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

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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

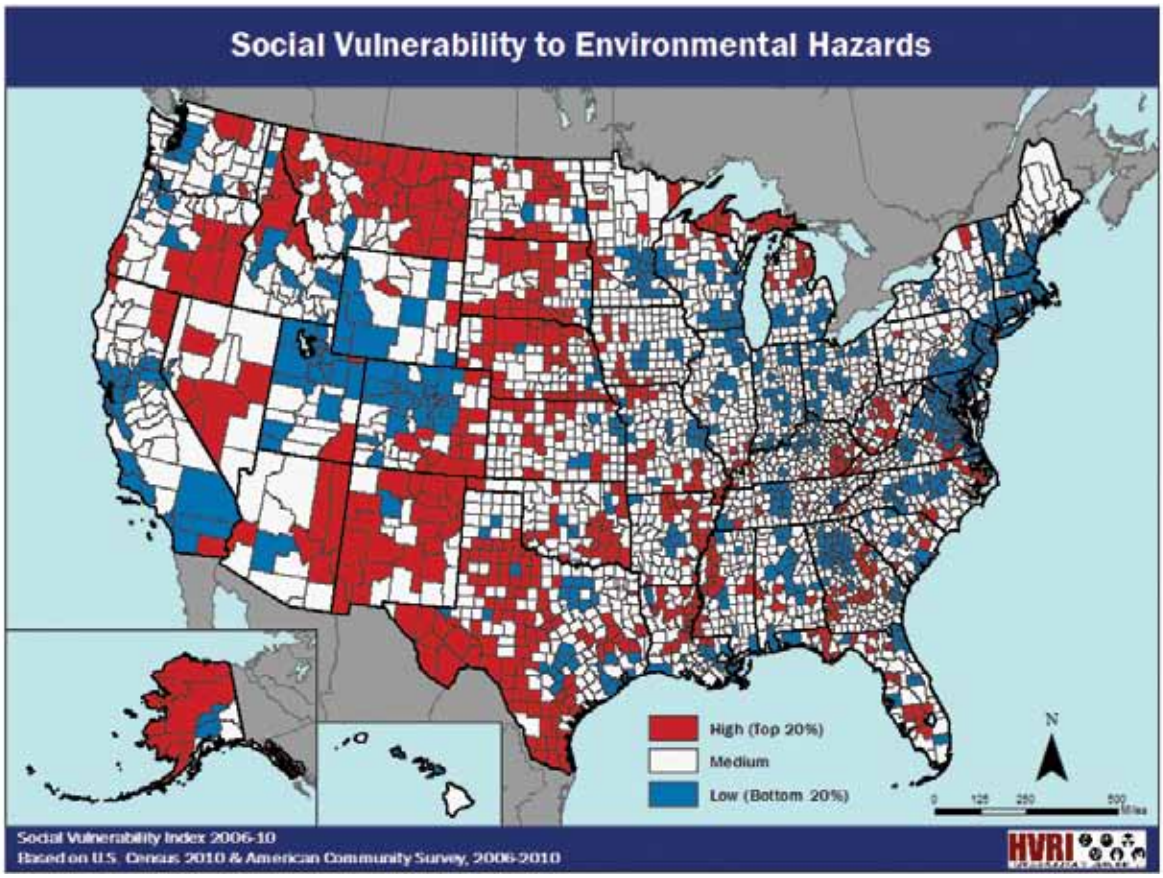

Figure 11.1—The Social Vulnerability Index (SoVI) to Environmental Hazards for U.S. Counties (managed and updated by the Hazards and Vulnerability Research Institute at the University of South Carolina; Cutter et al. 2003). The SoVI is based on 11 underlying factors identified to affect social vulnerability: 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.

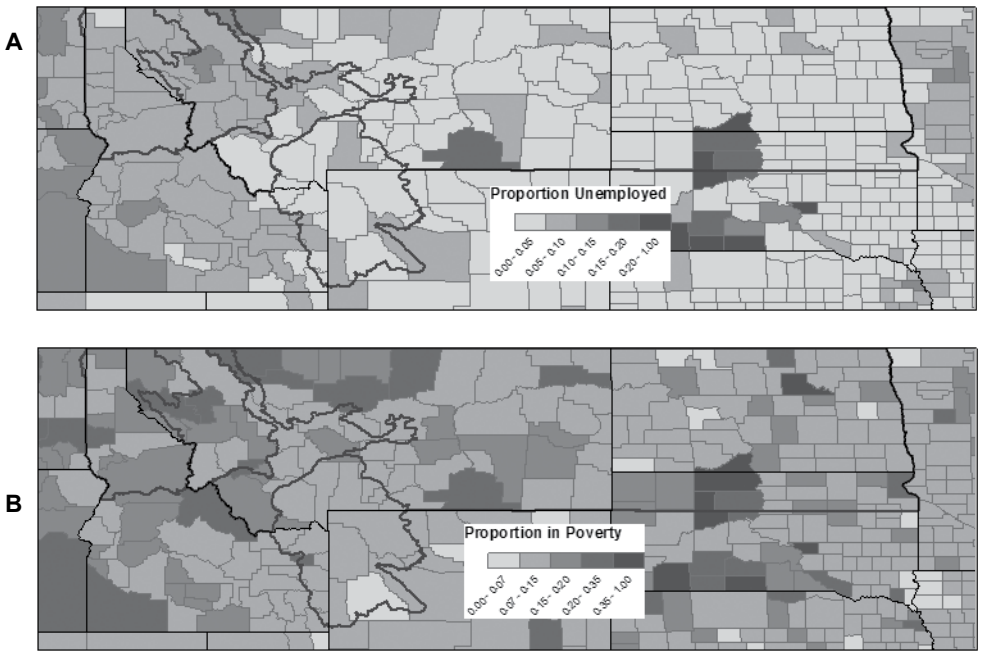

Figure 11.2—Demographic information for the Northern Rockies region, including (a) proportion unemployed, (b) proportion in poverty, (c) proportion without a vehicle, (d) proportion of minorities, (e) proportion with limited English skills, and (f) proportion over age 65.

