varied by tree size (diameter), stand type, and disturbance pattern (Larson 2011). Kulhavy et al. (1984) found that more than 90 percent of western white pine trees infected by bark beetles had either WPBR or some type of root disease, whereas Six and Adams (2007) found little evidence of interaction effects between MPB and WPBR. Simulations of MPB disturbance under current climate result in a decline in both lodgepole pine and whitebark pine, and a corresponding increase in subalpine fir (*Abies lasiocarpa*) and Douglas-fir (*Pseudotsuga menziesii*), with little change from the addition of WPBR (fig. 8.10). These trends are enhanced under a warmer climate, in which lodgepole pine declines are greater and stands are replaced primarily by Douglas-fir, but WPBR interaction has only minor effects on species composition (Keane et al. 2015).

White Pine Blister Rust, Fire, and Mountain Pine Beetle

Studies of interactions among fire, beetles, and rust are rare, but we posit that MPB and WPBR serve to reduce five-needle pine populations and create fuelbeds that may support wildfires that are more intense than historical counterparts, potentially resulting in high mortality of the dominant vegetation. Although fire reduces pine abundance in the short term, it apparently ensures the long-term persistence of pine by eliminating competitors (Keane and Morgan 1994). Modeling studies have shown that decades to centuries are required to reestablish populations of rust-resistant white pines after die-off (such as would occur with MPB), and increased frequency and extent of wildfire under climate change favored white pine regeneration and persistence over shade-tolerant species in some regions, even with WPBR infection and losses of some white pine to fire (Loehman et al. 2011a,b). The largest decline in whitebark pine has been found in those areas affected by both WPBR and MPB, but not fire (Campbell and Antos 2000).

Interactions among fire, MPB, and WPBR can occur only in areas that have the potential to support five-needle pines, which are rare in many landscapes. However, recent simulation efforts have found that fire frequency under current climate is 10 percent lower when all three disturbances are allowed to interact, and average tree mortality is also lower (fig. 8.10). In a warmer climate, fire frequency decreases, high-severity fires increase, and interactions among disturbances create different landscapes than when each disturbance acts separately (or in the absence of disturbance) (Keane et al. 2015) (fig. 8.11).

Unknowns and Uncertainties

It is difficult to mechanistically simulate WPBR population dynamics because the disease is governed by processes from fine-scale (e.g., microclimate, spore production and germination, tree size and health) to coarse-scale (e.g., spore dispersal, wind, alternate host distributions, topographic controls) processes. Therefore, the representation of WPBR in most models will tend to be both stochastic and empirical, and this will tend to reduce the robustness of model predictions and add to the uncertainty of future WPBR predictions.

White pine trees will also directly respond to climate change, and responses will have interacting effects on WPBR infection potential. The key to the future abundance of white pines on the Northern Rocky Mountain landscapes will hinge on the ability of the three pine species to develop rust-resistant populations that are resilient to climate change. This probably will not happen without human intervention. The rapid pace of predicted climate change coupled with the

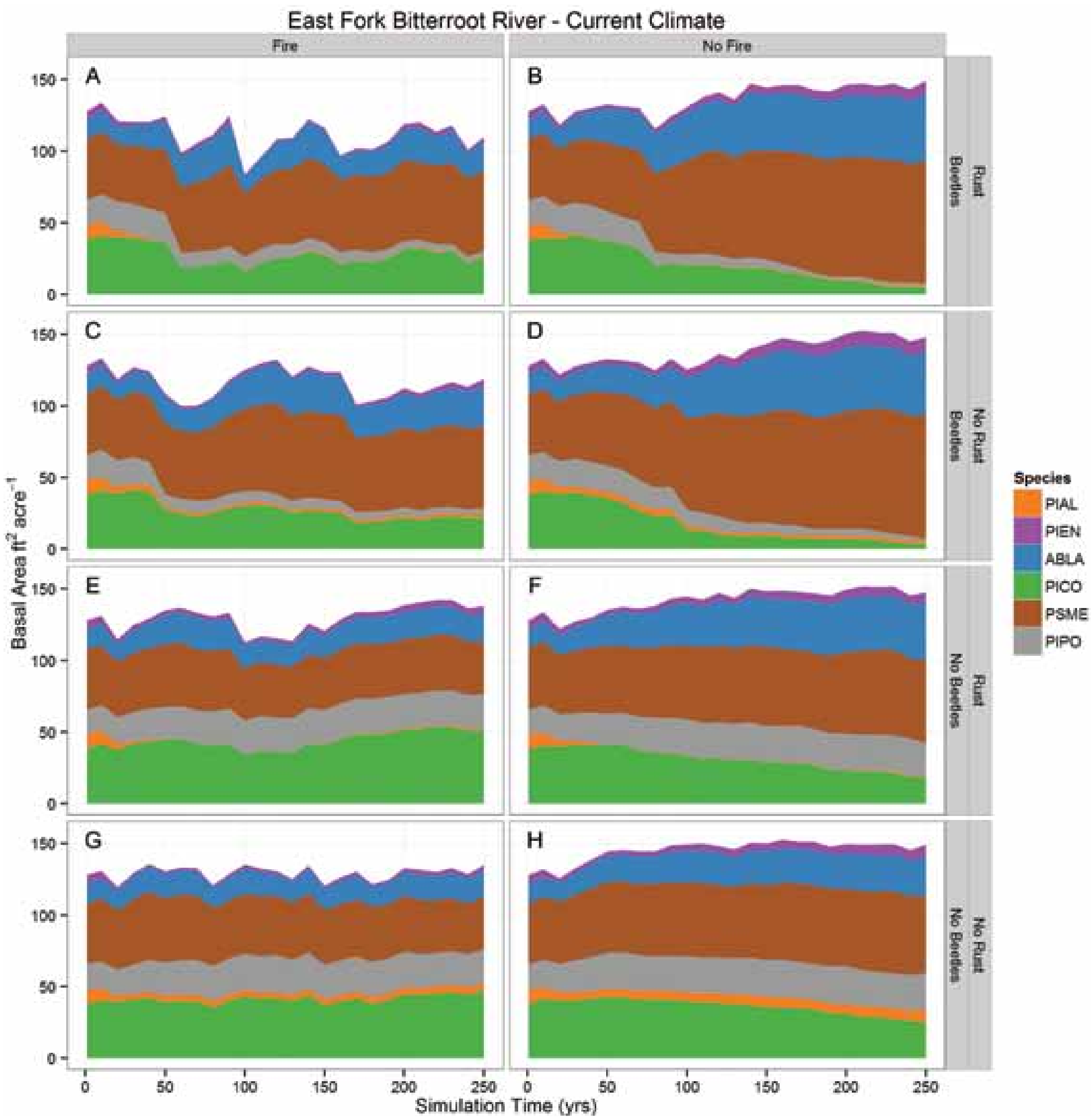

Figure 8.10—Landscape composition of species cover types using the plurality of basal area for current climate for the East Fork of the Bitterroot River landscape with all combinations of fire, white pine blister rust (WPBR), and mountain pine beetle (MPB): (a) fire, WPBR, and MPB; (b) no fire, WPBR, MPB; (c) fire and MPB; (d) MPB only; (e) fire and WPBR; (f) WPBR only; (g) fire only; and (h) no disturbances. Species: PIAL-whitebark pine, PIEN-Engelmann spruce, ABLA = subalpine fir, PICO-lodgepole pine, PSME-Douglas-fir, and PIPO-ponderosa pine. Produced using the FireBGCv2 mechanistic ecosystem-fire process model (Keane et al. 2015).

long maturation times of the three pine species may exacerbate the species decline. It is essential that natural resistance is fostered by land management agencies to ensure that these valuable species and the forests that they create are not lost forever.

Forest Diseases

Overview

Forest diseases are found in all forest ecosystems of the Northern Rockies region. They are one of three major disturbance groups that affect ecosystem development and change, but the overall impacts of forest diseases on various resources are difficult to quantify. This is partly due to our inability to separate predisposing effects of some of the most important diseases, which act over a long term, from mortality caused by short-term factors such as insect outbreaks and drought. Forest diseases tend to be more cryptic and chronic in their effects, so estimating their occurrence and abundance is difficult. Here we rely mostly on older studies and observations to quantify disease effects in what were formerly called commercial timberlands. Spatial distributions of most forest diseases have not changed much, although the effects of individual diseases may change due

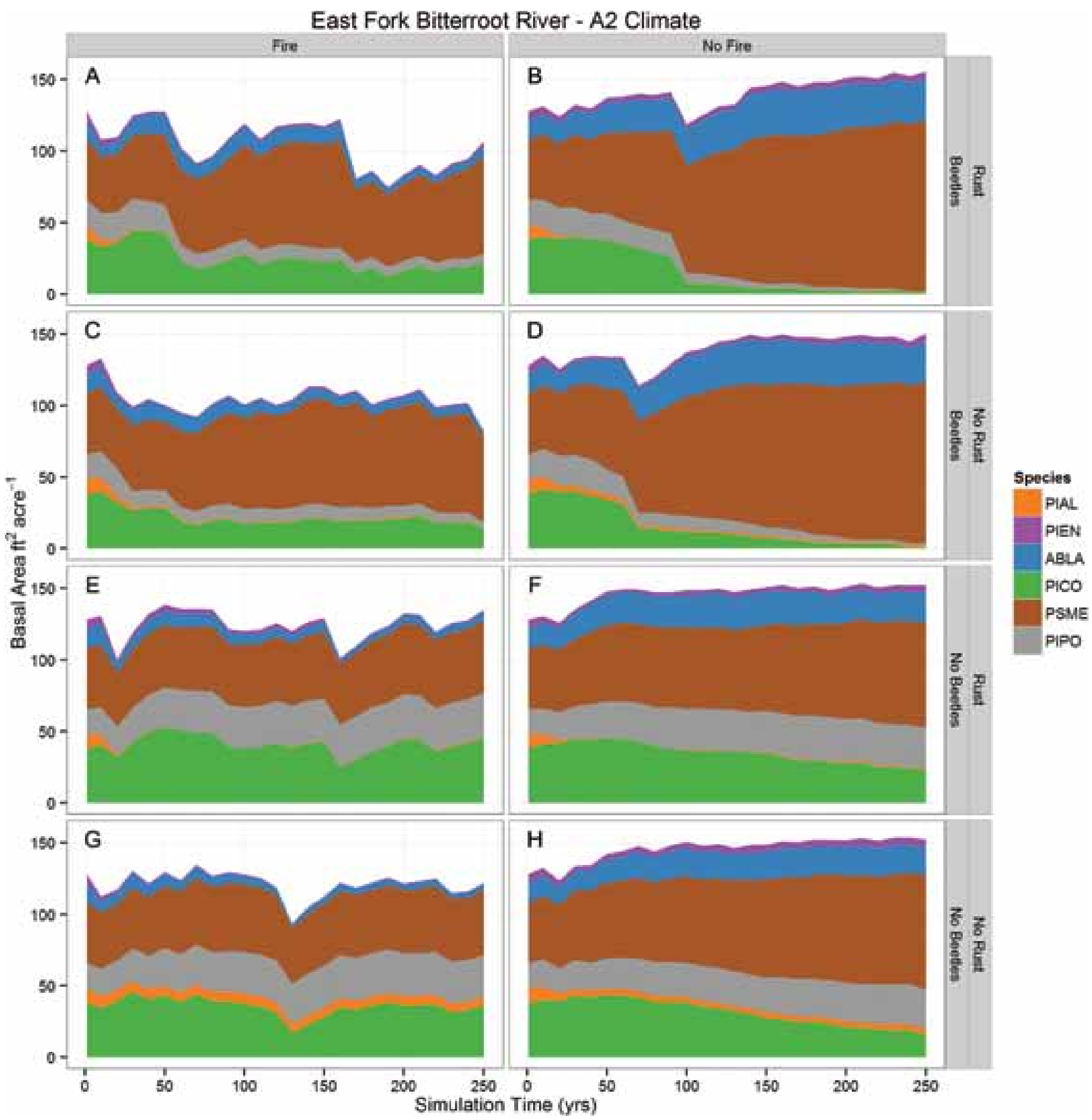

Figure 8.11—Landscape composition of species cover types using the plurality of basal area for a warmer climate (A2 emission scenario) for the East Fork of the Bitterroot River landscape with all combinations of fire, white pine blister rust (WPBR), and mountain pine beetle (MPB): (a) fire, WPBR, and MPB; (b) no fire, WPBR, MPB; (c) fire and MPB; (d) MPB only; (e) fire and WPBR; (f) WPBR only; (g) fire only; and (h) no disturbances. Species: PIAL = whitebark pine, PIEN = Engelmann spruce, ABLA = subalpine fir, PICO = lodgepole pine, PSME = Douglas-fir, and PIPO = ponderosa pine. Produced using the FireBGCv2 mechanistic ecosystem-fire process model (Keane et al. 2015).

to effects of climate on disease organisms, hosts, and environmental predisposition.

We focus on the major groups of forest diseases in the Northern Rockies known to have significant effects on ecosystems and ecosystem services, and for which at least some information is available on effects of climate.

Dwarf Mistletoe

Dwarf mistletoes (*Arceuthobium* spp.) are a group of parasitic seed plants that are widespread across the Northern Rockies region and primarily cause reduced tree growth and productivity, but in some cases also cause tree mortality. Five species of dwarf mistletoe are found in the region, mostly on these primary hosts: *A. americanum* on lodgepole pine, *A. campylopodum* on ponderosa pine, *A. cyanocarpum* on limber pine, *A. douglasii* on Douglas-fir, and *A. laricis* on western larch (*Larix occidentalis*). Mistletoes may occasionally infect trees of other species when they are growing interspersed with infected primary hosts.

Approximately 28 percent of lodgepole pine forest is infested by *A. americanum*. *Arceuthobium cyanocarpum* occurs primarily east of the Continental Divide, although the area affected has not been estimated. Douglas-fir is infested in more than 13 percent of its range by *A. douglasii*. About 38 percent of the western larch type is infested by *A. laricis*. The distribution of *A. campylopodum* in the region is limited to a portion of Idaho, where it occurs on ponderosa pine. Drummond (1982) estimated that 2.1 million acres of national forest lands were infested by the three most important species of dwarf mistletoe in the Northern Rockies. An estimated 31 million cubic feet of wood are destroyed by these pathogens each year.

Root Disease

Root disease is a major cause of tree growth loss and mortality in the Northern Rockies region. These diseases are primarily a problem west of the Continental Divide, but also affect local areas east of the divide. Various species of fungi cause root disease; the two most important native pathogens in the Northern Rockies region are *Armillaria* species and *Heterobasidion irregulare,* which causes annosus root diseases. These and other root diseases co-occur in many mesic to moist forests west of the divide. Armillaria root disease kills conifers of all species when they are young, but is especially damaging to Douglas-fir, subalpine fir, and grand fir (*Abies grandis*) because these species remain susceptible throughout their lives (Kile et al. 1991). In addition, root diseases often affect canopy closure and create small gaps. The effects of these root pathogens are persistent on a site and have impacts on multiple generations of trees. Armillaria and other root diseases influence forest species composition, structure, and successional trajectories by accelerating a transition to species that are more tolerant of root disease or by maintaining stands of more susceptible species in early-seral stages (Byler and Hagle 2000). They can also affect ecosystem services by affecting visual and recreational resources.

At least 3.3 million acres in the Northern Rockies have moderate to severe root disease, with up to 60 percent caused by *Armillaria ostoyae* (Smith 1984; USDA FS 2007). A recent evaluation of USFS Forest Inventory and Analysis data in the Northern Region identified 2.3 million acres of national forest lands with moderate to severe root disease (Lockman et al., in preparation). Shrub fields have replaced forest cover on 3 percent of forest lands in Idaho and Montana as a result of severe root disease. A study of Ecosection M333d (Bailey 1983), which includes the southern Idaho Panhandle National Forest and southern Kootenai National Forest, found evidence of root disease on 94 percent of the area (Byler and Hagle 2000). Root disease has reduced forest canopy cover in affected stands in northern Idaho and western Montana by an average of 20 to 30 percent.

The National Insect and Disease Forest Risk Assessment (Krist et al. 2014) identified locations where significant tree mortality and basal area losses from insects and diseases could occur between 2013 and 2027, modeling the potential for damage in standing live basal area across all ownerships from a variety of insects and pathogens. Root disease had the highest basal area loss as a percentage of total basal area; projected losses ranging from 0 to 20 percent in most national forests.

Needle Disease

Needle diseases have historically been of limited significance in the Northern Rockies region; 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 casts usually cause loss of needles in the year following a season that has been favorable for infection. In western larch, needle cast and needle blight are observed in the year of infection.

Needle casts and needle blights in lodgepole pine, ponderosa pine, western white pine, Douglas-fir, grand fir, and western larch generally cause little damage in the Northern Rockies region, although periodic outbreaks can cause severe damage in local areas (Lockman and Hartless 2008). These diseases are favored by long, mild, damp springs. Their occurrence at epidemic levels depends on favorable weather conditions and presence of an adequate host population.

Abiotic Disease

Most abiotic diseases result from the effects of adverse environmental factors on tree physiology or structure. This group of diseases can affect trees directly or interact with biotic agents, including pathogens and insects. A number of abiotic and environmental factors can affect foliage or individual branches, or entire trees, tree physiology, and overall tree vigor. The most significant abiotic damage is tree mortality.

Forests in the Northern Rockies region are periodically damaged by weather extremes, such as temperature and drought. Factors such as air pollutants and nutrient extremes occur infrequently or locally. An injury known as “red belt,” caused by strong, dry, warm Chinook winds in winter that induce twig and needle necrosis and desiccation, often afflicts conifers on the east side of the Continental Divide, primarily Douglas-fir and lodgepole pine (Bella and Navratil 1987). 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. A well-studied decline of western white pine called pole blight occurred in the Northern Rockies in the 1930s and 1940s (Leaphart and Stage 1971). This disease occurred on pole-size trees, often in plantations that were growing on shallow soils with low moisture storage capacity that were exposed to extended drought.

Canker Disease

Canker diseases affect tree branches and boles, typically in trees that are poorly adapted to the sites in which they are growing. Damage is caused by breakage at the site of the cankers, or by mortality of branches and boles beyond girdling cankers. Although canker fungi are most active on trees under stress, lack of specific data on climate effects makes it difficult to infer the effects of climate change.

Broad-Scale Climate Drivers of Forest Diseases

Climatic variability and change can alter patterns of pathogen distribution and abundance through (1) direct effects on development and survival of a pathogen, (2) physiological changes in tree defenses, and (3) indirect effects on abundance of natural enemies, mutualists, and competitors (Ayres and Lombardero 2000). Sturrock et al. (2011) suggest that climate change will affect pathogens, hosts, and their interaction; changes in these interactions may become the most substantial drivers of future disease outbreaks.

Fungi cause most forest diseases in the Northern Rockies region. Fungus life cycles are significantly influenced by climate-related factors such as timing and duration of precipitation, humidity, and temperature for spore germination, fungus growth, and inactivation. Fungus life cycles are short compared to their hosts, so fungi can respond more rapidly to a changing climate than their hosts, with potentially serious consequences (Boland et al. 2004). Dwarf mistletoe reproduction and infection are also affected by temperature and moisture (Hawksworth and Wiens 1996), and dwarf mistletoes are generally most prevalent in sites that have undergone past disturbances.

Overall health of host trees has a major role in determining if a pathogen successfully infects a tree or kills it. Many forest diseases, such as canker diseases, are caused by "facultative pathogens" that attack weakened hosts under specific environmental conditions. Impacts of climate change on host physiology may modify host resistance and alter stages and rates of development of pathogens (Coakley et al. 1999). Drought, or limited soil moisture availability, is a major driver that affects the incidence and severity of facultative pathogens. Soil moisture deficit, flooding, and water table fluctuation can all predispose trees to pathogens. Even if there are areas that may have a net gain in precipitation, projected longer growing seasons could cause recurring water deficit stress. Some diseases may be considered threshold diseases; that is, they are damaging but only under certain climatic conditions (Hepting 1963). These diseases may become more damaging if thresholds that trigger infections are reached more frequently, such as in recurring drought.

Effects of Climate Change on Forest Diseases

One of the difficulties of predicting sensitivity to a changing climate is that the scales available for GCMs, pathogen/disease models, and microsite environments do not always match (Seem 2004). For example, some GCM projections provide only mean monthly and annual estimates, rather than daily data useful for modeling forest diseases. In addition, pathogen ecology and effects are sensitive to local site and environmental conditions that may not be well represented by GCMs. There is also considerable uncertainty and lack of knowledge of impacts of a changing climate on future forest conditions and interactions with pathogens (Woods et al. 2005, 2010). Compared to trees, for which available soil moisture is critical, pathogens are affected more by precipitation events, especially timing, duration, and pattern, all of which are poorly projected by climate models. Facultative pathogens respond to weakened or less vigorous hosts, and their importance could increase if climatic conditions less favorable to tree growth become more frequent.

A changing climate will affect forest disease occurrence and severity, through effects on the pathogen, the host, or their interaction (Sturrock et al. 2011) (table 8.7). Interactions between pathogens and abiotic stressors (e.g., temperature and moisture) may represent the most substantial drivers of increased disease outbreaks (Sturrock 2012). Epidemics also depend on relatively constrained conditions for spread and infection to occur. For example, increased drought could affect host susceptibility to pathogens and predispose hosts to disease outbreaks (Coakley et al. 1999). Although models usually generate mean climatic conditions, it is often the extremes that have the greatest influence on pest conditions (Hepting 1963). Increased host stress

Table 8.7—Risk assessment for forest diseases.[a]

Pathogen component	Direction of change	Main driver(s) of change	Projected duration of change	Likelihood of change
Needle disease	Significant increase if appropriate precipitation timing occurs	Increased precipitation in spring and early summer	May occur sporadically in association with weather events	High
Root disease	Little change	Host stress	While hosts are maladapted	Moderate
Dwarf mistletoe	Could decrease mistletoe populations	Temperature could influence flowering and seed production/dispersal	Unknown	Low
Abiotic disease	Significant increase	Temperature and decreased precipitation	Unknown	High

[a] Developed using expert opinion and information from literature as summarized in this chapter.

could result in increased disease occurrence and interactions among multiple agents (Coakley et al. 1999). There is likely to be an increase in declines and dieback syndromes (Manion 1991) caused by changes in disease patterns involving a variety of diseases.

A changing climate may indirectly affect competitors, antagonists, and mutualists that interact with plant pathogens (Kliejunas et al. 2009). Some of the most profound effects of temperature and moisture changes could be on soil microflora, and on and in roots and shoots, where a complex of organisms live in relationships at the transition between pathogenesis, symbiosis, and saprogenesis. The balance among organisms could be upset, for example, turning a normal mycorrhizal association to pathogenesis, shifting pathogens from saprogenic to pathogenic phases, or shifting the order of ascendency of competing organisms due to their different temperature or moisture optima; consequently a pathogen might even take dominance from a saprophyte (Hepting 1963). Given that root pathogens of trees can often exploit a large food reserve in a tree once a defense is breached and then use those reserves to bolster attacks on nearby trees, even small changes in the frequency of shifts in relationships among fungal communities could have large effects.

Despite considerable knowledge about climatic conditions required by specific forest pathogens, little has been done to determine how changing climates may affect these pathogens (Kliejunas et al. 2009). Recent modeling work by Klopfenstein et al. (2009) used a subset of GCMs to project how the geographic distribution of the climate envelope for *Armillaria solidipes* and Douglas-fir could change in the interior northwestern United States. Their analysis suggests that Douglas-fir will have a considerably smaller geographic space that matches its current climate envelope and that this space will shift, whereas only minor changes are projected for *A. solidipes*. They suggest that areas where Douglas-fir is maladapted could increase, which could increase its susceptibility to Armillaria root disease.

Klopfenstein et al. (2009) used information for climatic variables based on the current distribution of *A. solidipes* on its Douglas-fir host in a network of plots. Climate space for *A. solidipes* modeled for current and 2060 climate are shown in figure 8.12. These preliminary projections are not necessarily the current or future distribution of *A. solidipes*, but identify only the modeled climate space matching where the pathogen currently occurs. It is unknown how the climate envelope could change because the distribution of competitor fungi and hosts will change as well.

Spring precipitation is projected to increase in most of the mountainous area of the Northern Rockies (see Chapter 3). This may increase frequency and severity of years when needle diseases cause significant needle loss in conifer species. This could affect the energy balance of susceptible trees, with potential effects on yield and vigor, particularly for species that normally carry multiple years of needles and cannot re-flush later in the season in response to defoliation.

There may be elevation and location maladaptation in resistance to the increased needle disease pressure resulting from climate change, as areas of tree host ranges and disease occurrences shift in location. Lophodermella needle cast in lodgepole pine (caused by *Lophodermella concolor*) occurred in northern Idaho in the early 1980s (Hoff 1985), and has also had outbreaks at high elevation in some Idaho locations in recent years. Lodgepole pine at high elevation normally has only infrequent outbreaks because bud break occurs near or after the time when spring rains that favor infection have ended, whereas needles in lower elevation trees expand when spores are present and able to infect. A provenance study under natural conditions during the outbreak in the 1980s showed that low elevation populations were generally more resistant and had heritable resistance, but high elevation populations were susceptible. About 6

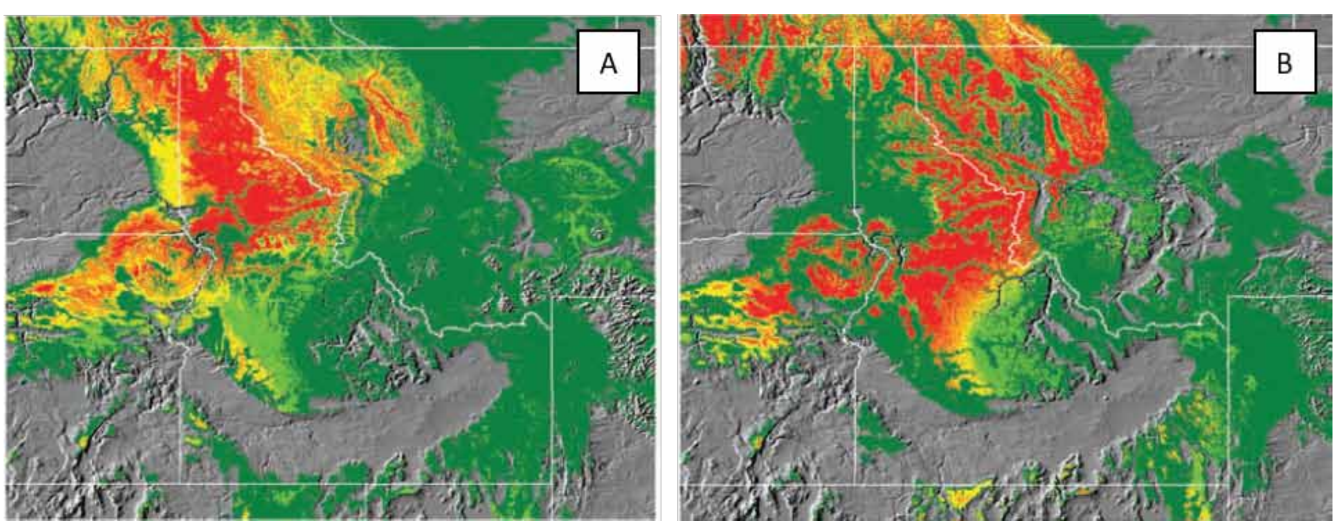

Figure 8.12—Modeled (a) current and (b) future (year 2060) climate space for *Armillaria solidipes* (Klopfenstein et al. 2009). Colors represent the probability of occurrence. Yellow = moderate, red = high.

percent of trees in this mixed provenance planting showed no infection, but 5 percent had almost complete defoliation. If moist conditions following bud break continue to occur at high elevation where natural selection for resistance has not occurred, recurrent needle disease outbreaks could stress trees and make lodgepole pine more susceptible to other factors (Hoff 1985).

Another example of a needle disease that may increase in the Northern Rockies region under climate change is Swiss needle cast (caused by *Phaeocryptopus gaeumannii*). This disease severely limits productivity of Douglas-fir west of the Cascade divide in Oregon and Washington, causing growth losses of up to 50 percent (Manter et al. 2005). Needle loss is very highly correlated with increasing winter temperatures and spring needle wetness. The disease, which is expected to become more severe in forests west of the Cascade crest in a warmer climate (Stone et al. 2008), has periods of local occurrence in northern Idaho (Navratil and Bella 1988) and Montana (Weir 1917). Milder winters and wetter springs that could increase the future distributions and severity of the disease might occur, but as yet, investigations and modeling have not been conducted to map and quantify potential effects.

Kliejunas (2011) performed a qualitative risk assessment of the effect of projected climate change on a number of forest diseases, several of which occur in the Northern Rockies. Dothistroma needle blight (caused by *Dothistroma septosporum*) provides a good example of potential effects of climate change. Kliejunas (2011) estimates that the risk potential is low if a warmer and drier climate occurs. A warmer and wetter climate could increase the risk potential to moderate. His assessment of the effect of climate change on dwarf mistletoes indicated a high risk potential regardless of precipitation levels because dwarf mistletoe survival and infection increases with temperature. His assessment of Armillaria root disease indicated a high to very high risk potential depending on moisture availability, with drier conditions increasing the potential.

Forest Pathogen Interactions

Direct effects of fire on pathogens are generally minimal. Fire directly and indirectly influences distribution, severity, and persistence of forest diseases; similarly, forest diseases influence fire behavior and severity. Diseases are generally host-specific, so removal of susceptible tree species by fire will usually reduce disease, whereas improving habitat for susceptible tree species will usually increase disease over time.

Forest pathogens are directly damaged by smoke and heat of fires. Smoke can inhibit dwarf mistletoe seed germination (Zimmerman and Laven 1987), and heat from fire can kill pathogens that cause root disease in the top 3 inches of soil (Filip and Yang-Erve 1997). Forest diseases are affected more by tree mortality from fire. Frequency and intensity of fire can affect persistence, as well as distribution and severity of certain diseases. High-intensity fires can completely remove a pathogen with its host, as with lodgepole pine-dwarf mistletoe (Kipfmueller and Baker 1998; Zimmerman et al. 1990), or remove species susceptible to root disease and prepare the site for regeneration of less susceptible seral species, such as pines and western larch (Hagle et al. 2000). Low-intensity fires often leave mosaics of pathogens along with their susceptible hosts, which can cause substantial increases of diseases such as dwarf mistletoe (Kipfmueller and Baker 1998). However, low-intensity fires in some habitats maintain species tolerant of root disease such as western larch (Hagle et al. 2000).

Human-caused fire exclusion has led to an increase in root disease and dwarf mistletoe (Hagle et al. 2000; Rippy et al. 2005), which can influence fire behavior and severity. Root disease creates pockets of mortality and scattered mortality; the resulting standing and down woody debris increases fuel loading, especially large fuels (Fields 2003). Increased litter accumulation and resinous witches' brooms from dwarf mistletoe infections can provide ladder fuels that may cause a ground fire to move into the canopy (Geils et al. 2002).

Climate effects that increase frequency or intensity of fires may affect incidence and severity of dwarf mistletoes (Zimmerman and Laven 1985). Fire affects dwarf mistletoes by changing canopy structure and stand density (Alexander and Hawksworth 1975; Dowding 1929); eliminating lower branches, which may have the heaviest infections and mistletoe seed production; thinning stem density, which may reduce lateral spread; and causing mistletoe shoots to abscise. Loss of shoots eliminates some infections directly, but even if infections remain within the bark, loss of shoots prevents seed production for several years, slowing mistletoe intensification within stands. Trees heavily infested with mistletoe often retain low infected branches and are prone to torching in fire, which could increase the risk of crown fire (Conklin and Geils 2008). Alternatively, torching in individual trees could eliminate the most heavily infected sources of mistletoe seed that infect understory regeneration.

An increase in severe weather events or fires could increase occurrence of other diseases. For example, root and bole wounds could be used as "infection courts" for root disease, and such wounds from management, windfalls, and fire are major avenues of infection for true firs and western hemlock (Smith 1989) and lodgepole pine (Littke and Gara 1986). Fire damage and other stresses can release root disease infections that have been walled off by host resistance responses (Hagle and Filip 2010). Relative importance of different root diseases could be altered under some climate change scenarios. Except as a sapling, western larch is considered resistant to Armillaria root disease due to its ability to generate multiple corky barriers at infection sites (Robinson and Morrison 2001). The response of this species to wounds and the thick bark that it generates also make it among the most resistant to fire damage, and a species more likely to persist and regenerate under increased fire frequency.

Illustrating interactions between bark beetles and disease, a study in lodgepole pine forests of central Oregon showed that altered stand structure following an MPB epidemic increases dwarf mistletoe in lodgepole pine stands, thereby reducing stand growth and productivity and slowing stand recovery (Agne et al. 2014). The influence of dwarf mistletoe on stand structure heterogeneity could increase landscape resistance and resilience to disturbances. Another example of complex interrelationships is the interaction between stem decay, bark beetles, and fire frequency in central Oregon lodgepole pine. After fire damaged the roots of lodgepole pines, stem decay fungi infected these damaged roots and over time caused extensive heartwood decay in the boles of these trees. Data show these decay-infected trees grew at a slower rate than uninfected trees and trees with stem decay were preferentially attacked by MPB years later (Littke and Gara 1986).

Nonnative Plants

Overview

Projecting how nonnative plants and climate change may interact to alter native plant communities, ecosystems, and the services they provide is challenging because of our limited ability to project how climate change will alter specific local abiotic conditions that define the fundamental niches of plants (Gurevitch et al. 2011; Thuiller et al. 2008). We start with knowledge of structure and function of current ecosystems, and then apply first principles of ecology to explore how climate change might alter these systems, their susceptibility to invasion, and invasiveness of introduced plants from a general perspective. We do not project changes in individual plant species, but define the parameters that bound potential community change based on climate projections and discuss how community invasibility might be affected across that range of potential conditions.

Effects of Climate Change on Nonnative Species

Hundreds of nonnative species have been introduced into the Northern Rockies region (Rice n.d.). Not all of these species are abundant, but recent surveys showed that nonnative plants account for an average of 40 percent of species present (richness), and 25 percent of those nonnatives have significant effects on native grassland flora (Ortega and Pearson 2005; Pearson et al. in review). Invasive plant species represent a threat to ecosystem integrity because they compete with native species in many plant communities and can alter ecological processes. These negative impacts can reduce biological diversity, forage for wildlife, and recreation opportunities. Most nonnative invasive species are herbaceous species (graminoids and forbs), but some are shrub and tree species that commonly occur in riparian areas (e.g., Russian olive [*Elaeagnus angustifolia*], tamarisk [*Tamarix ramosissima*]).

Although extensive work has been done to understand the biology of some of the most common nonnatives, such information is far from complete. Few studies have explored how changes in temperature and moisture related to climate change may affect nonnative plant populations in the Northern Rockies region.

It has historically been assumed that climate change will favor nonnative plants over native species (Dukes and Mooney 1999; Thuiller et al. 2008; Vila et al. 2007; Walther et al. 2009), but this may be an overgeneralization (Bradley et al. 2009, 2010; Ortega et al. 2012). Numerous attributes associated with successful invaders suggest nonnative species could flourish under certain climate change scenarios. For example, many nonnative plants are fast-growing early-seral species (ruderals) that tend to respond favorably to increased availability of resources, including temperature, water, sunlight, and CO_2 (Milchunas and Lauenroth 1995; Smith et al. 2000; Walther et al. 2009). Extensive work shows that nonnative species respond favorably to disturbance (Zouhar et al. 2008), which can increase resource availability (Davis et al. 2000). Nonnative species may also exploit the disturbances associated with postfire conditions better than many native species (Zouhar et al. 2008), despite the adaptations of native plants to fire. In bunchgrass communities, many nonnative plants recruit more strongly 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, both of which can allow them to migrate more quickly than slow-growing and slowly dispersed species (Clements and Ditommaso 2011). Greater plasticity of successful invaders could also favor their survival in place and ability to expand their populations (Clements and Ditommaso 2011). Collectively, these attributes suggest that many nonnative species would benefit if climate change results in increased disturbance.

Few studies have manipulated CO_2, moisture, or temperature to quantify the effects of climate change on nonnative versus native plants in the Northern Rockies region. Of the work that does exist, most has targeted grassland and sagebrush communities, presumably because these are among the most susceptible to invasion (Forcella 1992; see also Chapter 7). Experimentally increasing temperatures in a Colorado meadow system resulted in increases in native upland shrubs, with big sagebrush (*Artemisia tridentata*) increasing in drier conditions and shrubby cinquefoil (*Dasiphora fruticosa*) in wetter conditions (Harte and Shaw 1995). These different responses indicate the importance of background moisture in driving species-specific responses to elevated temperatures.

Recent experimental work in western Montana showed that reduced precipitation can significantly impact spotted knapweed (*Centaurea melitensis*), whereas native bluebunch wheatgrass (*Pseudoroegneria spicata*) populations were unaffected by the same drought stress (Ortega et al. 2012; Pearson et al., unpublished data). This result is consistent with historical observations of spotted knapweed declines following drought conditions (Pearson and Fletcher 2008). In Wyoming sagebrush-steppe systems,

Table 8.8—Prominent nonnative species in the Northern Rockies and their primary habitats.

Species	Habitat
Cheatgrass (*Bromus tectorum*)	Xeric shrublands and grasslands
Spotted knapweed (*Centaurea maculosa*)	Xeric shrublands and grasslands, dry forest openings
Rush skeletonweed (*Chondrilla juncea*)	Xeric shrublands and grasslands
Canada thistle (*Cirsium arvense*)	Wetland/riparian areas, disturbed sites in moist grasslands
Houndstongue (*Cynoglossum officinale*)	Highly disturbed mesic and xeric grasslands, roadsides
Leafy spurge (*Euphorbia esula*)	Riparian areas, mesic and xeric grasslands
Orange hawkweed (*Hieracium aurantiacum*)	Forest openings, moist meadows, roadsides
Yellow hawkweed complex (*Hieracium* spp.)	Forest openings, roadsides
St. Johnswort (*Hypericum perforatum*)	Xeric grasslands and shrublands
Dalmatian toadflax (*Linaria dalmatica*)	Xeric grasslands and shrublands
Yellow toadflax (*Linaria vulgaris*)	Mesic to xeric grasslands and shrublands, burned areas
Sulfur cinquefoil (*Potentilla recta*)	Xeric grasslands and shrublands
Common tansy (*Tanacetum vulgare*)	Riparian areas

bluebunch wheatgrass outperformed both cheatgrass and medusahead (*Taeniatherum caput-medusae*) in dry years, but the opposite was true in wet years (Mangla et al. 2011). Community-level studies in other grasslands have shown that drought periods can shift vegetation away from annual grasses and forbs and toward drought-tolerant native perennial grasses (Tilman and El Haddi 1992). Hence, heating and drying could favor drought-tolerant native species in dry grassland and sagebrush systems and reduce their susceptibility to invasion by nonnative species (see Chapter 7). However, these conditions might increase susceptibility of native vegetation to invasive species in wetter locations.

Xeric Grasslands and Shrublands

Of the many dominant cover types that occur in the Northern Rockies region, the most vulnerable to weed invasion are typically those on warm, dry (xeric) sites, although riparian and wetland sites can be invaded by several invasive plant species. The most susceptible plant communities tend to have low vegetation cover, high bare ground, and unproductive soils; various nonnative plant species exploit these more open sites. However, disturbances resulting from fire or vegetation management can provide opportunities for invasion in most kinds of dominant vegetation. Hundreds of nonnative plant species occur in the Northern Rockies, the most serious of which are described in table 8.8.

Xeric grasslands and shrublands are highly vulnerable to establishment of nonnative species (see Chapter 7). Many of the native plants in Northern Rockies grasslands are perennials that tolerate environmental variability over long time scales in contrast with the life history strategies of weedy invasive species (Grime 1977; MacArthur and Wilson 1967). Whether native or nonnative species benefit, or more specifically, which native or nonnative species benefit, will probably depend on the specific ways in which climate change plays out.

If temperature increases but precipitation does not, this will likely reduce resource availability and increase stress, potentially favoring nonnative species. Projections of the effects of climate change need to consider how nonnative plants respond, as well as how recipient communities and their invasibility may change. Many successful nonnative species flower later and have different phenologies from native species, allowing nonnative species to potentially exploit an empty niche (Pearson et al. 2012). Therefore, nonnative species may increase if this niche expands with climate change, or decline if the niche is disrupted.

Invasive species primarily spread into disturbed areas with sufficient bare ground and sunlight for germination and establishment, although some species such as spotted knapweed, houndstongue (*Cynoglossum officinale*), yellow sweet clover (*Melilotus officinalis*), and yellow toadflax (*Linaria vulgaris*) can readily establish in undisturbed plant communities. Nonforested landscapes (e.g., shrublands, grasslands) have been invaded in many areas of the Northern Rockies region (see Chapter 7). As fires and other disturbances increase in intensity and frequency, invasive species can occupy and potentially dominate native plant communities that were previously resistant to invasion, although numerous factors such as fire resistance of native species, propagule availability, and variation in burn severity can affect establishment (Zouhar et al. 2008). Native and domestic livestock grazing and browsing of native species can reduce plant vigor and open up sites for establishment of invasive species. Silvicultural prescriptions that decrease canopy cover also increase the likelihood that invasive species may establish and increase in both cover and density,

Table 8.9—Risk assessment for nonnative plant species.[a]

Invasive species component	Direction of change	Main driver(s) of change	Likelihood of change
Area infested	Variable by species, from low to high	Altered temperature and precipitation patterns; increased atmospheric CO_2; altered fire regimes	High
Species response to habitat disturbance	High	Increased fire frequency and severity, which can increase the amount of habitat vulnerable to nonnative invasion	High
Altered fire regimes	High	Increased fire frequency in areas with fire-tolerant and flammable invasive species (e.g., cheatgrass-fire cycle)	High

[a] Developed using expert opinion and information from literature as summarized in this chapter.

although subsequent succession may suppress those species as canopy closure returns.

Climate change is likely to result in a range of responses among invasive species, due to differences in their ecological amplitude and life history strategies (table 8.9). Bioclimatic envelope modeling indicates that climate change could result in both range expansion and contraction for five widespread and dominant invasive plants in the western United States. Yellow starthistle (*Centaurea solstitialis*) and tamarisk are likely to expand, whereas leafy spurge (*Euphorbia esula*) is likely to contract; cheatgrass and spotted knapweed are likely to shift in range, leading to both expansion and contraction (Bradley 2009; Bradley et al. 2009). Invasive species are generally inherently adaptable and capable of relatively rapid genetic change, which can enhance their ability to invade new areas in response to ecosystem modifications (Clements and Ditomaso 2011), including short-term disturbance (fire) or long-term stressors (e.g., prolonged drought, increased temperatures, chronic improper grazing). Increased concentrations of CO_2 in the atmosphere have been shown to increase the growth of weed species, which could have an influence on their invasiveness (Ziska 2003).

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Chapter 9: Climate Change and Wildlife in the Northern Rockies Region

Kevin S. McKelvey and Polly C. Buotte

How Climate Affects Wildlife

Temperature and moisture affect organisms through their operational environment and the thin boundary layer immediately above their tissues, and these effects are measured at short time scales. When a human (a mammal) wearing a dark insulative layer walks outdoors on a cold but sunny day, he or she feels warm because energy from the sun is interacting with the dark clothing, creating a warm boundary layer to which his or her body reacts. Conditions beyond that thin boundary layer are physiologically irrelevant. Walk into the shade, and suddenly one is cold because the warm boundary layer has been replaced with one at the ambient temperature of the air. This example demonstrates many factors to consider when evaluating the degree to which a change in climate will affect an organism. Climate is defined as the long-term average of temperature, precipitation, and wind velocity. "Long term," when applied to climate, is a relative term and can refer to periods of weeks to centuries. In the context of climate models, results are generally reported as averages across 30-year intervals, which for many animal species represent multiple generations. Our ability to infer the biological effects of projected long-term changes in temperature and precipitation relies both on our ability to directly relate these multiyear averages to biological responses, and the trophic distance between climate-induced ecological change and its effects on specific biological relationships.