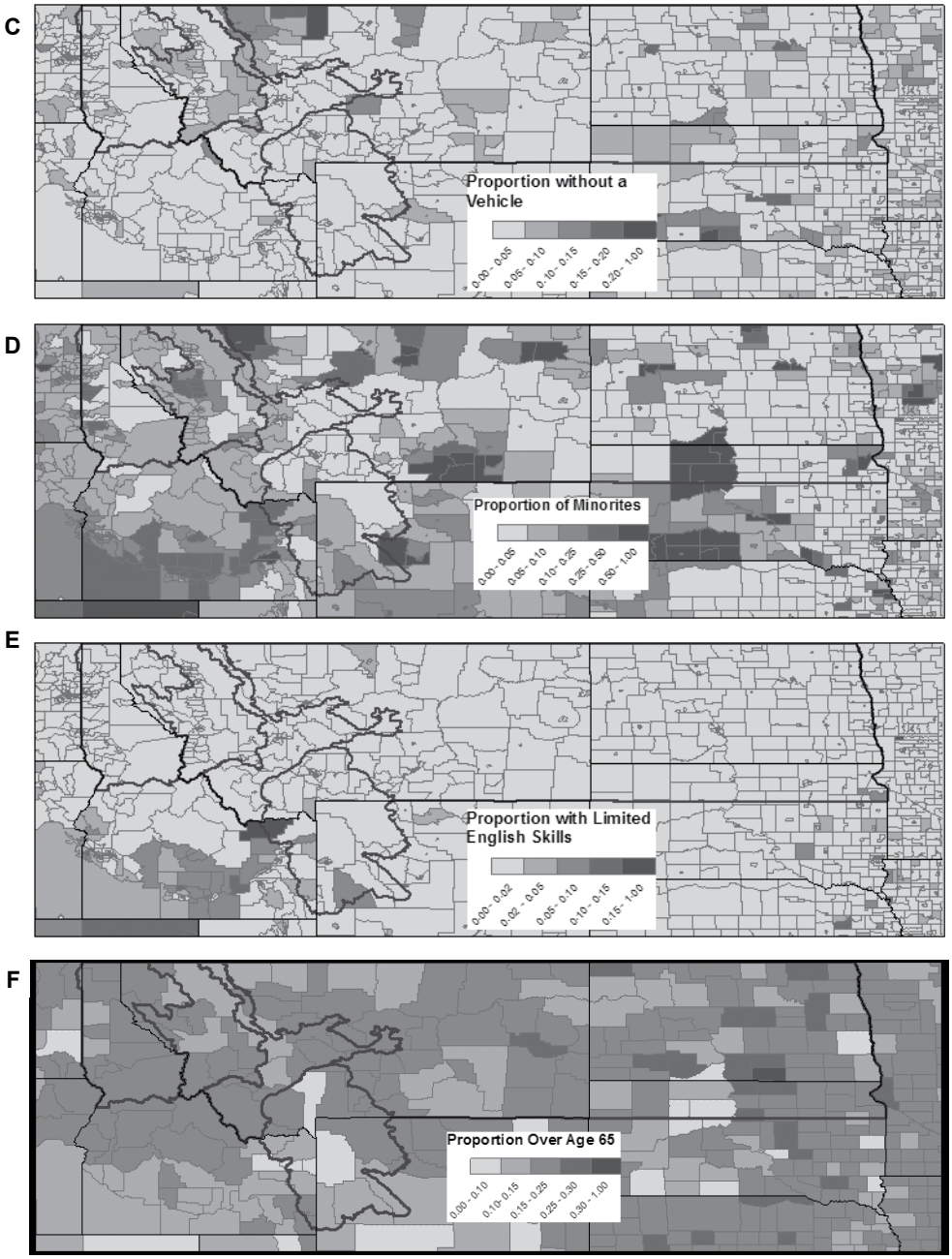

Figure 11.2—*Continued*.

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

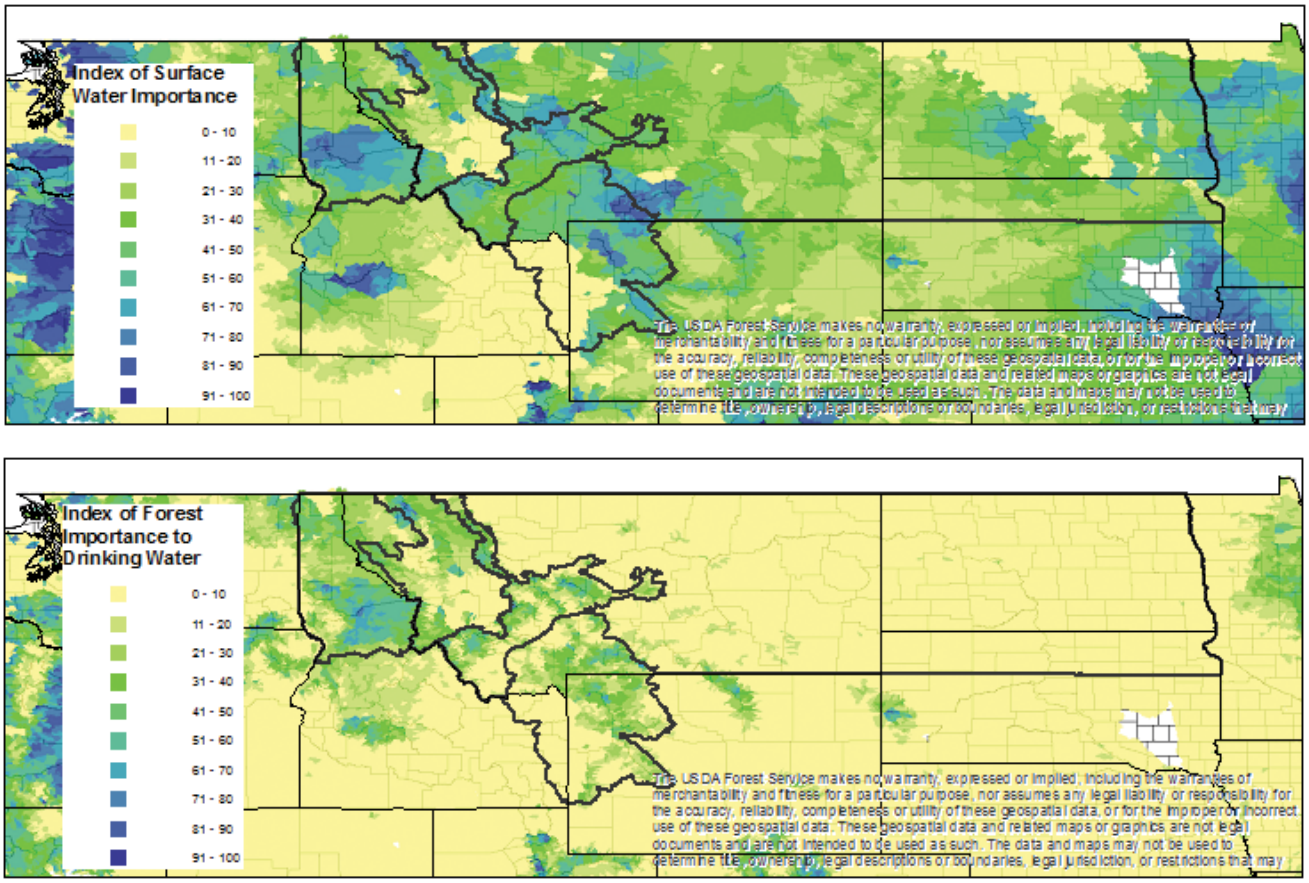

Figure 11.3—Forests to Faucets data showing the relative importance of surface water for municipal water supply (top) and forests for maintaining watershed health (bottom). The index depends on both the amount of water coming off forests and the population served by that water. Higher numbers indicate 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.

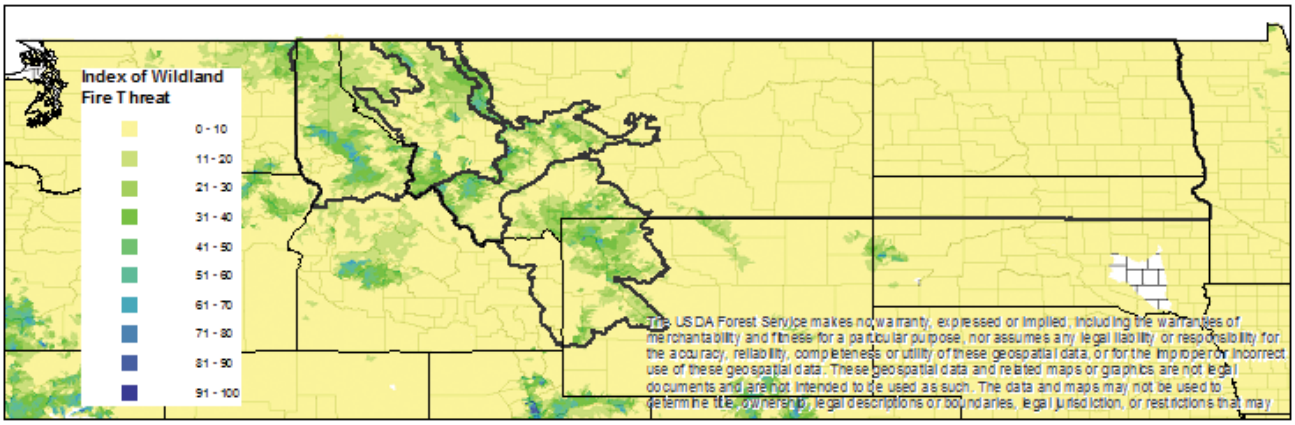

Figure 11.4—Wildland fire threat to forests and importance to surface drinking water. Higher numbers indicate higher risk of wildland fire (from Weidner and Todd 2011).