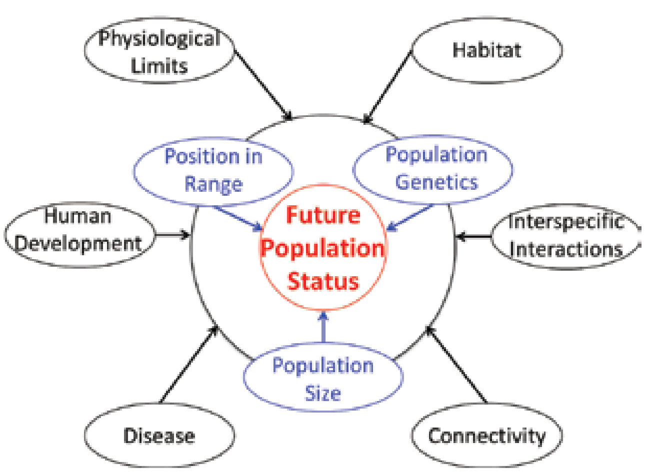

Figure 9.1—Visual summary of workshop discussions on the influence of climate on wildlife populations in the Northern Rockies Adaptation Partnership. Pathways of climate influence (black) interact with population characteristics (blue) to affect the future population status (red). A given pathway affects multiple species, and multiple pathways affect a given species.

As just noted, a human's response to change in radiant energy is fast, measured in seconds to minutes, so its relation to 30-year average temperature is obscure. Climate changes the frequency of weather events, which in turn change the frequency of nearly instantaneous shifts in boundary layer conditions around one's body. In aggregate, these changes in frequency lead to conditions that an individual either can navigate and tolerate—or cannot. This is further complicated for endotherms (warm-blooded animals), which maintain a constant body temperature. Cold or excessive heat affects endotherms by requiring them to burn more calories to maintain the required core temperature. Thus, endotherms can function in a wide variety of environmental conditions if they have enough food to supply the necessary energy. Fish, reptiles, and amphibians are ectotherms (cold-blooded organisms), which react to the cold not by feeling cold and metabolizing energy to maintain core temperature, but by having their metabolism slow until they are torpid.

Many of the species described here occupy terrestrial habitats. Terrestrial organisms can manipulate their operational environment in a myriad of ways, choosing to stand in the sun or shade, moving uphill or down, changing aspect, or seeking cooler or warmer environments by digging into a burrow in the ground or under the snow. Endothermic animals can change the thickness of the boundary layer by modifying their hair or feathers, both seasonally and on a short-term basis, thus responding to variable thermal conditions while minimizing energy expenditures. The ability of terrestrial organisms to manipulate their operational environment contrasts with aquatic organisms, which have a harder time avoiding adverse temperatures because water is an excellent conductor of heat. In addition, aquatic ectotherms have no way to avoid overheating when water temperatures rise, so it is more straightforward to evaluate the effects of climate change for fish with known warm-water limits than it is for terrestrial endotherms (see Chapter 5).

Terrestrial endotherms are more likely to experience effects associated with changes in precipitation amounts and types than effects associated with changes in temperature. These species have less flexibility in dealing with changes in precipitation patterns than with changes in temperature

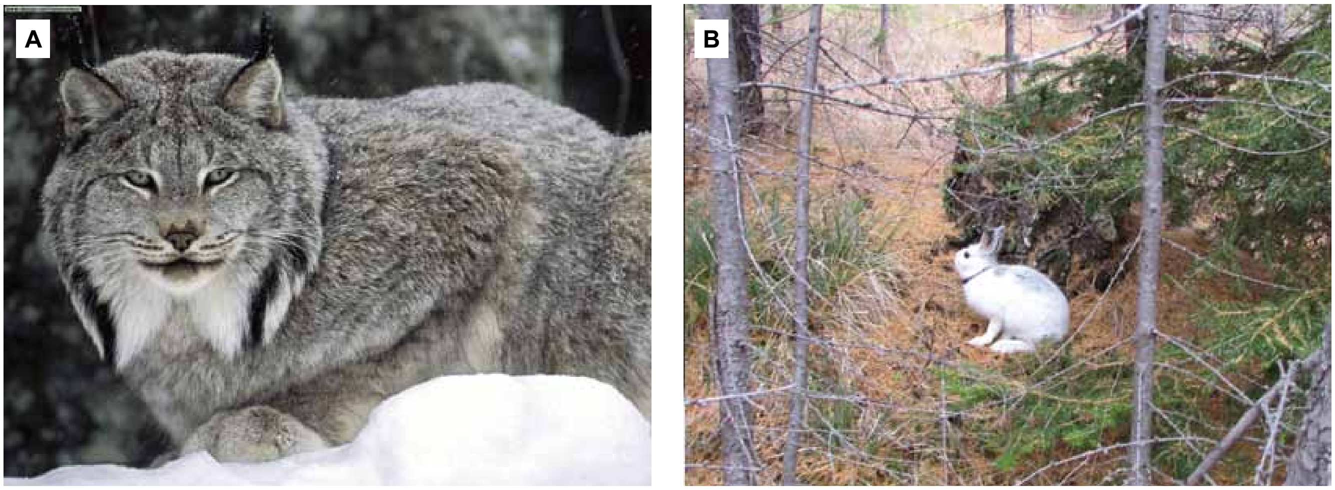

Figure 9.2—Canada lynx (a) have snow-specific adaptations (oversized feet, long legs, and a thin, light skeleton), and snowshoe hares (b) dominate their diets. Snowshoe hares undergo seasonal pelage changes from brown to white, and the effectiveness of this strategy depends on synchrony with snow cover. A mismatch between the hare's fur color and its environment would make it more vulnerable to predation by lynx (photo (a): U.S. Fish and Wildlife Service; (b) photo: L. Scott Mills, used with permission).

because water produces physical features that serve as habitat for which they are specifically adapted. In the Northern Rockies region, and in other areas with cold winters, snow provides physical habitat for which a number of organisms have specific adaptations. An obvious adaptation is seasonal color change in pelage: being white in a snowy landscape enhances the likelihood of escaping detection if the animal is prey, and approaching prey if the animal is a predator. Therefore, white pelage in winter confers specific fitness advantages if pelage change is properly timed to coincide with snow cover. But it is a disadvantage if mistimed (see discussion of snowshoe hare [*Lepus americanus*] later in this chapter) (fig. 9.2). Specific morphological features such as oversized feet, long legs, and light bone structures also provide benefits in snow-covered landscapes but may be disadvantageous in environments without snow.

Deep snow provides a relatively warm, stable environment at the interface between snow and soil; soils in areas characterized by deep snow generally remain above freezing throughout the winter (Edwards et al. 2007), and the subnivean environment (beneath the snow surface) is used by many organisms to den or feed. For organisms that depend on a stable subnivean environment or that have specific phenological adaptations to snow, reduced snowpack caused by a shift in precipitation from snow to rain represents a loss of critical habitat (see later discussion of American pika [*Ochotona princeps*]). Similarly, water bodies are the physical habitats for a wide variety of animals, providing sources of prey, temperature control, and safety from predation. In addition, open or flowing water can provide important microclimates. For example, pikas can be found in what appear to be hot, dry environments if water flow beneath the talus produces cool microsites (Millar and Westfall 2010a).

Physical features associated with snow and water integrate across longer time periods and are therefore closely associated with projected climate. For example, depth of snowpack integrates seasonal moisture and temperature. Seeps, springs, bogs, and persistent streams dependent on continuous sources of groundwater can integrate longer climatic periods. In some areas, water features are dependent on glaciers, which integrate seasonal weather and long-term climate. Therefore, areas with these features and the species that depend on them are vulnerable to climate change, reacting at time scales reasonably consistent with the temporal projections of global climate models (GCM) and providing opportunities to project effects on habitats and species.

As noted earlier, terrestrial endotherms have many options for controlling both their operational environments and the physiological effects of these environments. Terrestrial plants are stationary ectotherms and, lacking the behavioral and physiological plasticity of endothermic animals, are more directly affected by climate changes (see Chapter 6). Therefore, climate effects on wildlife will frequently occur due to changes in plant assemblages that constitute wildlife habitat. For predators, these effects may be either direct (e.g., changes in the number and locations of vegetation boundaries used by predators) or indirect through changes in prey densities or prey availability to predators. Climate-induced changes in trophic structures are expected to be common, complex, and interactive, but are at least one step removed from climate (e.g., Post et al. 1999).

The effects of habitat changes on a specific animal are difficult to project and require specific understanding of the functional roles that ecological attributes play in the life history of the animal, and the consequences associated with alternative life history strategies. These types of data are often lacking, and although current behaviors can be studied, they may not be informative relative to climate change effects, and responses may be novel and unanticipated. For example, polar bears (*Ursus maritimus*) are historically adapted to pack-ice hunting for seals, but with recent reductions in pack ice, they have in some areas shifted to feeding on the eggs of snow geese (*Chen caerulescens*) (Rockwell and Gormezano 2009), whose populations have erupted because of their ability to feed in agricultural fields (Fox et al. 2005).

In addition to changes in vegetation and prey, trophic effects include the presence and abundance of disease and parasitic organisms. For example, for greater sage-grouse (*Centrocercus urophasianus*), the potential spread of West Nile virus (*Flavivirus* spp.) associated with climate change may increase stress in grouse populations (Schrag et al. 2011), but the effect is difficult to project. For many organisms, current ranges are often strongly limited by human activities. For example, greater sage-grouse range is limited by conversion of native sagebrush (*Artemisia* spp.) habitat to agricultural uses (Connelly et al. 2004; Miller and Eddleman 2001).

Last, climate change is likely to alter the nature and location of human activities that affect wildlife. In the western United States, changes in water availability and the amounts required for irrigation can be expected to have profound effects on human activity and settlement patterns (Barnett et al. 2005). In addition, societal effects associated with local changes will occur within the context of societal changes across much larger spatial domains. Changes in technology, standards of living, infrastructure, laws, and the relative impacts of climate changes in other areas, will all affect local human activities.

In summary, the ways that climate change affects endothermic terrestrial species are likely to be complex and difficult to project. In addition to the uncertainty of future climate itself (see Chapter 3), effects on most species will be indirect through proxies such as ecological disturbance, habitat structure, prey availability, disease dynamics, and shifts in human activities.

The Importance of Community in Defining Habitat

Our understanding of wildlife ecology, particularly at broad spatial scales, is generally limited to the correlation of occurrence patterns to landscape features rather than direct studies of those factors that limit species distributions. In some cases, patterns of occurrence are clear, consistent, and highly correlated with climate (see later discussion on wolverine [*Gulo gulo*]), but the causal relationships remain obscure. For instance, many passerine birds nest only in specific habitats; an example is Brewer's sparrow (*Spizella breweri*) (see later discussion), which is obligate to sagebrush. Although the pattern is clear and invariant, the nature of the obligate links to sagebrush is unknown. Species such as ruffed grouse (*Bonasa umbellus*) (see later discussion) clearly have northern distributions, but the factors that define the southern limits of their current distributions are not well understood (Lowe et al. 2010).

This lack of causal understanding may be unimportant for current management of these species because management takes place only in areas where the species currently occurs or where it occurred in the recent historical past. Based on observed patterns of use and distribution, enough information exists to identify and manage current habitat. However, it cannot be assumed that measured correlations will persist in an altered climate. We typically characterize habitat elements within the context of assemblages of mostly unmeasured plants and animals. For example, assume that an organism's occurrence is strongly correlated with mature Douglas-fir (*Pseudotsuga menziesii*) forests. These forests contain other tree and understory species, animal communities, and successional trajectories (e.g., habitat types; Daubenmire [1952]). However, Douglas-fir projected onto a future landscape may be associated with different plant and animal communities. Due to the correlational nature of most of our habitat knowledge, it is difficult to know which of these community members are critical to habitat quality for a target species and thus the habitat quality of novel species assemblages.

In addition, factors identified as important are restricted to those that currently limit behavior. Therefore, in correlation-based habitat relationships, changes in non-limiting but essential factors will not produce strong correlations with behaviors. For example, distance to water may be a strong habitat correlate in desert environments but may not be correlated with habitat quality in a rainforest. Water may be no less important in the rainforest, but it is currently not limiting. As climate change alters biophysical attributes of landscapes, limiting factors and definitions of what constitutes habitat may change. Water availability might become the most critical habitat attribute in a previously wet environment that has become dry. For the most part, these important but latent habitat attributes will remain unknown until exposed by changes in climate.

In addition to potentially changing vegetation communities and limiting factors, the effects of climate on future habitats are further complicated by altered disturbance regimes. Regeneration, growth, and disturbance patterns collectively create landscapes that provide habitats. Changing disturbance dynamics (see Chapter 8) alter the characteristics of landscape mosaics and fundamentally alter habitats. As climate change causes shifts in plant and animal distributions, a temporal mismatch between decrease of current habitat and increase of new habitat may occur, a mismatch that will be exacerbated by increased levels of disturbance. Wildfire can destroy current habitat in a day, but generation of new habitat may require centuries, depending on the time necessary to create critical elements through regeneration, growth, and succession. The fisher provides an example of these uncertainties. In Idaho and Montana, fishers are currently limited to mature forests in the Inland Maritime climatic zone. However, GCMs indicate that this zone will move to the east, and mature forest may take a century or more to grow in these new locations, creating uncertainty about the future range of fisher (see later discussion).

Given the uncertainty associated with determining likely trajectories of species and their habitats under climate change, assessments of general vulnerability and projected changes can best be viewed as hypotheses to be tested. Therefore, it is desirable to develop proactive management strategies that maintain valued species and landscape attributes, including objectives such as creating resilience to disturbance. Prioritizing which things are measured can improve the connection between environmental change and management. A monitoring program designed to test specific hypotheses associated with specific organisms (Nichols and Williams 2006) can improve our understanding of relationships between climate change and landscapes, providing data that inform science-based management.

Evaluating Sensitivity of Species to Climate Change

Evaluating the potential effects of climate change on animal species begins with determining which species are of interest, collecting biological information about them, and paying special attention to biological traits that might lead to changes in distribution and abundance in a warmer climate (e.g., Glick et al. 2011). Some species have received significant attention, and this interest has generated peer-reviewed articles that formally analyze the effects of climate change, although this is relatively uncommon.

Foden et al. (2013) identify three dimensions associated with climate change vulnerability—sensitivity, exposure, and adaptive capacity—and apply a framework based on assessing these attributes to nearly 17,000 species. Other expert systems have been developed to evaluate the relative degree of climate sensitivity and vulnerability for various species including the Climate Sensitivity Database (Lawler and Case 2010) and NatureServe Climate Change Vulnerability Index (NatureServe n.d.). These tools do not seek to understand specific responses of animals to climate, but rather to identify species that are likely to be vulnerable based on current habitat associations, life history traits, and distributions (Foden et al. 2013). Bagne et al. (2011) formalized this process in the System for Assessing Vulnerability of Species (SAVS). In SAVS, species are assessed based on a large number of traits associated with habitat (seven traits), physiology (six traits), phenology (four traits), and biotic interactions (five traits). For each of these 22 traits, a score of –1, 0, or 1 is assigned; positive scores indicate vulnerability, and negative scores indicate resilience. The raw scores are multiplied by correction factors associated with the number of traits in a category and possible scores across traits to achieve a standardized score between –20 and 20 that indicates the relative vulnerability of the species.

Formalizing traits that can lead to vulnerability provides a framework for collecting biological data associated with a species and for considering the effects of climate change. However, existing expert systems cannot be used to infer that sensitivities for disparate topics such as habitat and phenology are proportionally important or that estimated vulnerability has quantitative meaning (Bagne et al. 2011; Case et al. 2015). Even if these issues were considered unimportant, accurately identifying vulnerability for most of the species evaluated here would not be possible given current biological understanding. Because data on climate-species relationships are so sparse, this assessment focuses primarily on evaluation of each trait as it relates to the biology of animal species.

Following are assessments for animal species identified as high priority by Forest Service, U.S. Department of Agriculture (USFS) Northern Region resource specialists, and for additional species identified by participants in five workshops convened by the Northern Rockies Adaptation Partnership (see Chapter 1). Species were not necessarily chosen based on their perceived level of vulnerability. In many cases, species are associated with specific habitats that were considered vulnerable; for example, some species are associated with sagebrush communities, others with snow depth and cover, and others with dry forests that have large trees. These assessment summaries contain projections of climate change effects based on interpretation of the pertinent literature. Level of detail differs considerably among species and is mostly driven by the degree to which the species have been evaluated in the context of climate change. Species are listed in alphabetical order within each taxonomic class.

Mammals

American Beaver

American beavers (*Castor canadensis*), like their European counterpart (*C. fiber*), tend to spend most of the winter in their lodges or swimming to retrieve food, so climate may be more influential during spring through autumn than during winter (Jarema et al. 2009). However, body weights of juvenile European beavers were lighter when winters were colder (Campbell et al. 2013). The cost of thermodynamic regulation may be greater for juveniles because they have higher surface area-to-volume ratios than adults (on whom winter temperature had no effect) (Campbell et al. 2013).

In Quebec, beaver density was highest in areas with the highest maximum spring and summer temperatures (Jarema et al. 2009). Conversely, European beavers in Norway achieved heavier body weights when spring temperatures were lower, and the rate of vegetation green-up was slower (Campbell et al. 2013). This apparent contradiction may have been caused by the timing and measurement of climate and response variables. Although beavers create and require ponds, survival and body weight in European beavers have been linked to lower, and more consistent, precipitation

Figure 9.3—Maintenance and restoration of American beaver populations are adaptation tactics for maintaining water on the landscape. Although beavers are not particularly climate sensitive themselves, the structures beavers create and their effects on aquatic habitats and floodplains may help to ameliorate the effects of climatic change on cold-water fish species and other aquatic organisms (photo: E. Himmel, National Park Service).

from April through September (Campbell et al. 2012, 2013). Higher water levels during high precipitation years were thought to lead to decreased riparian plant growth caused by waterlogging (Campbell et al. 2012).

Climate can indirectly influence beavers through effects on vegetation. Climate change and climate-driven changes in streamflow are likely to reduce the abundance of dominant early-successional tree species in riparian habitats (Perry et al. 2012), reducing food and building materials for beaver. Beavers can be used as a management tool to buffer riparian systems from drought (Lawler 2009) (fig. 9.3). Beaver ponds increase the amount of open water (Hood and Bayley 2008), and beaver management can be used as a surrogate for amphibian conservation (Stevens et al. 2007).

American Pika

The American pika (*Ochotona princeps*) is a small (5–8 ounces) lagomorph that often inhabits rocky alpine areas in western North America (Smith and Weston 1990) (fig. 9.4). The species has been extensively studied in the Great Basin, where pika habitat typically occurs as small islands near mountaintops. Relatively little study of pikas had occurred in the Northern Rockies until recently, with the exception of research on occupancy and abundance in relation to microclimate, topography, and vegetation in the Bighorn Mountains and Wind River Range (Wyoming) (Yandow 2013). Studies are in process in the Bridger-Teton National Forest and Greater Yellowstone Area (Erik Beever, U.S. Geological Survey, Northern Rocky Mountain Science Center, Bozeman, MT, August 2014, personal communication).

Research suggests that pikas depend on moist, cool summer conditions and winter snow (Beever et al. 2011), and on low water-balance stress and green vegetation (Beever et al. 2013). Across paleontological time scales (Grayson 2005) and during the 20th century, pikas across the Great Basin have reacted to increasing temperature by moving upslope or becoming locally extirpated when the climate becomes hot and dry (Beever et al. 2011). Results from field research from 2012 through 2014 in the Great Basin indicate that local extirpations and retractions are continuing (Erik Beever, U.S. Geological Survey, Northern Rocky Mountain Science Center, Bozeman, MT, August 2014, personal communication). Local changes in pika distribution have also been recorded in Utah, the southern Sierra Nevada, and southern and central Cascade Range (Beever et al. 2011 and references therein).

In the Great Basin, pika extirpation (1994–2008) occurred in microsites that were generally hotter in summer (more frequent acute heat, and hotter average temperature across the whole summer) and were more frequently very cold in winter than in locations where pikas persisted. In the latter case, warming reduced insulating snow, causing near-ground temperatures to decrease (Beever et al. 2010). Furthermore, density of pikas in surveys from 2003 through 2008 was best predicted by maximum snow water equivalent and growing-season precipitation (Beever et al. 2013). Some extirpations have occurred at sites with low annual precipitation (Beever et al. 2011, 2013), reinforcing study results in the southern Rocky Mountains (mostly Colorado), where surveys indicated that 4 pika extirpations (among 69 total sites with historical records) occurred at the driest sites (Erb et al. 2011).

Winter snowpack not only insulates pikas during cold periods, but also provides water during the summer, when plant senescence at drier sites occurs earlier in the year, eliminating available metabolic water for pikas. Surveys, mostly in the Sierra Nevada, found that pika extirpations

Figure 9.4—The American pika is a small lagomorph that collects grass and herbs throughout the summer as winter food and remains active throughout the winter. It depends on the relatively warm subnivean environment associated with deep winter snowpack (photo: Will Thomson, U.S. Geological Survey).

were associated with sites with higher maximum temperatures and lower annual precipitation (Millar and Westfall 2010b). Chronic stresses (average temperature during summer, maximum snowpack, and growing-season precipitation), acute temperature stresses (hot and cold), and vegetation productivity apparently contributed to pika declines in the Great Basin (Beever et al. 2010, 2011, 2013).

Individual mountain ranges are thought to act as discrete areas without any pika migration between adjacent ranges across valley bottoms (Castillo et al. 2014), although disjunct metapopulations of pikas separated by short distances may exist. In a study of pika populations in ore dumps separated by tens to hundreds of yards, individual populations that were extirpated were recolonized, and abundance across all ore piles remained constant (Smith 1980). This process apparently occurs only at very short distances because habitats isolated by more than 1,150 feet were generally unoccupied. Connectivity of pika populations apparently depends on context, with lower connectivity between sites that occur in hotter, drier landscapes (Castillo et al. 2014; Henry et al. 2012). Thus, recolonization may occur at distances less than 0.5 mile and in areas where between-population dispersal occurs within cool, moist landscapes, whereas recolonization at longer distances is rare. In the Great Basin, once pikas have been extirpated from a site, they have never been detected in subsequent surveys across 21 years of contemporary research (Beever et al. 2011).

At the broadest spatial scales, there is genetic evidence for historical isolation; pikas across the Intermountain West separate into five distinct groups (Galbreath et al. 2010). At smaller scales, inbreeding and high levels of genetic structure exist between high and low elevation populations in British Columbia, even when the populations are geographically proximal. Castillo et al. (2014) found that gene flow is restricted primarily by topographic relief, water, and west-facing aspects, suggesting that physical restrictions related to small body size and mode of locomotion, as well as exposure to relatively high temperatures, limited pika dispersal.

Studies in the Sierra Nevada (Millar and Westfall 2010a,b) and southern Rocky Mountains (Erb et al. 2011), at sites in which pikas were common and not generally subject to extirpation across most of the landscape, indicated that physiological limits for this species had not been reached. This will probably be the case for most pika populations in the Northern Rockies region in the near term. Although hot, dry climate may limit pika distributions, local moisture sources, rock-ice features, aspect, and the physical structure of talus fields may climatically buffer pikas from macroclimatic stresses (Millar and Westfall 2010a). Existence of pikas at Lava Beds National Monument, Craters of the Moon National Monument, and the Columbia River Gorge—all of which have warm, dry climates—underscores the importance of microclimate for species vulnerability assessments, and indicates that microclimate and macroclimate are decoupled in some locations (Rodhouse et al. 2010; Simpson 2009; Varner and Dearing 2014).

Because pikas are sensitive to high temperature, we expect that pika populations will respond to climate change in the Northern Rockies region. However, site-specific factors contribute to highly variable microclimates, so response to climate change will vary considerably over space and time. A large amount of data has been collected on this species over the past decade, and it should be possible to develop more-accurate projections of population response as monitoring data continue to accrue.

Canada Lynx

The Canada lynx (*Lynx canadensis*) is a mid-sized cat with several specific adaptations that allow it to travel across soft snow. The most obvious adaptation is oversized feet: foot loading is 0.5 times that of the similar sized bobcat (*L. rufus*) (Buskirk et al. 2000). Canada lynx prey nearly obligately on snowshoe hares (fig. 9.2). Not only do snowshoe hares constitute 33 to 100 percent of lynx diet (Mowat et al. 2000), but a low proportion of hares in the diet indicates scarcity of hares, not diet plasticity (Mowat et al. 2000). Studies of lynx winter diet in the Clearwater River watershed (western Montana) found 94 to 99 percent of the diet consisted of snowshoe hares (Squires and Ruggiero 2007). Snowshoe hares are also specially adapted to snowy environments. When compared to similar sized leporids, they have oversized feet. They also exhibit seasonal pelage change from brown to white. Because lynx and hares have a close association and have specialized adaptations to allow survival in snowy environments, climate relationships for both species are explored in this section.

The Canada lynx is found exclusively in North America, its distribution extending across the interior of Canada and Alaska and northward into tundra vegetation. In the conterminous United States, both current and likely historical populations are located in the extreme northern portions of this region: Maine, historically New York and New Hampshire, Minnesota north of Lake Superior, western Montana, and northern Washington (McKelvey et al. 2000). A tiny population existed and may still exist in the Greater Yellowstone Area. Periodically, in the years immediately after major population eruptions in the north, lynx distributions expand; lynx were found ephemerally in North Dakota, and populations temporarily increased in Montana (McKelvey et al. 2000). Bobcats and lynx were not well differentiated in the fur market (Novak et al. 1987)—with large bobcats often recorded as "lynx"—so trapping records are typically untrustworthy (McKelvey et al. 2000). Recently, a population was translocated to Colorado, and appears to be persisting; after initial high mortality rates, annual survival has exceeded 90 percent (Devineau et al. 2010). However, the historical evidence for lynx in Colorado is weak, with most of the verified records occurring in years consistent with immigration from the north (McKelvey et al. 2000). Hare densities in Colorado are generally less than the threshold of 0.5 hare per acre (Ivan et al. 2014) thought to be the minimum hare density associated with stable lynx populations (Mowat et al. 2000).

When evaluating the potential distribution of lynx, it is important to note that large populations of lynx are located in the interior of the continent. Lynx are common in Alberta and Saskatchewan, where more than 20,000 were trapped per year in recent eruptions (Novak et al. 1987), but they are and were rare along both the Atlantic and Pacific coasts. Lynx are more common in areas with a northern continental climate, probably because soft powdery snow is more common there.

Maintaining population connectivity is central to lynx conservation. However, maintaining connectivity may become increasingly difficult as southern populations of boreal species become more isolated with climate change (van Oort et al. 2011). This is of particular concern because disturbance processes that include wildfire, insects, and disease make some boreal forests vulnerable to climate change (Agee 2000; Carroll et al. 2004; Fishlin et al. 2007; Fleming et al. 2002; Intergovernmental Panel on Climate Change [IPCC] 2007a,b; Logan et al. 2003).

In the Northern Rockies region, lynx exist in only a few areas: the Clearwater River watershed, Bob Marshall Wilderness, and the northwestern corner of Montana. A few lynx were known to inhabit the Greater Yellowstone Area in 2000 (Squires and Laurion 2000), but their current status is unknown. Dens are located in boulder fields and spruce-fir forests with high horizontal cover and abundant coarse woody debris. Eighty percent of dens are in mature forest and 13 percent in mid-seral regenerating stands (Squires et al. 2008). For winter foraging, lynx preferentially forage in mature, multilayer spruce-fir forests composed of larger diameter trees with high horizontal cover, abundant snowshoe hares, and deep snow (Squires et al. 2010). During summer, lynx occupy young forests with high horizontal cover, abundant total shrubs, abundant small diameter trees, and dense spruce-fir saplings (Squires et al. 2010). Lynx select home ranges with vegetative conditions consistent with those identified for foraging and denning, primarily at mid-elevations (Squires et al. 2013). Assuming that preferences for movement between home ranges are similar to those associated with moving within the home range, dispersal pathways consist of areas with similar properties to those used for foraging (Squires et al. 2013).

The range of snowshoe hare (Hall and Kelson 1959) is more extensive than that of lynx, extending into the mid-Sierra Nevada and areas such as the Olympic Peninsula, where there are no records of lynx occurrence (McKelvey et al. 2000). The more extensive hare distribution, which includes areas with limited snow (e.g., the Pacific coast), is probably caused by greater genetic differentiation for snowshoe hares than for lynx. Across the continent, lynx exist in a single, largely panmictic (random mating) population (Schwartz et al. 2004), whereas hares are subdivided into six subspecies (Wilson and Reeder 2005).

Hares exhibit variation in timing of pelage change across western North America, but variation is low in any specific location, and timing appears to be genetically controlled and linked to photoperiod (e.g., Hall and Kelson 1959; Zimova et al. 2014). Timing of pelage change is critical for hare survival, because mismatches—a white hare on a dark background and vice versa—cause most hares to die from predation (Hodges 2000) (fig. 9.2). Initiation of pelage change is apparently driven by photoperiod rather than background color, so the ability of hares to shift the timing of pelage change to match patterns of snow cover is limited (Mills et al. 2013). Given projections of snow cover by 2100 (see chapters 3 and 4), current patterns of pelage change in the Northern Rockies region will be mismatched with the period of snow cover. Unless a significant change occurs in the population genetics of hares, they will be the wrong color for about 2 months per year (one month in spring, one month in fall) in the region (Mills et al. 2013).

Both lynx and hares require specific amounts and duration of winter snow. An example of this for lynx occurs in Minnesota, where current and historical populations are limited to the "arrowhead" north of Lake Superior (McKelvey et al. 2000; Schwartz et al. 2004). This area is characterized by lake-effect snow, and outside of it, bobcats dominate and lynx are not found. Both lynx and hares require forests with dense understory canopies. In western Montana, lynx and hares use older spruce-fir forests. If climate change and associated disturbance reduce the abundance of these forest types, habitat loss could be significant, reducing populations of lynx and hares.

Fisher

The fisher (*Martes pennanti*) is a mid-sized, forest-dwelling mustelid. The range of the fisher covers much of the boreal forest in Canada, a broad area of the northeastern United States extending from the Lake States to Maine, and a scattered distribution in the western United States. Males and females are similar in appearance, but the males are larger. Males are 35 to 47 inches long and weigh 8 to 13 pounds; females are 30 to 37 inches long and weigh 4 to 6 pounds (Powell 1993).

Fishers are common in the eastern United States and are often associated with urban environments, but they are uncommon in the western United States and apparently have very specific habitat associations. Although the current distribution of fishers is reduced from the historical range, populations have typically been disjunct. Genetic studies have shown that fisher populations in California have been historically isolated from those in Washington, and fishers in the southern Sierra Nevada have been isolated from those in the Klamath region (Tucker et al. 2012). Fishers in Montana contain unique haplotypes (DNA variations that tend to be inherited together) not found elsewhere (Schwartz 2007; Vinkey et al. 2006) and therefore were apparently isolated both from large populations in northern British Columbia and from coastal populations in Washington. Common attributes for resting sites across eight studies of western fishers were steep slopes, cool microclimates, dense forest canopy cover, high volume of logs, and prevalence of large trees and snags (Aubry et al. 2013). Although these features are important for managing fisher habitat, they do not necessarily explain the fragmented historical distribution in the West (Tucker et al. 2012).

Fishers have long been thought to have specific climatic associations. Krohn et al. (1995) compared fisher and marten (*Martes americana*) distributions in the Sierra Nevada, and found that areas occupied predominantly by marten were closely associated with forested areas with the deepest snow (>9 inches per winter month), whereas areas occupied predominantly by fishers were forested areas with low monthly snowfall (<5 inches). There is direct evidence that fishers avoid deep snowpack (Krohn et al. 1995, 2005; Raine 1983) and that deep snow can limit fisher dispersal (Carr et al. 2007). Fishers also avoid dry habitats (Jones and Garton 1994; Schwartz et al. 2013).

Presence in warmer, wetter forests is apparently common in distributions of fishers at both the macroscale and fine scale in the western United States, although large populations in northern interior British Columbia and Alberta are not associated with these specific climates. Therefore, defining fisher habitat in climatic terms and projecting future habitat is more challenging than for animals with more obvious climatic associations (Copeland et al. 2010; McKelvey et al. 2011).

In a recent modeling study of fisher habitat in an area consistent with its distribution in the Northern Rockies, Olson et al. (2014) built occurrence models for fisher populations in northern Idaho and western Montana that included variables such as canopy cover, climatic variables such as minimum winter temperature, and topographic variables such as slope. They found that most of the variability in the model was explained by mean annual precipitation (34 percent), topographic position index (29 percent), and mean temperature of the coldest month (27 percent). Therefore, fisher habitat was projected to be best in areas with high annual precipitation, low relief, and mid-range values for mean temperature in the coldest month. Krohn et al. (1997) and Olson et al. (2014) projected similar areas of fisher habitat and in similar places.

Olson et al. (2014) used downscaled data from a single GCM (Hadley Centre Coupled Model, version 3; Collins et al. 2001) and two emissions scenarios (A2-high, B2-low; IPCC 2007b), projecting habitat for 2030, 2060, and 2090. At the macroscale, results for both scenarios are similar: In the near term, habitat currently occupied by fishers might improve, but by 2090, habitat in areas that are currently occupied (primarily central Idaho) decline sharply, and new habitat is created to the east in northwestern Montana. The primary difference between the scenarios at this level of detail is the rate at which changes occur. The change is visibly apparent by 2060 in the A2 scenario, but not in the B2 scenario. As habitat shifts, it becomes increasingly fragmented, and the amount of usable habitat is strongly affected by how acceptable minimum patch size is defined (Olson et al. 2014).

Olson et al. (2014) bracketed the emissions scenarios, providing some measure of the potential range of results, but between-model variability exceeds variability between emissions scenarios. In addition, the performance of specific GCMs varies considerably at the regional scale (Mote and Salathé 2010), and the Hadley family of GCMs is considered to be on the hot-dry side of climate projections for the Northern Rockies region (Alder and Hostetler 2014). As a result, details within the model can influence patterns of projected habitat.

There are other uncertainties about the ability of habitat components to track climate. Given that fishers are associated with mature forests, significant time lags may exist between the loss of current habitat and formation of new habitat in areas that currently are unsuitable. If large trees cannot survive the shift in climate, mature forests may become rare for many decades. In climatic zones suitable for fishers, forests may be dominated by young trees and shrubs whose suitability for fisher habitat is unknown. Therefore, projections in Olson et al. (2014) are an optimistic view of habitat availability under climate change, and it is uncertain if fishers would disperse into new habitat should such changes occur.

Moose

Unlike Canada lynx or snowshoe hares, not all species with northern distributions have cold-weather related traits. Some organisms with broad historical distributions are currently limited to northern distributions because of southern extirpation, such as gray wolves (*Canis lupus*) and brown bears (*Ursus arctos*). These species are not considered to be strongly climate limited. Indirectly, cold climates lead to low densities of human populations in boreal forests and tundra, and interaction with large carnivores is therefore minimal. Were climates to warm, and people to relocate into these northern systems, this would obviously affect species such as wolves and brown bears.

For a second group of species, northern ranges are not defined by human impacts, but direct and indirect climate limits may not have been identified. Moose (*Alces alces*) are an example of a well-studied animal that has a northern distribution but whose dependence on boreal environments is not immediately obvious. We suspect that other species with northern distributions may exhibit similar constraints that define the southern extents of their ranges.

A limited amount of climate change research has been conducted on moose (Murray et al. 2006, 2012). Several factors have been identified as influencing the biogeographical distribution of moose including food supply, climate, and habitat. Based on metabolic research, moose are intolerant of heat but well adapted to cold, and summer temperatures may define their southerly distribution (Renecker and Hudson 1986). When winter temperatures were greater than 23 °F or summer temperatures were greater than 57 °F, moose showed an increase in metabolism and heart and respiration rates (Renecker and Hudson 1986, 1990), reduced feed intake (Belovsky and Jordan 1978; Renecker and Hudson 1986), and reduced body weight (Renecker and Hudson 1986). When ambient air temperatures exceeded 68 °F, moose resorted to open-mouthed panting to regulate core body temperature (Renecker and Hudson 1986). Heat stress was particularly apparent in the spring when moose were still in their winter coats (Schwartz and Renecker 1997).

However, moose may be able to avoid being exposed to high midday summer temperatures. In Minnesota, Lenarz et al. (2009) found that temperature was highly correlated with moose survival, but winter temperature was more critical than summer heat. High temperatures in January were inversely correlated with subsequent survival and explained more than 78 percent of variability in spring, fall, and annual survival. In northern Minnesota, moose populations were not viable, largely because of disease- and parasite-related mortality (Murray et al. 2006). In nearby southern Ontario, however, moose populations were apparently viable with favorable growth rates (Murray et al. 2012). Warming temperatures favor white-tailed deer (*Odocoileus virginianus*) expansion into moose range, and increased transmission of deer parasites to moose (Lankester 2010). Given both physiological and biological stressors, separating direct and indirect climate effects is difficult (Murray et al. 2012).

Northern Bog Lemming

As the name implies, northern bog lemmings (*Synaptomys borealis*) inhabit wet meadows, bogs, and fens within several overstory habitat types (Foresman 2012). Generally these wetlands have extensive sphagnum (*Sphagnum* spp.), willow (*Salix* spp.), or sedge components. These mammals were likely to occupy places that retained high water levels after the last glacial retreat (Foresman 2012). Given their dependence on wet habitats, it follows that climate changes that decrease the amount of surface water will probably have negative impacts on northern bog lemmings. Management practices that maintain surface water may therefore be beneficial. However, documented studies of climate and management effects are lacking.

Pronghorn

The pronghorn (*Antilocapra americana*) is an ungulate native to the prairies, shrublands, and deserts of the western United States and occupying a broad range of climatic conditions from southern Canada (Dirschl 1963) to Mexico (Buechner 1950). Although pronghorns occupy a broad climatic region and their diet is generalized, they are prone to epizootic diseases, notably bluetongue (a viral disease transmitted by midges [*Culicoides* spp.]) (Thorne et al. 1988). Bluetongue is thought to be cold-weather limited, and recent extensions of bluetongue in Europe have been attributed to climatic warming (Purse et al. 2005). Given their current range and food habits, the emergence of new disease threats caused by a warmer climate probably poses the greatest risk to pronghorns.

Pygmy Rabbit

The pygmy rabbit (*Brachylagus idahoensis*) is one of the smallest leporids in the world and is endemic to big sagebrush (*Artemisia tridentata*) (Katzner and Parker 1997), which is critical for food and cover. In southeastern Idaho, areas selected by pygmy rabbits had a significantly higher woody cover and height than other areas, with lower quantities of grasses and higher quantities of forbs. Sagebrush was eaten throughout the year, composing 51 percent of the diet in summer and 99 percent in winter (Green and Flinders 1980). These findings are similar to those reported for southern Wyoming (Katzner and Parker 1997) and Utah (Edgel et al. 2014). In addition, areas used by pygmy rabbits accumulate more snow than unused areas, and rabbits use the subnivean environment to reach food and avoid predators (Katzner and Parker 1997). The presence of significant snow for thermal protection may be important for winter survival, because of small body size, lack of metabolic torpor, and lack of food caching (Katzner and Parker 1997).

Structural characteristics of sagebrush are considered more important than food availability for pygmy rabbits (Green and Flinders 1980; Katzner and Parker 1997). Although large, dense sagebrush would be expected to be associated with older stands, Edgel et al. (2014) found no difference in age between occupied and unoccupied sites; structure was important, but age was not. As a result, processes that reduce the size and density of sagebrush are likely to have negative effects on pygmy rabbits, and processes that fragment sagebrush stands may decrease habitat quality. For example, Pierce et al. (2011) found that burrows, observed rabbits, and fecal pellets decrease in density with proximity (<300 feet) to edges.

Paleoecological studies show that both sagebrush and pygmy rabbits are sensitive to climate change. Both species decreased in the mid-Holocene, characterized in the Great Basin by extreme aridity (Grayson 2000). Big sagebrush is sensitive to fire, and 100 percent mortality and complete stand replacement after burning are common (Davies et al. 2011; see Chapter 7). In addition, big sagebrush cannot resprout from the root crown after a fire, so recruitment of sagebrush relies on wind dispersal of seeds from adjacent seed sources and on composition of the seedbank in the soil (Allen et al. 2008; Ziegenhagen and Miller 2009). Mountain big sagebrush (*A. tridentata* ssp. *vaseyana*) required 13 to 27 years after spring prescribed burning to return to conditions suitable for pygmy rabbit habitat (Woods et al. 2013). In areas where fire has been suppressed for many decades, sagebrush habitat can be displaced by conifer incursion (Miller and Rose 1999).

Pygmy rabbits are likely to be sensitive to climate change for several reasons. First, they depend on a single species (big sagebrush) and habitat condition (tall, dense stands). Climatic variability has affected sagebrush communities and pygmy rabbits in the past (Grayson 2000), and this could happen again in the future. Second, pygmy rabbit habitat is sensitive to altered disturbance. Increased fire frequency and area burned are projected as the climate continues to warm (see chapters 6, 7, and 8). Finally, changes in winter snow depth could affect overwinter survival by altering the protection provided by the subnivean environment.

Townsend's Big-Eared Bat

Climate change can affect foraging ability, drinking water availability, and timing of hibernation in bats (Sherwin et al. 2013). Townsend's big-eared bats (*Corynorhinus townsendii*) generally require cavern-like structures for diurnal, maternal, and hibernation roosting, although they also use large tree cavities, buildings, and bridges (Gruver and Keinath 2003). They forage for insects along riparian and forest edge habitats (Fellers and Pierson 2002). Their distribution is apparently limited by the availability of suitable roosting sites, as western populations have declined (O'Shea and Vaughan 1999) coincidental with mine closings (Gruver and Keinath 2003). Townsend's big-eared bats are not able to produce highly concentrated urine (Geluso 1978) and therefore require daily access to water sources for drinking (Gruver and Keinath 2003). Constructed water holes and mining ponds may serve as water sources (Geluso 1978); metal contaminants in the latter may cause some bat mortality (Pierson et al. 1999).

Bioaccumulation of pesticides in fat tissue apparently is one cause of declines in Townsend's big-eared bat populations (Clark 1988). Human activities that reduce moth populations can also negatively affect bat populations because moths are a primary food source of Townsend's big-eared bats (Burford and Lacki 1998; Whitaker et al. 1977). Bats may be especially sensitive to human disturbance during hibernation (Thomas 1995).

In Colorado, the reproductive success of bats of the *Myotis* genus declined during warmer and drier conditions, which are projected to be typical of future climatic conditions (Adams 2010). However, in other instances, warmer spring temperatures have led to earlier births, which promotes juvenile survival (Lucan et al. 2013). Higher summer precipitation may reduce reproductive success (Lucan et al. 2013). Future warming may also reduce the effectiveness of some bat echolocation calls (Luo et al. 2014).