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

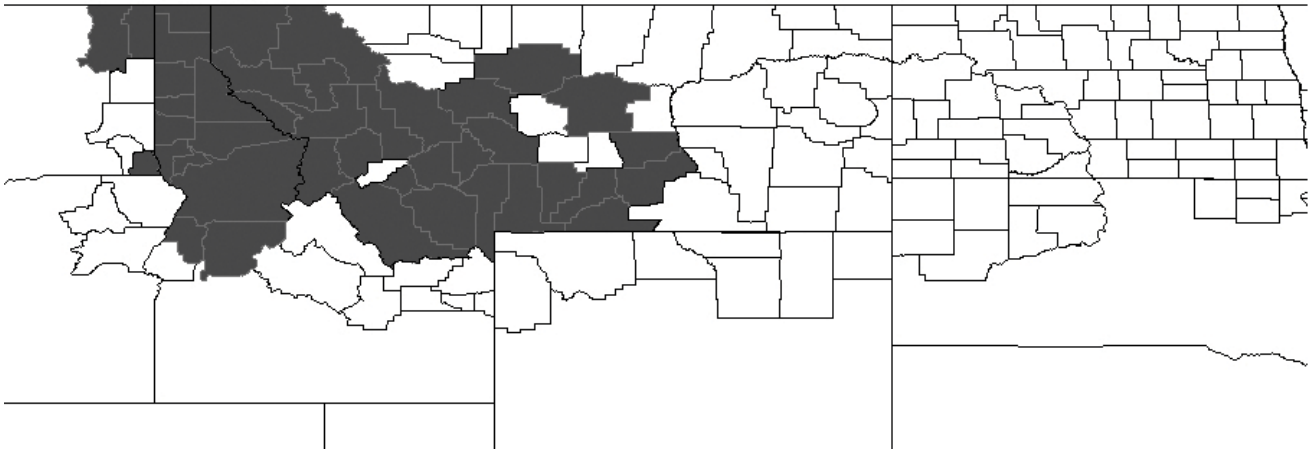

Figure 11.5—Primary area where timber is processed from national forests in the U.S. Forest Service Northern Region.

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).

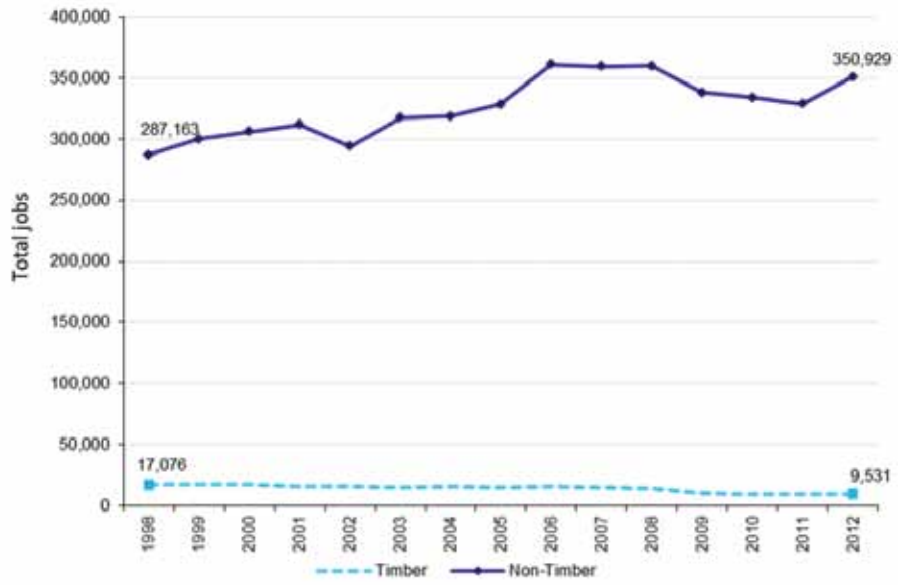

Figure 11.6—Total jobs in timber and non-timber for national forests in the U.S. Forest Service Northern Region (from U.S. Department of Commerce 2014).

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.

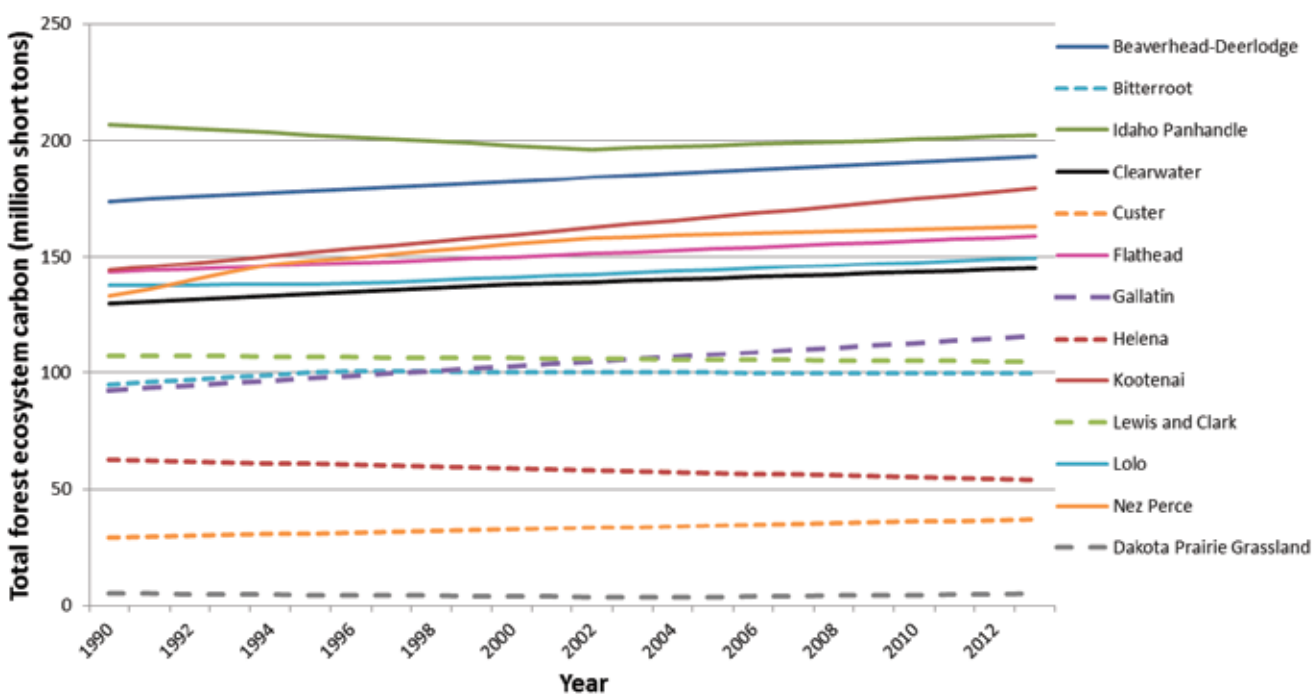

Figure 11.7—Total forest ecosystem carbon for national forests and grassland in the Northern Region from 1990 to 2013.

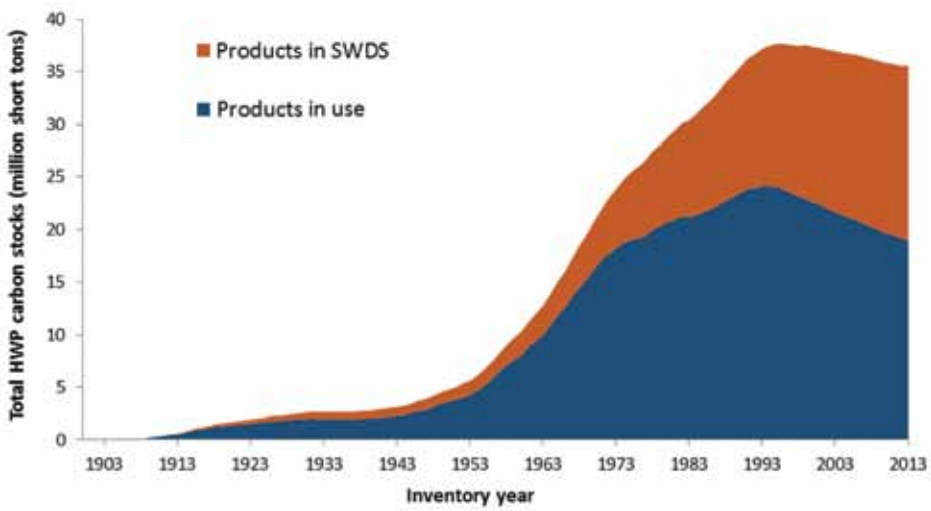

Figure 11.8—Cumulative total carbon stored in harvested wood products (HWP) manufactured from Northern Region timber. Carbon in HWP includes both products that are still in use and carbon stored at solid waste disposals sites (SWDS), including landfills and dumps (Stockmann et al. 2014).

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.

References

Adger, W.N.; Barnett, J.; Brown, K.; [et al.]. 2013. Cultural dimensions of climate change impacts and adaptation. Nature Climate Change. 3: 112–117.

Adger, W.N.; Barnett, J.; Chapin, F.S., III; [et al.]. 2011. This must be the place: Under representation of identity and meaning in climate change decision-making. Global Environmental Politics. 11: 1–25.

Aguirre, B.E. 1988. The lack of warnings before the Saragosa tornado. International Journal of Mass Emergencies and Disasters. 6: 65–74.

Agyeman, J.; Devine-Wright, P.; Prange, J. 2009. Close to the edge, down by the river? Joining up management retreat and place attachment in a climate change world. Environment and Planning A. 41: 509–513.

Allan, J.D.; Castillo, M.M. 2007. Stream ecology: Structure and function of running waters. Dordrecht, the Netherlands: Springer Science & Business Media. 436 p.

American Lung Association®. 2015. State of the air 2015. http://www.stateoftheair.org [Accessed May 28, 2015].

Bedsworth, L. 2011. Air quality planning in California's changing climate. Climatic Change. 111: 101–118.

Beyers, W.B.; Nelson, P.B. 2000. Contemporary development forces in the nonmetropolitan west: New insights from rapidly growing communities. Journal of Rural Studies. 16: 459–474.

Blaikie, P.; Cannon, T.; Davis, I.; [et al.]. 1994. At risk: Natural hazards, people's vulnerability, and disasters. London: Routledge.

Borrie, W.T.; Davenport, M.; Freimund, W.A.; [et al.]. 2002. Assessing the relationship between desired experiences and support for management actions at Yellowstone National Park using multiple methods. Journal of Park and Recreation Administration. 20: 51–64.

Boyd, J.; Krupnick, A. 2009. The definition and choice of environmental commodities for nonmarket valuation. RFF DP: 09–35. Washington, DC: Resources for the Future. 60 p.

Brandt, J.P.; Morgan, T.A.; Keegan, C.E.; [et al.]. 2012. Idaho's forest products industry and timber harvest, 2006. Resour. Bull. RMRS- RB-12. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 44 p.

Bytnerowicz, A.; Omasa, K.; Paoletti, E. 2007. Integrated effects of air pollution and climate change on forests: A northern hemisphere perspective. Environmental Pollution. 147: 438–445.

Centers for Disease Control and Prevention. 2009. BRFSS [Behavioral Risk Factor Surveillance System] annual survey data. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention. http://www.cdc.gov/brfss [Accessed May 28, 2015].

Chouinard, H.; Yoder, J. 2004. The political economy of river rats and Idaho's four rivers whitewater rafting lottery. Western Economics Forum. 3: 17–24.

Cleland, E.E.; Collins, S.L.; Dickson, T.L.; [et al.]. 2013. Sensitivity of grassland plant community composition to spatial vs. temporal variation in precipitation. Ecology. 94: 1687–1696.

Collins, S.; Larry, E. 2007. Caring for our natural assets: An ecosystem services perspective. In: Deal, R.L., tech. ed. Integrated restoration of forested ecosystems to achieve multiresource benefits: Proceedings of the 2007 national silviculture workshop. Gen. Tech. Rep. PNW-733. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 11 p.

Conley, D.J.; Paerl, H.W.; Howarth, R.W.; [et al.]. 2009. Controlling eutrophication: Nitrogen and phosphorus. Science. 323: 1014–1015.