Ungulates (Elk, Mule Deer, White-tailed Deer)

Rocky Mountain elk (*Cervus canadensis*), Rocky Mountain mule deer (*Odocoileus hemionus hemionus*), and white-tailed deer (*O. virginianus*) provide the core of big game hunting in the Northern Rockies region. All three have very broad ranges in North America. The current range for elk, which includes most of the Rocky Mountain West, also includes areas in the eastern and southwestern United States that were historically occupied by other subspecies. Rocky Mountain mule deer extend from the Yukon to northern Arizona. White-tailed deer extend across most of North America and into northern South America and include 38 recognized subspecies (De la Rosa-Reyna 2012).

Based on their broad ranges, it is clear that all three species exhibit a high degree of flexibility toward habitat. Habitat use by elk in forested areas is associated with edges (Grover and Thompson 1986; Irwin and Peek 1983; Thomas et al. 1979, 1988) in which areas containing high-quality forage and areas with forest cover are in proximity. In open habitats, they select areas of high vegetative diversity with intermixed patches of shrubs and grasslands (Sawyer et al. 2007). Both patterns of habitat use are apparently maximized by a disturbance regime with spatial heterogeneity at relatively fine scales.

A study of Rocky Mountain mule deer found that home range size increased in areas with few large patches and was smallest in fine-grained vegetation mosaics (Kie et al. 2002). Mule deer depend on disturbance to create forage (e.g., Bergman et al. 2014), but the size and juxtaposition of patches are important. Fine-grained disturbance mosaics are apparently optimal for white-tailed deer, especially in areas where thermal cover is important. In the Northern Rockies region, thermal cover prevents heat loss during winter, although in warmer climates, thermal cover reduces daytime heating. In Texas, male white-tailed deer chose areas with high cover and poor foraging opportunities during the midday, but chose areas with higher forage quantities during crepuscular and nocturnal periods (Wiemers et al. 2014).

Ungulates generally respond positively to disturbance (fig. 9.5), but the types of disturbance and the resulting landscape condition and species composition are equally important. Just as wildfire intensity affects patchiness in the postfire landscape, it also affects which plant species are likely to revegetate burned areas. For example, Emery et al. (2011) found that at lower temperatures several native plant species exhibited enhanced germination, whereas nonnative plant species did not. Vegetation growth after disturbance is important where nonnative species are common. For example, Bergman et al. (2014) found that treatments that removed trees and controlled weeds produced better mule deer habitat than treatments that removed only trees.

Climate change is expected to alter fire regimes, but for ungulates the exact nature of those changes will be critical.

Figure 9.5—Ungulates generally respond favorably to wildfires that create patchy habitat, especially if forage availability improves, as shown in this photo of an elk browsing adjacent to a recently burned lodgepole pine forest (photo: Jeff Henry, National Park Service).

For example, in the Greater Yellowstone Area subregion, wildfires are infrequent, large, and intense. If climate change causes more frequent fires (Westerling et al. 2011), then the landscape will be patchier compared to the current condition, and the distribution and abundance of forest species could change. In the short term, novel fire-climate-vegetation relationships can be expected. In the long term, the effects of altered vegetation on ungulate populations are uncertain, but it is unlikely that there will be highly negative consequences.

Wolverine

The wolverine (*Gulo gulo*) is the largest mustelid, occurring throughout the Arctic, as well as subarctic areas and boreal forests of western North America and Eurasia. At the southern extent of its distribution in North America, populations occupy peninsular extensions of temperate montane forests. Monitoring programs in Fennoscandia (Flagstad et al. 2004) and surveys in Canada (Lofroth and Krebs 2007) inform our understanding of wolverine occurrence in those regions, but the limits of wolverine distribution in other portions of its range are less understood.

Wolverines are often considered to be generalists with respect to habitat, and their occurrence has been associated with great distance from human development (Banci 1994; May et al. 2006; Rowland et al. 2003). However, unlike brown bear and gray wolf, whose northern distributions are the result of recent human hunting and habitat alteration, there is no historical evidence for wolverine presence in areas not characterized by arctic or boreal conditions (Aubry et al. 2007). Fossil evidence is consistent with this understanding (Alvarez-Lao and Garcıa 2010), and wolverines apparently have always been associated with cold northern climates.

Wolverines den in snow, and deep snow throughout the denning period is thought to be essential (Magoun and Copeland 1998). The strong, perhaps obligate, relationship between wolverine den selection and deep snow in the late spring has been reinforced by recent study results (Copeland et al. 2010; Dawson et al. 2010; Inman et al. 2012). A proxy for spring snowpack (areas where snow persisted through mid-May) effectively describes den site selection, current range limits, and year-round habitat use at the southern periphery of the wolverine range (Copeland et al. 2010). These areas are associated with successful dispersal (Schwartz et al. 2009) and historical range (Aubry et al. 2007). Although not all biological aspects of this association are understood, its universal nature in both space and time indicate that snow persistence will be associated with future distributions as well. The association applies to populations in Alaska, Idaho, and Scandinavia, and it describes both historical and contemporary distributions. Wolverines apparently travel within these areas when dispersing and strongly minimize travel through low elevation habitat, so we can project both current and future travel routes based on altered snowpack.

McKelvey et al. (2011) modeled future spring snowpack within the Columbia, Upper Missouri, and Colorado River basins, and projected changes in habitat and connectivity associated with future landscapes based on existing wolverine habitat relationships (Copeland et al. 2010) and dispersal preferences (Schwartz et al. 2009). A projection derived from an ensemble mean of 10 GCMs under an intermediate emissions scenario (A1B) (Mote and Salathé 2010) was used to produce climate projections (Elsner et al. 2010; Littell et al. 2011). Historical data across the area were reconstructed following methods in Hamlet and Lettenmaier (2005), and changes from historical patterns were modeled by using the "delta" method of downscaling, resulting in regionally averaged temperature and precipitation change for 2030–2059 and 2070–2099. Downscaled climate data were used as inputs to the Variable Infiltration Capacity (VIC) model (Hamlet and Lettenmaier 2005; Liang et al. 1994), which was used to project snowpack. Historical modeled snowpack depth was fit to most closely match the persistent snow cover data from Copeland et al. (2010), and this fit was then used to identify areas of future habitat for wolverines.

In the Columbia and Upper Missouri River basins, where most of the Northern Rockies region is located, snowpack projection indicated a loss of 35 and 24 percent, respectively, for spring snow by the mid-21st century, and 66 and 51 percent, respectively, by the end of the century. Central Idaho was projected to lose nearly all snow by the end of the century, whereas northern Montana, the southern Bitterroot Mountains, and the Greater Yellowstone Area retained significant spring snow (McKelvey et al. 2011). The ensemble mean model output was similar to results associated with the Parallel Climate Model (a cool extreme; U.S. Department of Energy and National Science Foundation 2004), but at the warm extreme, little spring snow was retained at the end of the century. A connectivity model (Schwartz et al. 2009) in conjunction with ensemble climate model projections indicated that all remaining habitat would be genetically isolated by the end of the 21st century (McKelvey et al. 2011).

The threshold between rain and snow causes estimates of snowpack loss to differ greatly between GCMs because timing of moisture and the temperature when it occurs affect model performance. Cool models (e.g., Goddard Institute for Space Studies model E; Schmidt et al. 2006) indicate increases in January snowpack at high elevation (e.g., Yellowstone Plateau, Colorado) through the mid-21st century, whereas warmer models (e.g., Model for Interdisciplinary Research on Climate; Watanabe et al. 2011) show large losses in snowpack across all regions (Alder and Hostetler 2014). All models, including the coolest and wettest, indicate a continuing reduction in spring snow, a pattern that has been ongoing since at least the 1950s (Mote et al. 2005).

Birds

Brewer's Sparrow

Brewer's sparrow (*Spizella breweri*) is apparently a sagebrush obligate during the nesting period when nest occupancy is positively related to tall, dense stands of sagebrush (Petersen and Best 1985; Reynolds 1981) (fig. 9.6). In areas where other sagebrush-obligate species exist (e.g., sage thrasher [*Oreoscoptes montanus*]), these sparrows may compete for nest locations (Reynolds 1981). In many areas, however, Brewer's sparrow is the most abundant bird species (Norvell et al. 2014). Some consider the closely related timberline sparrow (*S. breweri taverneri*) to be a separate species (i.e., *S. taverneri*) or subspecies but, in any case, no genetic mixing occurs between the alpine and sagebrush variants (Klicka et al. 1999).

Reasons for the obligate relationship of Brewer's sparrow with sagebrush are obscure. Although this relationship appears to be robust, especially patterns of nest occupancy (Petersen and Best 1985), evidence for why Brewer's sparrow nests in sagebrush rather than in other brush species is lacking. Therefore, we rely on correlative associations to project climate change effects and cannot speculate as to the flexibility of this species to shift to alternative shrub species should sagebrush become scarce.

Brewer's sparrow populations appear to be reasonably stable range-wide, although they have been in decline in some areas in Colorado (USGS 2013). Although Brewer's sparrow selects for areas with tall, dense sagebrush, sparrow abundance was unaffected by treatments designed to modify sagebrush cover and improve habitat for greater sage-grouse (Norvell et al. 2014). Similarly, a study of the effects of (nonnative) smooth brome (*Bromus inermis*) found that nest success was higher in areas with brome establishment (Ruehmann et al. 2011). In general, the effects of climate change on Brewer's sparrow will probably depend to a great degree on changes in the distribution, abundance, composition, and structure of sagebrush communities. Increased wildfire is likely to reduce the distribution, abundance, and age of sagebrush stands in a warmer climate. Within sagebrush communities, Brewer's sparrows do exhibit flexibility in response to nest predation, shifting locations of sequential nests in response to previous predation (Chalfoun and Martin 2010).

Flammulated Owl

The flammulated owl (*Otus flammeolus*) is a nocturnal owl, approximately 6 inches long with a 14-inch wingspan. It is migratory but breeds in montane areas across much of western North America, ranging from southern British Columbia to central Mexico (Ridgely et al. 2003). It is a cavity nester, associated with mature forests with large diameter

Figure 9.6—Because climate change is expected to reduce the extent of mature sagebrush through increased wildfire, sagebrush-obligate species such as Brewer's sparrow (shown here) and greater sage-grouse may have less nesting habitat in the future (photo: Tom Koerner, U.S. Fish and Wildlife Service).

trees. It is also associated with open forests, but does not appear to be specific to any particular tree species. In New Mexico, it is found in pinyon pine (*Pinus edulis*) (McCallum and Gehlbach 1988), ponderosa pine (*P. ponderosa*) (Bull et al. 1990; Linkhart et al. 1998), and Douglas-fir (Powers et al. 1996; Scholer et al. 2014) forest. In the Sierra Nevada, it has been associated with (from low to high elevation) black oak (*Quercus kelloggii*), mixed-conifer, Jeffrey pine (*P. jeffreyi*), white fir (*Abies concolor*), and red fir (*A. magnifica*) forest (Stanek et al. 2011).

Flammulated owls are thought to be obligate secondary cavity nesters, although it has been anecdotally observed to nest in the ground (Smucker and Marks 2013). Flammulated owls feed almost exclusively on insects, primarily Lepidoptera, which they gather from trees, on the ground, or in flight (Linkhart et al. 1998). During the nesting period, males are single-trip, central-place foragers, so the energetics of prey selection are important; distance traveled and energy content of prey differ by forest type. Little information is available on the diet of flammulated owls and their relationships to forest habitat. Interactions with other owl species are apparently minimal (Hayward and Garton 1988).

The extensive latitudinal range of flammulated owls, lack of specific forest associations, and generalized insect diet indicate that straightforward links to specific climatic regimes are unlikely. If climate change is to affect flammulated owls, then it will most likely be through disturbance processes that remove large diameter trees. Shifts to denser forest structure would be problematic for this species, but there is little evidence that this would occur, because drought and wildfire are projected to increase throughout the Northern Rockies (Alder and Hostetler 2014). As with other long-lived owl species (Linkhart and Reynolds 2004), flammulated owl populations will be very sensitive to adult survival (Noon and Biles 1990).

Greater Sage-Grouse

Greater sage-grouse (*Centrocercus urophasianus*) is the largest grouse in North America (Mezquida et al. 2006). It is considered an obligate with sagebrush (Miller and Eddleman 2001). Its distribution is currently about half of its presettlement range (Schroeder et al. 2004), and many populations have been steadily declining in recent decades (Braun 1998; Connelly and Braun 1997; Connelly et al. 2004). In some areas, land conversion that eliminated sagebrush apparently has caused the declines (Connelly et al. 2004; Miller and Eddleman 2001). Extirpation of sage-grouse is more likely in areas with high human population densities, land conversion to cropland, severe droughts (Aldridge et al. 2008), sagebrush displacement by conifers, and corvid predation. It is also more likely in areas with less than 25 percent sagebrush cover near the edge of the historical range.

Declines in sage-grouse have also occurred in areas still dominated by sagebrush (Miller and Eddleman 2001). In addition to reduced sagebrush cover, declines have been attributed to nonnative plants (Connelly et al. 2004; Knick et al. 2003; Wisdom et al. 2002), energy exploration and extraction (Braun et al. 2002; Doherty et al. 2008; Holloran et al. 2005; Lyon and Anderson 2003; Walker et al. 2007a), grazing (Beck and Mitchell 2000; Hayes and Holl 2003), altered fire regimes (Connelly et al. 2000, 2004), and a warmer climate (Neilson et al. 2005). In recent years, West Nile virus has also been implicated (Naugle et al. 2004, 2005; Walker et al. 2007b).

Assessing the effects of climate change on this species is challenging because so many factors potentially affect sage-grouse population dynamics. Nevertheless, Schrag et al. (2011) produced a detailed climate change assessment for greater sage-grouse that evaluated changes in distribution of sagebrush and transmission of West Nile virus. They first built bioclimatic models for sagebrush distribution, then modeled West Nile spread based on temperature thresholds. They used six GCMs and one emissions scenario (A1B), and GCM output was statistically downscaled to 7.5-mile pixels. Both the envelope model and temperature thresholds were projected to 2030 based on the downscaled GCM output. Results varied greatly across models, but it was concluded that the cumulative effects of projected climate change on both sagebrush and West Nile virus transmission would reduce suitable sage-grouse habitat in the Northern Rockies and northern Great Plains (Schrag et al. 2011). Sage-grouse require large areas of mature sagebrush, so future increases in wildfires are expected to significantly reduce habitat.

Creutzburg et al. (2015) evaluated the likely trajectory of greater sage-grouse habitat in southeastern Oregon. They simulated the effects of climate change, disturbance, and cheatgrass (*Bromus tectorum*) invasion by coupling a linked dynamic global vegetation model, climate envelope model, and state-and-transition simulation model, based on three climate models chosen to cover a range of possible futures. In the near term, loss of sagebrush from wildfire and cheatgrass invasion leads to habitat deterioration. In all three climate projections, however, native shrub-steppe communities increased circa 2070, leading to habitat improvement. In this simulation, all projected climate futures had better long-range prospects for sage-grouse than was simulated based on current climate.

Harlequin Duck

Harlequin ducks (Histrionicus histrionicus) in the Intermountain West breed and summer on fast-flowing mountain streams and winter on rocky coastal areas (Robertson and Goudie 2015). In Grand Teton National Park, breeding pairs used streams with dense shrubs along the banks (Wallen 1987). During summer they feed primarily on larval insects on stream bottoms and in winter on a variety of small food items including snails, small crabs, barnacles, and fish roe (Robertson and Goudie 2015). They are relatively rare in Montana, with a concentration in Upper McDonald Creek in Glacier National Park (Reichel 1996). Climate change may alter the timing, duration, and levels of streamflows. In Glacier National Park, harlequin duck reproductive success declined with higher and less predictable streamflows (Hansen 2014).

Mountain Quail

The mountain quail (*Oreortyx pictus*) is a small ground-dwelling bird that occupies upland forest and woodland habitats in the western United States and northern Mexico (Brennan et al. 1987). In the Pacific Northwest, its range extends into deep canyons such as Hells Canyon of the Snake River (Pope and Crawford 2004), where populations of the species have been declining. Population augmentation through translocation is common. Population studies have focused on survival, but connections to climate-related change are minimal. Stephenson et al. (2011) found that climate-related variables were important to survival, with lower survival being linked both to hot, dry conditions and to cold winter weather. Seasonal movements to avoid snowpack led to increased rates of movement, which were also important predictors of survival.

Pygmy Nuthatch

The pygmy nuthatch (*Sitta pygmaea*), a bird about 4 inches long, is found throughout montane coniferous forests in western North America and as far south as central Mexico (McEllin 1979; Ridgely et al. 2003). It is a cavity nester, often associated with ponderosa pine forests (McEllin 1979) but also found in other forest types such as quaking aspen (*Populus tremuloides*) (Li and Martin 1991). Pygmy nuthatches can exhibit a social structure of cooperative breeding in which "helpers" aid breeding birds by feeding the incubating female, feeding nestlings and fledglings, and defending nesting territory (Sydeman et al. 1988).

Pygmy nuthatches nest in cavities in both live and dead trees, as observed at a study site in Arizona (Li and Martin 1991), and population responses to disturbance are modest. For example, Hurteau et al. (2008) found that population densities across a variety of thinning and fuels treatments at a study site in Arizona remained constant except in thin-and-burn treatments, where densities increased by more than 500 percent. In a study of the interior western United States, Saab et al. (2007) found that nuthatches showed a negative response to fire the first year after wildfire, but a neutral response in subsequent years. Due to their apparent neutral response to disturbance, coupled with flexibility in habitat and wide latitudinal range, it is difficult to project whether they will respond positively or negatively to climate change. Extirpation of the pygmy nuthatch due to climate change appears unlikely, other than from the effects of land-use conversion from forest to nonforest.

Ruffed Grouse

Ruffed grouse (*Bonasa umbellus*) are characterized by a boreal distribution that includes peninsular extensions into the Rocky Mountains and Appalachian Mountains (USGS 2014). Throughout much of their range, ruffed grouse occupy quaking aspen (*Populus tremuloides*) forest (Kubisiak 1985; Stauffer and Peterson 1985; Svoboda and Gullion 1972), which provides important food sources (Jakubas and Gullion 1991). Although ruffed grouse exist in forests that contain no aspen (e.g., oak-dominated forest) (Haulton et al. 2003), they are mostly limited to aspen habitats in many areas of the West (e.g., Mehls et al. 2014). Ruffed grouse were identified as a species of concern in the Northern Rockies in the context of aspen-dominated forest, so we focus here on the use of aspen by ruffed grouse.

In central Wisconsin, ruffed grouse densities were highest in young (<25 years) aspen stands (Kubisiak 1985). Similarly, ruffed grouse preferred stand structures characteristic of early successional stages in Idaho (Stauffer and Peterson 1985) but also use aspen stands of all ages (Mehls et al. 2014). Thus, optimal grouse habitat consists of aspen forests with stands in a variety of age classes, including a large component of young stands.

Aspen may be sensitive to heat and drought in some locations (Anderegg et al. 2013; Huang and Anderegg 2011). Although higher temperatures are expected to cause increased stress in aspen, differences in forest structure and age affect the relationship between aspen mortality and drought (Bell et al. 2014), and mortality can be reduced by controlling stand densities and ages and limiting competition from conifers. If climate change causes decreased extent of aspen in the Northern Rockies region, reduced habitat would have detrimental effects on ruffed grouse populations. However, significant options exist to mitigate these changes through silviculture that favors aspen over conifers and through active manipulation of stand densities and ages.

Amphibians

Columbia Spotted Frog

The Columbia spotted frog (*Rana luteiventris*) breeds in montane ponds throughout western North America (Green et al. 1996, 1997) (fig. 9.7). Funk et al. (2008) built a phylogeny for this species based on samples across western North America. Populations separated into three distinct clades; within the Northern Rockies region, all samples were associated with the northern clade and were fairly closely related. The effects of climate change on Columbia spotted frogs are unclear. In Utah, the frog was more likely to occur in persistent, shady ponds that maintained constant temperatures (Welch and MacMahon 2005). In Yellowstone National Park, pond desiccation led to sharp declines in frog populations (McMenamina et al. 2008).Throughout their range, populations in large stable water bodies were doing well, whereas those in smaller more ephemeral ponds were subject to rapid declines (Hossack et al. 2013). In Montana, warmer winters were associated with improved reproduction and survival of Columbia spotted frogs (McCaffrey and Maxell 2010). This species does not appear to be sensitive to stand-replacing fires (Hossack and Corn 2007).

Columbia spotted frog populations are stable in areas with stable water supplies, and are capable of rapid population expansion into restored wetlands (Hossack et al. 2013). However, the amphibian chytrid fungus (*Batrachochytrium dendrobatidis*, hereafter referred to as Bd), is prevalent in many populations (Pearl et al. 2009; Russell et al. 2010) and warming waters would, in most systems, favor Bd (see discussion on western toad). Although the fungus is common, the population effects of infection are unclear.

Western Toad

Western toads (*Anaxyrus boreas*) are montane amphibians broadly distributed across the western United States (Muths et al. 2008); in the southern Rocky Mountains, the subspecies boreal toad (*A. b. boreas*) is recognized. The western toad has suffered apparently widespread declines, particularly at the southern extent of its range (Corn et al. 2005), a phenomenon well documented in Colorado (Carey 1993). This species suffers from amphibian chytrid fungus, which is often fatal. Laboratory studies of Bd have found that it grows optimally at 63 to 77 °F, and colonies are killed at 86 °F (Piotrowski et al. 2004). Although Bd can grow in temperatures as cold as 39 °F, warming waters would increase its prevalence.

In a study across Colorado, Wyoming, and Montana, Bd was consistently found in western toad tissues, and was more prevalent in warmer, lower elevation sites (Muths et al. 2008). A warmer climate may allow Bd to spread to higher elevations and become even more widespread. But there is some question about how susceptible the western toad is to the effects of Bd because increased mortality is not always associated with high infection rates. Recent studies indicate that the skin of the toad contains bacterial colonies that inhibit Bd (Park et al. 2014).

Figure 9.7—Warmer air temperature and less snowpack are expected to decrease the presence of shallow water during the summer, reducing habitat for the Columbia spotted frog (shown here) and western toad. Higher air and water temperatures may also increase infections from amphibian chytrid fungus (photo by Roger Myers, Alaska Department of Fish and Game).

Assessing Subregional Differences in Vulnerability

When considering how climate change would affect wildlife populations in their subregion, Northern Rockies Adaptation Partnership (NRAP) workshop participants tended to think in terms of pathways through which climate could exert an influence (fig. 9.1, black text and arrows). These pathways can interact with each other, and with population characteristics (fig. 9.1, blue text and arrows) to produce an effect on the population of interest (fig. 9.1, red text). However, a given pathway influences multiple species, and multiple pathways influence a given species. Following is a summary of the subregional workshop discussions.

Upper temperature thresholds for moose were discussed for the Greater Yellowstone Area (GYA) subregion. This was the only species and subregion with a discussion of direct physiological sensitivities to climate. However, it was noted in all subregions that there is a general lack of understanding of direct physiological sensitivities to climate for most wildlife species. Even when these sensitivities have been measured (e.g., the lower thermoneutral limits for wolverines [e.g., Iversen 1972]), however, it is unclear how this laboratory-derived knowledge can be interpreted in the context of habitat use and demographic performance.

Position within a species' niche can influence population vulnerability. Some species are at the climatic limits of their range in particular subregions. Exposure to climate change in these places is likely to have a strong effect on the ability of a species to persist, whereas the same amount of change in the center of its range probably would have less effect. The Western Rockies and Central Rockies subregions are at the junction of maritime and continental climates, and many species are at the edges of their ranges. For example, participants in the Central Rockies workshop discussed how future climate change is expected to increase habitat suitability for the fisher, such that this species may expand its range into the subregion.

Some species had different habitat associations in different subregions. For example, in the GYA, ruffed grouse was linked to aspen habitat but was associated with a broader range of habitats in the Central Rockies subregion. Therefore, ruffed grouse was seen as more sensitive to climate effects on aspen in the GYA than in the Central Rockies.

The importance of previous habitat loss, potentially caused by recent warming, differed across the subregions. In the Eastern Rockies subregion, extensive lodgepole pine (*Pinus contorta* var. *latifolia*) mortality has been caused by mountain pine beetle (*Dendroctonus ponderosae*); amplified pine beetle outbreaks are probably the result of warmer winters (Bentz et al. 2010). Cavity nesting birds were thought to be more sensitive to potential future habitat loss because they have already lost a substantial portion of their habitat. Prior habitat loss was not discussed in the other subregions.

Another pathway for habitat loss discussed in the Central Rockies workshop was an increase in invasive species. For example, flammulated owls feed on insects that depend on understory plant composition, and that composition could be altered by increased abundance of invasive plants such as cheatgrass.

Negative effects on wildlife populations from an increase in disease occurrence and transmission caused by climate change (e.g., West Nile virus) were discussed in three of the five subregions. Participants also noted that relatively little is known about disease ecology and the future potential for disease to affect wildlife populations.

Connectivity was a primary concern in four of the five subregions. Participants considered different scales of connectivity to be important: the ability for individuals to move through the landscape to meet their daily needs, the ability to complete seasonal migrations, and the ability to track potentially shifting habitat. Numerous indirect influences on each of those scales of connectivity were discussed.

Indirect pathways that increase vulnerability to climate change can also arise when a changing climate influences landscape configurations such that species are then more at risk from other stressors. Participants discussed the need to understand how potential shifts in residential development (e.g., into riparian habitats) in the GYA and Central Rockies subregions could affect wildlife. Changing demands for energy sources and the influence of energy development on wildlife habitat were discussed in the Central Rockies and Grassland subregions.

Another source of variation within the Northern Rockies region was the importance of multiple collaborative efforts focused on conservation issues in the Central Rockies subregion. USFS participants stated that these collaboratives increased their range of achievable management tactics.

There were differences in the amount of climate change expected (exposure), the response of individuals and populations to that change (sensitivity), and the ability of organisms and organizations to adapt to that change (adaptive capacity) across Northern Rockies subregions. However, participants agreed on the lack of understanding about mechanisms of climate influence. Identifying and contrasting the importance of *pathways* of climate influence across subregions can suggest potential *mechanisms* of climate influence. Hypotheses can be developed to account for these mechanisms, and management actions can be monitored to test those hypotheses. Based on the results of those tests, decisions can be made to continue with management actions, or develop new actions or hypotheses, creating an adaptive monitoring program (Lindenmayer and Likens 2009) and increasing knowledge of the needs and climate sensitivities of species (table 9.1). Sensitivities listed in tables 9.2 through 9.9 provide a starting point for identifying potential hypotheses.

Adapting Wildlife Management to the Effects of Climate Change

Adaptation to climate change for wildlife resources in NRAP subregions was focused on maintaining adequate habitat and healthy wildlife populations, and increasing knowledge of the needs and climate sensitivities of species. Workshop participants identified the major habitats in their subregion and then developed adaptation strategies for species they regarded as important and for which they believed viable management options exist. For example, participants in the GYA workshop discussed climate sensitivities of American pika, but decided not to work through adaptation options because they did not see how management efforts could influence pika population viability. Participants tended to address species or habitats that had not been covered in prior workshops, even if some were important in their subregion. Adaptation options are summarized according to major habitats (tables 9.2 through 9.7), which can then be associated with individual species (table 9.1).

Riparian habitats are important across the Northern Rockies region. The primary strategy for improving riparian habitat resilience is maintaining healthy American beaver populations (table 9.2). Beaver complexes can buffer riparian systems against both low and high streamflows, and provide habitat structure and foraging opportunities for multiple species. Nonriparian wetlands were discussed as important habitats, but no adaptation strategies were developed.

Quaking aspen habitats are common in the four western subregions and occur occasionally in the Grassland subregion. Aspen was identified as important because of its high productivity, role in structural diversity, and habitat for cavity nesting birds. In the GYA, ruffed grouse were 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 (see Chapter 6). The most common tactics for promoting aspen resilience were allowing wildfire or using prescribed fire in older aspen stands, providing protection from grazing, and reducing conifer encroachment in any age stand (table 9.3).

Dry ponderosa pine forests are common in the Central Rockies and Eastern Rockies subregions and provide habitat for cavity nesting birds such as the flammulated owl. Douglas-fir has encroached on these habitats as a result of fire exclusion, increasing vulnerability of pine to future fires. Tactics for promoting ponderosa pine resilience included reducing competition from Douglas-fir through understory burning and cutting, protecting mature stands, and planting ponderosa pine where it has been lost (table 9.4).

The Western Rockies and Central Rockies subregions support older, mesic forests because they experience a maritime climate influence (see Chapter 3). These forests, which provide important habitat for fisher, may have younger age classes (caused by increased disturbance; see Chapter 8) and different species composition in a warmer climate (see Chapter 6). Adaptation strategies included restoring historical structure, conserving current structure, and promoting potential future mesic forest habitats (table 9.5).

Mountain sagebrush-grassland habitat occurs in all regions except the Grassland. In the Western Rockies subregion, mountain sagebrush-grassland habitats are unique in that they have less of a sagebrush component, primarily occur in

Table 9.1—Species included in the Northern Rockies Adaptation Partnership vulnerability assessment, including species discussed at subregional workshops.

Habitat/Species	Western Rockies	Central Rockies	Eastern Rockies	Greater Yellowstone Area	Grassland
Dry forest					
Flammulated owl		X		X	
Pygmy nuthatch		X	X	X	
Riparian/wetland					
American beaver		X	X	X	
Moose				X	
Northern bog lemming				X	
Townsend's big-eared bat		X	X	X	
Harlequin duck		X		X	
Columbia spotted frog		X		X	
Western toad		X		X	
Quaking aspen					
Avian cavity nesters		X	X	X	
Ruffed grouse				X	
Sagebrush grasslands					
Pronghorn				X	
Pygmy rabbit			X		
Brewer's sparrow				X	
Greater sage-grouse				X	X
Mountain grasslands					
Mountain quail	X				
Mesic old-growth forest					
Fisher		X		X	
Snow-dependent species					
American pika				X	
Canada lynx		X		X	
Wolverine		X		X	

steep mountain canyons, and support populations of mountain quail. Differences in aspect have a strong influence on climate in these canyons. In a warmer climate, these habitats could lose some of their forb component, making them vulnerable to increased abundance of nonnative species (see Chapter 7). Specific tactics for restoring historical habitat and maintaining current habitat included managing fire, controlling nonnative species, and restoring formerly cultivated lands (table 9.6).

Sagebrush habitats are common in the Eastern Rockies, GYA, and Grassland subregions, supporting gallinaceous birds (greater sage-grouse, greater prairie chicken [*Tympanuchus cupido*], sharp-tailed grouse [*T. phasianellus*]), and pygmy rabbits, among other species. Tactics for maintaining adequate sagebrush habitat included managing fire, controlling nonnative species, preventing fragmentation, and restoring degraded habitat (table 9.7). Current focus on conservation of greater sage-grouse within sagebrush habitat in the western United States will benefit from including a climate-smart approach to management.

Developing on-the-ground management tactics requires understanding how climate change will influence species. In all subregions, and independent of habitat association, participants identified the need for better understanding of species requirements and the mechanisms of climate change impacts. In addition, connectivity and the potential for increases in disease were identified as important processes affecting multiple habitats and species in each subregion, although climate sensitivities of diseases are not well understood. Accordingly, several adaptation strategies were suggested to fill knowledge gaps (table 9.8). There is wide agreement on the need to better understand the mechanisms of climate sensitivities relative to the life histories of individual species. Examples of tactics to accomplish this objective include analyzing female Canada lynx home ranges to determine the necessary distribution and size of habitat patches, quantifying and monitoring pygmy rabbit distribution, and understanding sagebrush succession after fire. The influence of low snow years on wolverine

Table 9.2—Adaptation options that address climate change effects on riparian habitat and associated wildlife species in the Northern Rockies.

Sensitivity to climatic variability and change: Decreased streamflow reduces riparian vegetation, affecting food supply and habitat structure for multiple species.			
Adaptation strategy/approach: Improve riparian habitat by maintaining healthy beaver populations on the landscape.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Inventory current and potential habitat (include multiple factors).	Restore riparian habitat e.g. plant willows, manage grazers, raise water level.	Translocation, manage trapping
Where can tactics be applied? (geographic)	Range-wide	Suitable habitats range-wide	Suitable habitats range-wide

Table 9.3—Adaptation options that address climate change effects on quaking aspen habitat and associated wildlife species in the Northern Rockies.

Sensitivity to climatic variability and change: A warmer climate will lower water tables, leading to loss of quaking aspen.			
Adaptation strategy/approach: Promote aspen resilience.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Promote disturbance (fire, cutting) in older aspen stands.	Protect from grazing (fencing, manage grazing).	Reduce conifer competition (fire, cutting) in any age aspen stand.
Where can tactics be applied? (geographic)	Range-wide	Range-wide	Range-wide

denning success is an example of a mechanistic relationship with climate that needs more data.

Connectivity, although not tied to a particular habitat type, is considered an important conservation strategy for most species in all Northern Rockies subregions, although climate influences on connectivity are uncertain. Several forms of connectivity were identified: daily, seasonal, dispersal, and range shift. Connectivity can be affected by changes in water supply, habitat loss, habitat shifts, vegetation phenology shifts, human population expansion and redistribution, and snowpack dynamics. Specific tactics for increasing knowledge that would enable the maintenance of connectivity include monitoring connectivity with genetic, tracking, and remote-sensing tools; identifying dispersal habitats; and identifying and removing or mitigating barriers to connectivity (table 9.9).

Disease is also important in most subregions, not tied to a particular habitat, and not well understood. Specific tactics for addressing disease include monitoring the presence of white-nose syndrome (caused by the fungus *Pseudogymnoascus destructans*) in bat hibernacula (ongoing through collaboration of the USFS, other agencies, and Northern Rocky Mountain Grotto), monitoring disease trends in moose and bighorn sheep, and coordinating with State agencies to monitor West Nile virus.

More specific details on adaptation strategies and tactics that address climate change effects on wildlife in each NRAP subregion are in Appendix 9A.

Acknowledgments

We thank all of the workshop participants without whose participation this chapter would not be possible. Their critical thinking regarding issues of wildlife and management response to climate change was both important and greatly appreciated. We would like to extend special thanks to Erik Beever, who assisted in writing the section on American pika.

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Table 9.4—Adaptation options that address climate change effects on dry forest (ponderosa pine) habitat and associated wildlife species in the Northern Rockies.

Sensitivity to climatic variability and change: A warmer climate will potentially convert drier ponderosa pine to grassland; in addition, many ponderosa stands have converted to Douglas-fir because of fire exclusion and are susceptible to projected increases in fire frequency.

Adaptation strategy/approach: Promote ponderosa pine resilience

	Specific tactic – A	Specific tactic – B	Specific tactic – C	Specific tactic – D
Tactic	Reduce competition from Douglas-fir and grand fir (thin, burn) in current mature ponderosa pine stands.	Frequent understory burning.	Retain current mature and older ponderosa pine stands.	Plant ponderosa pine where it has been lost.
Where can tactics be applied? (geographic)	Range-wide	Range-wide	Range-wide	Range-wide

Table 9.5—Adaptation options that address climate change effects on old-growth, mesic forest habitat and associated wildlife species in the Northern Rockies.

Sensitivity to climatic variability and change: A warmer climate will create drier conditions and cause more wildfire, potentially eliminating old forest structure and mesic habitat.

Adaptation strategy/approach: Maintain current habitat, restore historical habitat, and promote potential future inland maritime forest habitat.

	Specific tactic – A	Specific tactic – B	Specific tactic – C	Specific tactic – D
Tactic	Conserve current old-growth western redcedar and western larch, but reduce density to increase resilience to drought.	Restore western white pine with a western redcedar understory to create future habitat.	Maintain or create necessary structure in modeled future fisher habitat.	Conserve current old-growth western redcedar and western larch, but reduce density to increase resilience to drought.
Where can tactics be applied? (geographic)	Northern Idaho, Kootenai, Bitterroot divide Where risk of loss is greatest (edge of range) Need redundancy across landscape to buffer against future fire or drought mortality.	Northern Idaho, Kootenai, Bitterroot divide. Need redundancy across landscape to buffer against future fire or drought mortality.	Mission side of Swan Range. Need redundancy across landscape to buffer against future fire or drought mortality.	Northern Idaho, Kootenai, Bitterroot divide Where risk of loss is greatest (edge of range) Need redundancy across landscape to buffer against future fire or drought mortality.

Table 9.6—Adaptation options that address climate change effects on mountain sagebrush-grassland habitat and associated wildlife species in the Northern Rockies.

Sensitivity to climatic variability and change: A warmer climate will dry soils, reducing the forb component of mountain sagebrush-grassland habitat.			
Adaptation strategy/approach: Maintain current and restore historical habitat.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Manage fire to maintain desired habitat.	Control invasive vegetation.	Restore formerly cultivated land.
Where can tactics be applied? (geographic)	Range-wide	Range-wide	Range-wide

Table 9.7—Adaptation options that address climate change effects on sagebrush habitat and associated wildlife species in the Northern Rockies.

Sensitivity to climatic variability and change: A warmer climate and increased wildfire will reduce the distribution and abundance of sagebrush habitat.				
Adaptation strategy/approach: Maintain adequate sagebrush habitat.				
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**	**Specific tactic – D**
Tactic	Manage fire to maintain desired habitat.	Control invasive vegetation.	Restore formerly cultivated land.	Prevent fragmentation of sagebrush habitat (roads, energy development lines).
Where can tactics be applied? (geographic)	Range-wide	Range-wide	Range-wide	Range-wide

Table 9.8—Adaptation options that address knowledge gaps in climate change effects on wildlife populations in the Northern Rockies.

Sensitivity to climatic variability and change: Species requirements and/or climate sensitivities are largely unknown for many species.				
Adaptation strategy/approach: Increase knowledge of species needs and climate sensitivities				
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**	**Specific tactic – D**
Tactic	Analyze female lynx home ranges to determine necessary mix of habitat patches: distribution and size.	Update and expand knowledge of existing pygmy distribution.	Understand climate influences on pygmy rabbits.	Understand succession after fire in sagebrush.
Where can tactics be applied? (geographic)	Range-wide	Range-wide	Range-wide	Range-wide
Sensitivity to climatic variability and change: Loss of connectivity can be caused by changes in water supply and snowpack dynamics, habitat loss, habitat shifts, vegetation phenology shifts, and human population expansion and redistribution.				
Adaptation strategy/approach: Maintain multiple levels of connectivity (daily, seasonal, dispersal range shift).				
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**	**Specific tactic – D**
Tactic	Monitor connectivity using genetics, tracking, remote sensing tools (e.g., multi-carnivore genetic monitoring across the Northern Continental Divide Ecosystem with multiple partners.	Compile table of connectivity vulnerability by species (daily through range shift).	Identify dispersal habitat requirements for selected species (e.g., wolverine).	Identify and remove or mitigate barriers.
Sensitivity to climatic variability and change: Disease transmission may increase with warmer temperatures.				
Adaptation strategy/approach: Increase knowledge of disease-climate relationships.				
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**	
Tactic	Monitor environmental conditions at bat hibernacula to understand environmental conditions that promote white-nose syndrome.	Monitor moose and bighorn sheep disease trends to determine if there are climatic drivers.	Work with the State wildlife departments to monitor West Nile virus.	
Where can tactics be applied? (geographic)	Region-wide	Region-wide	Region-wide	

Table 9.9—Adaptation options that address climate change effects on connectivity for wildlife populations in the Northern Rockies.

Sensitivity to climatic variability and change: Connectivity depends multiple factors, including water supply, habitat shifts, vegetation phenology, snow pack dynamics, and human population expansion and redistribution.

Adaptation strategy/approach: Maintain connectivity.

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactic	Monitor connectivity through genetics, tracking, and remote sensing.	Compile table of known connectivity vulnerabilities by species.	Identify and remove barriers.
Where can tactics be applied? (geographic)	Region-wide	Region-wide	Region-wide

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Appendix 9A—Adaptation Options for Wildlife in the Northern Rockies.

The following tables describe climate change sensitivities and adaptation strategies and tactics for wildlife, developed in a series of workshops as a part of the Northern Rockies Adaptation Partnership. Tables are organized by subregion within the Northern Rockies. See Chapter 9 for summary tables and discussion of adaptation options for wildlife.

Table 9A.1—Adaptation options that address climate change effects on wildlife in the Central Rockies subregion.

Sensitivity to climatic variability and change: Potential conversion to grassland type; many ponderosa pine forests have converted to Douglas-fir types with fire exclusion and are therefore more susceptible to future fires (putting dry forest cavity nester habitat at risk).

Adaptation strategy/approach: Restore fire-adapted ponderosa pine stand conditions for dry forest cavity nesters.

Strategy objective: Promote resilience.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Reduce competition from Douglas-fir and grand fir (thin, burn) in current mature ponderosa pine stands.	Conduct frequent understory burning.	Retain current mature and older ponderosa pine stands and plant where it has been lost.
Tactic effectiveness (risks)	High	High	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Low elevations with emphasis on where compatible with wildland urban interface (WUI) objectives; need redundancy across the landscape to buffer against future fire or drought mortality	Has to follow tactic A in the WUI, not necessarily in non-developed areas; need redundancy across the landscape to buffer against future fire or drought mortality	Wherever they occur; need redundancy across the landscape to buffer against future fire or drought mortality
Opportunities for implementation	Collaboration with other landowners	Collaboration with other landowners	Collaboration with other landowners
Cost	Low in places with market size Douglas-fir, otherwise moderate.	Moderate, depending on location	Low for retaining, moderate for planting
Barriers to implementation	Some	Major	None

Table 9A.2—Adaptation options that address climate change effects on wildlife in the Central Rockies subregion.

Sensitivity to climatic variability and change: Drying of inland maritime forest types that fishers depend on.

Adaptation strategy/approach: Maintain current, restore historical, and promote potential future fisher habitat. Conserving fisher habitat preserves cool wet forest types that provide habitat for multiple other wildlife species.

Strategy objective: Promote resilience, facilitate transition

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Conserve current old-growth cedar and larch, but reduce density to increase resilience to drought.	Restore white pine with a cedar understory to create future habitat.	Maintain or create necessary structure in modeled future fisher habitat.
Tactic effectiveness (risks)	Moderate	Uncertain	Unknown (will that be habitat) and uncertain (can the conditions be effectively created)
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Northern ID, Kootenai, Bitterroot divide; where risk of loss is greatest (edge of range); need redundancy across the landscape to buffer against future fire or drought mortality.	Northern ID, Kootenai, Bitterroot divide; need redundancy across the landscape to buffer against future fire or drought mortality.	Mission side of Swan; need redundancy across the landscape to buffer against future fire or drought mortality.
Opportunities for implementation	Fits with Collaborative Forest Landscape Restoration Program (CFLRP) objectives	Fits with CFLRP objectives	Fits with CFLRP objectives
Cost	Inexpensive	Moderate	Varies
Barriers to implementation	Major	None	Some

Table 9A.3—Adaptation options that address climate change effects on wildlife in the Central Rockies subregion.

Sensitivity to climatic variability and change: Snow melt occurring earlier in the spring creates snowshoe hare pelage mismatch. Lynx adapted to deep soft snow and denser snow could give other predators a competitive advantage. Burn intensity is predicted to increase, and repeat burns can reduce tree seed source; in winter, lynx avoid high intensity burns until tree regeneration allows for branches at snow surface.

Adaptation strategy/approach: Manage vegetation for long-term lynx and hare habitat and connectivity.

Strategy objective: Promote resilience, reduce stressors, and facilitate transition.