Cordalis, D.; Suagee, D.B. 2008. The effects of climate change on American Indian and Alaska Native tribes. Natural Resources and Environment. 22: 45–49.

Cutter, S.L.; Boruff, B.J.; Shirley, W.L. 2003. Social vulnerability to environmental hazards. Social Science Quarterly. 84: 242–261.

DeCoster, L.A. 2000. Summary of the forest fragmentation 2000 conference: How forests are being nibbled to death by DUCs and what to do about it. In: DeCoster, L.A., ed. Proceedings of the forest fragmentation 2000 conference: Sustaining private forests in the 21st century. Alexandria, VA: The Sampson Group, Inc.: 2–12.

Field, C.B.; Mortsch, L.D.; Brklacich, M.; [et al.]. 2007. North America. Climate change 2007: Impacts, adaptation and vulnerability. In: Parry, M.L.; Canziani, O.F.; Palutikof, J.P.; [et al.], eds. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press: 617–652.

Field, D.R.; Burch, W.R.J. 1988. Rural sociology and the environment. Middleton, WI: Social Ecology Press. 135 p.

Fothergill, A.; Peek, L.A. 2004. Poverty and disasters in the United States: A review of recent sociological findings. Natural Hazards. 32: 89–110.

Foti, R; Ramirez, J.A.; Brown, T.C. 2012. Vulnerability of U.S. water supply to shortage: A technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. RMRS-GTR-295. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 147 p.

Headwaters Economics. 2017. National Forest timber sales and timber cuts, FY 1980–2015. http://headwaterseconomics.org/interactive/national-forests-timber-cut-sold [Accessed April 26, 2017].

Healey, S.P.; Urbanski, S.P.; Patterson, P.L.; [et al.]. 2014. A framework for simulating map error in ecosystem models. Remote Sensing of Environment. 150: 207–217.

Hicke, J.A.; Allen, C.D.; Desai, A.R.; [et al.]. 2012. Effects of biotic disturbances on forest carbon cycling in the United States and Canada. Global Change Biology. 18: 7–34.

Igor, K. 2005. Attachment and identity as related to a place and its perceived climate. Journal of Environmental Psychology. 25: 207–218.

Intergovernmental Panel on Climate Change [IPCC]. 2007. Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S.; Qin, D.; Manning, M. [et al.]. Cambridge, UK: Cambridge University Press. 996 p.

Irland, L.C.; Adams, D.; Alig, R.; [et al.]. 2001. Assessing socioeconomic impacts of climate change on US forests, wood-product markets, and forest recreation. BioScience. 51: 753–764.

Isaak, D.J.; Wollrab, S.; Horan, D.; [et al.]. 2012. Climate change effects on stream and river temperatures across the northwest US from 1980–2009 and implications for salmonid fishes. Climatic Change. 113: 499–524.

Johnson, W.C.; Millett, B.V.; Gilmanov, T.; [et al.]. 2005. Vulnerability of northern prairie wetlands to climate change. BioScience. 55: 863–872.

Kardol, P.; Todd, D.E.; Hanson, P.J.; [et al.]. 2010. Long-term successional forest dynamics: Species and community responses to climatic variability. Journal of Vegetation Science. 21: 627–642.

Karetinkov, D.; Parra, N.; Bell, B.; [et al.]. 2008. Economic impacts of climate change on North Dakota. College Park, MD: University of Maryland, Center for Integrative Environmental Research. http://www.cier.umd.edu/climateadaptation [Accessed May 28, 2015].

Karl, T.R.; Melillo, J.M.; Peterson, T.C., eds. 2009. Global climate change impacts in the United States. New York, NY: Cambridge University Press. 196 p.

Keegan, C.E.; Sorenson, C.B.; Morgan, T.A.; [et al.]. 2012. Impact of the Great Recession and housing collapse on the forest products industry in the western United States. Forest Products Journal. 61: 625–634.

Keegan, C.E., Todd A.M., Wagner, F.G.; [et al.]. 2005. Capacity for utilization of USDA Forest Service, Region 1 small-diameter timber. Forest Products Journal. 55: 143–147.

Kellogg, R.L.; Wallace, S.; Alt, K. 1997. Potential priority watersheds for protection of water quality: From nonpoint sources related to agriculture. [Poster]. In: 52nd annual SWCS conference; 1997 July; Toronto, Ontario, Canada.

Kinney, P.L. 2008. Climate change, air quality, and human health. American Journal of Preventive Medicine. 35: 459–467.

Kline, J.D.; Mazzotta, M.J. 2012. Evaluating tradeoffs among ecosystem services in the management of public lands. Gen. Tech. Rep. PNW-GTR-865. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 48 p.

Kunce, M.; Shogren, J.F. 2005. On interjurisdictional competition and environmental federalism. Journal of Environmental Economics and Management. 50: 212–224.

Lynn, K.; Daigle, J.; Hoffman, J.; [et al.]. 2013. The impacts of climate change on tribal traditional foods. Climatic Change. 120: 545–556.

Maher, A.T. 2007. The economic impacts of sagebrush steppe wildfires on an eastern Oregon ranch. Thesis. Corvallis, OR: Oregon State University. 159 p. http://ir.library.oregonstate.edu/xmlui/handle/1957/7489 [Accessed April 1, 2016].

Maldonado, J.K.; Shearer, C.; Bronen, R.; [et al.]. 2013. The impact of climate change on tribal communities in the US: Displacement, relocation, and human rights. Climatic Change. 120: 601–614.

Mansfield, C.; Phaneuf, D.J.; Johnson, F.R.; [et al.]. 2008. Preferences for public lands management under competing uses: The case of Yellowstone National Park. Land Economics. 84: 282–305.