	Specific tactic – A	Specific tactic – B	Specific tactic – C	Specific tactic – D
Tactic	Thin some young stands to create a variety of multi-storied hare habitat across the landscape to prevent boom and bust cycles.	Maintain forest cover connections between good habitat patches.	Maintain current multi-storied forest conditions, prevent large monoculture stand conditions (burning, harvest).	Analyze female home ranges to determine necessary mix of habitat patches (distribution and size).
Tactic effectiveness (risks)	Uncertain	Moderate	Moderate	Moderate
Implementation urgency	Near Term	Near Term	Near Term	Near Term
Where can tactics be applied? (geographic)	Anywhere in current range of lynx	Anywhere in current range of lynx	Anywhere in current range of lynx	Anywhere in current range of lynx
Opportunities for implementation	Forest Planning; U.S. Fish and Wildlife Service	U.S. Fish and Wildlife Service	Northern Rockies Lynx Management Direction; critical habitat rule; U.S. Fish and Wildlife Service	U.S. Fish and Wildlife Service; Rocky Mountain Research Station; Collaborative Forest Landscape Restoration Program; Southwest Crown Partnership
Cost	Moderate	Inexpensive	Moderate	Inexpensive
Barriers to implementation	Major	Major	None	None

Table 9A.4—Adaptation options that address climate change effects on wildlife in the Central Rockies subregion.

Sensitivity to climatic variability and change: Townsend's big-eared bat maternal colonies winter hibernacula are sensitive to temperature change, loss of access to habitat, and spread of white-nose syndrome.

Adaptation strategy/approach: Maintain maternal colony and hibernacula sites, and reduce non-climate stressors.

Strategy objective: Increase knowledge, promote resilience, reduce stressors, engage coordination

	Specific tactic – A	Specific tactic – B	Specific tactic – C	Specific tactic – D
Tactic	Identify, and protect current maternal colony sites.	Monitor environmental conditions at identified sites, compared to unoccupied sites.	Educate the public (caver groups) about spread of white-nose syndrome and stress decontamination procedures.	Maintain, or create, open wetland complexes (for insects) near maternal colony sites.
Tactic effectiveness (risks)	High	Moderate, but not an end point itself	Moderate	Unknown
Implementation urgency	Near term	Near term	Near term	Near to mid term
Where can tactics be applied? (geographic)	Range wide	Public land	Range wide	Public land
Opportunities for implementation	Local caving clubs	Local caving clubs	Local caving clubs	Mostly on private lands
Cost	Moderate	Inexpensive	Inexpensive	Variable
Barriers to implementation	Some	Some	None	Some

Table 9A.5—Adaptation options that address climate change effects on wildlife in the Central Rockies subregion.

Sensitivity to climatic variability and change: Increasing winter temperatures reduce snowpack, and snow melt occurs earlier in the spring. Wolverines are obligate snow denners.

Adaptation strategy/approach: Maintain wolverine female reproductive capacity and core habitat connection.

Strategy objective: Reduce stressors.

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactic	Map areas with high persistent snow potential; identify protection status and development potential to identify areas of concern and connection between mountain ranges.	Identify dispersal habitat requirements.	Conduct multi-carnivore genetic monitoring.
Tactic effectiveness (risks)	High	Variable	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Range wide	Range wide	Range wide
Opportunities for implementation			Coordinate existing monitoring, and develop regional monitoring goals.
Cost	Inexpensive	Expensive	Expensive
Barriers to implementation	None	Some	Some

Table 9A.6—Adaptation options that address climate change effects on wildlife in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Pygmy rabbits are dependent on big-sage, which may be vulnerable to climate change, but range could expand with climate change.

Adaptation strategy/approach: Increase information on distribution and sensitivities of pygmy rabbit.

Strategy objective: Increase knowledge.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Produce more accurate sage distribution layer.	Update and expand knowledge of existing pygmy distribution.	Understand climate influences on pygmy rabbits.
Tactic effectiveness (risks)	Moderate	Moderate	Moderate
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Eastern subregion	Eastern subregion	Eastern subregion
Opportunities for implementation		Heritage program.	Wildlife Conservation Society study at the Idaho National Lab; candidate for State Wildlife Grant funding
Cost	Moderate	Moderate	Moderate
Barriers to implementation	Some: funding priority	Some: funding priority	Some: funding priority, not on anyone's radar screen

Table 9A.7—Adaptation options that address climate change effects on wildlife in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Pygmy rabbits are dependent on big-sage, which may be vulnerable to climate change, but range could expand with climate change.

Adaptation strategy/approach: Conserve pygmy rabbit habitat.

Strategy objective: Promote resilience.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Obtain conservation easements in current sagebrush areas.	Lease sagebrush.	Understand succession after fire in sagebrush in the region.
Tactic effectiveness (risks)	High	High	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Sagebrush habitat on unprotected private land	Sagebrush habitat on private and State land	Sagebrush habitat
Opportunities for implementation	Land Reliance; partners		
Cost	Inexpensive (cost-sharing and is happening now, even though a lot of money is spent)	Inexpensive (happening now, even though a lot of money is spent)	Inexpensive to moderate
Barriers to implementation	Some: land owner willingness; political consequences	Some	Funding priorities; lack of understanding for the need for the information; difference of opinion about what we already know

Table 9A.8—Adaptation options that address climate change effects on wildlife in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Bat hibernaculum temperature change linked to white-nose syndrome; alternative energy development impacts (wind power).

Adaptation strategy/approach: Maintain healthy bat populations.

Strategy objective: Reduce stressors; increase knowledge and coordination.

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactic	Consider summer roosting in vegetation management.	Protect hibernacula from disturbance.	Survey for hibernacula.
Tactic effectiveness (risks)	Uncertain	Moderate	Uncertain
Implementation urgency			
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 9A.9—Adaptation options that address climate change effects on wildlife in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Reduced stream flow, loss of riparian vegetation, incised stream channels due to flood events.

Adaptation strategy/approach: Maintain healthy beaver populations on the landscape.

Strategy objective: Promote resilience; reduce stressors; increase public knowledge (slow down the water).

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Inventory current and potential habitat (include multiple factors).	Restore riparian habitat (e.g., plant willows, manage grazers, raise water level).	Translocate beavers, manage trapping.
Tactic effectiveness (risks)	High	High	High
Implementation urgency			
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 9A.10—Adaptation options that address climate change effects on wildlife in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Habitat shifts and disease transmission in bighorn sheep from direct and indirect effects of climate change (e.g., increase in overlap with domestics, increased disease transmission, shifts in pressure from recreation).

Adaptation strategy/approach: Maintain healthy bighorn sheep populations.

Strategy objective: Increase knowledge; reduce stressors; promote resilience.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Monitor sheep disease trends to determine if there are climate drivers.	Identify locations and improve connectivity between seasonal ranges; maintain separation from domestic sheep.	Maintain communication among research groups and promote sharing of information and collaboration of research/management efforts.
Tactic effectiveness (risks)	Unknown	High	Moderate
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation	Focus of current attention (state, federal, non-governmental organizations, universities)	Focus of current attention (state, federal, non-governmental organizations, universities)	Focus of current attention (state, federal, non-governmental organizations, universities)
Cost	Inexpensive	Moderately to expensive depending on scale	Inexpensive
Barriers to implementation	None	Some to major (social, legal, jurisdiction)	None

Table 9A.11—Adaptation options that address climate change effects on wildlife in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Loss of mountain sage and grassland habitat for Brewer's sparrow.

Adaptation strategy/approach: Maintain adequate mountain sage grassland communities for Brewer's sparrow.

Strategy objective: Promote resilience, reduce stressors, and increase knowledge.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Manage fire to maintain desired habitat (see sage-grouse conservation strategy).	Control invasive vegetation.	Restore formerly cultivated land.
Tactic effectiveness (risks)	High	Low to high depending on the invasive species	Low to high depending on site conditions
Implementation urgency			
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 9A.12—Adaptation options that address climate change effects on wildlife in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Water supply; habitat loss; habitat shifts; vegetation phenology shifts; human population expansion and redistribution; snowpack dynamics.

Adaptation strategy/approach: Maintain connectivity within and through the Greater Yellowstone Area (GYA), including daily, seasonal, dispersal, and range shift connectivity.

Strategy objective: Facilitate transition; engage coordination; increase knowledge

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactic	Monitor connectivity (genetics, tracking, remote sensing).	Compile table of connectivity (daily through range shift) vulnerability by species.	Identify and remove barriers.
Tactic effectiveness (risks)	Moderate	High	High
Implementation urgency			
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation	New technologies (e.g., eDNA, remote cameras, GPS collars) make this more accessible		
Cost			
Barriers to implementation			

Table 9A.13—Adaptation options that address climate change effects on wildlife in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Moose prefer colder temperatures; increased disease potential in warmer climates; increased algal growth in warmer ponds; precipitation patterns affect growth of preferred vegetation.

Adaptation strategy/approach: Maintain healthy moose habitats (e.g., riparian, aspen, spruce-fir) and populations.

Strategy objective: Reduce stressors; engage coordination.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Reduce mortality; coordinate with state agencies to reduce hunting quotas; coordinate to reduce highway mortality.	Increase knowledge and monitoring of disease and pests.	Improve riparian habitat: see beaver sheet.
Tactic effectiveness (risks)	Moderate	Moderate	High
Implementation urgency			
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 9A.14—Adaptation options that address climate change effects on wildlife in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Loss of aspen due to warmer, drier climate and lower water table.

Adaptation strategy/approach: Maintain adequate habitat structural diversity to support ruffed grouse populations.

Strategy objective: Promote resilience; increase knowledge.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Promote disturbance (fire, cutting) in older aspen stands.	Protect from grazing (fencing, manage grazing).	Reduce conifer competition (fire, cutting) in any age aspen stand.
Tactic effectiveness (risks)	High	High	High
Implementation urgency			
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 9A.15—Adaptation options that address climate change effects on wildlife in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Loss of sage and grassland habitat for greater sage-grouse.

Adaptation strategy/approach: Maintain adequate sage grassland communities, with inclusion of mesic meadows (brood rearing), for greater sage grouse.

Strategy objective: Promote resilience, reduce stressors, increase knowledge

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**	**Specific tactic – D**
Tactic	Manage fire to maintain desired habitat (see sage-grouse conservation strategy).	Control invasive vegetation.	Restore formerly cultivated land.	Limit human disturbance (e.g., grazing, hunting, infrastructure).
Tactic effectiveness (risks)	High	Low to High depending on the invasive species	Low to high depending on site conditions	High
Implementation urgency				
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation				
Cost				
Barriers to implementation				

Table 9A.16—Adaptation options that address climate change effects on wildlife in the Western Rockies subregion.

Sensitivity to climatic variability and change: Conversion to nonnatives; change in fire frequency; reduction in cover; change of available forage could affect insects, affecting mountain quail habitat.

Adaptation strategy/approach: Reduce stressors on mountain quail.

Strategy objective: Promote resilience, reduce stressors

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactic	Reduce high-intensity burns using fuel breaks and late winter burning to reduce fuel buildup.	Maintain conifer components, including north face and higher elevation riparian stringers to retain moisture in microsites; replant; protect from burning; avoid harvesting.	Need more information on insect production and the forb component associated with moist areas; how will insects react with phenology changes?
Tactic effectiveness (risks)			
Implementation urgency			
Where can tactics be applied? (geographic)	Western Rockies subregion	Western Rockies subregion	Western Rockies subregion
Opportunities for implementation			
Cost			
Barriers to implementation			

Chapter 10: Effects of Climate Change on Recreation in the Northern Rockies Region

Michael S. Hand and Megan Lawson

Introduction

Outdoor recreation is an important benefit provided by Federally managed and other public lands throughout the Rocky Mountains. National forests in the Forest Service, U.S. Department of Agriculture (USFS) Northern Region and Greater Yellowstone Area (a region hereafter called the Northern Rockies region) have an estimated 13.3 million visits per year; Yellowstone, Grand Teton, and Glacier National Parks account for another 8 million visits per year. National forests and national parks provide recreation opportunities at sites that offer a wide variety of characteristics. Recreation on public lands in the Northern Rockies region is inseparable from ecosystems and natural features. Whether visitors ski, hike, hunt, or camp, explore developed sites or the backcountry, or simply drive through a park or forest, natural and ecological conditions in large part determine their overall recreation experience.

Climatic conditions and environmental characteristics that depend on climate are key factors that determine the availability of and demand for different recreation opportunities (Shaw and Loomis 2008). Changing climatic conditions may alter the supply of and demand for recreation opportunities, resulting in changes in visitation patterns and the benefits derived from recreation in the future. Climate change is projected to increase outdoor recreation participation in general (Bowker et al. 2014). Benefits provided by recreation are expected to increase under climate change scenarios because anticipated increases in summer and warm-weather activities will outweigh losses in winter activities (Loomis and Crespi 2004; Mendelsohn and Markowski 2004).

Public lands managers will face a complex task of managing recreation opportunities under changing recreational preferences and ecological conditions. Investments in infrastructure, the provision and maintenance of facilities, and decisions about recreation development are important inputs that determine recreational setting and the type of recreational opportunities available to visitors. These inputs can be classified by using the Recreation Opportunity Spectrum, which has been used for decades by public lands managers for planning and allocation of recreation opportunities (Clark and Stankey 1979). Recreation visitation behavior and values can be mapped to the Recreation Opportunity Spectrum, providing managers with information about the tradeoffs associated with different types of investments and development (Rosenthal and Walsh 1986; Swanson and Loomis 1996). A changing climate may alter types of recreation experiences desired and the opportunities that can be provided by public lands.

Although broad trends in recreation participation under climate change scenarios may be borne out at the regional scale, little is known about how recreation in the Northern Rockies region will change. This chapter describes the broad categories of recreation activities that may be sensitive to climate-related changes in the region, and assesses the likely effects of projected climate changes on recreation participation.

Relationships Between Climate Change and Recreation

The supply of and demand for recreation opportunities are sensitive to climate through (1) a direct effect of changes in temperature and precipitation on the availability and quality of recreation sites, and (2) an indirect effect of climate on the characteristics and ecological condition of recreation sites (Loomis and Crespi 2004; Mendelsohn and Markowski 2004; Shaw and Loomis 2008) (fig. 10.1).

Direct effects of changes in 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; Stratus Consulting 2009). Warm-weather activities are also sensitive to direct effects of climate change. Increases in minimum temperatures have been associated with increased national park visits in Canada, particularly during nonpeak "shoulder" seasons (Scott et al. 2007). The number of projected warm weather days is positively associated with expected visitation for a national park in the United States, although visitation is expected to be lower under extreme-heat scenarios (Bowker et al. 2012; Richardson and Loomis 2004). Temperature and precipitation may also directly affect the comfort and enjoyment that participants derive from engaging in an activity on a given day (Mendelsohn and Markowski 2004).

Indirect climate effects tend to be important for recreation activities that depend on additional ecosystem inputs, such as wildlife, vegetation, and surface water.

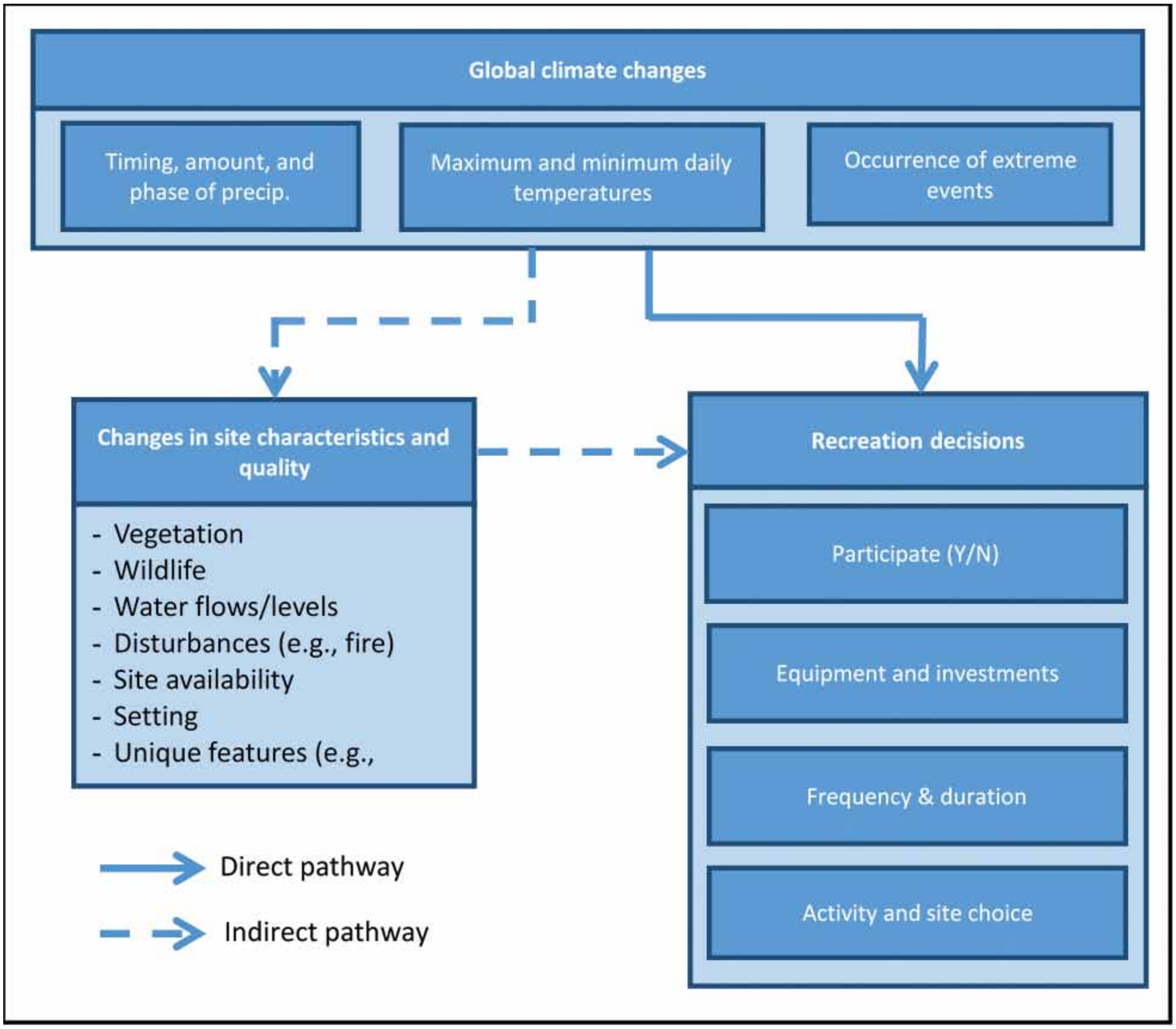

Figure 10.1—Direct and indirect effects of climate on recreation decisions.

Cold-water fishing is expected to decline in the future due to climate effects on temperature and streamflow that threaten cold-water fish species habitat (Jones et al. 2013) (see Chapter 5). Surface water area and streamflows are important for water-based recreation (e.g., boating), and forested area affects several outdoor activities (e.g., camping and hiking) (Loomis and Crespi 2004). Recreation visits to sites with highly valued natural characteristics, such as glaciers or popular wildlife species (see chapters 4 and 9) or scenic and aesthetic qualities, may be reduced in some future climate scenarios if the quality of those characteristics is threatened (Scott et al. 2007). The indirect climate effect on disturbances, and wildfire in particular (see Chapter 8), may also play a role in recreation behavior, although the effect may be diverse and vary over time (Englin et al. 2001).

Identifying Climate-Sensitive Outdoor Recreation Activities

People participate in a wide variety of outdoor recreation activities in the Northern Rockies region. The National Visitor Use Monitoring (NVUM) survey, conducted by the USFS to monitor recreation visitation and activity on national forests, identifies 27 different recreation activities in which visitors may participate. These include a wide variety of activities and ways that people enjoy and use national forests and other public lands.

The NVUM surveys roughly one-quarter of forest units in each region every year, and each unit is surveyed again every 5 years. For this analysis, we used the latest survey data available for each forest. Sample years for the units included in this analysis are as follows: 2008—Bridger-Teton, Custer, Helena; 2009—Gallatin, Idaho Panhandle, Shoshone; 2010—Beaverhead-Deerlodge, Caribou-Targhee, Flathead;

2011—Clearwater, Lolo, Nez Perce; 2012—Bitterroot, Kootenai, Lewis and Clark. Visitors are sampled by using a stratified random sampling technique designed for assessing use on national forests. Sampling sites are stratified according to type of recreation site and times of day and week. Visitors are asked about different categories of trip-related spending incurred within 50 miles of the site where they are interviewed. Interviewees are selected at random, and interviewers conduct as many surveys as possible (English et al. 2001).

All outdoor recreation activities depend to some degree, directly or indirectly, on climatic conditions or environmental conditions that are determined by climate. For example, skiing opportunities depend on the availability of areas with snow-covered terrain, which is determined by patterns of temperature and precipitation as snow. As climate change affects seasonal trends in temperature and precipitation, the availability of certain skiing sites may change in the future.

To assess how recreation patterns may change in the Northern Rockies region, categories of outdoor recreation activities that may be sensitive to climate changes were identified (fig. 10.2). For this assessment, a recreation activity was considered sensitive to climate change if changes in climate or environmental conditions that depend on climate would be an important factor affecting the demand for or supply of that recreation activity within the study area. However, there is no hard rule by which activities satisfy this requirement, and other types of activities not explicitly covered in this chapter may be affected by climate changes.

The 27 recreation activities identified in the NVUM survey were grouped into 5 climate-sensitive categories of activities, plus an "Other" category of activities that are less sensitive to climate changes. Each category includes activities likely to be affected by changes in climate and environmental conditions in similar ways. Table 10.1 lists the activities in the climate-sensitive categories and summarizes their sensitivity to climate changes. The categories were developed to capture the most common types of recreation that people engage in on public lands in the Northern Rockies region that would be affected by climate changes. Seventeen activities were identified as sensitive to climate changes.

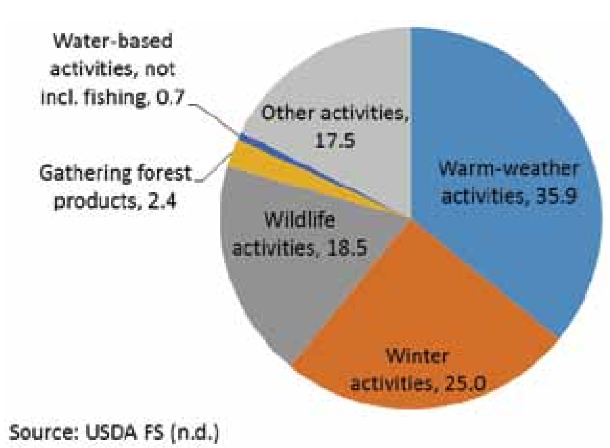

Figure 10.2—Percent of total national forest visits by climate-sensitive primary activity.

These 17 activities account for the primary recreation activities for 83 percent of visits to national forests in the study area. Activities in the "Other" category were judged to be less sensitive to climate changes and tend to be less frequently listed as a primary recreation activity in the Northern Rockies region. Although participation in many of these activities may be linked to climate in some way, other factors are likely to be more important determinants of participation (for example, maintenance of infrastructure for visiting interpretive sites). 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 35.9 percent of national forest visitors (4.8 million visitors per year) (table 10.1). Of these, hiking/walking was the most popular, and is the primary reason for a visit for 16.9 percent of visitors (2.2 million people). Snow-based winter activities are also a large draw, and include downhill skiing, snowmobiling, and cross-country skiing. They were the primary activity for 25.0 percent of all visitors (3.3 million people). Wildlife-related activities, including hunting, fishing, and viewing wildlife, were the primary activity for 18.5 percent of visitors (2.5 million people). Of these, hunting was the most popular with 11 percent of visitors (1.5 million people). Gathering forest products such as berries and mushrooms was the primary activity for 2.4 percent of visitors (300,000 people). Motorized and nonmotorized water activities (other than fishing) attracted 0.7 percent of visitors (97,000 people) (table 10.1).

Non-local visitors—those who report a home ZIP code that is more than 30 miles from the forest boundary—spend $601 million (in 2014 dollars) per year within 50 miles of the forest boundaries. Note that some nonlocal respondents may have second homes near the forest boundary that would qualify as local had they reported the ZIP code associated with the second home (Stynes and White 2005). Table 10.2 summarizes expenditures by visitors to national forests in the Northern Rockies region. We focus on spending by nonlocal visitors because their expenditures in local communities would not have occurred otherwise. Lodging expenses account for nearly 31 percent of total expenditures, followed by restaurants (18 percent), gas and oil (17 percent), and groceries (12 percent). The remaining expenditure categories of other transportation, activities, admissions and fees, and souvenirs represent 21 percent of all spending.

Climate Change Vulnerability Assessment

The overall effect of climate change on recreation activity is likely to be an increase in participation and increase in the benefits derived from recreation. This is due primarily to warmer temperatures and increased season length appropriate

Table 10.1—Participation in different recreational activities in national forests in the Northern Region and Greater Yellowstone Area.

Activity	Relationship to climate and environmental conditions	National Forest visitors who participated in this activity as their main activity[a]	
		Percent of total NF visits	*Number*
Warm-weather activities	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.	35.9	4,770,616
Hiking/walking		16.9	2,248,171
Viewing natural features		8.6	1,136,245
Developed camping		2.8	375,174
Bicycling		2.2	286,707
Other non-motorized		2.0	265,476
Horseback riding		1.3	168,175
Picnicking		1.2	164,638
Primitive camping		0.6	74,876
Backpacking		0.4	51,154
Winter activities	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 inter-annual weather patterns.	25.0	3,318,426
Downhill skiing		12.8	1,695,621
Snowmobiling		6.4	843,778
Cross-country skiing		5.9	779,027
Wildlife activities	Wildlife availability 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.	18.5	2,452,053
Hunting		11.3	1,503,520
Fishing		5.3	708,589
Viewing wildlife		1.8	240,944
Gathering forest products	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.	2.4	313,475
Water-based activities, not including fishing	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 heat refuge during periods of extreme heat.	0.7	96,643

[a] Source: USDA FS (n.d.). Total estimated National Forest visits is 13,273,685. Percentage calculations are based on the percent of total visits accounted for by each activity and category.

for warm-weather activities, outweighing decreased winter activities that depend on snow and consistently cold temperatures (Mendelsohn and Markowski 2004). However, these general findings mask potential variation in the effects of climate on recreation between types of activities and geographic locations (boxes 10.1, 10.2).

This section assesses the likely effects of climate on major climate-sensitive recreation activities in the region (table 10.3). 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 recreation and studies of how recreation 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 Northern Rockies region, as detailed in the other chapters of this volume, are paired with the recreation literature to link expected responses of recreation behavior to specific expected climate effects.

Table 10.2—Total annual expenditures by non-local and local visitors to Northern Rockies and Greater Yellowstone Area national forests, by spending category.

Spending category	Non-local spending[a,b] Total annual expenditures	Non-local spending[a,b] Spending for each category	Local spending Total annual expenditures	Local spending Spending for each category
	Thousands of $ (2014)	%	*Thousands of $ (2014)*	%
Lodging	185,355	31	14,743	6
Restaurant	109,743	18	29,618	13
Groceries	74,003	12	44,886	19
Gasoline, oil	104,319	17	78,880	34
Other transportation	3,013	1	1,059	0
Activities	36,376	6	14,195	6
Admissions, fees	39,482	7	19,103	8
Souvenirs	48,839	8	28,075	12
Total	601,128		230,562	

[a] Non-local refers to trips that required traveling more than 50 miles.
[b] Source: USDA FS (n.d.).

Current Conditions and Existing Stressors

Public lands in the Northern Rockies region provide an abundance and variety of recreational options, offering opportunities for people of all interests and abilities. Opportunities range from high-use developed sites near urban areas and popular tourist destinations, to vast areas of remote wilderness and seldom used sites off the beaten path. The facilities and services available also exhibit a wide range of conditions and characteristics. Some sites are developed with modern amenities and staffed by agency employees or volunteers. Others may exhibit scant evidence of human influence other than a trailhead.

Current conditions reflect wide variation in intra-annual and interannual (within and between years) weather and ecological conditions. Temperature, precipitation, water flows and levels, wildlife distributions, vegetative conditions, and wildfire activity may vary widely. Recreationists are most likely already accustomed to some degree to making decisions with a significant degree of uncertainty about conditions at the time of participation.

Several existing challenges and stressors affect recreation in the Northern Rockies region. Increased population, particularly in proximity to public lands, can strain visitor services and facilities due to increased use; projected population increases in the future may exacerbate these effects (Bowker et al. 2012). Increased use due to population growth can also reduce site quality because of congestion at the most popular sites (Yen and Adamowicz 1994). Changes in land use may alter access to public lands, fragmentation of landscapes and habitat, and disturbance regimes that relate to recreation activities.

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. 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 (due to site quality and characteristics), but may also damage physical assets or exacerbate other natural hazards such as erosion (see chapters 4 and 12).

Current Management

Recreation is an important component of public land management in the Northern Rockies region. For lands managed by the USFS, sustainable recreation serves as a guiding principle for planning and management purposes (USDA FS 2010, 2012b). Recreation is included with other major multiple uses of national forests, such as timber products and livestock grazing. Sustainable recreation seeks to sustain and expand the benefits to the United States that quality recreation opportunities provide (USDA FS 2010). At the heart of this principle is the desire to manage recreational resources to increasingly connect people with natural resources and cultural heritage, and adapt to changing social needs and environmental conditions. Recreation managers aim to provide diverse recreation opportunities that span the recreation

Box 10.1—Subregional Assessment of Climate Change Effects on Recreation

The broad links between climate, ecological changes, and recreation behavior that form the basis of the activity category assessments are designed to be generally applicable to all locations in the Northern Rockies region. However, in a region that encompasses parts of five States and stretches hundreds of miles from east to west, significant subregional heterogeneity in climate effects may exist. The five Northern Rockies Adaptation Partnership (NRAP) subregions (Western Rockies, Central Rockies, Eastern Rockies, Greater Yellowstone Area [GYA], Grassland) represent a wide variety of geographic and ecological features, and each has distinctive recreation opportunities that may be sensitive to climate changes. Assessing differences between the subregions can yield more geographically specific information about the effects of climate on recreation.

Table 10.B1 summarizes national forest visits by primary activity category for each subregion. Warm-weather activities are the most common category for all subregions, but there are significant differences in the relative importance of each activity category. Snow-based recreation is relatively more important in the Central Rockies, Eastern Rockies, and GYA subregions, where there are multiple sites with consistently viable snow seasons and developed ski areas. In contrast, much less snow-based recreation (as a share of total visits) occurs in the Western Rockies and Grassland subregions. Wildlife recreation activities (hunting, fishing, wildlife viewing) are most important in the Western Rockies and Grassland, although the Central Rockies, Eastern Rockies, and GYA see a significant minority of visitors engaging in these activities. Forest product gathering and water-based (not fishing) activities represent a small share of visits in all subregions, but the Grassland subregion sees almost no visitation for these activities.

The differences in activity participation also suggest that climate will have different effects on recreation in each subregion. The largest differences in activity participation are for snow-based activities; these activities are also the most likely to have negative impacts due to warming temperatures and decreased precipitation as snow. The Grassland subregion and to a lesser extent the Western Rockies have relatively low exposure to this effect because snow-based recreation is less prominent. The Central Rockies, Eastern Rockies, and GYA have higher participation in snow-based activities that could be exposed to climate change, although it is unclear to what extent snow-based sites will experience changes that degrade conditions for snow-based activities.

Other differences between subregions are likely to depend on differences in climate effects between subregions. For example, one subregion could experience warming that increases the incidence of extreme heat days, which has a negative impact on warm-weather recreation, whereas another subregion might experience warming that extends the warm-weather season without a significant increase in the incidence of extreme heat days.

Table 10.B1—National Forest visits by NRAP subregion and activity category.

	Subregion[a]				
Activity category	**Western Rockies**	**Central Rockies**	**Eastern Rockies**	**Grassland**	**Greater Yellowstone Area**
	Percent of annual visitors reporting main activity				
Warm-weather activities[b,c]	36.7	36.9	33.3	60.8	36.2
Snow-based winter activities	7.4	26.0	27.2	1.6	31.3
Wildlife activities	23.3	19.6	18.8	30.5	15.1
Forest product gathering	6.5	1.9	2.1	0.0	1.1
Water-based activities, not including fishing	0.5	0.8	1.6	0.2	0.1

[a] To estimate activity participation, subregions are defined by groups of national forests: Western Rockies (Idaho Panhandle, Kootenai, Nez Perce-Clearwater), Central Rockies (Bitterroot, Flathead, Lolo), Eastern Rockies (Beaverhead-Deerlodge, Custer, Gallatin, Helena, Lewis and Clark), Grassland (Dakota Prairie Grasslands), Greater Yellowstone Area (Bridger-Teton, Caribou-Targhee, Shoshone). Geospatial definitions of the subregions include parts of several forests divided between two subregions—for example, parts of Custer, Beaverhead-Deerlodge, and Gallatin National Forests are divided between the Eastern Rockies and Greater Yellowstone Area subregions, but tabulated as part of the Eastern Rockies subregion; these forests are also summarized in table 10.B2 separately from the other Greater Yellowstone Area forests.

[b] Source: USDA FS (n.d.).

[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).

Box 10.2—Climate Change in the Greater Yellowstone Area and Glacier National Park

The Greater Yellowstone Area (GYA) provides a wide range of recreation opportunities. The GYA is composed of two national parks (Yellowstone, Grand Teton), parts of six national forests (Beaverhead-Deerlodge, Bridger-Teton, Caribou-Targhee, Custer, Gallatin, Shoshone), and other Federally administered protected areas (John D. Rockefeller Memorial Parkway, National Elk Refuge, Red Rock Lakes National Wildlife Reserve). These areas offer the full spectrum of recreation opportunities, from developed and urban settings to wilderness and primitive sites. Glacier National Park, which straddles the Western and Eastern Rockies subregions in northwestern Montana, also provides a broad range of recreation opportunities comparable to those in the GYA.

Recreation visitation to Federal units within the GYA and Glacier National Park is summarized in table 10.B2. Yellowstone National Park and Grand Teton National Park receive an annual average of 3.4 million and 2.6 million visitors, respectively. For both parks, two of the most common activities were viewing wildlife and viewing scenery and natural features. Most Yellowstone visitors also indicated that they engaged in developed camping, walking or hiking, and visiting museums and visitor centers. Grand Teton visitors indicated pleasure driving and walking or hiking as common activities (NPS 2006). Wildlife viewing is also an important activity for visitors to the Red Rock Lakes National Wildlife Refuge and the National Elk Refuge, although these sites receive only a fraction of the visitors compared with the national parks (NPS 2006). Sightseeing is the dominant activity for the 2.1 million annual visitors in Glacier National Park.

Table 10.B2—Recreation visits to Greater Yellowstone Area units and Glacier National Park.

Unit	Total annual visits	Most frequent activity	Year
Yellowstone National Park[a,b]	3,390,000	Viewing wildlife (93% of visitors)	2010–2014 annual average
Grand Teton National Park[a,b]	2,650,000	Viewing scenery (88% of visitors)	2010–2014 annual average
Red Rock Lakes National Wildlife Reserve[c]	12,000	Viewing wildlife (45% of visitors)	2014
National Elk Refuge[a,d]	900,000	Viewing wildlife (53% of visitors)	2008, 2004
Gallatin National Forest[e]	2,010,000	Hiking/walking (29% of visitors)	2009
Beaverhead-Deerlodge National Forest[e]	583,000	Hunting (32% of visitors)	2010
Caribou-Targhee National Forest[e]	1,850,000	Hiking/walking (18% of visitors)	2010
Shoshone National Forest[e]	646,000	Viewing natural features (25% of visitors)	2009
Bridger-Teton National Forest[e]	2,180,000	Downhill skiing (31% of visitors)	2008
Custer National Forest[e]	314,000	Downhill skiing (26% of visitors)	2008
Glacier National Park[b,f]	2,149,000	Sightseeing (97% of visitors)	2010–2014 annual average 1990 (visitor activities)

[a] Source: NPS (2006).
[b] Source: NPS (2014).
[c] Source: USDI (2014).
[d] Source: Sexton et al. (2012).
[e] Source: USDA FS (n.d.); most frequent activity is the reported main activity (visitors may engage in other secondary or tertiary activities).
[f] Source: Littlejohn (1991).
Note: Visitor data are not available for John D. Rockefeller Parkway.

Box 10.2—*Continued.*

National forests in the GYA receive a combined 7.6 million visitors annually. The most popular activity for visitors varies across forests. In the Gallatin and Caribou-Targhee National Forests, hiking and walking are the most popular activities, whereas downhill skiing is the most popular activity in Bridger-Teton and Custer National Forests. In Beaverhead-Deerlodge National Forest, hunting is the most popular activity (32 percent of visitors) and in Shoshone National Forest, viewing natural features is the most popular activity (25 percent of visitors).

Most of the general assessment of climate change effects on recreation in the Northern Rockies applies to the GYA and Glacier National Park, although the different activity profile means that exposure to the effects of climate change differs in this subregion. Visitation is dominated by warm-weather visits; 80 percent of visits to Yellowstone and Grand Teton National Parks are during the June–September period. An additional 11 percent of visits occur during the "shoulder" season months of May and October. Warmer temperatures are expected to increase warm-weather recreation; earlier- and later-season periods of snow- and ice-free sites in the parks may encourage additional off-peak visitation. Some visitors may also substitute early- or late-season visits to avoid extreme summer heat. However, seasonal shifts in visitation may be constrained by summer vacation months determined by academic calendars.

Changes in the distribution and abundance of wildlife may affect recreation visitation and enjoyment for the large number of Yellowstone and Grand Teton visitors who engage in wildlife viewing. However, many climate-related changes in target wildlife species are ambiguous because of complex interactions between species, vegetation and forage opportunities, and disturbances (see Chapter 9).

Other popular activities, such as driving for pleasure on roads and viewing scenery and special features (e.g., geysers and thermal features in Yellowstone, driving the Going-to-the-Sun Road in Glacier National Park), may be more or less sensitive to climate changes. In some cases the qualities, characteristics, and features that draw visitors to these activities have a limited connection to climate changes. However, features such as glaciers and snow-capped mountains are a particular draw for some visitors, and visitation tied to such features is likely to be affected. Longer warm-weather seasons will probably increase access to roads and sites inaccessible when snow and ice are present; greater accessibility would have a positive effect on visitation. In addition, wildfire and other disturbances can affect site access and the desirability of visiting fire-affected sites. For example, wildfires in Yellowstone National Park are associated with decreased visitation in the subsequent month, but there does not appear to be a lasting negative effect on visitation or wildfire occurrence (Duffield et al. 2013).

opportunity spectrum, from modern and developed to primitive and undeveloped (Clark and Stankey 1979).

Warm-Weather Activities

Warm-weather activities as a category are the most common recreation activities in national forests and national parks in the Northern Rockies region. Slightly more than one-third of all visits involve one of these activities as the primary activity of visitors. Warm-weather recreation is sensitive to the length of appropriate season, depending on the availability of snow- and ice-free trails and sites, and the timing and number of days with temperatures within the range of comfortable temperatures (which may vary with activity type and site). The number of warm-weather days has been shown to be a significant predictor of visitation behavior (Richardson and Loomis 2004), and studies of national park visitation show that minimum temperature is a strong predictor of monthly visitation patterns (Scott et al. 2007).

Participants are also sensitive to site quality and characteristics, such as the presence and abundance of wildflowers, condition of trails, and vegetation and cover (e.g., cover for shade, wildfire effects). The condition of unique features that are sensitive to climate changes, such as glaciers, may affect the desirability of certain sites (Scott et al. 2007). Forested area is positively associated with warm-weather activities, such as camping, backpacking, hiking, and picnicking (Loomis and Crespi 2004), and is sensitive to future climate changes (USDA FS 2012a).

Wildfire can also affect participation in warm-weather activities through changes to site quality and characteristics (fig. 10.3). Wildfires 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 have been associated with decreased recreation visitation, whereas low-intensity 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); these effects are attenuated over time. Visitation in Yellowstone National Park tends to be lower following months with high wildfire activity, although there is no discernable effect of previous-year fires (Duffield et al. 2013).

Overall demand for warm-weather activities is expected to increase due to a direct effect of climate change on season length. Temperatures are expected to increase 5 to 12 °F across the region by 2100 (see 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 fall. For example, higher minimum temperatures

Figure 10.3—Expectations for extent and severity of wildfires in a warmer climate will create forest conditions that may be less desirable for hiking and other recreational activities (photo courtesy of Dave Pahlas, http://IdahoAlpineZone.com).

are associated with increased number of hiking days (Bowker et al. 2012). More extreme summer temperatures can dampen participation during the hottest weeks of the year, and extreme heat scenarios for climate change are expected to reduce visitation (Richardson and Loomis 2004); higher maximum summer temperatures are associated with reduced participation in warm-weather activities (Bowker et al. 2012). The temperature that is considered "extreme" may vary between individuals and chosen activities. In Bowker et al. (2012), a linear effect of maximum summer temperature in the visitor's home county was included in participation models. 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).

Indirect effects of climate change on forested area may have a negative effect on warm-weather recreation if site availability and quality (e.g., scenic and aesthetic attributes) are compromised. However, the effect on warm-weather recreation in the Northern Rockies region and its various subregions will depend on local effects of climate on forest resources.

Potential increases in the likelihood of extreme wildfire activity may reduce demand for warm-weather activities in certain years because of degraded site desirability, impaired air quality from smoke, and limited site access due to fire management activities. The Northern Rockies region is expected to experience increases in area burned by wildfire, average fire size, and fire severity (see Chapter 8), which tend to have a negative impact on recreation visitation and benefits derived from recreation.

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 may decrease even if substitute activities or sites are available (Loomis and Crespi 2004). For example, some alternative sites may involve higher costs of access (because of remoteness or difficulty of terrain) or congestion costs if demand is concentrated among fewer desirable sites. In addition, visitors' ability to alter seasonality of visits may be limited because of the timing of scheduled academic breaks. Although recreationists' ability to substitute sites and activities is well established, there is less understanding of how people substitute across time periods or between large geographic regions (e.g., choosing a site in the Northern Rockies instead of the Southwest) (Shaw and Loomis 2008). In some cases, unique features or strong individual attachment to particular places may limit substitutability.

Projected climate scenarios are expected to result in a moderate increase in warm-weather recreation activity and benefits derived from these activities. Longer warm-weather seasons are likely to increase the number of days when warm-weather activities are viable and to 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; 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. Climate scenarios outlined in Chapter 3 differ in the projected magnitude of warming, but overall project warmer temperatures. Indirect effects on recreation, primarily through wildfire effects, may be harder to project with certainty and precision (particularly at a fine-grained geospatial scale).

Cold-Weather Activities

The Northern Rockies region boasts many winter recreation sites that in total exhibit a wide range of site characteristics and attract local, national, and international visitors. Several sites support developed downhill skiing and snowboarding operated by special-use permit on lands administered by the USFS. 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 and the length of viable seasons (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). Indirect effects of climate, such as changes in scenery and unique features (e.g., glaciers) may also affect winter recreation, although these effects are expected to be small relative to the effect of changes in amount and timing of snowfall.

Climate change is expected to have a generally negative effect on snow-based winter activities, although a wide range of effects at local scales is possible 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 (see 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). However, the highest elevation areas in the region remain snow dominated for a longer portion of the season in future climate scenarios.

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 (Wobus et al. 2017). Climatic projections for the Northern Rockies region (see Chapter 3) are consistent with studies of the vulnerability of ski areas to climate change in other regions, where projected effects of climate change on skiing, snowboarding, and other snow-based recreation activities are negative (Dawson et al. 2009; Scott et al. 2008; Stratus Consulting 2009).