Mason, J. 2012. Bakken's maximum potential oil production rate explored. Oil and Gas Journal. 110: 76.

McIver, C.P.; Sorenson, C.B.; Keegan, C.E.; [et al.]. 2013. Montana's forest products industry and timber harvest 2009. Resour. Bull. RMRS-RB-16. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 42 p.

MIG, Inc. 2012. IMPLAN system (data and software). Stillwater, MN: Minnesota Implan Group. http://www.implan.com [Accessed May 28, 2015].

Millennium Ecosystem Assessment (MA). 2005. Ecosystems and human well-being: Synthesis. Washington, DC: Island Press. 155 p.

Montana Department of Natural Resources and Conservation [DNRC]. 2014. Montana State water plan draft. 21 August 2014. Helena, MT: Montana Department of Natural Resources and Conservation. 64 p. http://leg.mt.gov/content/Committees/Interim/2013-2014/EQC/Meetings/September-2014/state-water-plan-draft-lowres.pdf [Accessed May 28, 2015].

Morrow, B.H. 1999. Identifying and mapping community vulnerability. Disasters. 23: 1–18.

Murdoch, P.S.; Baron, J.S.; Miller, T.L. 2000. Potential effects of climate change on surface-water quality in North America. Journal of the American Water Resources Association. 36: 347–366.

National Park Service. 2014. A call to action: Preparing for a second century of stewardship and management. http://www.nps.gov/calltoaction/PDF/C2A_2014.pdf [Accessed May 28, 2015].

North Dakota Wheat Commission. 2007. Report to the 2007 North Dakota legislative assembly: Economic importance of wheat. http://www.ndwheat.com/uploads%5Cresources%5C614%5C071legreport.pdf [Accessed May 28, 2015].

O'Laughlin, J. 2005. Economic impact of salmon and steelhead fishing in Idaho: Review of the Idaho Rivers United report. Issue Brief 6. Moscow, ID: University of Idaho, College of Natural Resources.

Pan, Y.; Birdsey, R.; Hom, J.; [et al.]. 2009. Separating effects of changes in atmospheric composition, climate and land-use on carbon sequestration of U.S. mid-Atlantic temperate forests. Forest Ecology and Management. 259: 151–164.

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

Pederson, G.T.; Gray, S.T.; Fagre, D.B.; [et al.]. 2006: Long-duration drought variability and impacts on ecosystem services: A case study from Glacier National Park, Montana. Earth Interact. 10: 1–28.

Perry, L.G.; Andersen, D.C.; Reynolds, L.V.; [et al.]. 2012. Vulnerability of riparian ecosystems to elevated CO_2 and climate change in arid and semiarid western North America. Global Change Biology. 18: 821–842.

Phillips, B.D. 1993. Cultural diversity in disasters: Sheltering, housing, and long-term recovery. International Journal of Mass Emergencies and Disasters. 11: 99–110.

Phillips, B.D.; Ephraim, M. 1992. Living in the aftermath: Blaming processes in the Loma Pieta earthquake. Working Paper No. 80. Boulder, CO: University of Colorado, Natural Hazards Research and Applications Information Center.

Polley, H.W.; Jin, V.L.; Fay, P.A. 2012. Feedback from plant species change amplifies CO_2 enhancement of grassland productivity. Global Change Biology. 18: 2813–2823.

Poole, G.C.; Berman, C.H. 2001. An ecological perspective on in-stream temperature: Natural heat dynamics and mechanisms of human-caused thermal degradation. Environmental Management. 27: 787–802.

Power, T.M. 1998. Lost landscapes and failed economies: The search for a value of place. Washington, DC: Island Press. 317 p.

Rahel, F.J. 2002. Homogenization of freshwater faunas. Annual Review of Ecology and Systematics. 33: 291–315.

Rasker, R. 1993. A new look at old vistas: The economic role of environmental quality in Western public lands. University of Colorado Law Review. 65: 369–399.

Raymond, C.L.; Healey, S.P.; Peduzzi, A.; [et al.]. 2015. Representative regional models of post-disturbance forest carbon accumulation: Integrating inventory data and a growth and yield model. Forest Ecology and Management. 336: 21–34.

Reeves, M.C.; Mitchell, J.E. 2012. A synoptic review of U.S. rangelands: A technical document supporting the Forest Service 2010 RPA Assessment. Gen.Tech. Rep. RMRS-GTR-288. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 128 p.

Riebsame, W.E.; Hannah G.; Theobald, D.; [et al.]. 1997. Atlas of the New West: Portrait of a changing region. New York: Norton.

Rosenzweig, C.; Iglesias, A.; Yang, X.B.; [et al.]. 2000. Climate change and U.S. agriculture: The impacts of warming and extreme weather events on productivity, plant diseases, and pests. Cambridge, MA: Harvard Medical School, Center for Health and the Global Environment.

Ryan, M.G.; Archer, S.R.; Birdsey, R.; [et al.]. 2008. Land resources. In: Walsh, M.; Backlund, P.; Janetos, A; Schimel, D., eds. The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States. Washington, DC: Climate Change Science Program, Subcommittee on Global Change Research.

Schindler, D.W.; Hecky, R.E.; Findlay, D.L.; [et al.]. 2008. Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment. Proceedings of the National Academy of Sciences. 105: 11254–11258.

Sham, C.H.; Tuccillo, M.E.; Rooke, J. 2013. Effects of wildfire on drinking water utilities and best practices for wildfire risk reduction and mitigation. Web Rep. 4482. Denver, CO: Water Research Foundation. 98 p.