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 (for example, cross-country skiing, backcountry skiing, snowmobiling, snowshoeing), recreationists may seek higher elevation sites with higher likelihoods of viable seasons. Although developed downhill skiing sites are fixed improvements, potential adaptations include snowmaking, development at higher elevations, and development of new runs (Scott and McBoyle 2007). However, the ability of winter tourism sector businesses to adapt probably varies considerably. 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.

Figure 10.4—Cross-country skiing at lower elevation locations (shown here in the Beaverhead-Deerlodge National Forest) may be vulnerable as snowpack decreases in future decades (photo courtesy of U.S. Forest Service).

Changes in Northern Rockies sites relative to other regions may also be important. If other regions experience relatively large effects of climate on snow-based recreation, recreationists may view Northern Rockies sites as a substitute for sites in other regions (e.g., the Southwest), although interregional substitution patterns for recreation activities are poorly understood (Shaw and Loomis 2008). Further, increased interregional substitution combined with shorter seasons may result in concentrated demand at fewer sites on fewer days, creating potential congestion effects.

The magnitude of climate 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 adjacent area is available and feasible for expanded development. In comparison to other regions, Northern Rockies winter recreation sites may see fewer effects from climate change; interregional substitution could mitigate losses in some years if participants from other regions are more likely to visit Northern Rockies sites. The likelihood of 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 mean that additional sites would be left exposed to the risk of shorter seasons.

Wildlife Activities

Wildlife 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, birding, 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 catching or seeing an individual of the target species. Sites with higher catch rates can reduce the costs associated with a wildlife 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 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). Changes to 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 activities may also be sensitive to other direct and indirect effects of climate change. The availability of highly valued targets affects benefits derived from wildlife activities (e.g., cutthroat trout [*Oncorhynchus clarkii*] for cold-water anglers) (Pitts et al. 2012), as does species diversity for hunting (Milon and Clemmons 1991) and nonconsumptive activities (Hay and McConnell 1979). Temperature and precipitation are related to general trends in participation for multiple wildlife activities (Bowker et al. 2012; Mendelsohn and Markowski 2004), although the precise relationship may be specific to the activity or species. Some activities such as 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 direct climate effects similar to warm-weather activities, in which moderate temperatures and snow- and ice-free sites are desirable.

Warming temperatures projected for the Northern Rockies region are expected to increase participation in terrestrial wildlife activities because of an increased number of days that are desirable for outdoor recreation. In general, warmer temperatures are associated with greater 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 hunting season dates managed by States) may depend on weather conditions during a short period of time. The desirability of hunting during established seasons may decline as warmer weather persists later into the fall and early winter and the likelihood of snow cover decreases, reducing harvest rates.

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) (see chapter 9), and are likely to be heterogeneous across species and habitat types. 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 (see Chapter 9). Similarly, the effects of disturbances on target species harvest rates are ambiguous because it is unknown exactly how habitat composition will change in the future.

Higher temperatures are likely to decrease populations of native cold-water fish species as climate refugia retreat to higher elevations (see Chapter 5). This change favors populations of fish species that can tolerate warmer temperatures. However, it is unclear whether shifting populations of species (e.g., substituting rainbow trout [*O. mykiss*] for cutthroat trout) will affect catch rates because relative abundance of fish may not necessarily change.

Total precipitation is not projected to change under future climate scenarios (see Chapter 3), but increased interannual variability in precipitation, the possibility of extreme drought, and reduced snowpack could result in higher peakflows in winter and lower low flows in summer, creating stress for fish populations during different portions of their life histories. The largest patches of habitat for cold-water species will be at higher risk to shrink and fragment. Increased incidence and severity of wildfire may increase the likelihood of secondary erosion events that degrade waterways and game species habitat. 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.

The magnitude of climate effects on activities involving terrestrial wildlife is expected to be low overall for terrestrial wildlife activities and moderate for fishing. Ambiguous effects of vegetative change on terrestrial wildlife populations and distribution suggest that conditions may improve in some areas and decline in others. Overall warming tends to increase participation, but may create timing conflicts for activities with defined regulated seasons (e.g., big game hunting) unless the timing of seasons is changed. 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 retreat to higher elevations or are eliminated in some areas. Cold-water species tend to be the highest value targets, indicating 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.

Gathering Forest Products

Forest product gathering for recreational purposes accounts for a relatively small portion of primary activities during visits in the Northern Rockies region, although it is relatively more common as a secondary activity. Forest products are also important for cultural and spiritual uses, which are discussed in Chapters 11 and 12. A small but avid population of enthusiasts for certain types of products supports a small but steady demand for gathering as a recreational 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.

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 akin to warm-weather recreation activities because it also depends 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 (see chapters 6 and 7). Increased incidence and severity of wildland fires may eliminate sources of forest products in some locations (e.g., for berries), but in some cases fires may enhance short- or medium-term productivity for other products (e.g., mushrooms). Long-term changes in vegetation that reduces forest cover may reduce viability of forest product gathering in areas that have a high probability of vegetative transition to less productive vegetation types.

Recreationists engaged in forest product gathering may have the ability 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 a secondary or tertiary activity may choose alternate activities to complement primary activities. Commercial products serve as an imperfect substitute for some forest products such as Christmas trees.

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 or tertiary 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 is expected to be moderate, although significant uncertainty exists regarding direct and indirect effects on forest product gathering. Vegetative changes caused by climate changes and disturbances may alter abundance and distribution of target species, although the magnitude and direction of these effects are unclear.

Water-Based Activities, not Including Fishing

Separate from angling, water-based activities are 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 wildland fires).

Even if total precipitation does not change significantly under future climate scenarios (see Chapter 3), 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 (including the possibility of severe droughts), and decreased precipitation as snow. Reduced water levels may also have an indirect effect on the aesthetic qualities of some water-based recreation sites (e.g., exposure of "bathtub rings" at reservoirs with low water levels). 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). 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).

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 (see Chapter 4), which are associated with

Figure 10.5—Algal blooms, shown here in Hayden Lake, Idaho, may become more common in a warmer climate. These conditions are undesirable for water-based recreation and some fish species (photo courtesy of Panhandle Health District).

reduced site quality and suitability for certain activities (fig. 10.5). Increased demand for surface water by downstream users may exacerbate water levels in drought years. Warmer temperatures are expected to increase the demand for water-based recreation as the viable season lengthens. Extreme heat encourages some people to seek water-based activities as a climate refuge, although extreme heat also 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 broad population and economic shifts (Bowker et al. 2012).

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 and potential reductions to site aesthetic quality 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 increases due to warmer temperatures.

Summary

Several recreation activities are considered highly sensitive to changes in climate and ecosystem characteristics. However, recreation in the Northern Rockies 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, primarily because longer warm-weather seasons will make more recreation sites available for longer periods of time.

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 in recreation patterns in response to climate 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, activity type (e.g., downhill or cross-country skiing), location, frequency of participation, and duration of stay per trip depend somewhat on climate and ecological 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 between sites, climate and ecological characteristics, 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 precise effect of climate on target species or other quality characteristics may be difficult to predict or 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. Interregional and intertemporal substitution behavior is not yet well understood (Shaw and Loomis 2008). This may be important for the Northern Rockies region if in the future some sites exhibit relatively little effect from climate change compared with sites in other regions. For example, winter recreation sites in the Northern Rockies may experience shorter or lower quality seasons in the future but see increased demand if the quality of sites in other regions becomes relatively worse in the future.

Substitution is likely to be an important adaptation mechanism for recreationists. Many recreation activities that are popular in the region may have several alternate sites, or timing of visits can be altered to respond to climate changes. However, 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 slightly more costly to access, or slightly lower quality than the preferred visit prior to climate change. This represents a decrease in benefits to the person engaging in recreation.

Adapting Recreation to the Effects of Climate Change

Adapting recreation management to climate change in the Northern Rockies region will be critical to ensure that recreation opportunities exist in the future.

Adaptation by Recreation Participants

Increasing temperatures with changing climate will have significant negative effects on snow-based recreation. Length of the snow-based recreation season is likely to decrease, and the quality of the snow during the season may also decrease (be wetter).

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 need to adapt by altering the timing and location of hunts. However, State rules on hunting season dates impose a constraint on this behavior unless States change hunting seasons based on expected climate changes. Hunters may also target different species if the abundance or distribution of preferred species changes in the future.

Like hunters, wildlife viewers may change the timing and location of viewing experiences and target different species. Viewing is not typically governed by State-regulated seasons, so wildlife viewers may have more flexibility to shift timing to coincide with appropriate weather conditions or the movement of species into accessible areas. However, adaptation options may be more limited if the abundance or distribution of highly valued species significantly decreases the likelihood of viewing, and limited high-quality substitute species are available.

Anglers may adapt by choosing different species to target (for example, shifting from cold-water to warm-water tolerant species) and choosing sites that are relatively less affected by climate change (e.g., higher elevation secondary-stem reaches of streams). The former is less costly than the latter, although some anglers may place a high value on certain target species and have a lower willingness to target warm-water species that may thrive in place of cold-water species.

Adaptation by Public Land Managers

Managers may need to reconsider how infrastructure investments and the provision and maintenance of facilities align with changing ecological conditions and demands for recreation settings. The Recreation Opportunity Spectrum 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 may involve helping to shape the settings and experiences that are available to recreation users on public lands in the future.

For winter recreation, a general adaptation strategy may be a transition to recreation management that addresses shorter winter recreation seasons and changing recreation use patterns (table 10.4). 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 runs at higher elevations. In some cases, however, adaptations related to the supply and quality of winter recreation opportunities could result in tradeoffs with other activities, such as warm-weather access to undeveloped higher elevation sites or effects of snowmaking on streamflow in winter versus summer.

With higher temperatures and earlier snowmelt, warm-weather activity seasons are likely to lengthen. 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 (table 10.4). Then, adjustments can be made to increase the capacity of recreation sites that are showing increased use (e.g., campgrounds can be enlarged, and more fences, signs, and gates can be installed where necessary). The potential for congestion and damage to resources due to increases in use for some sites may, in part, drive such adjustments. However, there may be some limits to increasing the capacity of recreation sites (e.g., restrictions for developed recreation sites under the U.S. Fish and Wildlife Service [USFWS] Northern Continental Divide Ecosystem Grizzly Bear Conservation Strategy; USFWS 2013). The timing of actions such as trail closures, food storage orders, and special-use permits may also need to

Table 10.4—Adaptation options that address climate change effects on recreation in the Northern Rockies.

Sensitivity to climatic variability and change: Ice- and snow-based recreation is highly sensitive to variations in temperature and the amount and timing of precipitation as snow.			
Adaptation strategy/approach: Transition to address shorter average winter recreation seasons and changing use patterns.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Maintain current infrastructure and expand facilities in areas where concentrated use increases.	Develop options for diversifying snow-based recreation, such as cat-skiing, helicopter skiing, additional ski lifts, additional higher elevation runs, toboggan runs, snow making, and back country yurts.	Conduct safety education to make the public aware of increased risk of avalanche and thin ice.
Where can tactics be applied?	Snow recreation areas and major lakes	In and around existing permitted areas; within driving distance of population centers	Snow recreation areas and major lakes
Sensitivity to climatic variability and change: The warm weather recreation season will increase in length with increasing temperatures and earlier snowmelt.			
Adaptation strategy/approach: Provide sustainable recreation opportunities in response to changing demand.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Assess to understand changes in use patterns and identify demand shifts.	Adjust capacity of recreation sites (e.g., enlarge campgrounds, collect additional fees, and install infrastructure such as fences, signs and gates).	Adjust timing of actions such as road and trail closures, food storage orders, and special-use permits.
Where can tactics be applied?	At multiple levels (national, regional, forest-level, and local)	Where demand increases on Federal lands, as appropriate	Federal lands
Sensitivity to climatic variability and change: The seasonality of whitewater rafting will shift with increasing temperatures and shifts in the timing of peak streamflows.			
Adaptation strategy/approach: Increase management flexibility and facilitate transitions to meet user demand and expectation.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Vary permit season to adapt to changes in peakflow and duration.	Educate the public about changing river conditions.	n/a
Where can tactics be applied?	Permitted rivers	Permitted rivers	n/a
Sensitivity to climatic variability and change: Increases in flooding, fire, and other natural disturbances will cause damage to infrastructure.			
Adaptation strategy/approach: Manage recreation sites to mitigate risks to public safety and infrastructure and to continue to provide recreation opportunities.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Assess to determine which recreation sites and infrastructure are at risk from increased flooding and other natural hazards.	Prioritize post-disturbance treatments, including relocation, arming, and other mitigation measures.	Invest strategically in developed recreation facilities, prioritizing those that will be viable in the future and accommodate changing use patterns.
Where can tactics be applied?	Federal lands	Federal lands	Federal lands

be adjusted within the context of providing sustainable recreation. For example, the season for whitewater rafting permits may need to be modified to adjust to shifts in timing of peakflows (table 10.4).

Increased frequency of disturbances, such as fire and flooding, is likely to cause increased damage to infrastructure associated with multiple types of recreation activities. Recreation sites can be managed to decrease risks to public safety and infrastructure (table 10.4). Assessments can be used to determine which sites and infrastructure are most at risk from disturbance, and strategic investments can be made in those facilities that are expected to be viable in the future and accommodate changing use patterns.

More-specific details on adaptation strategies and tactics that address climate change effects on recreation in each Northern Rockies Adaptation Partnership subregion are in Appendix 10A.

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Appendix 10A—Adaptation Options for Recreation in the Northern Rockies.

The following tables describe climate change sensitivities and adaptation strategies and tactics for recreation, developed in a series of workshops as a part of the Northern Rockies Adaptation Partnership. Tables are organized by subregion within the Northern Rockies. See Chapter 10 for summary tables and discussion of adaptation options for recreation.

Table 10A.1—Adaptation options that address climate change effects on recreation in the Central Rockies subregion.

Sensitivity to climatic variability and change: Risk to infrastructure with changes in the frequency and severity of natural hazards and disturbances.

Adaptation strategy/approach: Manage recreation sites to mitigate natural hazards.

Strategy objective: Increase the resiliency of recreation sites by reducing threats and encouraging coordination with partners.

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactic	Maintain safety by assessing risk factors.	Identify flood plains and risks to campgrounds (developed sites) and dispersed recreation sites.	Identify effects after disturbance to recreation sites and prioritize treatments or conversions (e.g., relocate, arming, and/or mitigation measures).
Tactic effectiveness (risks)	Moderate–high	Moderate–high	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Forest lands or adjacent lands; high risk disturbance areas	Forest wide	National Forest System lands
Opportunities for implementation	Work with other agencies, such as the Federal Emergency Management Agency; use existing data for tree mortality and add species and overlay of use areas	Model risk of storm events, such as rain-on-snow events and flood events (including post-fire floods)	Rapid assessment teams; learn from other agencies, such as the National Park Service
Cost	Moderately expensive	Moderately expensive	Moderately expensive
Barriers to implementation	Some: organizational will; leadership commitment; internal resistance, priority setting; integration and interpretation of data and models	Some: external partner support and coordination	Some: forest capacity (resources and funding); public resistance to relocations and closures

Table 10A.2—Adaptation options that address climate change effects on recreation in the Central Rockies subregion.

Sensitivity to climatic variability and change: Changes in demand for warm-weather recreation.

Adaptation strategy/approach: Transition to address extended seasons or changing use patterns.

Strategy objective: Provide sustainable recreation opportunities in response to changing demand.

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactic	Assess use patterns to understand demand shifts and address recreation niches identified for the area.	Identify natural resource impacts and increase coordination with partners and concessionaires.	Adjust capacity issues such as enlarging campgrounds and fee opportunities.
Tactic effectiveness (risks)	Moderate	Moderate-high	High
Implementation urgency	Near term	Mid term	Mid term
Where can tactics be applied? (geographic)	National, regional, forest and local levels	Forest level	Local level
Opportunities for implementation	Coordinate with states, local communities; enhance National Visitor Use and Monitoring processes with sub-surveys	Annual operation meetings, meetings with target user groups, special interest groups meetings	Limited opportunities
Cost	Moderately expensive	Moderately expensive	Moderate – expensive
Barriers to implementation	Ability to acquire or predict patterns of use is difficult because demand is difficult to determine; lack of leadership support to engage in studies; low priority in program of work regionally and nationally; declining budgets and staffing	Shifting demographics	Political and environmental justice fees

Table 10A.3—Adaptation options that address climate change effects on winter recreation in the Central Rockies subregion.

Sensitivity to climatic variability and change: Threats to winter recreation			
Adaptation strategy/approach: Transition to address shorter average season and changing use patterns.			
Strategy objective: Provide sustainable recreation in response to changing demand.			
	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Shift winter use, address safety concerns, and engage partners to implement changes needed in use.	Create management areas and direction addressing concentrated winter use areas through forest planning; communicate with partners, cooperators and other agencies and maintain recreation internet sites with access information.	Relocate sites as necessary and add signs to guide the public.
Tactic effectiveness (risks)	Moderate	Moderate-high	Moderate
Implementation urgency	Mid term	Near term	Mid term
Where can tactics be applied? (geographic)	Winter recreation sites	Designated management areas	Winter recreation sites
Opportunities for implementation	Forest plan revision; project planning; avalanche centers; state agreements	Forest Planning – Revision Efforts Project planning Avalanche Centers State Agreements	Integrate projects to include recreation; large landscape efforts; adjusted stewardship law to include recreation
Cost	Moderately expensive	Moderately expensive	Expensive
Barriers to implementation	Our ability to respond	Timing, unclear direction for those not in revision; lacks leadership support to engage	Environmental resources; cultural and political

Table 10A.4—Adaptation options that address climate change effects on recreation in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Recreation access needs may change with climate change, including change to location, season of use, type of use, and duration of use.

Adaptation strategy/approach: Ensure that access is adequate for projected recreation use and demand and compatible with resource and climate change conditions.

Strategy objective: Facilitate transition of recreation access to ensure relevancy and resiliency by season of use and changing use patterns.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Evaluate and prioritize existing access by season (e.g., trailheads and trails) to ensure consistency with changing recreation opportunity spectrum settings with climate change.	Identify new access needs and potential changes to existing access by season.	Strategically invest in new and potential changes to existing access by season.
Tactic effectiveness (risks)	High	High	High/moderate
Implementation urgency	Near term	Mid term	Mid term
Where can tactics be applied? (geographic)	Federal lands	Federal lands	Federal lands
Opportunities for implementation	Partners	Partners	Partners
Cost	Moderate	Moderate	Moderate
Barriers to implementation	Some (funding/capacity)	Some (funding/capacity)	Some (funding)

Table 10A.5—Adaptation options that address climate change effects on recreation in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Recreation settings (Recreation Opportunity Spectrum and scenery), both motorized and non-motorized, during all seasons will be affected by the expected changes in climate.

Adaptation strategy/approach: Align our recreation settings with changing landscape conditions and demand.

Strategy objective: Facilitate transition of recreation settings to achieve flexibility, relevancy and resiliency; maintain those recreation settings that complement our niches.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Assess existing recreation opportunity spectrum settings and scenic character to determine which are most vulnerable to climate change effects.	Develop management strategies to shift or maintain existing recreation opportunity spectrum settings and scenic character in response to climatic change.	Develop a sub-regional niche.
Tactic effectiveness (risks)	High	High	Moderate/low
Implementation urgency	Mid term	Mid term	Near term
Where can tactics be applied? (geographic)	Federal lands	Federal lands	Federal lands
Opportunities for implementation	None	None	None
Cost	Moderately expensive	Moderately expensive	Inexpensive
Barriers to implementation	Some barriers	Some barriers	None

Table 10A.6—Adaptation options that address climate change effects on recreation in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Cultural and heritage resources may be affected by changes in climate, technology, demographics, and culture.

Adaptation strategy/approach: Protect cultural and heritage sites and the sacred uses of traditional cultural landscapes.

Strategy objective: Acknowledge the importance of cultural and heritage sites and protect valuable sites.

	Specific tactic – A	**Specific tactic – B**
Tactic	Inventory and identify those areas at most risk to climate change and changes in use patterns, and mitigate the effects	Develop interpretation and education opportunities to educate the public in areas or resources most at risk.
Tactic effectiveness (risks)	Moderate	Moderate
Implementation urgency	Near term	Near term
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation	Tribes; Tribal Historic Preservation Office; universities, State Historic Preservation Officer; Passport in Time volunteers	Tribes; Tribal Historic Preservation Office; universities, State Historic Preservation Officer; Passport in Time volunteers
Cost	Expensive	Moderately expensive
Barriers to implementation	Some: Forest Service capacity and funding	Some: Forest Service capacity and funding

Table 10A.7—Adaptation options that address climate change effects on recreation in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: Recreation user demand and the shift in recreation activity, amount of use, and patterns of use will be driven by climate change, technology, demographics, and culture.

Adaptation strategy/approach: Align our recreation opportunities with future demand to commercial (permitted) and non-commercial recreation users.

Strategy objective: Facilitate transition of recreation opportunities to achieve flexibility, relevancy and resiliency.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**
Tactic	Understand the changes in demand, demographics, and economic trends, both regionally and nationally.	Conduct research to clearly identify localized impacts of climate change.	Conduct research to understand the latest and upcoming technology that impacts recreation.
Tactic effectiveness (risks)	High	High	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)			
Opportunities for implementation	Partners, research, university, non-governmental organizations	Partners, research, university, non-governmental organizations	Partners, research, university, non-governmental organizations
Cost	Moderate	Moderate	Moderate
Barriers to implementation	Some: expertise, agency culture	Some: expertise, agency culture	Some: expertise, agency culture

Table 10A.8—Adaptation options that address climate change effects on recreation in the Eastern Rockies subregion.

Sensitivity to climatic variability and change: The future viability of recreation facilities will be affected by changes in climate.

Adaptation strategy/approach: Provide recreation facilities that accommodate future demand, and reduce user and natural resource conflicts.

Strategy objective: Facilitate transition of recreation opportunities to achieve flexibility, relevancy and resiliency.

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactic	Prioritize existing recreation facilities, by season, for viability, investment, and change in services.	Invest strategically in developed recreation facilities.	Design facilities for flexibility in use.
Tactic effectiveness (risks)	Moderate	Moderate-high	Moderate
Implementation urgency	Near term	Mid term	Mid term
Where can tactics be applied? (geographic)			
Opportunities for implementation	Partners, including permittees, public and non-governmental organizations	None	None
Cost	Moderate	Expensive	Moderate
Barriers to implementation	Some: funding, internal agency	Some: funding	Some: funding and capacity

Table 10A.9—Adaptation options that address climate change effects on recreation in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Archeological sites are susceptible to damage and destruction with increase in wildland fires, erosion and floods, vandalism due to increased recreation activities and longer summer season, and rot from loss of protective snow cover hiding archeological sites.

Adaptation strategy/approach: Get cultural resources more involved in the climate change discussion.

Strategy objective: Increase education and reduce stressors.

	Specific tactic – A	**Specific tactic – B**	**Specific tactic – C**	**Specific tactic – D**
Tactic	Increase pro-active surveys and site recording.	Increase post-fire inventories.	Prioritize site sensitivities and management allocation.	Mitigate adverse effects.
Tactic effectiveness (risks)	High	High	Medium	Medium-high
Implementation urgency	Near term	Near term	Near term	Near term
Where can tactics be applied? (geographic)	High elevation – determine locations by predictive modeling	In burned areas	Unit wide	Site specific
Opportunities for implementation	Section 110 of National Historic Preservation Act; engage with university partners; historical societies; Passport in Time projects	Burned area emergency response; engage with university partners	Forest Service manual	Section 110 of National Historic Preservation Act (when not related to specific undertaking)
Cost	Moderately expensive	Moderately expensive	Inexpensive	Expensive
Barriers to implementation	Forest leadership team may not see benefit, would rather concentrate on support to other functions	Limitation of use of burned area emergency response funds	None	Major costs

Table 10A.10—Adaptation options that address climate change effects on recreation in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Infrastructure location, sizing, safety, and resource protection. Will our infrastructure be able to accommodate the projected future use in a safe manner, considering shorter winters with less snow, increased and earlier runoff, increased erosion, increased hazard trees from insects, disease and windthrow mortality, population shifts to higher elevation, and rapidly growing outdoor recreation locations?

Adaptation strategy/approach: Proactively determine sites where projected climate change impacts may cause safety, resource or recreation-quality issues.

Strategy objective: Assess infrastructure and set priorities while considering limited funding and capacity.

	Specific tactic – A	**Specific tactic – B**
Tactic	Install appropriately sized culverts; relocate infrastructure; or eliminate infrastructure.	Develop additional restrictions in the permitting process, seasonal closures or allowable uses.
Tactic effectiveness (risks)	Very high	Medium
Implementation urgency	Near to mid term, unless major infrastructure, then 50 years	Near term
Where can tactics be applied? (geographic)	After catastrophic events using burned area emergency response funds; first priorities from climate analysis	Where needed – site specific
Opportunities for implementation	Department of Transportation, Emergency Relief for Federally Owned Roads	Existing user groups
Cost	Expensive, except when incorporated in already funded projects.	Moderately expensive – staff time
Barriers to implementation	None to major: funding; political and social barriers to road closures	Some barriers: social and political

Table 10A.10 (cont.)—Adaptation options that address climate change effects on recreation in the GYA Subregion

Sensitivity to climatic variability and change: Infrastructure location, sizing, safety, and resource protection. Will our infrastructure be able to accommodate the projected future use in a safe manner, considering shorter winters with less snow, increased and earlier runoff, increased erosion, increased hazard trees from insects, disease and windthrow mortality, population shifts to higher elevation, and rapidly growing outdoor recreation locations?

Adaptation Strategy / Approach: Proactively determine sites where projected climate change impacts may cause safety, resource or recreation-quality issues.

Strategy Objective: Assess infrastructure and set priorities while considering limited funding and capacity.

	Specific Tactic – C	**Specific Tactic – D**
Tactic	Develop new opportunities or new recreation sites; be proactive in encouraging use in locations where the use will be sustainable and resources can support the use.	Monitor closure and restriction dates and set trigger points to determine changes.
Tactic effectiveness (risks)	Very high	Moderate
Implementation urgency	Near – mid term	Near term
Where can tactics be applied? (geographic)	Urban interface	Site specific
Opportunities for implementation	Any rec site planning process	Unit level; user groups
Cost	Expensive	Moderately expensive – staff time
Barriers to implementation	Some	Some: lack of staff time; lack of priority

Table 10A.11—Adaptation options that address climate change effects on recreation in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Lower snow amounts, earlier snowmelt and a longer summer season.

Adaptation strategy/approach: Focus on regulation, education, enforcement, and infrastructural changes.

Strategy objective: Increase education and reduce stressors.

	Specific tactic – A	Specific tactic – B	Specific tactic – C	Specific tactic – D
Tactic	Adjust dates of orders, as needed, such as extended dates of food storage, travel management, closures and trail shares.	Implement social media technology to disperse use, direct users, educate, and promote etiquette.	Engage Chambers of Commerce and Development organizations to help deal with the increased pressures on forest and park resources.	Install infrastructure as needed (e.g., fences, signs, gates).
Tactic effectiveness (risks)	Medium–high	Medium–high	Low–medium	Moderate
Implementation urgency	Near term	Near term	Mid to long term	Near term
Where can tactics be applied? (geographic)	Anywhere appropriate, but especially in areas with high occurrence of resource-user conflicts	Everywhere – messages can be general or site specific	Starting with the larger urban centers (i.e. Jackson, Bozeman, Cody, Idaho Falls and Billings)	Anywhere appropriate
Opportunities for implementation	Laws; revised travel management	The "GYA app"; National Geographic Magazine	Chambers of Commerce; state departments of tourism; state development councils; regional-scale employers; influential people who settle in the GYA	User groups; businesses
Cost	Inexpensive	Inexpensive to medium	Medium	Inexpensive (with partners)
Barriers to implementation	Small to large, depending on social/cultural opposition from users and communities	Medium to small: lack of coverage in remote areas and seniors not using social media; cost barrier	Medium to high: internal cultural barriers and political differences and external barriers	Low to implement; high to avoid vandalism

Table 10A.12—Adaptation options that address climate change effects on recreation in the Greater Yellowstone Area subregion.

Sensitivity to climatic variability and change: Shorter winters with less snow, and wetter or icier snow.

Adaptation strategy/approach: Consider diversifying permitted activities, assess infrastructure and recreation sites, and develop prioritization process and criteria.

Strategy objective: Increase knowledge, assess options, and engage industry and community partners.

	Specific tactic – A	Specific tactic – B	Specific tactic – C	Specific tactic – D
Tactic	Develop options for diversifying snow-based recreation.	Use master development plan to determine if we can add uses and extend seasons (or modify the plan).	Examine viability of agency snow-based recreation sites, permitted downhill resorts and all permitted winter operations.	Monitor snow dates, snow event dates, and snowpack depth.
Tactic effectiveness (risks)	High in the short-term; must consider cost exclusivity and resource impacts	Low–medium	Low	Moderate
Implementation urgency	Mid term	Mid term	Mid–long term	Near term
Where can tactics be applied? (geographic)	For permitted areas, in and around the existing permitted area, within driving distance of population centers	Within and around permitted area	In and around recreation area	Existing snow telemetry (SNOTEL) sites
Opportunities for implementation				Unit
Cost				Inexpensive (especially with partners)
Barriers to implementation				Low to implement; high to avoid vandalism

Table 10A.13—Adaptation options that address climate change effects on recreation in the Western Rockies subregion.

Sensitivity to climatic variability and change: Increased human exposure to contaminated sediment due to dropping lake levels in the Coeur d'Alene basin and/or increased desire for water-based recreation in higher temperatures in the contaminated areas.

Adaptation strategy/approach: Avoidance of contaminated areas.

Strategy objective: Reduce stressors/threat and increase knowledge.

	Specific tactic – A	Specific tactic – B	Specific tactic – C
Tactic	Cap or harden contaminated areas.	Establish vegetation barriers.	Concentrate use in areas that have been hardened.
Tactic effectiveness (risks)	High in the short-term (requires maintenance)	High	Moderate to low.
Implementation urgency	Near term (but ongoing in long term)	Near term (but ongoing in long term)	Near term (but ongoing in long term)
Where can tactics be applied? (geographic)	Throughout the basin, but focus on priority areas identified in the Coeur d'Alene Basin Restoration Plan Environmental Impact Statement	Throughout the basin, but focus on priority areas identified in the Coeur d'Alene Basin Restoration Plan Environmental Impact Statement	Throughout the basin, but focus on priority areas identified in the Coeur d'Alene Basin Restoration Plan Environmental Impact Statement
Opportunities for implementation	Federal, State, tribal, non-governmental organization partners	Federal, State, tribal, non-governmental organization partners	Federal, State, tribal, non-governmental organization partners
Cost	Moderately expensive	Moderately expensive	Moderately expensive
Barriers to implementation	Issues with sensitive species or other resource concerns	Minimal to none	Social

Table 10A.14—Adaptation options that address climate change effects on recreation in the Western Rockies subregion.

Sensitivity to climatic variability and change: Increased desire for water-based recreation with higher temperatures will lead to increased dispersed recreation sites in riparian areas.

Adaptation strategy/approach: Limit expansion of sites and pioneering of new sites.

Strategy objective: Coordinate (e.g., with other agencies and the public); reduce stressors/threat.

	Specific tactic – A	**Specific tactic – B**
Tactic	Educate the public and post signs to prevent expansion of dispersed recreation sites in riparian areas.	Design measures for resource protection, such as blocking access to riparian areas, and revegetating impacted areas.
Tactic effectiveness (risks)	Moderate	Moderate
Implementation urgency	Near term (ongoing to long term)	Near term (ongoing to long term)
Where can tactics be applied? (geographic)	Riparian areas on Federal lands	Riparian areas on Federal lands
Opportunities for implementation	Federal, State, tribal, and private partnerships	Federal, State, tribal, and private partnerships
Cost	Moderately expensive	Moderately expensive
Barriers to implementation	Social	Social; recognizing treaty rights to maintain access to traditional family use areas

Table 10A.15—Adaptation options that address climate change effects on recreation in the Western Rockies subregion.

Sensitivity to climatic variability and change: Cultural/heritage recreation and tourism (e.g., Nimiipuu Trail and Lewis and Clark Trail) and associated scenic driving recreation will likely be affected by increased wildland fire with changing climate.

Adaptation strategy/approach: Manage vegetation to limit wildfire impacts on recreation and tourism.

Strategy objective: Promote resiliency.

	Specific tactic – A	**Specific tactic – B**
Tactic	Reduce stand density, and vary age class and species composition through vegetation management and/or prescribed fire.	Re-establish native vegetation (e.g., forbs, grasses, and conifers such as whitebark pine); slow spread and reduce populations of invasive species.
Tactic effectiveness (risks)	High to moderate	Moderate to low
Implementation urgency	Near term	Near term
Where can tactics be applied? (geographic)	Within scenic corridors	Within scenic corridors
Opportunities for implementation	Tribal partnerships and collaborative partnerships	Cross-regional genetics improvement programs; Federal, tribal, State, and private partnerships
Cost	Moderately expensive	Expensive
Barriers to implementation	Some (opponents to vegetation management as a tool)	Some (difficulty with implementation success)

Table 10A.16—Adaptation options that address climate change effects on recreation in the Western Rockies subregion.

Sensitivity to climatic variability and change: Seasonality of whitewater rafting will likely shift with changing climate and timing of peak flows.

Adaptation strategy/approach: Increase management (primarily permitting) flexibility.

Strategy objective: Promote resiliency.

	Specific tactic – A	**Specific tactic – B**
Tactic	Vary permit season to adapt to changes in peak flow and duration.	Educate the public about changes in peak flows and permitting.
Tactic effectiveness (risks)	Moderate	High to moderate
Implementation urgency	Mid term	Mid term
Where can tactics be applied? (geographic)	Permitted rivers	Permitted rivers
Opportunities for implementation	Agency partnerships	Agency partnerships
Cost	Low	Low
Barriers to implementation	Social	Social

Table 10A.17—Adaptation options that address climate change effects on recreation in the Western Rockies subregion.

Sensitivity to climatic variability and change: Winter recreation (ice fishing, cross-country skiing, snowmobiling) will be at risk with increased temperatures.		
Adaptation strategy/approach: Increase management (primarily permitting) flexibility.		
Strategy objective: Promote resiliency.		
	Specific tactic – A	Specific tactic – B
Tactic	Maintain current infrastructure and expand facilities in areas where concentrated use increases (anticipate additional use as lower elevation areas [Missoula] have reduced snowpacks).	Conduct safety education for increased risk (avalanche potential and thinning ice sheets).
Tactic effectiveness (risks)	Moderate	Moderate
Implementation urgency	Near term	Near term
Where can tactics be applied? (geographic)	Snow play areas and major lakes	Snow play areas and major lakes
Opportunities for implementation	Fees	Partnerships
Cost	Moderately expensive	Low
Barriers to implementation	Social; expense	Social (people do not always listen)

Chapter 11: Effects of Climate Change on Ecosystem Services in the Northern Rockies Region

Travis Warziniack, Megan Lawson, and S. Karen Dante-Wood

Introduction

In this chapter, we focus on the ecosystem services provided to people who visit, live adjacent to, or otherwise benefit from natural resources on public lands. Communities in the Forest Service, U.S. Department of Agriculture (USFS) Northern Region and the Greater Yellowstone Area (GYA), hereafter called the Northern Rockies region, are highly dependent on ecosystem services from water, soil, and air that will be affected by climate change in a variety of ways. Every community in the region will feel these impacts. We link biophysical effects associated with climate change, as described in previous chapters, with potential effects on the well-being of humans and communities, and identify strategies for adapting to climate-induced changes and prioritizing among competing interests. First, we introduce ecosystem services and how to describe and measure them. Second, we describe how people and communities currently use and benefit from public lands in the Northern Rockies region, as well as existing stressors that may affect the ability of communities to adapt to a changing climate. Third, we discuss climate change effects on specific ecosystem services. Finally, we identify adaptation strategies that can help reduce negative effects on ecosystem services, and discuss the ability of public agencies and communities to respond to climate change (adaptive capacity).

Ecosystem services are benefits to people from the natural environment. These include timber for wood products, clean drinking water for downstream users, recreation opportunities, and spiritual and cultural connection to the environment and natural resources. An ecosystem services perspective extends the classification of multiple uses to a broader array of services or values (Collins and Larry 2007).

Ecosystem services are commonly placed in the following four categories (Millenium Ecosystem Assessment 2005):

- 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

Categorizing ecosystem services in this manner helps identify the ways in which natural resources and processes benefit humans, and how changes in the natural environment will affect these benefits. Climate change will affect the quality and quantity of ecosystem services provided by public lands. Establishing the link among natural processes, ecosystem services, and human benefits helps clarify the communities or types of people most vulnerable to a changing climate.

Although ecosystem service categories help organize our understanding of the relationship between natural resources and human benefits, this simple approach may obscure 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 fresh water can be considered a provisioning service, the process of purifying water a regulating service, the use of fresh water for recreation a cultural service, and the role of fresh 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.

To address the challenges of ecosystem services falling into multiple, interdependent categories, Boyd and Krupnick (2009) describe ecosystems as collections of commodities linked by a range of biophysical processes, delineating biophysical inputs and outputs, ecological endpoints, and transformations. In this framework, fresh water is an output from a filtration process, an ecological endpoint in itself as drinking water, and then an input for the endpoints of recreation and plant and animal populations. This framework facilitates assessment of ecosystem service vulnerability by allowing analysts to identify ecosystem service endpoints and connect changes in inputs and processes caused by climate change to changes in ecosystem service provision.

This framework and the subsequent distinction between natural resources that are endpoints, inputs, and outputs, provide a helpful approach to measuring ecosystem services. Later in this chapter, we identify the most significant ecosystem services in the Northern Rockies region and describe how they are expected to change.

Ecosystem Services and Public Lands

The evaluation of ecosystem services in this assessment is consistent with Federal agency management requirements. Under the Forest Planning Rule of 2012, the USFS is required to formally address ecosystem services in land management plans for national forests (USDA FS 2012). The National Park Service (NPS) 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), U.S. Department of the Interior (USDOI) has also identified nonmarket environment values, synonymous with ecosystem services, as an increasingly important consideration for land management (Winthrop n.d.).

Although all natural systems provide some type of ecosystem services, managing for ecosystem services on public lands involves specific considerations that make it especially important to identify the endpoints, how they are used, and which ones are most susceptible to disruption from a changing climate. There are many beneficiaries from ecosystem services provided by public lands, including neighboring communities, nonlocal visitors, and people who may never visit or directly use the lands but gain satisfaction from knowing a resource exists and will be there for future generations (Kline and Mazzotta 2012). This is particularly true for iconic landscapes and rivers in the study area such as Yellowstone National Park, Glacier National Park, the Salmon River, and the Selway River (Borrie et al. 2002; Chouinard and Yoder 2004; Mansfield et al. 2008; O'Laughlin 2005; Pederson et al. 2006).

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, but it could complement management for biodiversity and some wildlife species. Ecosystem services from public lands are critical for neighboring communities, particularly in rural areas of the Northern Rockies region, where people rely on these lands for fuel, food, water, recreation, and cultural connection. Decreased quantity and quality of ecosystem services produced by public lands will affect human systems that rely on them, requiring neighboring communities to seek alternative means of providing these services or to change local economies and lifeways.

Management decisions for public lands can substantially affect ecosystem service flows, with cascading effects on numerous users. 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 the tradeoffs in the decisionmaking process. The concept of ecosystem services is somewhat new, so data on ecosystem services are scarce. In this chapter, we use quantitative data when possible, but we often rely on qualitative descriptions or proxy measures. Demographic and economic factors often have a significant effect on ecosystem services, providing an important context for understanding the effects of climate change.

Ecosystem Services in the Northern Rockies Region

The USFS Northern Region Resource Information Management Board identified ecosystem services that are used by a large number of people and can also be affected by management decisions. Using the standard categories just discussed, we focused on provisioning, regulating, and cultural ecosystem services. Supporting services were not included because, although important, they are largely indirect services that are inputs to other biophysical processes, and are unlikely to be directly affected by management decisions. Note that even though we have grouped ecosystem services into provisioning, regulating, and cultural services in this chapter, these categories are not definitive; many could have been included in an alternative category. Although the USFS designated these ecosystem services, many of the following services are also important for other public agencies in the Northern Rockies region:

Provisioning ecosystem services.

- Abundant fresh water for human (e.g., municipal and agricultural water supplies) and environmental (e.g., maintaining streamflows) uses
- Building materials and other wood products
- Mining materials
- Forage for livestock
- Fuel from firewood and biofuels
- High air quality and scenic views
- Genetic diversity and biodiversity

Regulating ecosystem services:

- Water filtration and maintenance of water quality associated with drinking, recreation, and aesthetics
- Protection from wildfire and floods
- Protection from erosion
- Carbon sequestration

Cultural ecosystem services:

- Recreation opportunities
- Aesthetic values from scenery
- Protection and use of cultural sites
- Native American treaty rights

The amount of detail presented for these ecosystem services varies as a function of how much information is available and can be interpreted in the context of climate change. Many of the ecosystem services are also discussed in other chapters of this assessment, including recreation (Chapter 10), genetic diversity and biodiversity (Chapter 6), protection from wildfire and floods (Chapter 9) and cultural resources (Chapter 12). Most of the others are covered to some extent in this chapter. Ecosystem services are combined in a single section if all of them are likely to be affected by the same changes in natural resource conditions.

Social Vulnerability and Adaptive Capacity

Communities that have the social structure and resources to adapt to one environmental impact generally have the capacity to adapt to others. A growing literature on social vulnerability seeks to identify which institutions, resources, and characteristics make communities more or less resilient to environmental hazards. This discussion addresses the first part of social vulnerability—exposure to negative changes related to specific ecosystem services and possible adaptation strategies. The capacity to adapt to those changes often depends on factors that transcend specific resources, so capacity is addressed more broadly here.

The most widely used measure of social vulnerability is the Social Vulnerability Index (SoVI), managed and updated by the Hazards and Vulnerability Research Institute at the University of South Carolina (Cutter et al. 2003). The SoVI is based on 11 underlying factors identified to affect social vulnerability: personal wealth, age, density of the built environment, single-sector economic dependence, housing stock and tenancy, race, ethnicity, occupation, and infrastructure dependence. For each county in the United States, scores based on these 11 factors are summed to form a composite vulnerability score. To highlight counties with the most "extreme" scores, composite scores are then converted to standard deviations and mapped (fig. 11.1).

Figure 11.1 shows that most counties in the region fall in the high to medium vulnerability range. A large factor in the region's vulnerability is its rural character. Among the region's counties, the average proportion of county populations living in rural areas is 75.3 percent, compared to a national average of 19.3 percent (all demographic data in this section are based on the 2012 Census American Community Survey). Rural counties tend to be reliant on a single industry, have older populations, and have fewer social resources (e.g., hospitals) than urban areas. Loss of youth is also a primary concern among ranching communities, where the younger generation is often reluctant to take over the ranching business and more likely to move outside the region. The oldest mean average age in the region is found in Prairie County, Montana, where the mean age is 56. The average median age among the counties is 43.4, and the low is 22 in Madison County, Idaho. Figure 11.2f shows the proportion of each county over the age of 65. An aging population and decline in youth in rural counties worries many because of the potential loss of a traditional culture in many Western communities.

The median household income of Region 1 counties is $45,235, which is considerably lower than the national average of $53,046. The high-income counties tend to be in the eastern part of the region, with ties to the oil and gas industry, and areas with high concentrations of recreation-based industries. Income is lowest in the counties dependent on grazing and timber.

Figures 11.2a and 11.2b show relatively widespread unemployment and poverty in the region. Theodossiou (1998) found employment is more important than income in predicting life satisfaction. The region on average had an average unemployment rate in 2012 of 5.4 percent, which was lower than the national average of 9.3 percent. Spatially, unemployment follows median income closely, with counties in the east having low unemployment and counties in the west having high unemployment. A few counties have very high unemployment, particularly in the timber-dependent counties where jobs are concentrated among a few large employers.

The service industry typically pays low wages, maintains part-time positions, and does not pay benefits like retirement and health insurance. Employment fluctuates with overall economic conditions. For these reasons, workers in the service industry can be vulnerable to economic fluctuations. The mean percentage employed in the region's service industry is 17.8. In some counties, more than 30 percent of the labor force is employed in the service industry.

Many of the factors that make individuals more vulnerable are compounded among migrants and minorities. They tend to have fewer economic resources, lack political power, and sometimes struggle with communication (fig. 11.2e) (Aguirre 1998; Blaikie et al. 1994; Fothergill and Peek 2004; Morrow 1999; Phillips 1993; Phillips and Ephraim 1992). Such factors make minorities less likely to participate in disaster planning, be familiar with support services, and have basic resources such as a vehicle for use during an evacuation or to transport the injured and sick to hospitals (fig. 11.2c). On average, the region has very few foreign-born residents, 2.7 percent compared to a national average of 12.9 percent. But a few counties have large concentrations of migrant agricultural workers (fig. 11.2d). Clark County, Idaho was home to more than 350 immigrants though it had only 982 people in the 2010 census. Minorities are also concentrated among a few counties. Between 39 and 56 percent of the populations in the Idaho counties in the region are minorities, compared to a regional average of

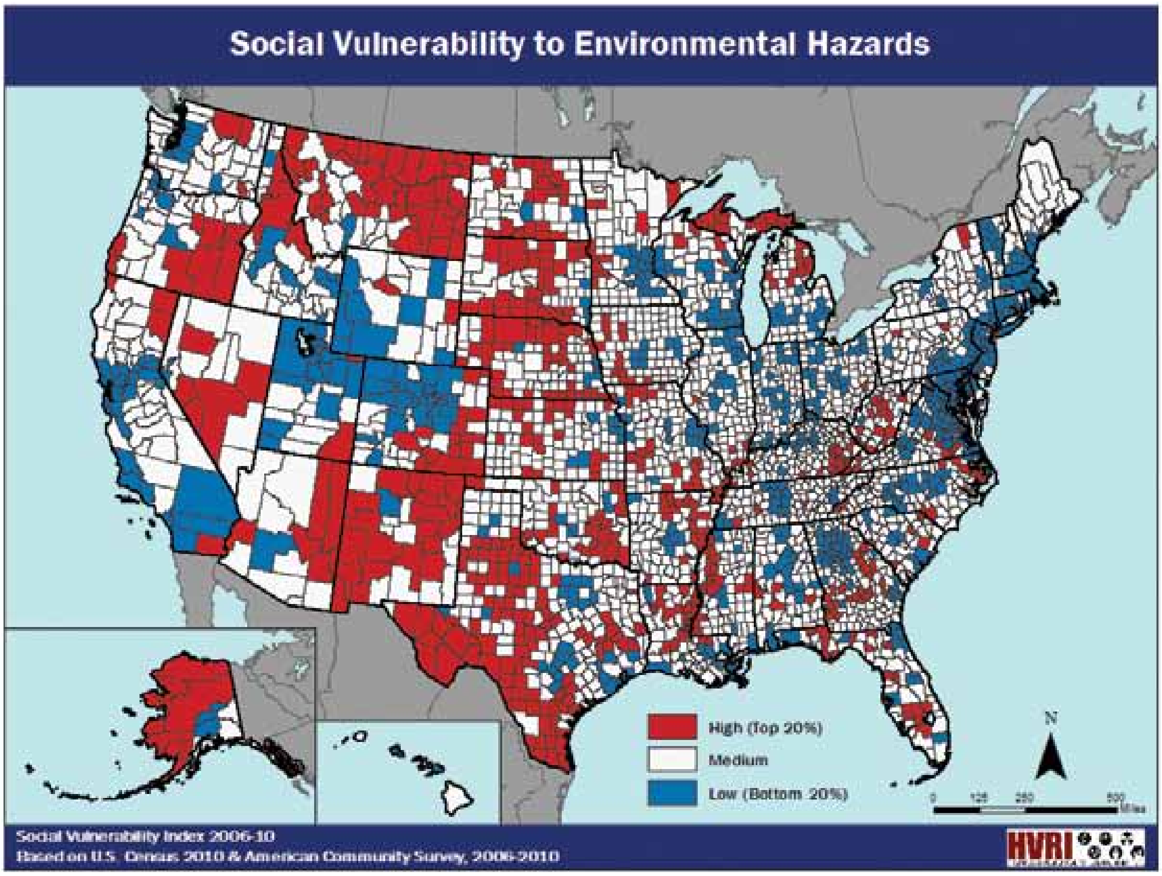

Figure 11.1—The Social Vulnerability Index (SoVI) to Environmental Hazards for U.S. Counties (managed and updated by the Hazards and Vulnerability Research Institute at the University of South Carolina; Cutter et al. 2003). The SoVI is based on 11 underlying factors identified to affect social vulnerability: personal wealth, age, density of the built environment, single-sector economic dependence, housing stock and tenancy, race, ethnicity, occupation, and infrastructure dependence. For each county in the U.S., scores based on these 11 factors are summed to form a composite vulnerability score. To highlight counties with the most "extreme" scores, composite scores are then converted to standard deviations and mapped.

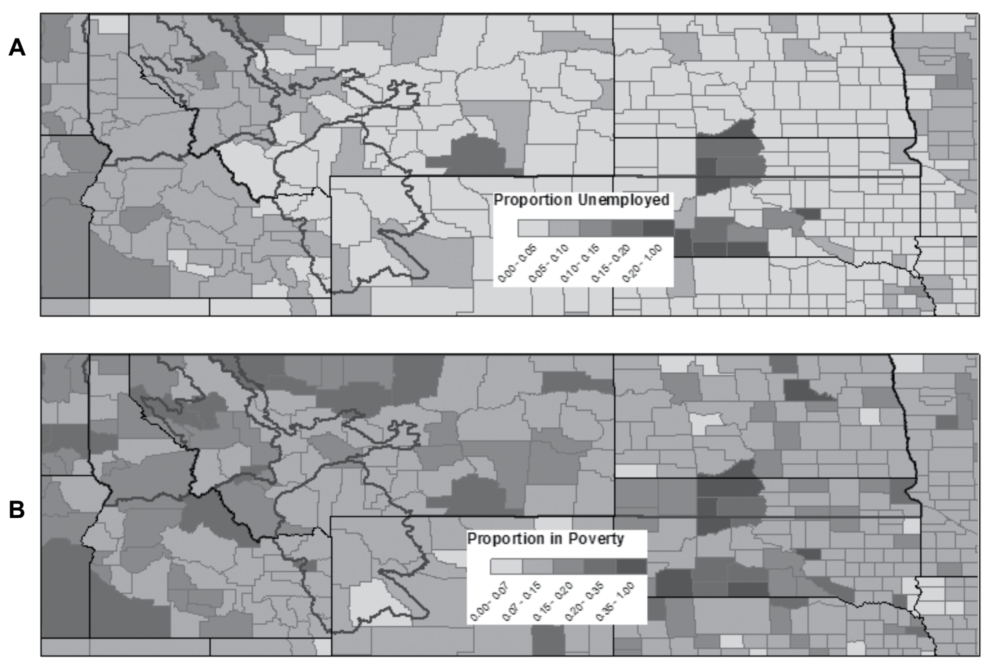

Figure 11.2—Demographic information for the Northern Rockies region, including (a) proportion unemployed, (b) proportion in poverty, (c) proportion without a vehicle, (d) proportion of minorities, (e) proportion with limited English skills, and (f) proportion over age 65.

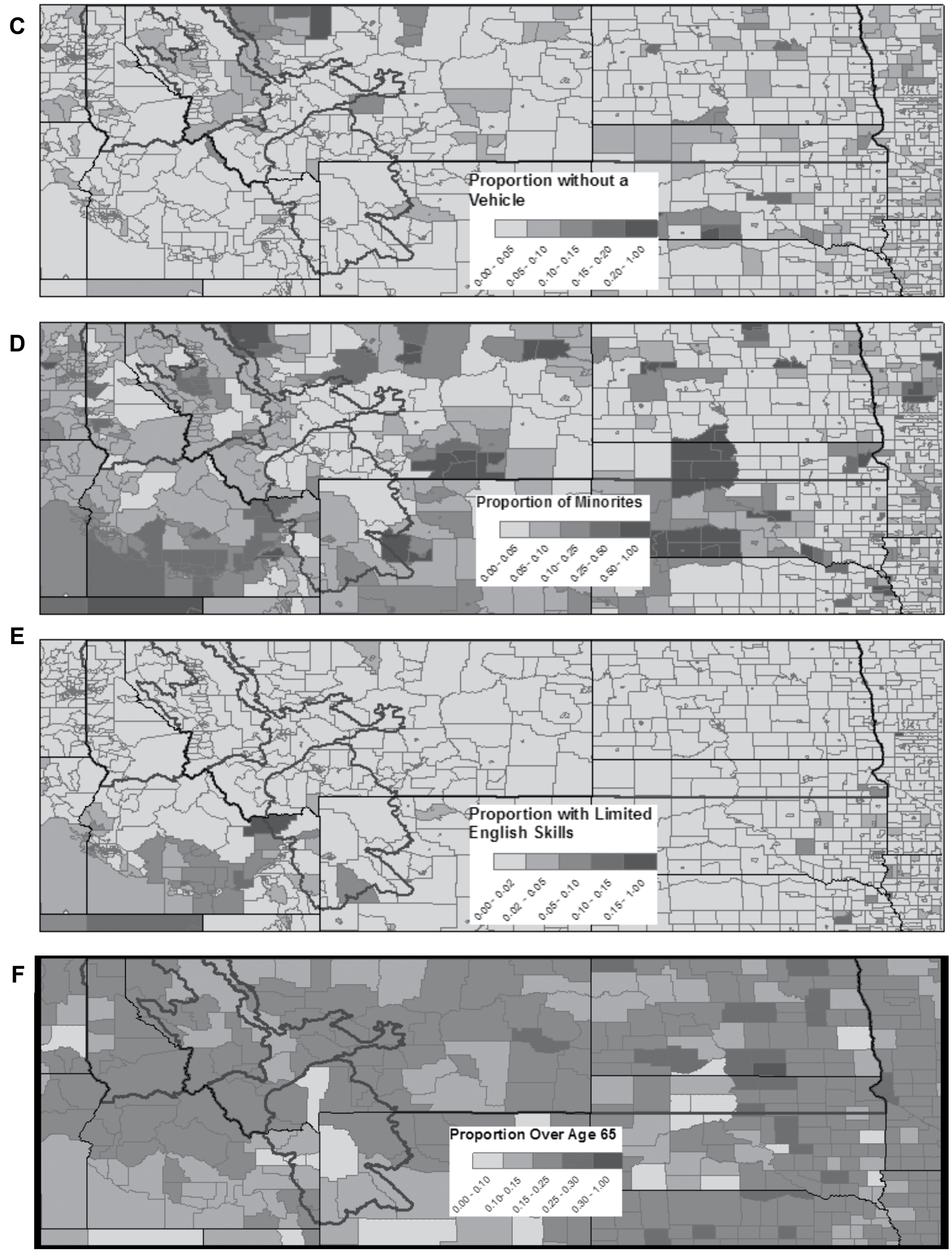

Figure 11.2—*Continued.*

only 15.9 percent. In comparison, many counties in eastern Montana and North Dakota have less than 5 percent minorities. The predominant minority group in the region is Native American in those counties with more than 56 percent of their population from minorities.

Some of the regional trends in vulnerability and demographics are tied to traditional uses of the land and major industries in the counties. Table 11.1 shows mean SoVI scores by industry. Grazing communities tend to be older, poorer, and more rural, so they score significantly higher on the SoVI than communities without grazing. Communities dependent on timber, oil and gas, and recreation have significantly lower SoVI scores than other counties. Counties in the national forest economic impact zones of Region 1 have higher SoVI scores, though the difference is not significant (table 11.1).

Table 11.2 shows the number of counties significantly below or above the regional mean SoVI, by industry. Among grazing counties, 54 counties have unemployment rates significantly below the regional average of 5.4 percent and 18 counties have unemployment rates significantly above the regional average (based on 95 percent confidence intervals). Grazing counties tend to have the lowest median incomes, the oldest populations, and the highest percentage of people living in rural settings. Timber counties tend to have the highest unemployment rates and the highest percentages of foreign-born residents and minorities. Counties where many people have recreation-based employment are among the least vulnerable despite high employment in the service industry. Counties with oil and gas tend to have lower unemployment rates and higher wages than most places in the United States.

Table 11.1—Mean Social Vulnerability Index scores across industries. Counties were ranked by industry shares for each industry and separated into quartiles. Scores are first (on the left) compared scores for the lower and upper quartiles, then (on the right) the lower and upper half of counties, sorted by shares of employment in that industry. Significance levels are shown by the test statistics for comparison of the means and the associated p-values.

	Lower quartile	Upper quartile	Test statistic	P-value	Lower half	Upper half	Test statistic	P-value
Timber	2.93	0.94	4.32	0.00	2.90	0.76	5.44	0.00
Grazing	-0.20	3.69	-8.03	0.00	0.61	3.04	-6.37	0.00
Recreation	2.56	0.63	3.56	0.00	2.39	1.28	2.67	0.01
Oil & gas	2.45	1.68	1.38	0.17	1.94	1.74	0.47	0.64

Table 11.2—Number of counties significantly below and above regional means. Each row shows data for counties that are in the top half of counties sorted by share of employment in that industry. For example, the "Grazing" row shows results for counties for which grazing represents a larger share of total employment than half the other counties in the region.

	Unemployment rate (5.4%)		Percent employed in service industry (17.8%)		Median household income ($45,235)		Median age (43.4)		Percent foreign born (2.7%)		Percent population minority (15.9%)		Percent population in rural areas (75.3%)	
	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above
Grazing	54	18	44	21	49	24	16	57	57	12	62	15	13	66
Timber	27	40	19	43	43	34	34	39	25	32	57	23	45	29
Recreation	37	36	18	44	41	32	37	36	31	26	59	21	47	31
Oil and gas	54	21	31	34	33	43	32	39	38	25	65	12	37	41

Ecosystem Service: Water Quantity

Water use can be broadly classified as consumptive or nonconsumptive. Water allocated to a consumptive use is not available for other uses, whereas water allocated to a nonconsumptive use is available for other uses. Most economic uses of water have components of both consumptive and nonconsumptive uses. For example, a portion of water applied to croplands is taken up by plants and does not return to the waterways; this portion represents consumptive use of water by the crop. The portion of water applied to cropland that returns to the waterways via runoff is the nonconsumptive portion. Major consumptive uses of water in the Northern Rockies region include domestic and municipal water supply, industrial use of water, and water for oil and gas development (drilling and hydraulic fracturing). Nonconsumptive uses of water in the region include recreational uses (e.g., boating, maintaining fish habitat) and hydroelectric power production. Most water in the Northern Rockies is already appropriated, and many uses are tied to junior water rights. Junior water rights can be exercised only during high-flow years, so they are unreliable from season to season or year to year. Any new uses of water require a transfer of water rights, increased water supply through reservoir storage, or mining of groundwater.

A recent draft of the Montana State Water Plan (Montana Department of Natural Resources and Conservation [DNRC] 2014) details water use in Montana (tables 11.3, 11.4) and is representative of most of the Northern Rockies region. Hydroelectric power generation (hydropower) accounts for 86 percent of total water demand in Montana, although hydropower is considered a nonconsumptive use because it does not affect instream flow or total water available downstream. However, reservoirs needed for hydropower have high rates of water loss to evaporation. Fort Peck Reservoir, in the lower Missouri River basin, annually loses 611,400 acre-feet of water to evaporation.

The largest consumptive use of water in Montana is irrigated agriculture, which accounts for 96 percent of all water diversions and 67 percent of all consumptive use (accounting for return flows). In the Yellowstone River basin, irrigation accounts for 83 percent of consumptive use.

Due to the downstream location of fish and wildlife habitat, preserving instream water for habitat often requires explicit water rights. Montana Fish, Wildlife and Parks maintains 3.6 million acre-feet of instream flow rights downstream of Fort Peck Reservoir and below the Milk River confluence with the Missouri River. The agency

Table 11.3—Total water use in Montana[a].

Planning basin	Hydropower (non-consumptive)	Irrigation	Reservoir evaporation	Municipal, industrial, livestock	In-stream flow (non-consumptive)
	Percent				
Statewide	86.0	12.4	1.2	0.5	0
Clark Fork / Kootenai River	94.4	4.7	0.5	0.4	0
Upper Missouri	88.0	11.2	0.5	0.3	0
Lower Missouri	39.4	19.5	6.0	0.3	35.0
Yellowstone River	24.5	23.0	0.4	1.4	50.7

[a] Data from Montana DNRC (2014).

Table 11.4—Consumptive water use in Montana.[a]

Planning basin	Irrigation	Reservoir evaporation	Domestic & municipal	Livestock	Industrial	Thermo-electric
	Percent					
Statewide	67.3	28.0	2.4	1.2	0.3	0.8
Clark Fork / Kootenai River	67.0	27.0	3.9	0.5	1.2	0
Upper Missouri	82.2	13.7	3.0	0.9	<0.1	0
Lower Missouri	42.0	56.3	0.4	1.4	<0.1	0
Yellowstone River	83.3	7.2	2.8	2.1	0.3	4.2

[a] Data from Montana DNRC (2014).

maintains 5.5 million acre-feet of instream flow rights for the Yellowstone River at Sidney. Although population is increasing in the Western Rockies and Greater Yellowstone Area subregions, water demand for urban uses has not increased significantly; even in the most populated regions, consumptive use by households is below 4 percent.

The share of any particular water use does not imply anything about relative values of water among uses. The marginal value of water in agriculture is typically lower than the marginal value of water for municipal uses, particularly in areas of recent population growth. Prices for municipal uses are $290 to $3,145 per acre-foot, whereas prices for leased agricultural water diverted for instream conservation are $42 to $3,614 per acre-foot (Montana DNRC 2014). In general, prices increase for more senior water rights and when few other options for obtaining water exist in the area. Current rates paid by agricultural users of water from Bureau of Reclamation and Montana DNRC facilities are $2.32 to $7.50 per acre-foot per year, or a capitalized value of $76 to $244 per acre-foot. Accounting for delivery and operating costs, the capitalized costs of agricultural water range from $189 to $615 per acre-foot.

Effects of Climate Change

A warming climate is expected to cause a transition in the form of precipitation from snow to rain (see Chapter 3), which will affect the timing of water availability (see Chapter 4). Warmer temperatures will make drought more frequent, despite small increases in precipitation shown in some climate models; consequently, overall competition for water will increase. This will amplify many of the effects of population growth and demographic changes already occurring. Agricultural and municipal users will experience major impacts, making it more difficult to allocate instream flows for recreation and wildlife.

Agriculture

Timing of snowmelt is a chief concern in the Columbia and Missouri Basin headwaters (see Chapter 4). Earlier runoff may be out of sync with many of the water rights currently held by agriculture, even as warmer months extend the growing season. Future water quantities in North Dakota and the eastern plains of Montana are likely to be more variable.

North Dakota has already seen an increase in regional temperatures that has brought a mixture of impacts to agriculture, the largest industry in the State. Wheat production alone generates $4.5 billion annually in economic activity (North Dakota Wheat Commission 2007). Warmer temperatures and higher commodity prices have pushed wheat and corn production into areas of the State where they were not previously grown or where shorter-season varieties dominated.

Higher temperatures increase plant demand for water, contributing to droughts even though the Grassland subregion is expected to see a slight increase in precipitation (see Chapter 3). Drier soils and more-intense precipitation events may increase flood frequency, leading to increased dependence on tile drainage. In 2002, drought cost North Dakota $223 million, and heavy rains in 2005 ruined more than 1 million acres of cropland and prevented another 1 million acres from being planted. These heavy rains caused $425 million in damage to North Dakota crops, and the State's livestock industry lost $32 million, largely from the increased price of feed, which was in short supply (Karetinkov et al. 2008). More droughts and intense temperatures may also make plants more susceptible to insect pests (Rosenzweig et al. 2000).

Domestic and Municipal Uses

If the frequency of drought and heavy rain events increases, they will stress municipal water supply systems and built infrastructure. Decreased permeability of soils associated with drought conditions will also lead to more flash floods, endangering lives and affecting water supply systems and infrastructure. In regions with clay soils, increased frequency of drought is already causing sidewalks, driveways, and streets to crack. Although the cost of fixing one sidewalk one time is relatively small, these persistent costs add up and have been shown to cause large financial burdens on communities.

Warmer months and growing populations will increase demand for both air conditioning and lawn watering. There will be a slight decrease in demand for heat, but net household demand for electricity is expected to rise. Therefore, demands for water for power generation and other municipal uses are expected to increase.

Recreation and Wildlife

The effects of climate change on skiing, boating, and fishing are summarized in Chapter 10, and the effects of wildfire are described in Chapter 8. Beyond effects mentioned in those chapters, it may become harder to preserve instream flows even though demographic changes will increase demand for such preservation. Particularly vulnerable habitats include small streams in the mountains and highly valued fisheries throughout the Northern Rockies.

Climate models suggest a drier climate will shift some of the most productive waterfowl breeding grounds of the northern prairie wetlands and pothole region (which produces 50 to 80 percent of ducks in North America) to the wetter eastern and northern fringes of the Northern Rockies, an area where many wetlands have been drained. Unless these wetlands are restored, bird populations will be significantly affected (Johnson et al. 2005). Some estimates show that the north-central duck population in the United States could be reduced by 50 percent (Sorenson et al. 1998).

Adaptive Capacity

As noted earlier, adaptive capacity refers to institutional capability to modify management, decisionmaking, and policy to ensure sustainable production of ecosystem services. Objectively assessing the capacity of the Northern Rockies region to respond to changes in ecosystem services is difficult, with little guidance in general from science and no guidance specific to the region. This section, therefore, mostly focuses on adaptation strategies.

Transfer of water rights from one use to another is legally possible within the Northern Rockies region but is realistically constrained by the ability to transport water. Transfers between agricultural and municipal uses, for example, can occur only between users in the same watershed. Because municipal values of water are usually higher than those of agriculture, these transfers are likely to occur should the need be dire enough.

Reuse of effluent and other conservation methods will be important tools for adaptation. Groundwater pumping is also available as a short-term solution, but is not sustainable in the long run. These methods are expensive and will be cost prohibitive for most rural communities in the Northern Rockies. New municipal demands are more likely to be met by purchasing or leasing reliable senior water rights (Montana DNRC 2014). Water rights are still available in some water basins, but these new appropriations are junior in priority and not likely to be reliable enough for municipal uses.

A drier climate in the central and western prairie pothole habitats of the Grassland subregion will diminish the benefits of preserving waterfowl habitat in that area and increase the importance of restoring wetlands along the wetter fringes (Johnson et al. 2005).

Risk Assessment

Compared to more arid regions of the western United States, changes in water yield in the Northern Rockies region are expected to be modest, although they may be disproportionately large for local residents who experience them (Foti et al. 2012). Changes in timing of runoff will be significant. Climate and hydrologic models consistently project changes in temperature and timing of runoff, making the likelihood of these effects high.

Ecosystem Service: Water Quality, Aquatic Habitats, and Fish for Food

Compared to many areas of the United States, the Northern Rockies region has excellent water quality. The headwater streams of the region generally provide safe, clean drinking water to downstream communities (fig. 11.3) and provide habitat for some of the Nation's premier

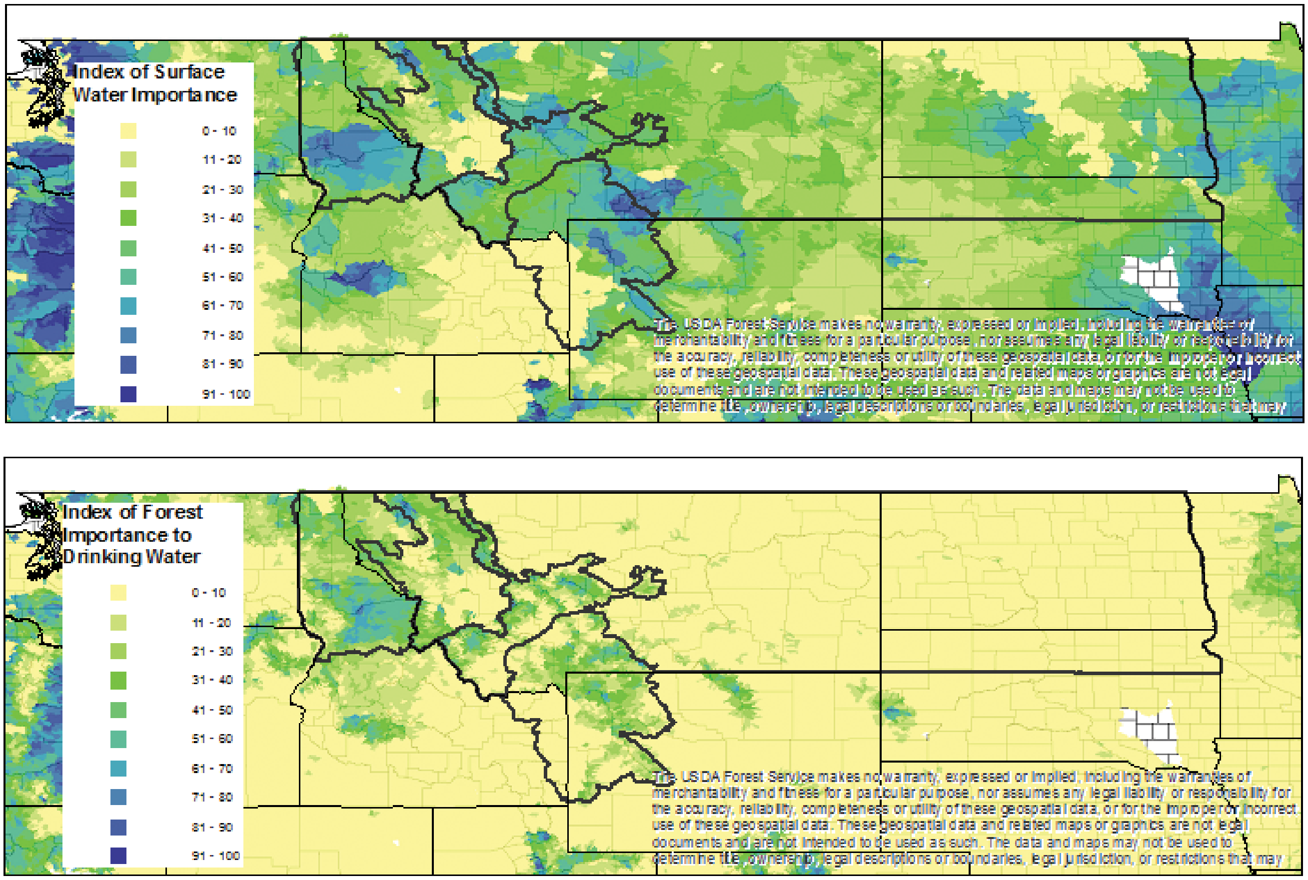

Figure 11.3—Forests to Faucets data showing the relative importance of surface water for municipal water supply (top) and forests for maintaining watershed health (bottom). The index depends on both the amount of water coming off forests and the population served by that water. Higher numbers indicate higher levels of importance (from Weidner and Todd 2011).

recreational and commercial fisheries (see Chapter 10). Fresh water is important to area tribes' cultural practices, including ability to exercise their indigenous fishing rights. Nonetheless, many of the streams and lakes in the region are already threatened or impaired according to U.S. Environmental Protection Agency standards (tables 11.5, 11.6, 11.7). In all Northern Rockies States, agriculture is the primary source of impairment in rivers and streams; impairment results from grazing in riparian and shoreline zones and from fertilizer sediment in runoff. In Montana, grazing leads to loss of streamside vegetation and increased sedimentation. Idaho has similar disturbances, but with increased water temperatures as the primary reason for impairment. In North Dakota, animal feeding operations add to riparian grazing, causing unsafe levels of fecal coliform and habitat alterations.

Major causes of impairment for lakes, reservoirs, and ponds differ between States. Runoff from roads and bridges is a problem in Idaho, leading to high levels of phosphorus and mercury. In Montana, abandoned mines can cause accumulation of mercury and lead. In North Dakota, grazing and animal feeding operations can produce levels of fecal coliform that can contaminate water bodies.

For municipal water supplies, disturbances such as wildfires and mudslides are a major concern (see Chapter 8) (fig. 11.4). Due to the generally high water quality in the region, water treatment plants are able to operate with lower capital investments. When there are sudden increases in sediment or other pollutants, such as often occurs after a wildfire, treatment plants need to shut down or incur high costs to treat the water and remove sediment from reservoirs.

Some Northern Rockies residents worry about the effects of increased oil and gas extraction activities on watershed health. Groundwater contamination in northeastern Montana near the Fort Peck Indian Reservation has been linked to development of the East Poplar oilfield (Thamke and Smith 2014). Groundwater is the only source of drinking water in the area, and contamination has affected drinking water quality. Oil spills in the Yellowstone River (2011, 2015), a pipeline leak near Tioga, North Dakota (2014), and train derailments in Lac Megantic, Quebec (2013) and near Lynchburg, Virginia (2014) highlight the dangers to watersheds surrounding oil and gas fields, even if the activity that caused contamination does not occur in the watershed.

Table 11.5—Threatened and impaired waterways in Montana.[a]

	Rivers and streams	Lakes, reservoirs, and ponds
Use	*Percent*	
Agriculture	14.3	22.1
Aquatic life	83.6	76.7
Drinking water	29.3	65.5
Primary contact recreation	38.7	13.5
Causes of impairment		
Rivers and streams	*Miles*	
Alteration in streamside or littoral vegetation	8,352	
Sedimentation, siltation	7,456	
Phosphorus	5,091	
Low flow alterations	4,936	
Nitrogen total	4,846	
Lakes, reservoirs, and ponds	*Acres*	
Mercury	311,192	
Lead	246,950	
Phosphorous, total	73,324	
Sedimentation, siltation	69,411	
Nitrogen, total	68,354	
Sources of impairment		
Rivers and streams	*Miles*	
Agriculture	6,000	
Grazing in riparian or shoreline zones	5,862	
Irrigated crop production	4,570	
Natural sources	4,518	
Source unknown	4,223	
Lakes, reservoirs, and ponds	*Acres*	
Impacts from abandoned mine lands	279,490	
Atmospheric deposition – toxics	250,570	
Historic bottom sediments (not sediment)	237,654	
Municipal point source discharges	97,542	
Source unknown	86,868	

[0] Data from U.S. Environmental Protection Agency (2016).

Table 11.6—Threatened and impaired waterways in Idaho.[a]

	Rivers and streams	Lakes, reservoirs, and ponds
Use	*Percent*	
Cold water aquatic life	52.5	91.3
Primary contact recreation	18.3	2.6
Salmonid spawning	45.9	86.0
Warm water aquatic life	68.0	99.4
Domestic water supply	3.2	0
Seasonal cold water aquatic life	0	100
Secondary contact recreation	15.3	97.0
Causes of impairment		
Rivers and streams	*Miles*	
Temperature, water	18,494	
Sedimentation, siltation	14,988	
Phosphorus	6,017	
Escherichia coli	4,480	
Combined benthic, fish bioassessments	4,306	
Other flow regime alterations	3,877	
Lakes, reservoirs, and ponds	*Acres*	
Phosphorus	146,576	
Mercury	121,329	
Other flow regime alterations	84,682	
Sediment, siltation	80,169	
Dissolved oxygen	77,473	
Sources of impairment		
Streams and rivers	*Miles*	
Grazing in riparian or shoreline zones	2,230	
Rangeland grazing	1,782	
Livestock (grazing, feeding)	1,152	
Flow alterations from water diversions	643	
Loss of riparian habitat	608	
Managed pasture grazing	561	
Lakes, reservoirs, and ponds	*Acres*	
Highways, roads, bridges, infrastructure	340	
Post-development erosion and sedimentation	340	
Natural sources	340	
Agriculture	340	
Loss of riparian habitat	340	

[a] Data from U.S. Environmental Protection Agency (2016).

Table 11.7—Threatened and impaired waterways in North Dakota.[a]

	Rivers and streams	Lakes, reservoirs, and ponds
Use	*Percent*	
Agriculture	0	0
Fish and other aquatic biota	16.6	0.1
Fish consumption	80.8	81.3
Industrial	0	0
Municipal and domestic	0	0
Recreation	27.2	0.9
Causes of impairment		
Rivers and streams	*Miles*	
Fecal coliform bacteria	3,820	
Physical substrate habitat alterations	2,423	
Escherichia coli	1,882	
Sedimentation, siltation	1,783	
Combined benthic, fish bioassessments	604	
Lakes, reservoirs, and ponds	*Acres*	
Fecal coliform bacteria	3,820	
Physical substrate habitat alterations	2,423	
Escherichia coli	1,882	
Sedimentation, siltation	1,783	
Combined benthic, fish bioassessments	604	
Sources of impairment		
Rivers and streams	*Miles*	
Grazing in riparian or shoreline zones	5,797	
Animal feeding operations	3,909	
Crop production (crop land or dry land)	2,549	
Loss of riparian habitat	2,415	
Source unknown	1,148	
Lakes, reservoirs, and ponds	*Acres*	
Grazing in riparian or shoreline zones	5,797	
Animal feeding operations	3,909	
Crop production (crop land or dry land)	2,549	
Loss of riparian habitat	2,415	
Source unknown	1,148	

[a] Data from U.S. Environmental Protection Agency (2016).

Effects of Climate Change

Climate change will influence water quality in ways that affect fishing, water-based recreation, and drinking water. Climate change will amplify the effects of development on water quality already occurring in the Northern Rockies region. Increased number and severity of wildfires will lead to deposition of more sediment in streams, lakes, and reservoirs. Increased air temperature and loss of vegetation along stream banks will raise the temperature of streams, and altered vegetation may affect water filtration and flow rate. Lower water quality may affect municipal water supplies, water-based recreation, and ecosystem services tied to the health of fish and wildlife and associated aquatic systems.

Warming air temperature due to climate change and loss of streamside vegetation due to development, grazing, and agriculture in the riparian zone will cause water temperatures to increase. Temperature is a significant abiotic factor influencing physiology, bioenergetics, behavior, and biogeography because most aquatic organisms are ectothermic (Rahel 2002; Sweeney et al. 1992). Some native fish species, such as bull trout (*Salvelinus confluentus*), are extremely sensitive to warm water, whereas some nonnative species can tolerate higher temperatures (see Chapter 5). The biggest and earliest temperature increases are likely to occur in fish habitats at lower elevations; consequently, these habitats will be the most vulnerable to shifts in species composition and distribution. The response of microbial and aquatic invertebrate communities to a warming climate and altered hydrologic patterns is poorly understood. Native fish species with high ecological plasticity will be able to withstand some environmental change by altering life history timing or distribution patterns. But the magnitude and rate of change will overwhelm species with narrow ecological niches or limited ability to withstand competition from nonnative species. In the Northern Rockies region, these more-vulnerable species include bull trout (*Salvelinus confluentus*) and cutthroat trout (*Oncorhynchus clarkii*).

Effects of climate change on fish are summarized in Chapter 5, and effects on recreational fishing are summarized in Chapter 10. Additional effects are likely to occur to culturally important fisheries. For example, the Nez Perce Tribe maintains fishing rights within the boundaries of its reservation and traditional fishing grounds, which include the mainstem of the Columbia River. Hydropower and stream modification have already significantly affected salmon and steelhead (*O. mykiss*) fisheries (Smith et al. 2002; Wagner et al. 2004; Williams et al. 2001). Climate change is expected to amplify these impacts, leading to decreased fish abundance and increased emphasis on conservation programs.

Threats to municipal watersheds from wildfire and insects are expected to increase considerably (see Chapter 8). Climate models project higher precipitation for the region and more frequent occurrence of storm events (see Chapter 3). These changes will potentially increase sedimentation in rivers and reservoirs, increase water treatment costs, and require expensive dredging in reservoirs to maintain water storage.

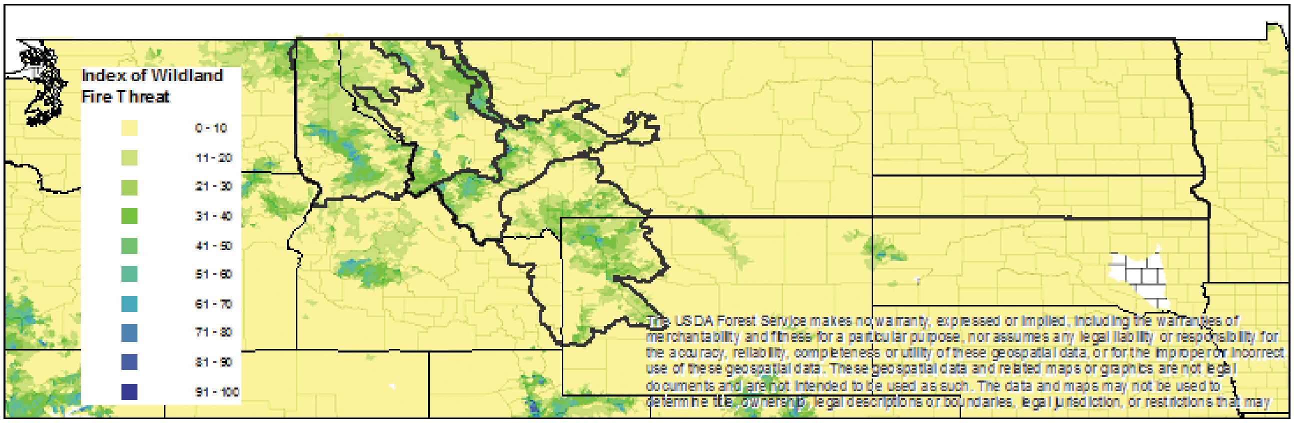

Figure 11.4—Wildland fire threat to forests and importance to surface drinking water. Higher numbers indicate higher risk of wildland fire (from Weidner and Todd 2011).

Warming has already led to expansion of agriculture in some areas of the western United States, including the Northern Rockies region. Higher precipitation could lead to increased dependence on tile drainage and increased levels of pollutants in waterways. Increased occurrence of drought would have the exact opposite effect. Expansion of agriculture would generally cause reduced water quality, but the net effects of both—more flooding and more drought—are uncertain (Warziniack 2014).

Many of the effects on water quality will be magnified if water quantity also falls substantially. Lower flows have been linked to increases in water temperature, eutrophication, and increases in nutrients and metals. Lower flows imply less water to dissipate solar radiation and dilute pollutants already in the water (Allan and Castillo 2007; Murdoch et al. 2000; Poole and Berman 2001; van Vliet et al. 2011). Low flows also increase the likelihood of eutrophication in nutrient-rich bodies of water (Conley et al. 2009; Schindler et al. 2008; Vollenweider 1968).

Adaptive Capacity

Restoration of streams, wetlands, and riparian areas may help stabilize temperatures in some locations, but in the long term, investments in water treatment infrastructure will be needed if sediment increases substantially or if large disturbances become more frequent. Enhancing fish populations through hatcheries is already occurring, and such human intervention may become more important in the face of climate change. Other adaptation strategies for aquatic species and water-based recreation are described in chapters 5 and 10.

Risk Assessment

The effects of increased fire frequency on municipal water supplies will be large, and are likely to be amplified by an increasing population reliant on surface water. Altered timing of precipitation and frequency of flooding may affect erosion rates (Sham et al. 2013). Given current knowledge gaps about the response of a species to climate change, it is difficult to provide a quantitative risk assessment. For example, a large portion of currently suitable habitat for native trout species could disappear in the Northern Rockies region by 2100 (Isaak 2012). This would be an example of a high-magnitude effect for ecosystem services and aquatic species.

The likelihood of effects on municipal water supplies is high, and is already occurring in some regions of the western United States. Sedimentation from severe wildfires in areas where fire has been excluded for many decades may cause more impacts than climate change. Nonetheless, climate change is expected to exacerbate these effects. Given the high levels of diversity and variability in how aquatic habitats will respond to a changing climate, it is difficult to quantify the likelihood of effects for these ecosystem services. Low-elevation habitats are expected to be affected the most and soonest, resulting in a high likelihood for a shift in ecosystem services in aquatic systems. High-elevation aquatic environments may be buffered by the influence of altitude on temperature, resulting in a lower likelihood of effects, at least in the near term.

Ecosystem Service: Building Materials and other Wood Products

Timber used for wood products is a provisioning ecosystem service. Much of the timber is exported from the Northern Rockies region, so the most important aspect of timber is its ability to provide jobs, particularly in rural communities. The timber industry also helps maintain a labor force capable of doing forest restoration work.

A timber processing area for the USFS Northern Region is defined by counties with processing facilities that receive timber from counties containing non-reserved timberland in the region (primarily located in Idaho north of the Salmon River and in Montana) (McIver et al. 2013). Timber processing spans 12 Idaho counties, 26 Montana counties, and 4

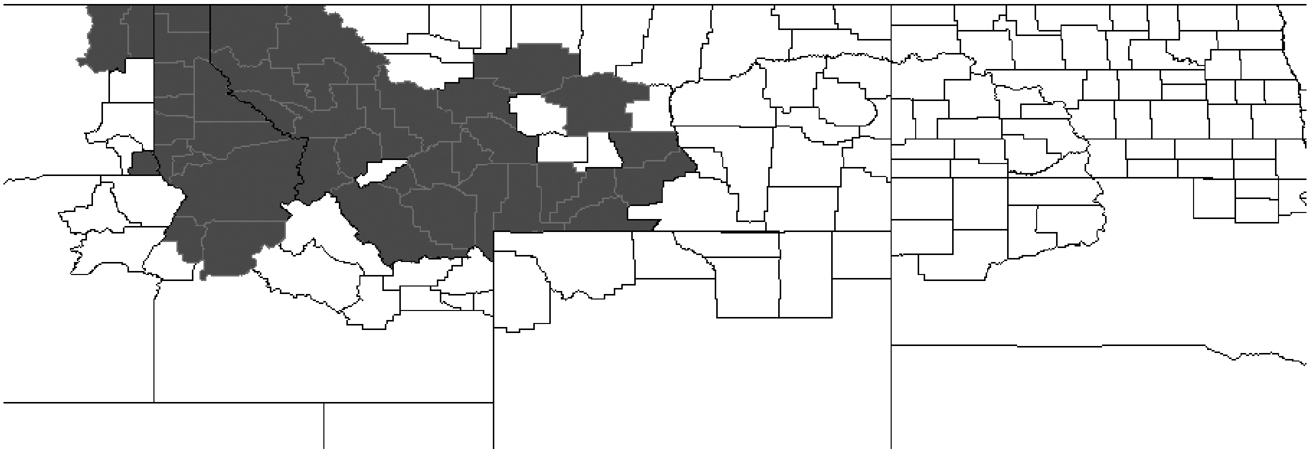

Figure 11.5—Primary area where timber is processed from national forests in the U.S. Forest Service Northern Region.