Sitch, S.; Cox, P.M.; Collins, W.J.; [et al.]. 2007. Indirect radiative forcing of climate change through ozone effects on the land-carbon sink. Nature. 448: 791–794.

Skog, K.E. 2008. Sequestration of carbon in harvested wood products for the United States. Forest Products Journal, 58: 56–72.

Smith, S.G.; Muir, W.D.; Williams, J.G.; [et al.]. 2002. Factors associated with travel time and survival of migrant yearling Chinook salmon and steelhead in the lower Snake River. North American Journal of Fisheries Management. 22: 385–405.

Sorenson, L.G.; Goldberg, R.; Root, T.L.; Anderson, M.G. 1998. Potential effects of global warming on waterfowl populations breeding in the northern Great Plains. Climatic Change. 40: 343-369.

Stockmann, K.; Anderson, N.; Young, J.; [et al.]. 2014. Estimates of carbon stored in harvested wood products from United States Forest Service Northern Region, 1906–2012. Unpublished report on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Forestry Sciences Laboratory, Missoula, MT. 27 p.

Sweeney B.W.; Jackson J.K.; Newbold J.D.; [et al.]. 1992. Climate change and the life histories and biogeography of aquatic insects in eastern North America. In: Firth P.; Fisher S.G., eds. Global climate change and freshwater ecosystems. New York: Springer Verlag: 143–176.

Thamke, J.N.; Smith, B.D. 2014. Delineation of brine contamination in and near the East Poplar oil field, Fort Peck Indian Reservation, northeastern Montana, 2004–09: U.S. Geological Survey Scientific Investigations Rep. 2014–5024. Reston, VA: U.S. Geological Survey. 40 p.

Theodossiou, I. 1998. The effects of low-pay and unemployment on psychological well-being: A logistic regression approach. Journal of Health Economics. 17: 85–104.

USDA Forest Service [USDA FS]. 2009. Watershed and air management. FSM 2550 Amend. 2500-2009-1. Washington, DC: U.S. Department of Agriculture, Forest Service.

USDA Forest Service [USDA FS]. 2012. National Forest System land management planning: Final rule and record of decision: 36 CFR Part 219. RIN 0596–AD02. Federal Register. 77(68): 21162–21276.

USDA Forest Service [USDA FS]. 2014. Nez Perce-Clearwater National Forest assessment (June 2014 review draft). On file with: U.S. Department of Agriculture, Forest Service, Nez Perce-Clearwater Forest, Kamiah, ID.

USDA Forest Service [USDA FS]. 2015. Baseline estimates of carbon stocks in forests and harvested wood products for National Forest System units; Northern Region. Unpublished report on file with: U.S. Department of Agriculture, Forest Service, Northern Region. 43 p. http://www.fs.fed.us/climatechange/documents/NorthernRegionCarbonAssessment.pdf [Accessed April 1, 2016].

U.S. Department of Commerce. 2014. County Business Patterns. Washington, DC: U.S. Department of Commerce, Census Bureau.

U.S. Department of the Interior, Bureau of Land Management [USDOI BLM]. [n.d.]. GeoCommunicator. Washington, DC: U.S. Department of the Interior, Bureau of Land Management. http://www.geocommunicator.gov/blmMap/Map.jsp?MAP=GA [Accessed August 24, 2015].

U.S. Department of Labor, Bureau of Labor Statistics. Forestry and logging. NAICS 113. http://www.bls.gov/iag/tgs/iag113.htm [Accessed May 28, 2015].

U.S. Environmental Protection Agency. 2016. WATERS (Watershed Assessment, Tracking and Environmental Results System) database. http://water.epa.gov/scitech/datait/tools/waters/index.cfm [Accessed April 25, 2017].

van Vliet, M.T.H.; Ludwig, F.; Zwolsman, J.J.G.; [et al.]. 2011. Global river temperatures and sensitivity to atmospheric warming and changes in river flow. Water Resources Research. 47: W02544.

Vollenweider, R.A. 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorous as factors in eutrophication. Report DAS/CSI/62.27. Paris, France: Organisation for Economic Co-operation and Development Report. 159 p.

Wagner, T.; Congleton, J.L.; Marsh, D.M. 2004. Smolt-to-adult return rates of juvenile Chinook salmon transported through the Snake-Columbia River hydropower system, USA, in relation to densities of co-transported juvenile steelhead. Fisheries Research. 68: 259–270.

Warziniack, T. 2014. A general equilibrium model of ecosystem services in a river basin. Journal of the American Water Resources Association. 50: 683–695.

Weidner, E.; Todd, A. 2011. From the forest to the faucet: Drinking water and forests in the US. Methods Pap. Washington, DC: U.S. Department of Agriculture, Forest Service, State and Private Forestry, Ecosystem Services and Markets Program Area.

Williams, J.G.; Smith, S.G.; Muir, W.D. 2001. Survival estimates for downstream migrant yearling juvenile salmonids through the Snake and Columbia rivers hydropower system, 1966–1980 and 1993–1999. North American Journal of Fisheries Management. 21: 310–317.

Winthrop, R. [n.d.]. Estimating nonmarket environmental values. Washington, DC: U.S. Department of the Interior, Bureau of Land Management. http://www.blm.gov/style/medialib/blm/wo/Information_Resources_Management/policy/im_attachments/2010.Par.49792.File.dat/IM2010-061_att1.pdf [Accessed August 23, 2015].

Woodall, C.; Smith, J.; Nichols, M. 2013. Data sources and estimation/modeling procedures for the National Forest System carbon stock and stock change estimates derived from the U.S. National Greenhouse Gas Inventory. http://www.fs.fed.us/climatechange/documents/NFSCarbonMethodology.pdf [Accessed April 1, 2016].