Washington counties (fig. 11.5). More than 95 percent of timber harvested from regional forests is processed by mills in northern Idaho and Montana. In 2011, Idaho and Montana contained 160 timber processing facilities including sawmills (73), house log/log home facilities (42), manufacturers of log furniture (18), post and small pole producers (18), cedar products producers (4), plywood and veneer plants (4), and a utility pole producer. More than 97 percent of timber is processed in sawmills, and 91 percent of timber processed is from trees with diameters greater than 10 inches. The proportion of timber processed in sawmills is up from 80 percent reported in Keegan et al. (2005).

Timber and forest products are dominant economic forces in the Northern Rockies region, with forest products (as defined by U.S. Department of Labor, Bureau of Labor Statistics [n.d.]) accounting for 23 percent of direct manufacturing employment in Montana (McIver et al. 2013) (table 11.8). Historically, much of the timber harvested in the area has come from national forests, although that share has decreased greatly. In 1979, 46 percent of timber harvested in Idaho came from national forests; by 2006 that share was only 7 percent (Brandt et al. 2012). Table 11.8 shows the sold volume for the Northern Rockies for the past two decades. Timber removal has varied over time in response to changing market and policy conditions, but the past decade has been particularly difficult for the timber industry.

Timber harvests have decreased since the late 1980s on national forests throughout the Nation due to changing economic conditions, environmental policies, and litigation against public agencies. The easily accessible larger tree stock has mostly been cut, increasing timber costs and decreasing profits. Increased housing starts spurred a slight recovery from 2003 through 2005, but the recession that followed led to the worst wood products markets since the Great Depression (Keegan et al. 2012). Between 2005 and 2009, employment in the wood products industry declined 29 and 24 percent in Idaho and Montana, respectively. Most of these losses were in the forestry and logging industries, for which employment declined 33 and 37 percent in Idaho and Montana, respectively (Bureau of Economic Analysis data, from Keegan et al. 2012).

Mills in the region are the major employer for some small communities, making the effects particularly pronounced in a few places. At the height of the downturn in 2008, initial unemployment claims in the wood products industry were more than 3,400 in 39 mass layoffs. Across the West, there were 30 percent fewer mills operating in 2009–2010 than in 2004–2005, a 27-percent decrease in timber-processing capacity (Keegan et al. 2012).

Timber jobs have generally been declining in the Northern Rockies region, whereas nontimber jobs have generally been increasing (fig. 11.6). These data include jobs in growing and harvesting, sawmills and paper mills, and wood products manufacturing. In 1998, there were 17,076 jobs in the timber industry, but in 2012, there were only 9,531 jobs, a 44-percent decrease. At the same time, nontimber employment increased from 287,163 to 350,929 jobs, a 22.2 percent increase. The absolute number of timber jobs has declined while the number of nontimber jobs has increased, so the proportion of employment in timber has decreased substantially, from 6 percent in 1998 to 3 percent in 2012.

However, regional trends in timber employment differ within the Northern Rockies region (table 11.9). The Western Rockies subregion, which includes the Idaho Panhandle, Kootenai, and Nez Perce-Clearwater National Forests, has the highest proportion of employment in the timber industry, accounting for 5 percent of private employment in 2012. Benewah County, Idaho has 32 percent of private employment in timber, the highest in the subregion. Employment in the timber industry has decreased most in the Western Rockies subregion, with 7 of 15 counties (Asotin, Washington; Bonner, Idaho; Clearwater, Idaho; Kootenai, Idaho; Lincoln, Montana; Pend Oreille, Washington; and Sanders, Montana) losing more than half of their timber-related jobs between 1998 and 2012. Only one county in the subregion (Idaho County, Idaho) increased employment in the timber industry (18 percent). Some counties in the Central Rockies and Eastern Rockies subregions have increased employment, but these are counties with a low proportion of

Table 11.8—Sold timber volumes from national forests in the U.S. Forest Service Northern Region and Greater Yellowstone Area subregion over the last two decades.[a]

	1980			2013			Difference		
National Forest	**Number of sales**	**Sold volume**	**Inflation adjusted sold value**	**Sales**	**Sold volume**	**Inflation adjusted sold value**	**Sales**	**Sold volume**	**Inflation adjusted sold value**
		Thousand board feet	*Dollars*		*Thousand board feet*	*Dollars*	*Percent*		
Beaverhead-Deerlodge	630	47,137	1,971,012	845	8,176	59,067	34	-83	-97
Bitterroot	268	42,751	3,883,685	266	8,123	459,684	-1	-81	-88
Bridger-Teton	425	20,141	885,087	627	9,641	150,834	48	-52	-83
Caribou-Targhee	7,347	98,301	7,726,627	743	7,234	93,922	-90	-93	-99
Custer	127	1,653	81,794	292	1,573	18,088	130	-5	-78
Flathead	289	194,340	22,504,836	334	14,797	963,163	16	-92	-96
Gallatin	310	23,575	628,518	551	4,480	44,820	78	-81	-93
Helena	113	21,916	1,451,979	393	3,431	34,000	248	-84	-98
Idaho Panhandle	669	317,157	64,207,103	866	40,180	3,562,340	29	-87	-94
Kootenai	616	175,803	36,705,744	820	35,589	1,820,020	33	-80	-95
Lewis and Clark	277	12,423	134,615	387	2,152	21,160	40	-83	-84
Lolo	367	40,744	2,281,829	597	6,402	298,537	63	-84	-87
Nez Perce-Clearwater	414	255,741	18,881,743	699	44,402	6,567,655	69	-83	-65
Shoshone	307	11,883	198,089	415	7,667	225,075	35	-35	14

[a] Source: Headwaters Economics (2017).

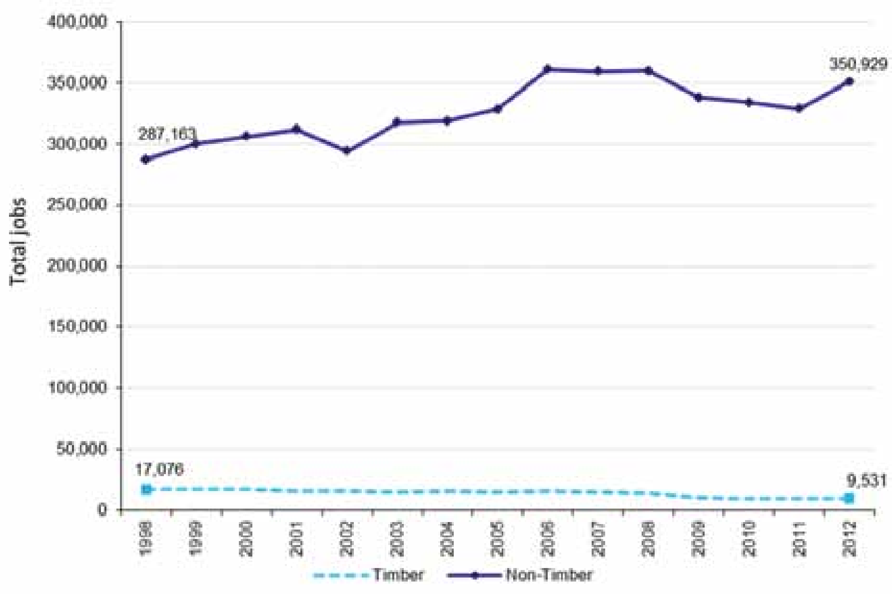

Figure 11.6—Total jobs in timber and non-timber for national forests in the U.S. Forest Service Northern Region (from U.S. Department of Commerce 2014).

Table 11.9—Employment in the timber industry, by county and region, 2012.[a]

County	Total private employment	Timber employment	Employment in timber (%)	Change in timber employment, 1998–2012 (%)
All subregions	365,255	9,531	2.6	-44
Western Rockies subregion	112,143	6,511	5.8	
Asotin County, WA	4,605	9	0.2	-95
Benewah County, ID	2,130	677	31.8	-25
Bonner County, ID	10,972	401	3.7	-70
Boundary County, ID	2,239	410	18.3	-3
Clearwater County, ID	1,896	358	18.9	-59
Idaho County, ID	3,165	386	12.2	18
Kootenai County, ID	44,080	913	2.1	-52
Latah County, ID	8,398	349	4.2	-11
Lewis County, ID	717	132	18.4	-47
Lincoln County, MT	3,771	191	5.1	-79
Nez Perce County, ID	16,061	1,693	10.5	-13
Pend Oreille County, WA	1,403	83	5.9	-67
Sanders County, MT	1,910	122	6.4	-55
Shoshone County, ID	4,183	94	2.2	-28
Stevens County, WA	6,613	693	10.5	-30
Central Rockies subregion	110,451	2,374	2.1	
Flathead County, MT	31,316	977	3.1	-45
Glacier County, MT	2,205	1	0.0	0
Lake County, MT	5,121	119	2.3	-51
Mineral County, MT	895	231	25.8	175
Missoula County, MT	47,885	574	1.2	-69
Powell County, MT	1,024	243	23.7	37
Ravalli County, MT	8,522	220	2.6	-69
Silver Bow County, MT	13,483	9	0.1	125
Eastern Rockies subregion	114,783	595	0.5	
Beaverhead County, MT	2,234	9	0.4	-40
Broadwater County, MT	790	178	22.5	78

Table 11.9—*Continued.*

County	Total private employment	Timber employment	Employment in timber (%)	Change in timber employment, 1998–2012 (%)
Carbon County, MT	2,169	3	0.1	50
Cascade County, MT	29,168	25	0.1	19
Chouteau County, MT	723	4	0.6	0
Fergus County, MT	3,291	9	0.3	-89
Gallatin County, MT	37,409	103	0.3	-59
Granite County, MT	481	47	9.8	-69
Jefferson County, MT	1,679	34	2.0	89
Lewis and Clark County, MT	23,623	48	0.2	129
Madison County, MT	1,943	10	0.5	67
Meagher County, MT	268	4	1.5	-73
Park County, MT	4,394	86	2.0	-28
Powder River County, MT	329	0	0.0	-100
Rosebud County, MT	2,562	0	0.0	-100
Stillwater County, MT	2,683	35	1.3	-58
Sweet Grass County, MT	1,037	0	0.0	-100
Greater Yellowstone Area subregion	26,609	50	0.2	
Fremont County, ID	1,429	19	1.3	-75
Park County, WY	9,876	25	0.3	-36
Teton County, WY	15,304	6	0.0	100
Grassland subregion	1,269	1	0.1	
Carter County, MT	184	0	0.0	-100
Harding County, SD	402	1	0.2	0
McHenry County, ND	683	0	0.0	0

[a] Source: U.S. Department of Commerce (2014).

jobs in the timber sector, so a small number of new jobs have a disproportionate effect.

Effects of Climate Change

Although temperature and precipitation may affect vegetation in the Northern Rockies region, the direct effect of climate on timber production is expected to be small. More important to the timber industry are the economic and policy changes that affect demand for forest products and timber quotas for national forests. The primary effects of climate change on timber will occur through the effects of temperature on disturbance and to a lesser extent on growth and productivity (see chapters 7 and 8).

The primary sensitivities of timber resources associated with climate change are wildfire, insects, and disease. Forest growth is expected to be lower in areas that experience higher temperature and decreased precipitation (Ryan et al. 2008) (see Chapter 7). In addition, warmer winters and associated freezing and thawing may increase forest road erosion and landslides, making winter harvest more difficult and expensive, and potentially reducing the timber supply (Karl et al. 2009). Reduced snowpack may promote insect or disease outbreaks, although harvests could increase in the short term through salvage of dead and dying trees. Climate change will result in larger, more frequent fires and a longer fire season. Increased fires may increase demand for fuels treatments, either through timber harvests or through mechanical and manual thinning that uses the timber labor force and infrastructure. Although this may affect the availability of harvestable wood products, the overall effect on timber-related jobs would be relatively small.

Forest Products (Commercial Use)

The provision of commercial timber from national forests could be affected by altered temperature and precipitation. Effects on the distribution and abundance of vegetation are expected to vary widely by species and location (see Chapter 6). Although overall wood production is projected to increase, the proportion of sawtimber (combining both softwoods and hardwoods) is somewhat larger with climate change in all scenarios, species, and regions. This shift in product mix reflects the effects of accelerated growth on rotation age, which is lengthened in the long term for all regions and species. With longer rotations come larger volumes of sawtimber relative to pulpwood (Irland et al. 2001).

Although direct effects of elevated temperature on tree growth rates can be positive (e.g., through lengthening the growing season), associated soil water deficits will probably occur in most locations except in the high elevations. Tree responses to soil water deficits vary among species as a result of differences in tree physiology and morphology. Within species, drought sensitivity of trees is usually largest in seedlings. Mortality can result directly from water stress or indirectly from insects and pathogens, and vulnerability of trees to more frequent outbreaks may increase during periods of water deficit (Kardol et al. 2010). Climate-driven changes in instream flow are likely to reduce abundance of early successional tree species, favor herbaceous species and drought-tolerant and late successional woody species (including introduced species), reduce habitat quality for some riparian animals, and slow litter decomposition and nutrient cycling (Perry et al. 2012).

Although direct effects on tree growth will vary by species and climate change scenario, one study observed that productivity and timber inventories will increase while timber prices decrease (Irland et al. 2001), the result of an adaptive timber market. Adaptation in U.S. timber and wood product markets is expected to offset some potentially negative effects of climate change. In the United States, lumber and plywood production increases under all scenarios, and pulpwood production decreases under some scenarios. Overall, consumers and mill owners would benefit from climate change, whereas landowners may have reduced economic benefits (Irland et al. 2001).

Markets generally adapt to short-term increases in mortality by reducing prices, salvaging dead and dying timber, and replanting new species that are favorably adapted to the new climate. Salvage during dieback ranges from 50 to 75 percent, depending on management intensity. Total benefits to producers plus consumers rise in all scenarios considered. Market adaptation can reduce or reverse potential forest carbon fluxes in the United States (Irland et al. 2001). New technologies represent another method of adapting to climate change. For example, new adhesives have led to new classes of wood panels and composites, which have displaced older products. These new products often enable the industry to draw on more abundant species of trees that are also closer to end-use markets. New technologies have also helped mills produce more product value from a given tree. If this trend continues, the forest-based economy will be more resilient if forest dieback occurs in the future (Irland et al. 2001).

Adaptive Capacity

Adaptive capacity will depend on the ability both to manage the natural resources (maintaining healthy forests) and to adapt to economic forces. Management actions may be able to mitigate drought stress and soil water deficits, moderating some of the effects of climate change. Land managers also have the option to conduct fuels treatments, which help decrease the probability of large, severe wildfires, and to salvage burned or insect-killed timber before it loses market value. Timber management can improve forest resistance and resilience to stressors in areas identified for treatment, usually in the portions of the forest that contain roads. Timber management is a relatively slow process, requiring 50 or more years from regeneration to harvest. Therefore, timber management cannot respond quickly to potential threats; it serves more as a long-term modification of forest composition and structure by helping the landscape gradually become more resistant and resilient. The wood products industry may also be able to adapt to changing conditions by using alternative species, changing the nature or location of capital and machinery, changing reliance on imports or exports, and adopting new technologies (Irland et al. 2001). Developing capacity within the industry to take advantage of emerging products will be important, though the most resilient communities will be those that diversify their economic bases, effectively reducing their exposure to adverse impacts to the timber industry.

Risk Assessment

In summary, the magnitude of effects for wood products is expected to be large, but mostly from nonclimate forces. The likelihood of effects is moderate, again from nonclimate forces. But it is uncertain how climate will affect forest disturbances, which could have a more dominant influence on timber supply.

Ecosystem Service: Mining Materials

Minerals are provisioning ecosystem services, but their primary role in the region is as an economic driver, providing jobs and incomes. Mineral development is important throughout the Northern Rockies, but particularly in northeastern Montana and northwestern North Dakota. In some counties, oil and gas development represents a third of total income to residents. According to 2012 IMPLAN data (MIG 2012), the percentages of total county income directly from the oil and gas sector are: Fallon County, Montana—33 percent; Williams County, North Dakota—32 percent; Slope County, North Dakota—29 percent; Dunn County, North Dakota—26 percent; Stark County, North Dakota—23 percent; Mountrail, North Dakota—22 percent; McKenzie, North Dakota—21 percent. Most of this income comes from the Bakken Formation, which lies under parts of North Dakota, Montana, and Saskatchewan. At full development (about four wells per square mile), the formation is expected to be the Nation's largest oilfield (Mason 2012).

The main stressors from oil and gas development are effects on other ecosystem services, such as water quality (discussed earlier). Traffic from trucks and heavy machinery also increases the risk of introducing nonnative species to surrounding rangelands (see Chapter 7).

Effects of Climate Change

Climate is not likely to directly affect minerals, but it is included in this assessment due to its prominence in the region and because of its potential to conflict with other ecosystem services. Power generation, oil and gas development, and mineral extraction are major users of water. Increased mudslides and fires may threaten oil and gas infrastructure, which would in turn threaten the ecosystem services that are collocated with mineral development.

Regional centers of oil and gas draw people from all over the country looking for high-paying jobs. Competition for workers in the oilfields causes wages in all other sectors of regional economies, including traditionally low-wage jobs in the service industry, to rise. If climate adversely affects other economic sectors, job opportunities in mining and energy will become more important. Climate change could affect the oil and gas infrastructure, but nonclimatic drivers will be more important, including international prices for oil and gas, national climate policy, and regional concerns about threats to watersheds.

Adaptive Capacity

Global economic forces primarily drive the oil and gas industry. Oil and gas development potential determines where drilling activity takes place, and regional growth occurs so quickly that communities respond to rather than plan for such development. Adaptive capacity is either not applicable to this ecosystem service or limited from the perspective of economic development. The most successful mineral-based economies are those that are able to collect some of the resource rents from drilling and invest them back into the community, extending prospects for long-term economic growth (Kunce and Shogren 2005). Oil and gas development is subject to booms and busts, and the most resilient communities are those that invest resource rents into efforts to diversify the economy.

Risk Assessment

Climate change is not expected to have significant effects on industries based on extraction of minerals and energy. The magnitude of effects is expected to be large from nonclimate forces, and the likelihood of effects is expected to be moderate from nonclimate forces.

Ecosystem Service: Forage For Livestock

The Northern Rockies region contains 158 million acres of rangeland. More than 85 percent of these rangelands are privately held; 43 percent of rangeland in the USFS Northern Region economic impact area is in Montana, which ranks third in the Nation, behind Texas and New Mexico, in non-Federal rangeland area. Of the Federal rangeland, 8.5 million acres are BLM lands, of which 8 million acres are in Montana (USDOI BLM n.d.). A variety of economic uses for rangeland exist in the Northern Rockies region, but grazing cattle is by far the largest. Almost all counties in the region have shares of total income derived from cattle above the national average, with some counties in Montana and the Dakotas having more than 100 times the national average (MIG 2012 IMPLAN data).

Cheatgrass (*Bromus tectorum*) and other nonnative plants have become a major nuisance throughout western rangelands, significantly reducing usable forage. The Nez Perce-Clearwater National Forest assessment (USDA FS 2014) states that forage has decreased in some places (table 11.10). Human modification has also converted rangeland to other uses (Reeves and Mitchell 2012). Between 1982 and 2007, Montana lost about 900 acres of rangeland, 3,100 acres of Conservation Reserve Program land, and 30 acres of cropland. This pattern of loss is consistent across the region, with the exception of small gains in pasture in Montana and Idaho (table 11.11). Rangeland losses in the West have been caused by agricultural development (17.0 percent), resource extraction (7.4 percent), and residential development (5.8 percent) with much smaller losses to mixed use, recreation, and transportation (Reeves and Mitchell 2012).

Rates of land conversion exceed population growth. Nationally, between 1945 and 1992, one additional person led to about half an acre converted to urban use; between 1992 and 1997, the rate reached 1.2 acres per additional person (DeCoster 2000). Human modification and fragmentation of rangelands have potential consequences for

Table 11.10—Unsuitable land area in the Christie Creek and Sherwin Creek allotments in the Nez Perce-Clearwater National Forest, including forage production reduced from conversion of desirable vegetation to "weedy" species.[a]

Allotment	Pasture	Unsuitable land area	Forage reduced
		Acres	*Animal unit months*
Christie Creek	Rhett	83	11
	Christie Creek	106	11
	Deer Creek	151	20
Sherwin Creek	Lower Center Ridge	238	32
Total		578	74

[a] Source: USDA FS (2014).

Table 11.11—Changes in non-Federal rangeland area, 1982–2007.[a]

	Net change						
	Rangeland	Pasture	Conservation Reserve Program land	Crop land	Historic rangeland	Change from historic rangeland	Rangeland threatened by residential development
		Acres			*Thousands of acres*	*Percent*	*Thousands of acres*
Montana	-897.8	671.6	-3,084	-28.8	67,604	-24	28
South Dakota	-784.8	-556.2	-245	1.6	45,924	-52	46
North Dakota	-507.4	-5.8	-3,034	85.1	43,214	-71	29
Idaho	-177.6	103.4	-1,154	94.6	29,763	-20	77
Wyoming	221.0	-178.0	-458	10.0	49,306	-8	13

[a] Source: Reeves and Mitchell (2012).

the socioeconomic sustainability of rural communities, including loss of rural character, loss of biodiversity, difficulty in managing interconnected lands for grazing, threats to watershed health, limited outdoor opportunities, compromised viewscapes, loss of native species, changes in disturbance regimes, and increased spread of nonnative species.

Effects of Climate Change

Warmer temperatures and increased precipitation are expected to increase productivity of rangelands (Reeves and Mitchell 2012) (see Chapter 7), and increased regional population will lead to fragmentation of rangelands. Arid grasslands are likely to show a short-term response in species richness to altered precipitation due to the prevalence of annual species (Cleland et al. 2013). Carbon dioxide (CO_2) enrichment may alter the relative abundance of grassland plant species by increasing the production of one or more species without affecting biomass of other dominant and codominant species. This favored-species pathway to species change is the most frequently reported mechanism by which CO_2 affects grassland communities (Polley et al. 2012).

Cattle stocking rates in the Northern Rockies region remain at or below current capacity of the land to support livestock (Reeves and Mitchell 2012), with few counties experiencing forage demand above current forage supply. In the long term, longer and wetter growing seasons would probably make rangeland more productive. The greatest threat to grazing from climate change may be increasing rates of spread of nonnative weeds and changes in fire regime (Maher 2007). Fire itself makes ranch planning difficult. Loss of access to grazing areas, on both private and public lands, requires emergency measures such as the use of hay, which can financially devastate ranchers already operating with thin margins. Across all rangelands, increased fire in the future has the general effect of converting more lands to invasive monocultures (e.g., cheatgrass, red brome [*B. rubens*]). Fire also kills shrubs, increasing the prevalence of grasses and herbs, which can reduce structural and floristic diversity. The net effect is a narrowing of options for ranch income diversification (e.g., loss of quail [*Oreortyx pictus*] habitat and loss of Rocky Mountain mule deer [*Odocoileus hemionus hemionus*] winter range).

Adaptive Capacity

Human modification of rangelands and associated fragmentation are driven by opportunities for economic growth, as land is converted to higher value uses. Conversion of rangeland to residential development has brought new populations, higher incomes, and higher tax bases to rural communities, creating what has been called the "New West" (Riebsame et al. 1997). During the 1990s, 67 percent of counties in the Rocky Mountains grew faster than the national average (Beyers and Nelson 2000). Natural amenities in the Northern Rockies region are often touted as an economic asset (Power 1998; Rasker 1993). Economic growth without preservation of these assets is not likely to be sustainable.

Risk Assessment

The magnitude of effects on rangeland reflected in potentially large increases in productivity will be high, but given that forage supply exceeds demand, the effect on grazing will be small. Effects of invasive species and development may be large. The likelihood of effects is high, given that change is already being observed and that these trends are likely to persist. Loss of rural character is a concern, but it is not likely that the region will become heavily urbanized in the foreseeable future.

Ecosystem Service: Viewsheds And Clean Air

Air quality is an important ecosystem service that can be altered by changes in vegetation composition and tree responses to climate change. For example, tropospheric ozone (O_3), air pollution episodes, plant sensitivity to air pollutants, and release of pollen all affect the provision of air quality by forests.

The Northern Rockies region generally has exceptional air quality, although a few counties in the region regularly have days with poor air quality (American Lung Association® 2015), and some areas are subject to wintertime inversions that trap air pollutants. During these inversions, wood-burning stoves used to heat homes become a major source of air pollution. In the summer, smoke from wildfires settles in valleys, leading to poor air quality. Counties in Idaho are often affected by burning of crop residues, and smoke can get trapped or settle into valleys, where it persists until strong winds clear the air. Major sources of air pollution in North Dakota include coal-fired power plants, oilfield emissions, and vehicle traffic in the mineral-rich areas of the State. However, the North Dakota topography does not contain any features that would trap pollutants, so air quality is generally good throughout the State.

A large percentage of Northern Rockies residents are in demographic groups (e.g., elderly, poor) that are sensitive to poor air quality. Almost 1 in 10 adults in the region have asthma (Centers for Disease Control and Prevention 2009). As more and more young people leave rural communities for more-urban settings, sensitive populations are left isolated in rural areas that often lack the health facilities needed to accommodate an aging, ailing population.

Effects of Climate Change

Air quality can decline rapidly during a wildfire, and increased frequency of wildfires will affect viewsheds and air quality. Extended fire seasons will affect both scenery and air quality, with detrimental effects to human health. Analyses of the effects of climate change on air pollution in general have shown that climate change will increase the severity and duration of air pollution episodes (Bedsworth 2011). Climate change may affect distribution patterns and mixtures of air pollutants through altered wind patterns and amount and intensity of precipitation. The intensity of precipitation determines atmospheric concentration and deposition of acidifying compounds, potentially altering frequency and extent of pollution episodes (e.g., O_3) (Bytnerowicz et al. 2007). By 2050, summertime organic aerosol concentration over the western United States is projected to increase by 40 percent and elemental carbon by 20 percent. Higher temperatures accelerate chemical reactions that synthesize O_3 and secondary particle formation. Higher temperatures, and perhaps elevated CO_2 concentrations, also lead to increased emissions by vegetation of volatile organic compound precursors to O_3 (Kinney 2008). In addition to earlier onset of the pollen season and possibly higher seasonal pollen loads in response to higher temperatures and longer growing seasons, elevated CO_2 itself may increase pollen levels in some plant species (Kinney 2008).

Adaptive Capacity

A number of systems are already in place to alert residents when air quality deteriorates. These systems may become more common, as will days with poor air quality and associated alerts. Adaptation options include limiting physical activity outdoors, using air conditioning, and taking medications to mitigate health impacts. Tighter restrictions on use of wood for heating homes and on agricultural burning can reduce pollutants, and fuels treatments can reduce wildfire risk and smoke intensity. These strategies reduce exposure and mitigate damages. Many may be possible in the long run, but the geographic diversity and rural character of the region makes quick adaptation unlikely. The effects of poor air quality also fall heaviest on the most vulnerable populations, such as the elderly, young, and poor—groups that make up much of the rural populations of the region, where shortages of health care already exist. These groups have little capacity to adapt.

Risk Assessment

The magnitude of effects is expected to be high because a large percentage of the population (rural poor and elderly) is at risk for health impacts from poor air quality. This percentage will increase as the population ages and young people move to urban areas. The likelihood of effects is expected to be high because many areas are already seeing diminished air quality from increased fires and longer pollen seasons.

Ecosystem Service: Regulation of Soil Erosion

A USFS soil management directive (USDA FS 2009) identifies six soil functions: soil biology, soil hydrology, nutrient cycling, carbon storage, soil stability and support, and filtering and buffering. Steep slopes are the key element associated with erosion and landslides in mountain landscapes, and open rangeland is susceptible to topsoil loss. Erosion and landslides threaten infrastructure, water quality, and important cultural sites.

General resource management practices are designed to limit erosion and soil impaction, but landslides and erosion are still a common problem. Roads and other human activities are the largest source of sediment in most watersheds.

Landslide-prone areas are generally on slopes greater than 60 percent with geomorphology and surficial geology sensitive to earth movement. Individual management units in public lands may have hundreds of landslides each year.

Loss of soil from farm fields is a problem in the eastern part of the Northern Rockies region (Kellogg et al. 1997), but best practices in agriculture and range management have begun to slow the loss. Soil loss rates still exceed natural regeneration of soil in much of the eastern part of the region, and recent expansion of agriculture is likely to make the problem worse.

Effects of Climate Change

Soil erosion is tied to many forces on the landscape that are affected by climate change. In mountainous areas, wildfire and precipitation interact to affect erosion rates. Frequency of wildfire, precipitation in the form of rain rather than snow, and intense precipitation events are expected to increase (see chapters 3, 4, and 8), a combination that will lead to greater erosion and more landslides.

In the eastern rangelands, increased precipitation and warmer temperatures may benefit grass productivity and limit erosion. However, the same changes that make rangelands more productive also make land more valuable for agriculture. Expansion of agriculture is already occurring and will increase soil erosion in some areas. A combination of increased drought and increased flooding will add to already high erosion rates. Erosion rates on rangelands are also likely to increase with greater fire prevalence and spread of nonnative species. Erosion is a significant concern for cultural sites, and is discussed in more detail in Chapter 12.

Adaptive Capacity

One of the key impacts of soil erosion in mountains is its effect on water quality and drinking water treatment costs. Without expensive dredging, the usable life of dams and reservoirs will shorten, and capital investments will be necessary to remove added sediment from drinking water sources (Sham et al. 2013). Limiting erosion on rangelands can be done with best management practices for agriculture, including the use of buffers and limiting activity in sensitive riparian areas. In all areas, more-resilient vegetation can be used to stabilize soils and support soil formation and nutrient cycling.

Risk Assessment

Landslides and flooding in mountainous areas have the potential for large, sudden damage to homes, infrastructure, and watersheds. Costs of soil erosion on the plains are high, but occur over extended periods of time. The likelihood of increased erosion in the mountains is high because it depends on natural processes (e.g., fire, flooding) that are already changing. If agricultural practices do not change, erosion on the plains is also fairly certain. Likelihood of effects on the plains could be low if best practices become more common in agriculture.

Ecosystem Service: Carbon Sequestration

Forests provide an important ecosystem service in the form of carbon sequestration, or the uptake and storage of carbon in forests 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 forests is "becoming more valuable as the impacts of greenhouse gas emissions are becoming more fully understood and experienced" (USDA FS 2015).

The National Forest System (NFS) contains 22 percent of the Nation's total forestland area and 24 percent of the total carbon stored in all U.S. forests, excluding interior Alaska. The management of these lands and disturbances such as fire, insects, and disease influence carbon sequestration rates. 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 disturbed by catastrophic wildfires and other natural events (e.g., mortality following windthrow).

The USFS champions the principles of considering carbon and other benefits together, integrating climate adaptation and mitigation, and balancing carbon uptake and storage in a wide range of ecosystem services, some of which have tradeoffs. The goal is to maintain and enhance net sequestration on Federal forests across all pools and age classes through protection of existing stocks and building resilience in stocks through adaptation, restoration, and reforestation. Carbon stewardship is an aspect of sustainable land management. It is also important to consider that carbon estimates are most useful at larger spatial scales; typically, baseline carbon estimates at the forest scale are not useful for project-specific applications.

Forests are highly dynamic systems that are continuously repeating the natural progression of establishment, growth, death, and recovery, while cycling carbon throughout the ecosystem and the atmosphere. This cycle, which drives overall forest carbon dynamics, varies geographically and by forest type, but also depends on the frequency, magnitude, and type of disturbance events. Natural and anthropogenic disturbances can cause both immediate and gradual changes in forest structure, which in turn affect forest carbon dynamics. For instance, a severe wildfire may initially release CO_2 to the atmosphere and cause tree mortality, shifting carbon from living trees to dead wood and the soil. As the forest recovers, however, new trees establish and grow, absorbing CO_2 from the atmosphere. Although disturbances may be the predominant drivers of forest carbon dynamics (Pan et al. 2011), environmental factors, such as the availability of key forest nutrients (e.g., CO_2 and nitrogen), as well as climatic variability, influence forest growth rates and consequently the cycling of carbon through a forest ecosystem (Pan et al. 2009).

Changes in carbon stocks and resulting net emissions may be influenced through vegetation management strategies. Land management and restoration strategies, plans, and actions, such as fire and fuels management, timber harvesting, reforestation, and other forest stand treatments, can be designed to integrate carbon sequestration capacity across broad landscapes and over the long term, while meeting other resource management objectives.

Wood uses for products can also complement land management by extending the storage of carbon in useful products and reducing emissions as wood products substitute for those that emit more CO_2 and other greenhouse gases. Harvested wood products (HWP), such as lumber, panels, and paper, can account for a significant amount of offsite carbon storage and estimates of this addition are important for both national-level accounting and regional reporting (Skog 2008). Products derived from the harvest of timber from the national forests extend the storage of carbon or substitute for fossil fuel use, both of which are part of the overall carbon cycle.

Baseline Estimates

The USFS 2012 Planning Rule and the Climate Change Performance Scorecard element 9 (Carbon Assessment and Stewardship) require NFS units to both identify baseline carbon stocks and to consider that information in planning and management. The Office of Sustainability and Climate facilitated work by USFS Research & Development to develop a nationally consistent carbon assessment framework and to deliver forest information for every NFS unit. Estimates of total ecosystem carbon and stock change (flux) have been produced at the forest level across the Nation, relying on consistent methodology and plot-level data from the USFS Forest Inventory and Analysis program (USDA FS 2015).

Carbon stocks reflect the amount of carbon stored in seven ecosystem carbon pools—aboveground live tree, belowground live tree, understory, standing dead trees, down dead wood, forest floor, and soil organic carbon—for 1990 to 2013. Carbon stock change (flux) reflects the year-to-year balance of carbon going into or being pulled from the atmosphere (Woodall et al. 2013). Carbon stock change measures the interannual change in carbon stock caused by tree growth, disturbance, management, and other factors. Negative stock change values indicate that carbon is being pulled from the atmosphere (i.e., net carbon sink); positive values mean carbon is being released (i.e., net carbon source).

Figure 11.7 displays carbon stock trends for each of the national forests in the Northern Region between 1990 and 2013.The Idaho Panhandle National Forest stored the largest amount of carbon in the region, about 207 million short tons in 1990 and 202 million short tons in 2013. During this period, the Beaverhead-Deerlodge, Kootenai, Nez Perce, Flathead, Lolo, Clearwater, Gallatin, and Custer National Forests all increased in ecosystem forest carbon stocks, while the Lewis and Clark, Helena, and Bitterroot National Forests and Dakota Prairie Grassland decreased.

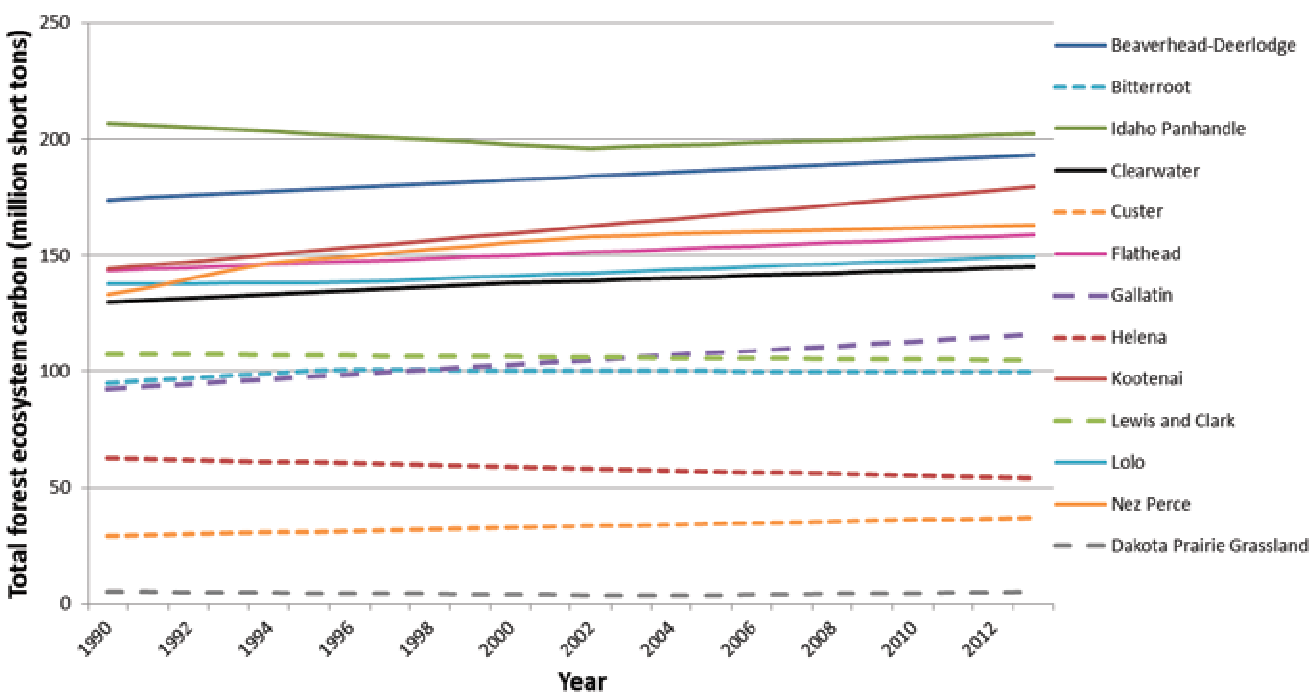

Figure 11.7—Total forest ecosystem carbon for national forests and grassland in the Northern Region from 1990 to 2013.

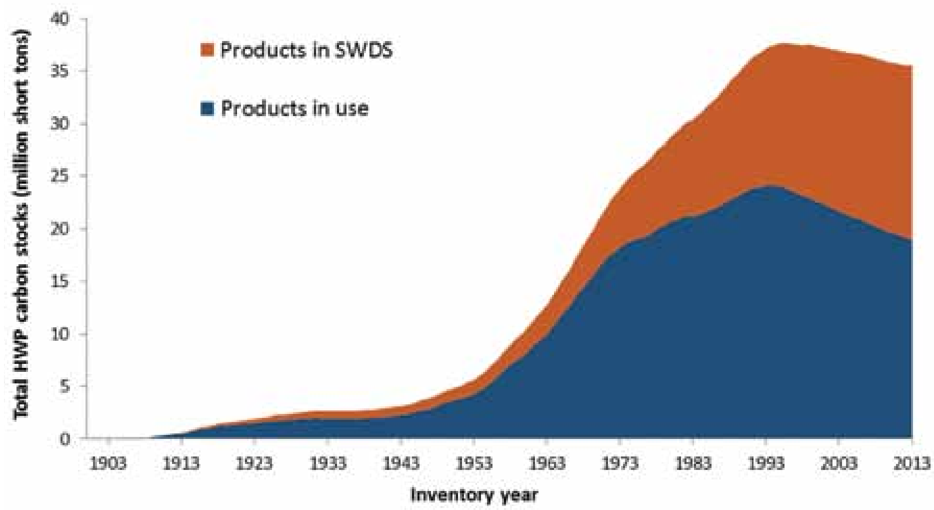

Figure 11.8—Cumulative total carbon stored in harvested wood products (HWP) manufactured from Northern Region timber. Carbon in HWP includes both products that are still in use and carbon stored at solid waste disposals sites (SWDS), including landfills and dumps (Stockmann et al. 2014).

The volume of cumulative carbon stored in Northern Region HWP rose sharply in 1955 and began to continually increase at a steady rate, peaking in 1995 with about 37 million short tons in storage (fig. 11.8). The HWP pool since then has decreased to 35 million short tons. This illustrates the influence of timber harvest on the HWP pool. The amount of HWP carbon entering that pool is less than the amount of carbon exiting it through various pathways, so HWP stocks are decreasing.

Effects of Climate Change

Many factors affect the capacity of forests to sequester carbon, and the net effect of climate change on carbon storage in forests is uncertain. The greatest vulnerability to forest distribution and health as a result of climate change is increased risk of fire, insects, and disease (mostly fungal pathogens). Preliminary results from the Forest Carbon Management Framework (Healey et al. 2014; Raymond et al. 2015), show, for example, that fire had the largest impact on carbon storage on the Flathead National Forest between 1990 and 2012, followed by harvest. The largest impact on carbon storage on the Idaho Panhandle National Forest was disease, followed by harvest.

Nitrogen often is a limiting nutrient in forests, so nitrogen deposition may increase wood production and accumulation of soil organic matter, thus increasing carbon sequestration. When carbon uptake is caused by increased growth, it is likely to be a transitory phenomenon. When soil accumulation is the primary cause of carbon uptake, forests could be a long-term carbon sink because belowground carbon has longer turnover times than aboveground carbon (Bytnerowicz et al. 2007).

Tropospheric O_3 damage in sensitive plant species may offset some productivity gains from elevated atmospheric CO_2, thus reducing carbon storage on land and possibly contributing further to climate change. Increasing O_3 will negatively affect plant productivity, reducing the ability of ecosystems to sequester carbon and indirectly providing feedback to atmospheric CO_2 (Sitch et al. 2007). Net carbon uptake by terrestrial ecosystems during the 21st century is likely to peak before mid-century and then weaken or even reverse, thus amplifying climate change (IPCC 2007).

Fungal pathogens, especially various types of root rot, are another key concern for forests and may affect the ability of forests to sequester carbon (Hicke et al. 2012). Increased temperature and humidity coupled with decreased snow and cold weather facilitate the spread of root rot. As more trees die and decompose, forests could switch from carbon sinks to carbon sources.

Adaptive Capacity

Adaptive capacity for sequestering carbon depends on the spatial and temporal scales at which an ecosystem service is defined. Carbon storage in any particular forest location may go up or down over time, but analysis of storage should occur at very large spatial scales. Adaptive capacity for this ecosystem service is probably low as most of the factors affecting carbon sequestration are external, including development pressures and wildfire.

Risk Assessment

Although increased temperature and drought will reduce forest growth, the most detrimental effects to carbon sequestration will be indirect, through increased risk and frequency of wildfires and insect outbreaks. Some deterioration in forest health is highly likely, so some change in the ability of forests to sequester carbon is also likely. However, the net effects on forest health and carbon sequestration are difficult to project, primarily due to the uncertainty in the magnitude of future occurrence of wildfire and insect outbreaks.

Ecosystem Service: Cultural and Heritage Values

The goods and services that ecosystems provide have spiritual, cultural, and historical value to many people. The effects of climate change will affect the provision of these services for individual locations, plant and animal species, and landscape characteristics. The majority of research on this topic pertains to forest resource values realized by Native American tribes and the effect of climate change on sense of place (see Adger et al. 2013 for a review).

Availability of resources (e.g., for food) and adequate habitat limit traditional lifeways, especially if the distribution and abundance of plants and animals change in response to increased temperature and disturbance (especially wildfire). In general, cultural and heritage values are high in the Northern Rockies region, and mostly threatened by changes in culture and the way humans interact with the landscape. Tribal values face ongoing stresses as Native American people attempt to preserve both culture and places on the land. Sources of stress range from legal struggles with Federal agencies (for example, the ongoing disagreement between the Blackfeet and Glacier National Park about access to resources on the park) to effects of recreation on sacred places. Educational programs and law enforcement on Federal lands protect many cultural sites, but funding is insufficient to protect all of them (see Chapter 12).

A large part of one's culture is his or her connection with physical places, often including an image of "home." The sense of place may be at risk to climate change effects if those connections and images change as a result of a changing climate. People may identify with livelihoods and activities that are no longer sustainable in a changing climate (Adger et al. 2011; Agyeman et al. 2009; Igor 2005). People who are tied to their communities are more reluctant to leave during economic and social hard times, which makes them more vulnerable to the effects of climate change (Field and Burch 1988).

Effects of Climate Change

Increased frequency of wildfire, floods, nonnative species establishment, and erosion all put cultural values, cultural sites, and historic sites at risk. Changes in climate that influence ranges of species which are traditionally harvested by Native Americans affect the ability of tribes to exercise their treaty rights. Impacts can be amplified or mitigated by management decisions and societal forces.

The economies of resource-dependent communities and indigenous communities in the region are particularly sensitive to climate change, with likely winners and losers controlled by effects on important local resources (Maldonado et al. 2013). Residents of high-elevation and northern-latitude communities are likely to experience the most disruptive impacts of climate change, including shifts in the range or abundance of wild species crucial to the livelihoods and well-being of indigenous people (Field et al. 2007). As traditional foods are affected by climate change through habitat alterations and changes in the abundance and distribution of species, traditional practices and knowledge tend to erode (Cordalis and Suagee 2008; Lynn et al. 2013). Tribal rights to harvest culturally important plants, animals, and fish are based on historical harvest areas, so tribes may lose their ability to exercise these rights if species leave their historical ranges.

Adaptive Capacity

This ecosystem service relates to preserving the past and maintaining access to current sites; thus, adaptive capacity is low. Increased resources for law enforcement and preservation of cultural sites can mitigate some of the expected damage, and traditional ecological knowledge has helped tribes adapt to past social and ecological periods of change. Fish hatcheries and other human assistance to survival of plant and animal species will become more important. Vegetation management can potentially be implemented near high-risk cultural and historic sites that are prone to fire, floods, nonnative species establishment, and erosion.

Risk Assessment

Loss of sacred places and heritage is largely irreversible, and many argue that the damage associated with such losses cannot be quantified. The overall magnitude of climate-induced changes may be moderate to high. Increased rates of erosion are already being observed at some cultural sites, and vandalism rates are increasing as human population increases. Culturally important fish populations are declining and in some cases rely on human assistance for migration and survival. Therefore, the likelihood of climate change effects is high.

Summary

Ecosystem services are the benefits people derive from landscapes and encompass the values that motivate people to live in the Northern Rockies region. Ecosystem services are the core of our sense of place and are important to protect in the face of a growing number of threats. Some of these threats are social (demographic changes, economics, policy) and some are environmental (e.g., climate change). In many cases, social and environmental forces will act to amplify the effects of the other, but opportunities exist for adaptation in some cases. Below are key findings from the ecosystem services vulnerability assessment.

- Total annual **water yield** is not expected to change significantly. However, timing of water availability is likely to shift, and summer flows may decline. These changes may result in some communities experiencing summer water shortages, although reservoir storage can provide some capacity. Snowmelt is already occurring earlier, and both floods and drought may become more common. Agriculture is currently the largest consumer of water and one of the largest economic forces in the region, and rural agricultural communities will be disproportionately affected by climate change.

- **Water quality** is closely tied to water yield. Increased occurrence of wildfires and floods will add sediment to rivers and reservoirs, affecting instream water quality and making water treatment more expensive. Agriculture is currently the major source of impairment, leading to loss in streamside vegetation, loss of aquatic habitat, increased water temperatures, and high levels of fecal coliform. Climate change is expected to amplify these effects.
- **Wood products** provide jobs in the region. Climate changes will lead to more wildfires and insect outbreaks, but in general effects will be small. The largest effects on wood products are likely to be from economic forces and policies. Timber production has been in steady decline, and that trend is likely to continue. Timber is a major employer in some small towns that have already seen an economic downturn, a trend that may continue as a function of economic factors at national to local levels.
- The Northern Rockies region contains one of the largest oilfields in the United States. Near the Bakken formation, about a third of regional income comes directly from oil and gas. **Minerals** and mineral extraction are not likely to be affected by climate change, making mining and energy development important economic drivers. The greatest effect on mineral and energy extraction is likely to be how it connects to other ecosystem services, particularly water quality. Wildfires, floods, and mudslides all put mineral extraction infrastructure in danger, which in turn increases risk to watersheds.
- Climate change is expected to increase the potential of rangeland to provide **forage for livestock**. Ranching and grazing, all else being equal, may benefit from climate change. Major threats to grazing are human induced, including loss of rural population, spread of nonnative grasses, and fragmentation of rangelands.
- **Viewsheds** and **air quality** will be affected by increasing wildfires and longer pollen seasons. A growing percentage of the region's population will be in at-risk demographic groups who will suffer respiratory and other medical problems on days with poor air quality.
- The ability to **regulate soil erosion** will be diminished by agricultural expansion, spread of invasive plants, and increased frequency of wildfire and floods. Increased capital investments may be needed for water treatment plants if water quality degrades significantly. Best practices in agriculture and construction of roads can mitigate some of these effects.
- The ability of forests to **sequester carbon** may be affected by wildfires, insect outbreaks, and plant disease; carbon sequestration in the western part of the Northern Rockies region will be affected by more frequent disturbance and stress. Managing forests for carbon sequestration is likely to become more important in response to national climate policies.
- Disturbances such as wildfires, floods, and soil erosion place **cultural and heritage values** at risk. Damage to cultural and historic sites is irreversible, making protection a key management focus. Climate-induced changes in terrestrial habitats and human modification of streamflow affect abundance of culturally important plants and animals (especially native fish), affecting the ability of Native American tribes to exercise their treaty rights. Effects on this ecosystem service are amplified by social forces that include a growing regional population, vandalism, and loss of traditional practices in a globalizing culture.

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Chapter 12: Effects of Climate Change on Cultural Resources in the Northern Rockies Region

Carl M. Davis

Background and Cultural Context in the Northern Rockies Region

People have inhabited the Northern Rocky Mountains of the United States since the close of the last Pleistocene glacial period, some 14,000 years B.P. (Fagan 1990; Meltzer 2009). Evidence of this ancient and more recent human occupation is found throughout the Forest Service, U.S. Department of Agriculture (USFS) Northern Region and the Greater Yellowstone Area, hereafter called the Northern Rockies region. Each of the five subregions, and the public and private lands they now encompass, contains thousands of years of human history.

The Northern Rockies region is the ancestral homeland or aboriginal territory of the Arikara, Assiniboine, Bannock, Blackfeet, Chippewa-Cree, Coeur d'Alene, Crow, Hidatsa, Kiowa, Kootenai, Mandan, Nez Perce, Northern Cheyenne, Pend d'Oreille, Salish, Shoshone, Sioux and other Plains, Intermountain, and Columbia Plateau American Indian Tribes (DeMallie 2001; Schleiser 1994; Walker 1998). Beginning in the 18th century, the region was explored and then settled by people of French, British, Irish, Scottish, Chinese, German, Scandinavian, and other ancestries (White 1993). The region then, as today, was a diverse blend of cultural backgrounds and lifeways.

The archaeological and historical evidence of these past cultural groups, interactions, and events—collectively called cultural resources—is extensive and varied across the Northern Rockies region. Cultural resources here include (1) ancient Indian camps and villages, rock art, tool stone quarries, and travel routes; (2) historic military forts and battlefields, mining and logging ruins, and homesteads; and (3) ranger stations, fire lookouts, and recreation sites built by the Civilian Conservation Corps. Currently, some 20,000 cultural resources have been documented, which represent probably only a small fraction of what exists in the Northern Rockies region.

Protection of cultural resources has been formally recognized since 1906, when the Antiquities Act was signed into law. This law 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 2015a), and gives the President of the United States authority to designate national monuments as a means to protect landmarks, structures, and objects of historical or scientific significance. The importance of cultural resources has been reaffirmed through the Historic Sites Act of 1935, the National Historic Preservation Act of 1966, the Archaeological Resources Protection Act of 1979, and the Native American Graves Protection and Repatriation Act of 1990. Although the focus of these laws differs, together they mandate the protection and management of cultural resources in Federal lands. The National Park Service has a particularly strong emphasis on protection of cultural resources (box 12.1).

Beyond physical sites, structures, and artifacts associated with past human use or events, protection of cultural resources involves the ongoing use of resources and associated activities relevant to the continuation of specified extant cultures. Many cultural resources are currently vulnerable to natural biophysical phenomena and human activities. 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. Agency land management actions can affect cultural sites and landscapes, and although Federal land managers protect and mitigate adverse effects to cultural resources, the enormity of this task often outstrips agency resources and capacity.

Broad-Scale Climate Change Effects on Cultural Resources

This assessment of the potential effects of climate change on cultural resources in the Northern Rockies region is fairly general because so little information has been generated on this topic, compared to the effects of climate change on natural resources. The broad diversity of cultural resources and locations where they are found makes it difficult to infer the spatial extent and timing of specific effects. Therefore, we have synthesized the relevant literature from diverse disciplines to cautiously project how an altered climate, both

Box 12.1—National Park Service Lands in the Northern Rockies Emphasize Preservation and Management of Cultural Resources

The National Park Service was created by Congress through the National Park Service Organic Act of 1916, whereby the Agency would allow “access to parks for the public enjoyment of cultural resources while ensuring their protection” (NPS 2011b). 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 2015b). Cultural heritage and its preservation are emphasized in the agency’s Cultural Resources, Partnerships and Science directorate, with goals 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.
- Enhance public understanding and appreciation for the Nation’s cultural heritage.

Cultural Resources of National Parks in the Northern Rockies

Glacier National Park

Glacier National Park has six National Historic Landmarks and 350 structures listed in the National Register of Historic Places. Archaeological resources found in the park include prehistoric campsites, mining claims, and homesteads. Cultural landscapes in the park include the Going-to-the-Sun-Road, Chief Mountain, and Headquarters Historic District.

Grand Teton National Park

Historical sites in Grand Teton National Park predate creation of the park, and many structures are found in the National Register of Historic Places. Some of these structures are remnants of homesteads of ranchers and other people who settled in the Jackson Hole area. Several of these structures have been incorporated into the park and restored to their original condition. An example of an early structure preserved in the park is Mining Ditch, which carried water near Schwabacher’s Landing. Cunningham Cabin, home to early settlers in the Jackson Hole area, has also been preserved. Menor’s Ferry operated for decades until 1927, taking passengers across the Snake River, and is now part of a Historic District that was recently added to the National Register.

Yellowstone National Park

Yellowstone National Park has been preserved not only for biodiversity but also for information about past human activities and significant archaeological and cultural resources contained within the park. Some historic structures and sites are Obsidian Cliff, where obsidian was first used for making tools more than 11,000 years B.P.; Yellowstone Lake, which has intact cultural deposits from more than 9,000 years B.P.; Mammoth Hot Springs, which includes the Mammoth Post Office and Roosevelt Arch from the late 1800s; and the town site of Cinnabar, Montana, which was established in 1883 as the last stop on the Northern Pacific Railroad line to Yellowstone Park. The potential effects of climate change on cultural resources have been described for Big Hole National Battlefield, Montana (NPS 2011a). A warmer climate will complicate the goal of management to restore and maintain the battlefield in a biological condition representative of 1877. Scientific understanding of climate change effects provides a foundation for reconciling biological effects with management goals based on historical conditions.

directly and indirectly (through increased disturbance), will create conditions that modify the condition of and access to cultural resource sites and their contents.

Climate change has the potential to exacerbate and accelerate existing effects to cultural resources (table 12.1). A warmer climate will alter the scale of wildfires across western North America (Schoennagel et al. 2004; Westerling et al. 2006) (see Chapter 8), thus having at least three general effects on cultural resources. First, wildfires readily burn cultural resources made of wood and other combustible materials, such as ancient aboriginal wood shelters and game drives, or historic homesteads, mining ruins, and buildings. Second, emergency wildfire suppression tactics, including fireline construction using heavy equipment, affect both standing structures and archaeological sites buried in forest soils. Third, post-wildfire flooding and debris flows threaten cultural resources exposed atop fire-charred landforms and soils. Alternatively, fire can expose cultural sites that might not have been otherwise visible (fig. 12.1).

Currently, Federal agencies implement various actions to reduce the effects of wildfire on cultural resources, such as encasing historic structures in fireproof wrap, routing of fireline away from sites, and armoring cultural resources vulnerable to postfire flooding events. However, these actions are often not commensurate with the scale of large wildfires or the ensuing cultural resource loss. Thus, damage

Table 12.1—Summary of climate change stressors and potential effects on cultural resources in the Northern Rockies (see also Rockman 2014, UNESCO 2007). Human activities can exacerbate some of the expected effects of climate change (see text).

Climate change stressor	Biophysical effects	Effects on cultural sites and landscapes
Temperature increase	• Wildfire • Drought, erosion • Vegetation changes • Spread of invasive species • Ice patch melt • Altered freeze-thaw cycles	• Combustion, damage, destruction • Exposed artifacts and cultural features • Altered physical appearance, integrity • Altered physical appearance, integrity • Artifact decay and theft • Saturation, desiccation, warping, biochemical changes
Altered precipitation	• Earlier seasonal runoff, flooding • Debris flows, slumping • Down-cutting, mass wasting • Increased moisture and humidity • Extreme precipitation events	• Removal, damage, degradation • Burial, removal, degradation • Removal, damage, degradation • Decay, oxidation, exfoliation, corrosion, biochemical changes • Removal, damage, degradation, collapse, exposure

Figure 12.1—Prehistoric stone cairn exposed by wildfire in Custer National Forest. Intense wildfires, suppression, and rehabilitation activities annually affect hundreds of cultural resources in the Northern Rockies (photo: Halcyon LaPoint, Custer-Gallatin National Forest).

is expected to continue as climate change amplifies amount of area burned, if not severity, across the Northern Rockies region.

Seasonal aridity and prolonged drought accelerate soil deflation and erosion, and thus expose archaeological sites once buried in plains and mountain soils. Wind and water roil across archaeological sites, blowing or washing away ground cover, revealing ancient artifacts and features such as cooking hearths and tool-making areas (fig. 12.2). Newly exposed ground leaves artifacts vulnerable to artifact collecting and illegal digging, effects that are intensified in areas where livestock grazing, recreation, and mining occur and the ground is already impacted. For example, livestock in grazing allotments typically converge around creeks and natural springs where ancient hunter-gatherer archaeological sites are commonly located.

Periods of dry climate and drought have occurred throughout the Holocene in the Intermountain West, with corresponding episodes of soil deflation, erosion, and down cutting (Meltzer 1990; Ruddiman 2007). However, increasing temperatures outside of the Holocene norm (Intergovernmental Panel on Climate Change 2007; Mayewski and White 2002; see also Chapter 3) will create additional potential for cultural resource loss through drought and erosion, particularly in drier areas such as southeastern Montana.

In addition, if winter precipitation increases (see Chapter 3) and reduced snowpack leads to higher winter streamflows (see Chapter 4), archaeological and historic sites will be increasingly vulnerable to flooding, debris flows, down cutting, and mass wasting of underlying landforms. This scenario is now common in the aftermath of large-scale wildfires, especially in the dry mountain ranges of central

Figure 12.2—Prehistoric artifacts exposed in soil-deflated surface caused by drought conditions. Exposed artifacts are vulnerable to illegal collecting and livestock trampling (photo: Carl Davis, U.S. Forest Service).

and eastern Montana (fig. 12.3). These severe events are likely to accelerate hydrologic impacts to cultural resources (National Research Council 2002).

Perennial high-elevation snowfields contain ancient artifacts, the result of hunting and gathering excursions to mountain environments (Lee 2012) (fig. 12.4). Melting ice caused by a warmer climate poses a risk to previously ice-encased and well-preserved cultural resources. For example, melting ice patches in the Beartooth Mountains of south-central Montana have yielded ancient bone, wood,

Figure 12.3—Post-wildfire debris flow that obliterated or covered cultural resources in Meriwether Canyon, Helena National Forest. Early, intense spring runoff events may become more common in the future (photo: Carl Davis, U.S. Forest Service).

Figure 12.4—Melting perennial ice patches expose prehistoric artifacts in Custer-Gallatin National Forest. These high-elevation locations document activities by Native American groups in the recent and distant past (photo: Craig Lee, Montana State University).

and fiber artifacts. Although melting ice patches provide research opportunities, the rapid rate of melting ice may preclude timely inspection by archaeologists, and newly exposed artifacts may decay or be stolen without adequate archaeological documentation.

Climate change also affects larger cultural landscapes whose integrity is derived from both cultural resources and environmental context (NPS 1994). Historic sites from the 1800s (e.g., Euro-American settlements, battlefields) are also valued historical resources, especially in some NPS units. Major shifts in dominant vegetation could potentially affect the physical and visual integrity of these landscapes (Melnick 2009). For example, whitebark pine (*Pinus albicaulis*) is an important historical component of the Alice Creek-Lewis and Clark Pass cultural landscape on the Continental Divide near Helena, Montana (fig. 12.5). Whitebark pine is currently in decline because warmer winter temperatures have accelerated the rate of mountain pine beetle (*Dendroctonus ponderosae*) outbreaks in addition to the effects of white pine blister rust (*Cronartium ribicola*), a nonnative fungal pathogen (Tomback and Kendall 2001; see also Chapter 8).

Cultural sites and landscapes are also recognized for their traditional importance to descendant communities, particularly American Indian tribes in the Intermountain West. Some traditional use areas provide foods, medicinal and sacred plants, pigments, and other resources, as well as ceremonial-religious places. Significant climate-induced effects in these landscapes, particularly altered distribution and abundance of vegetation, may curtail and even sever the continuous cultural connectivity and traditional use of these areas by indigenous peoples and local communities.

Figure 12.5—Whitebark pine mortality may affect the integrity and status of cultural sites, such as the Lewis and Clark Pass cultural landscape and National Register District shown here. Significant landscape change may also affect indigenous peoples and local communities who use the area and its resources (photo by Sara Scott, Montana Department of Fish, Wildlife and Parks).

Climate change also poses risks to historic buildings and structures though increases in wildfire, flooding, debris flow, and extreme weather events (fig. 12.6). In addition to these direct threats, period furniture, interpretive media, and artifact collections inside historic (and nonhistoric) buildings may likewise be affected by those events. More nuanced stressors include increased heat, moisture, humidity, freeze-thaw events, insect infestation, and micro-organisms (mold), all of which accelerate weathering, deterioration, corrosion, and decay of buildings, structures, and ruins made of wood, stone, and other organic materials (UNESCO 2007).

Finally, climate change may diminish the appeal of cultural sites and landscapes for public visitation and interpretation. Extensive outbreaks of mountain pine beetle and other insects, which have been facilitated by higher temperature, have turned some historic landscapes in southwestern Montana from green to brown to gray (e.g., Logan and Powell 2001). In addition to visual impacts, dead and dying forests present hazards to hikers, sightseers, and other forest users (see Chapter 10). Over time, altered ecological conditions in cultural landscapes of the Northern Rockies region may reduce their attractiveness and value for tourism, recreation, and other purposes, thus affecting local communities and economies (see chapters 10, 11).

Risk Assessment

Climate change effects on cultural resources are likely to be highly variable across the Northern Rockies region by the end of the 21st century, depending on the particular stressor and geographic location. Wildfire is expected to create the highest risk for cultural resources and is expected to broadly,

Figure 12.6—Installing emergency roof supports in the main lodge, OTO Dude Ranch, Custer-Gallatin National Forest. Routine and emergency projects to stabilize, protect, and maintain historic buildings are likely to increase in a warmer climate (photo by Marcia Pablo, Custer-Gallatin National Forest).

though unevenly, affect cultural resources on all national forests, national grasslands, and national parks, including locations that have already burned since the 1990s.

The prospect of prolonged aridity and drought caused by projected temperature increase may be partially offset if winter precipitation increases in the future (see Chapter 3). Thus, it is difficult to quantify the long-term effects of drought, floods, and extreme weather events on cultural resources. In general, these natural processes, exacerbated by climate change, are likely to pose a significant risk to cultural resources. Resource loss will be greatest in those areas prone to major hydrologic events, such as at canyon mouths and in river bottoms where cultural sites are often concentrated. Cultural sites located here are difficult to armor and protect in the face of significant flooding and debris flows. Furthermore, artifact collectors may eventually target these areas because newly exposed cultural materials are often strewn over a wide area in the aftermath of a flood or debris flow; protection of these materials depends on active law enforcement.

Other potential climate change-related effects on cultural resources will be more subtle and moderate. Shifting distribution and abundance of vegetation are likely to affect the visual integrity of some cultural landscapes. Climate change effects to historic buildings or structures will be both gradual and cumulative (i.e., decay and degradation) and sudden and direct (i.e., structural collapse caused by moisture and snow loading). Certain natural resources associated with traditional cultural landscapes that tribal peoples continue to use today, may be diminished or entirely disappear. However, increased wildfire may increase the abundance of some culturally valuable species, such as huckleberry (*Vaccinium* spp.), common camas (*Camassia quamash*), and nodding onion (*Allium cernuum*).

Agency proposals and efforts to control, abate, or mitigate the projected effects of climate change may also affect cultural resources. For example, in anticipation of significant flooding events in the future, historic culverts and bridge abutments made of stone may be replaced with larger metal ones. Although project design and mitigation measures would reduce many adverse effects to cultural resources, landscape restoration projects designed to increase resilience to climate stressors could diminish the cultural resource base in some locations.

The effects of climate change on cultural resource tourism are difficult to estimate because this is contingent on social and economic factors. Visiting historic sites is popular throughout the Northern Rockies (Nickerson 2014), and tourism is an important economic contributor to many local communities (see Chapter 10). Hot, dry summer weather could reduce public interest in visiting cultural resources, cultural landscapes, and interpretive sites located on Federal lands, particularly in areas recently affected by severe wildfires or floods. This potential impact on forest tourism could, in turn, affect local communities to some extent.

Adapting to the Effects of Climate Change

Federal agencies in the Northern Rockies region have the capacity to address some of the projected effects of climate change on cultural resources. Fuels reduction around significant cultural resources is already in place in some locations to reduce the intensity and severity of future wildfires. USFS heritage personnel are engaged in all aspects of wildfire suppression and recovery, which facilitates protection of cultural resources threatened by wildfires. However, fire vulnerability assessment and abatement programs for cultural resources may need further emphasis to address a potential for more wildfires in the future.

Less progress has been made in completing vulnerability assessments or implementing protection strategies for cultural resources located in areas prone to large-scale hydrologic events, and the full scope of this risk is unknown in the Northern Rockies region. Hydrologic events are unpredictable, and protection measures such as stabilization and armoring are expensive. Viable protection measures often require hydrologic, engineering, and other resource expertise. Nonetheless, Federal agencies have a strong mandate to implement measures to protect cultural sites threatened by such natural processes and emergency events.

Survey and evaluation in areas where cultural resources are concentrated or likely are ongoing, although intermittent, in the Northern Rockies region. It will be possible to locate and monitor cultural resources potentially at risk only if these efforts are significantly expanded. High-elevation melting ice patches are a particular priority, but surveys are critical in other locations where cultural resources are likely to be affected by flooding and debris flows in mountain canyon and foothills areas. Correlating areas where cultural resources are common with areas where ice melt and flooding are expected will help to focus attention on landscapes at greatest risk.

Some climate-induced vegetation shifts in designated cultural landscapes could be partially 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. Careful monitoring and tracking of vegetation stability and change in cultural landscapes will become increasingly important in future decades.

To date, the potential effects of climate change on the historic built environment in the Northern Rockies region has received relatively little attention. However, a variety of actions may eventually be necessary to abate or mitigate the projected effects of climate change on historic buildings and structures. Vulnerability assessments by qualified experts are necessary precursors to initiating any remediation work such as stabilization, armoring, and other interventions. In this context, historic preservation teams, volunteers, and partners will be important contributors to climate-related preservation work in the future.

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Chapter 13: Conclusions

S. Karen Dante-Wood and Linh Hoang

The Northern Rockies Adaptation Partnership (NRAP) provided significant contributions to assist climate change response in national forests and national parks of the Northern Rockies 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 in the region. 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 Forest Service, U.S. Department of Agriculture (USFS) National Roadmap for Responding to Climate Change (USDA FS 2010a) and Climate Change Performance Scorecard (USDA FS 2010b) (see Chapter 1), and the National Park Service (NPS) Climate Change Response Strategy (NPS 2010). The NRAP process allowed all forests in the USFS Northern Region to respond with "yes" to scorecard questions in the organizational capacity, engagement, and adaptation dimensions. Further, the NRAP process enabled participating national parks to make progress toward implementing several components (communication, science, and adaptation goals) of the Climate Change Response Strategy (NPS 2010).

Relevance to Agency Climate Change Response Strategies

In this section, we summarize the relevance of the NRAP 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 Northern Rockies region. This process can be replicated and implemented by any organization, and the adaptation options are applicable in the Northern Rockies region and beyond. Like previous adaptation efforts (e.g., Halofsky et al. 2011; Raymond et al. 2014), a science-management partnership was critical to the success of the NRAP. For others interested in emulating this approach, we encourage them to pursue this type of partnership as the foundation for increasing climate change awareness, assessing vulnerability, and developing adaptation plans.

Organizational Capacity, Education, and Communication

Organizational capacity to address climate change, as outlined in the Climate Change Performance Scorecard requires building institutional capacity in management units through training and education for USFS employees. Training and education were built into the NRAP process through workshops and webinars that provided information about the effects of climate change on water resources, fisheries, forest vegetation, nonforest vegetation, disturbance, wildlife, recreation, ecosystem services, and cultural resources. The workshops introduced climate tools and processes for assessing vulnerability and planning for adaptation.

The Climate Change Response Strategy challenges NPS staff to increase climate change knowledge among employees and to communicate this information to the public, in addition to the actions taken by the agency to respond to climate change. Although communication about climate change with the public was beyond the scope of the NRAP, knowledge generated through this process can be used for outreach and interpretive materials.

Partnerships and Engagement

The NRAP 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 several Federal agencies as well as other organizations (e.g., EcoAdapt, Headwaters Economics) and universities (Oregon State University, University of Washington).

Elements 4 and 5 of the 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 Climate Change Response Strategy emphasizes the importance of collaboration and building relationships, in addition to products that support decisionmaking and a shared vision. The NRAP process therefore allowed both the USFS and the NPS to achieve unit-level compliance in their agency-specific climate responses.

The NRAP process encouraged collaboration between the USFS and NPS, supporting a foundation for a coordinated regional response to climate change. By working with partners (Federal and nongovernmental), we increased our capability to respond to climate change. Responding to such a challenge requires using an all-lands approach, which this partnership fostered.

Assessing Vulnerability and Adaptation

Elements 6 and 7 of the Climate Change Performance Scorecard require units to assess the expected effects of climate change and determine which resources will be most vulnerable as a result, and identify management strategies to improve the adaptive capacity of the national forest lands. The NRAP vulnerability assessment used the best available science to identify sensitivity and vulnerability of multiple resources in the Northern Rockies region (table 13.1). Adaptation options for each of the resource areas were then developed and can be incorporated into resource-specific programs and plans.

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 NRAP process may not be feasible, resource managers can still draw from the menu of options

Table 13.1—Risk assessment for resources in the vulnerability assessment for the Northern Rockies. The qualitative and quantitative approach for estimating magnitude and likelihood of climate change effects varies by resource and availability of information (see individual chapters for more detail).

Resource	Habitat, ecosystem function or species	Magnitude of effects	Likelihood of effects
Water resources	Snowpack and glaciers	High to low, depending on elevation and winter temperatures	High
	Streamflow	High to low across the region, depending on local climate	High to low across the region, depending on local climate
Fisheries	Bull trout	Moderate for 2040s, high by 2080s	High for 2040s, moderate for 2080s
	Westslope cutthroat trout and Yellowstone cutthroat trout	Low for 2040s, moderate for 2080s	High for 2040s, moderate for 2080s
Vegetation – general types	Dry ponderosa pine and Douglas-fir	High	High
	Lodgepole pine and aspen mixed conifer	Moderate	High
	Mixed mesic white pine, western redcedar, western hemlock grand fir	Moderate	Low
	Western larch mixed conifer	High	Very high
	Whitebark pine/spruce-fir	High	High
	Big sagebrush	Highly variable	Moderate
	Mountain big sagebrush and basin big sagebrush	Mountain big sagebrush – moderate; basin big sagebrush – high	High
	Threetip sagebrush and silver sagebrush	Moderate	High
	Western grasslands	High	High
Vegetation – tree species	Alpine larch	High	High
	Cottonwood	Moderate	Moderate
	Douglas-fir	High	High
	Engelmann spruce	Moderate	Moderate
	Grand fir	Moderate	Moderate
	Green ash	Moderate	High
	Limber pine	Low	Low
	Lodgepole pine	Moderate	High
	Mountain hemlock	High	High
	Ponderosa pine - var. *ponderosa*	Moderate	Moderate
	Ponderosa pine – var. *scopulorum*	Moderate	Moderate
	Quaking aspen	Moderate	High
	Subalpine fir	High	High
	Western hemlock	Moderate	Moderate
	Western larch	High	Very high
	Western redcedar	Moderate	Moderate
	Western white pine	Moderate	Moderate
	Whitebark pine	Moderate	Moderate

Table 13.1—*Continued.*

Resource	Habitat, ecosystem function or species	Magnitude of effects	Likelihood of effects
Vegetation – resource concerns	Carbon sequestration	High	Moderate
	Landscape heterogeneity	Moderate	High
	Timber production	Moderate to high in northern Idaho	High in north Idaho
	Bark beetle disturbances	Moderate	Varies
	Invasive plant species	High	High
	Wildfire regimes	Low-moderate	Moderate-high
Wildlife	American beaver	Moderate by 2100	Moderate by 2100
	American pika	Low in 2030, 2050; moderate by 2100	Varies
	Canada lynx	Moderate by 2030, high by 2050, extreme by 2100	High
	Fisher	Low by 2030, moderate by 2050, probably high by 2100	High
	Moose	Moderate by 2100	Moderate by 2100
	Northern bog lemming	Moderate by 2050; high by 2100	High by 2050
	Pronghorn	Moderate by 2100	Moderate by 2100
	Pygmy rabbit	Moderate by 2050; could be high by 2100	High by 2050
	Townsend's big-eared bat	Moderate by 2100	Moderate by 2100
	Ungulates (elk, mule deer, white-tailed deer)	Uncertain, but probably low to moderate by 2100	Low to moderate in all time periods
	Wolverine	Low by 2030, moderate by 2050, high to very high by 2100	High in all time periods
	Brewer's sparrow	Low to moderate by 2050; moderate to high by 2100	Moderate, depending on sagebrush habitat
	Flammulated owl	Largely unknown across all time periods	Largely unknown across all time periods
	Greater sage-grouse	Largely unknown across all time periods; depends on fire	Largely unknown across all time periods; depends on fire
	Harlequin duck	Moderate across all time periods	Moderate across all time periods
	Mountain quail	Low to moderate across all time periods	Low to moderate across all time periods
	Pygmy nuthatch	Largely unknown across all time periods	Largely unknown across all time periods
	Ruffed grouse	Low to moderate across all time periods	Low to moderate across all time periods
	Columbia spotted frog	Moderate across all time periods, depending on fungal infections	Moderate across all time periods
	Western toad	Moderate across all time periods	Moderate across all time periods
Recreation	Warm-weather activities	Moderate	High
	Snow-based recreation activities	High	High
	Wildlife-based activities	Hunting, wildlife viewing–low; fishing–moderate to high	Hunting, wildlife viewing– moderate; fishing–high
	Gathering forest products	Low	Moderate
	Water-based activities	Low to moderate	Moderate
Ecosystem services	Building materials/wood products	Large from non-climate forces	Likely from non-climate forces
	Cultural and heritage values	Highly variable	Highly variable
	Erosion regulation	Landslides and flooding have the potential for large sudden damages; costs of soil erosion are high.	High
	Fuel (firewood/biofuels)	Firewood – low; biofuels – uncertain	High
	Mining, minerals	Large from non-climate forces	High
	Viewsheds/clean air	High	High
	Water quality	High	High
	Water quantity	Moderate	High

as needed. Some adaptation strategies and tactics can be implemented on the ground now, whereas others may require changes in policies and practices or can be implemented when management plans are revised or as threats become more apparent.

The NRAP process used many of the principles and goals for assessing vulnerability and planning for adaptation that are identified in the Climate Change Response Strategy. The strategy calls for NPS 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 Climate Change Performance Scorecard and in the Climate Change Response Strategy. Where applicable, the NRAP products identified information gaps or uncertainties in understanding climate change vulnerabilities of resources and management influences on vulnerabilities. These identified information gaps could drive the focus of monitoring and research intended to decrease uncertainties 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 NRAP participants to collaborate further in their research on climate change effects and effectiveness of implementing adaptation strategies and tactics.

Throughout the NRAP process, the best available science was used to understand projected changes in climate and effects on natural resources. This science can be incorporated into large landscape assessments such as forest/grassland planning assessments, environmental analysis for National Environmental Policy Act (NEPA) projects, or project design and mitigations.

Next Steps

The NRAP built on previous science-management partnerships by creating an inclusive forum for local and regional stakeholders to address issues related to climate change vulnerability and adaptation. Although this partnership was conducted at the regional scale, more work is needed to truly achieve an all-lands approach to adaptation. The Federal agencies involved have different missions and goals, and are at different stages in integrating climate change into resource management and planning. Although the differences allowed agencies to share approaches and experiences, it presented challenges in terms of creating a collaborative adaptation plan.

In the future, it may be valuable to develop partnerships around specific resource issues and implement adaptation options accordingly. Similarly, working at subregional scales would enable the assessment to target specific management concerns. Finally, engaging managers early through a query regarding priority information needs to support adaptation planning would help to generate “buy in” and ensure that products target important management needs.

The goal of this vulnerability assessment was to cover a range of natural resources that are critical to the Northern Rockies region. By exploring several resources in detail, participants identified species and ecosystems that are sensitive to climate change. More-detailed quantitative and spatially explicit vulnerability assessments would improve the scientific basis for detecting the effects of climate change and developing site-specific management responses and plans. Such assessments would also allow resource managers to prioritize locations for implementation. The process could also be expanded to include other systems and issues such as social and economic effects.

Implementing Adaptation Strategies and Tactics

Implementing adaptation strategies and tactics is the next, and most challenging, step. This will gradually occur with time, changes in policies, plan and program revisions, and major disturbances or extreme weather events. As previously noted, collaboration among landowners and management agencies will produce more-successful adaptation outcomes than operating independently.

Participants in the NRAP science-management partnership collaborated on two products: the vulnerability assessment and adaptation strategies and tactics. Before applying an adaptation strategy or tactic, land managers require a process to consider which actions are most important and identify the most important locations for implementing those actions. Landscape management strategies provide context for decisionmaking in which managers can be transparent in decisions about applying a strategy or tactic. Determinations of which adaptation options are most appropriate must consider the condition and context of the resource, social and ecological values, time scales for management, and feasible goals for treatment given changing climate (Peterson et al. 2011). Depending on the context and conditions, landscape management strategies can have various objectives, such as increasing resilience, resisting climate influences, facilitating transitions, or realigning/restoring systems to be more resilient (Peterson et al. 2011).

Developing critical questions based on the vulnerability assessment, other factors important for resources, and site-specific ecological and social situations in the context of larger landscapes would assist land managers in making reasoned and transparent decisions in applying adaptation strategies and tactics. Workshops with large and small planning teams to develop resource-specific critical questions and their response to those questions could result in the

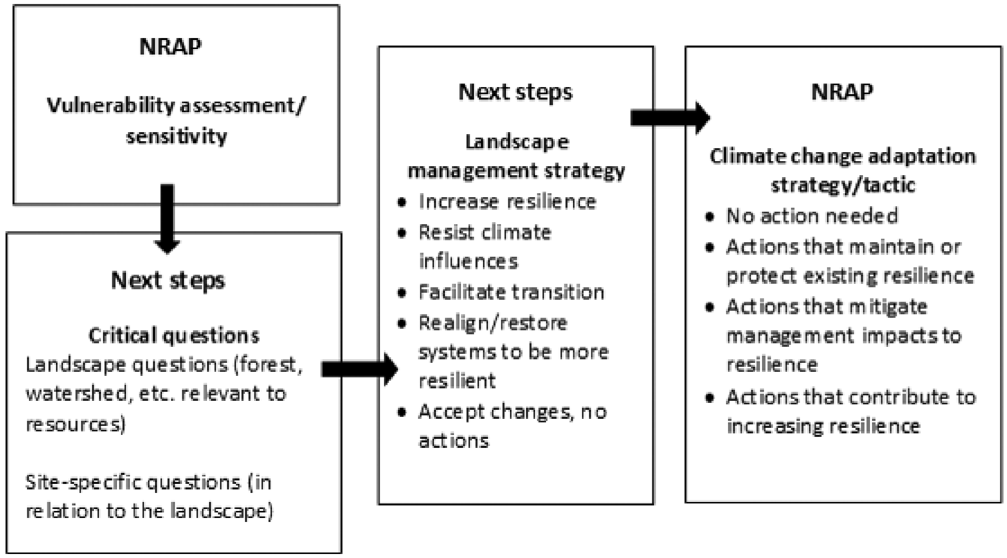

Figure 13.1—General framework for use of the Northern Rockies Adaptation Partnership vulnerability assessment and adaptation strategies and tactics to ask critical questions and develop a landscape management strategy.

development of broadly applicable management strategies (see fig. 13.1 for general framework and fig. 13.2 for example). A process similar to the Climate Project Screening Tool (Morelli et al. 2012) could be adapted to landscape management.

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.

Applications

The climate change vulnerability assessment and adaptation approach developed by the NRAP can be used by the USFS, NPS, and other organizations in many ways (fig. 13.3, table 13.2). From the perspective of Federal land management, this information can be integrated into the following aspects of agency operations:

- Landscape management assessments/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 desired forest/grassland conditions, objectives, standards, and guidelines for

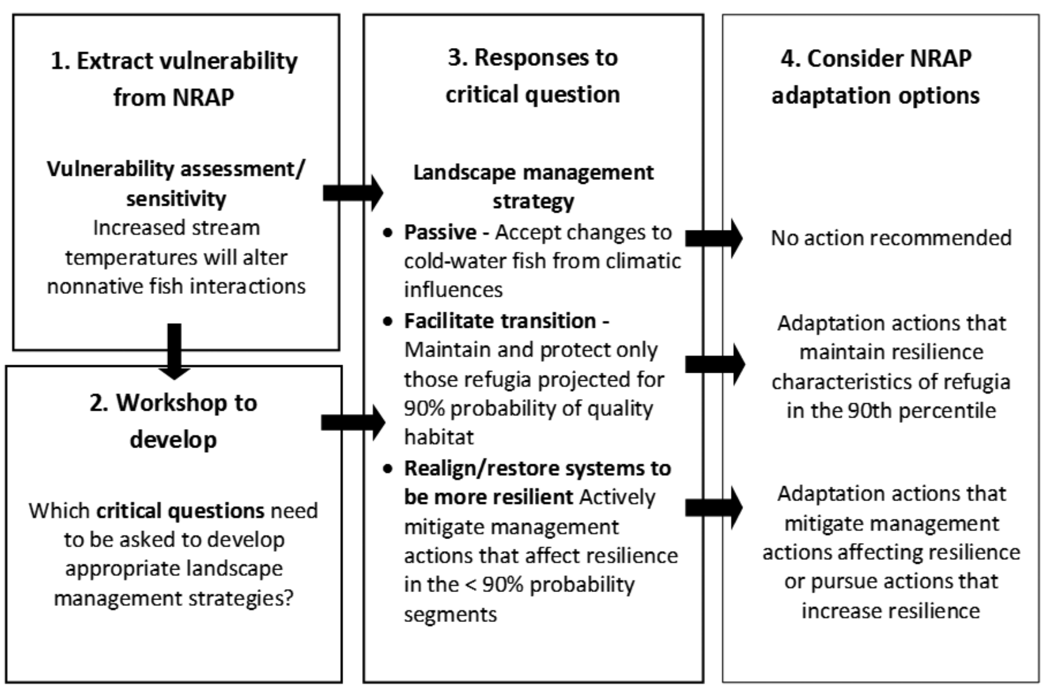

Figure 13.2—Example of how a workshop can be conducted to answer critical questions and develop a landscape management strategy for cold-water fish.

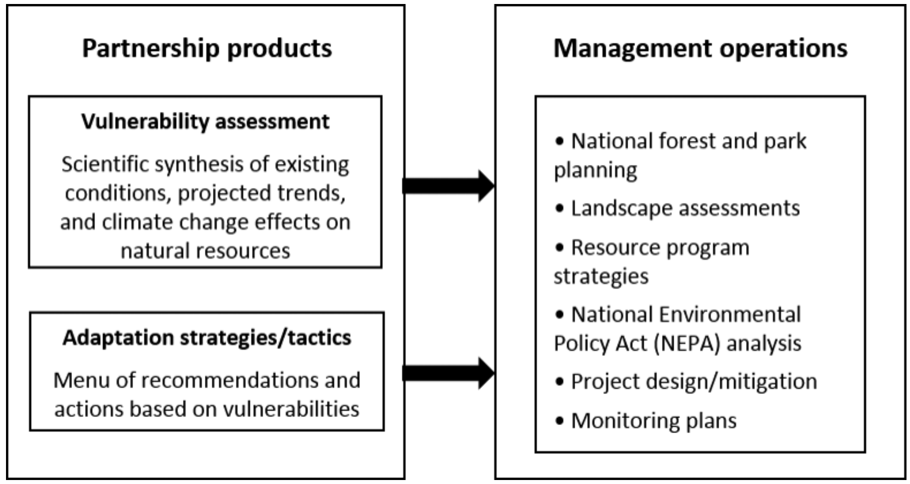

Figure 13.3—Example applications of Northern Rockies Adaptation Partnership products to land management operations.

land management plans and general management assessments.

- Resource management strategies: The vulnerability assessment and adaptation strategies and tactics can be used to incorporate NRAP best science into conservation strategies, fire management plans, infrastructure planning, and state wildlife action plans.
- Project NEPA analysis: The vulnerability assessment provides best available science for documenting resource conditions, analyzing effects, and developing 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.

We are optimistic that climate change awareness, climate-smart management and planning, and implementation of adaptation in the Northern Rockies region will continue to evolve. We anticipate that within the next decade:

- Climate change will become an integral component of business operations.
- The effects of climate change on natural and human systems will be continually assessed.
- 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.
- Managers will implement climate-informed practices in long-term planning and management.

Table 13.2—Example of how information on climate change vulnerability and adaptation can be used in land management applications for dry forests.

Vulnerability and adaptation information	Land management application
Sensitivity to climatic variability and change	
• Potential conversion to grassland • Many ponderosa pine forests have converted to Douglas-fir types due to fire exclusion and are therefore more susceptible to future fires	• Forest/grassland planning: assessment phase • Project National Environmental Policy Act (NEPA) analysis: existing condition and best science on effects of climate change on resource
Adaptation strategy	
• Restore fire-adapted ponderosa pine stand conditions in order to facilitate transition	• Forest/grassland planning: desired conditions • Project NEPA analysis: purpose and needs
Tactics	
• Reduce competition from Douglas-fir and grand fir (thin, burn) in current mature pine stands • Conduce frequent understory burning • Retain current mature and older ponderosa pine stands • Plant ponderosa pine where it has been lost	• Forest/grassland planning: objectives • Project NEPA analysis: project design features and other mitigation

This assessment provides the foundation for implementing adaptation options that help reduce the negative effects of climate change and assist resources in the transition to a warmer climate. We hope that through building on existing partnerships, the assessment will foster collaborative climate change adaptation in resource management and planning throughout the Northern Rockies.

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