# Chapter 10
# Effects of Climate Change on Ecosystem Services in the Northern Rockies

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

**Abstract** Ecosystem services are increasingly valued on federal lands, beyond just their economic value. Climate change effects will vary greatly within different subregions of the Northern Rockies, with some ecosystem services being affected in the short term and others in the long term. Of the many ecosystem services provided in the Northern Rockies, eight are considered here, including annual water yield, water quality, wood products, minerals and mineral extraction, forage for livestock, viewsheds and air quality, regulation of soil erosion, and carbon sequestration.

Although annual water yield is not expected to change significantly, timing of water availability will likely shift, and summer flows may decline. These changes may result in some communities experiencing summer water shortages, although reservoir storage can provide some capacity. Rural agricultural communities will be disproportionately affected by climate change if water does become limiting. Water quality will also decrease in some locations if wildfires and floods increase, adding sediment to rivers and reservoirs. Hazardous fuel treatments, riparian restoration, and upgrading of hydrologic infrastructure can build resilience to disturbances that damage water quality.

Forage for livestock is expected to increase in productive grasslands as a result of a longer growing season and in some cases elevated carbon dioxide. Therefore, ranching and grazing may benefit from climate change. Primary effects on grazing include loss of rural population, spread of nonnative grasses, and fragmentation of rangelands.

Viewsheds and air quality will be negatively affected by increasing wildfires and longer pollen seasons. A growing percentage of the Northern Rockies population

T. Warziniack (✉)
U.S. Forest Service, Rocky Mountain Research Station, Fort Collins, CO, USA
e-mail: twwarziniack@fs.fed.us

M. Lawson
Headwaters Economics, Bozeman, MT, USA
e-mail: megan@headwaterseconomics.org

S. Karen Dante-Wood
U.S. Forest Service, Office of Sustainability and Climate, Washington, DC, USA
e-mail: skdante@fs.fed.us



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will be in demographic groups at risk for respiratory and other medical problems on days with poor air quality. Hazardous fuel treatments can help build resilience to disturbances that degrade air quality.

Carbon sequestration will be increasingly difficult if wildfires, insect outbreaks, and perhaps plant disease increase as expected, especially in the western part of the Northern Rockies. At the same time, managing forests for carbon sequestration is likely to become more important in response to national policies on carbon emissions. Hazardous fuel treatments can help build resilience to disturbances that rapidly oxidize carbon and emit it to the atmosphere.

**Keywords** Water yield • Water quality • Wood products • Minerals • Viewsheds • Air quality • Soil erosion • Carbon sequestration • Climate change • Adaptation • Ecosystem services • Social vulnerability • Rocky Mountains • Natural capital

## 10.1 Introduction

Ecosystem services are benefits to people from the natural environment, including timber for wood products, clean water for downstream users, recreation opportunities, and spiritual and cultural connection to the environment and natural resources. As stated by Collins and Larry (2007), "An ecosystem services perspective encourages natural resource managers to extend the classification of multiple uses to include a broader array of services or values."

Categorizing ecosystem services (Box 10.1) helps identify ways in which natural resources benefit humans, and how changes in the natural environment will affect these benefits. These categories are not exclusive, and many natural resources fall

**Box 10.1 Ecosystem Services Definitions**

*From the Millennium 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.

under multiple categories. For example, *consumption of water* is a provisioning service, the process of *purifying water* a regulating service, *recreational use of water* a cultural service, and the role of *water in the life history of animals* a supporting service. Climate change will affect the quality and quantity of ecosystem services (positively and negatively) 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.

Lands in the Northern Rockies provide ecosystem services to people who visit, live adjacent to, or otherwise benefit from natural resources on public lands. First, we introduce ecosystem services and how to describe and measure them. Second, we describe how people and communities use and benefit from public lands, 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, and discuss the adaptive capacity of agencies and communities.

## 10.2 Ecosystem Services on Public Lands in the Northern Rockies

There are many beneficiaries from ecosystem services provided by public lands, including neighboring communities, non-local visitors, and people who may never visit or directly use the lands but gain satisfaction from knowing a resource exists (Kline and Mazzotta 2012). This is particularly true for iconic landscapes and rivers in the study area (e.g., Yellowstone National Park; Borrie et al. 2002). Managing for multiple use of natural resources can create situations in which some ecosystem services conflict with others. For example, managing for non-motorized 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 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 some communities to seek alternative means of providing services or to change local economies and lifeways.

Management decisions for public lands can affect ecosystem service flows, with cascading effects on numerous users. We will highlight climate change effects on ecosystem services flows, and how management decisions can help users mitigate or adapt to these effects. The concept of ecosystem services is relatively new, so data on this topic are scarce. Although we use quantitative data when possible, we often rely on qualitative descriptions or proxy measures. Demographic and economic factors provide an important context for understanding the effects of climate change on ecosystem services.

**Box 10.2 Ecosystem Services Assessed in the Northern Rockies**

**Provisioning Ecosystem Services**

- Abundant fresh water for human (e.g., municipal and agricultural water supplies) and environmental (e.g., maintaining streamflow) uses
- Building materials and wood products
- Mining materials
- Forage for livestock
- Fuel from firewood and biofuels
- 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

We focus on provisioning and regulating ecosystem services in the Northern Rockies (Box 10.2). The amount of detail for these ecosystem services varies, depending on how much information is available and can be interpreted in the context of climate change. Several of the ecosystem services are also discussed in other chapters, including genetic diversity and biodiversity (Chap. 5), protection from wildfire and floods (Chap. 7), and recreation (Chap. 9). 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.

## 10.3 Social Vulnerability and Adaptive Capacity

Social vulnerability analyses seek to identify which institutions, resources, and characteristics make communities more or less resilient to environmental hazards. The most widely used measure of social vulnerability is the Social Vulnerability Index (SoVI) (Cutter et al. 2003), which is based on 11 factors: personal wealth, age, density of the built environment, single-sector economic dependence, housing stock and tenancy, race (separate factors for African American and Asian), ethnicity (separate factors for Hispanic and Native American), occupation, and infrastructure dependence. Scores based on these factors are summed to form a composite vulnerability score for each county in the United States.

Most counties in the Northern Rockies are in the high to medium vulnerability range, which is typical for areas dominated by rural economies. The average percentage of county populations living in rural areas in the Northern Rockies is 75.3%, compared to a national average of 19.3% (based on the 2012 Census American Community Survey). Rural counties tend to rely on a single industry, have older populations, and have fewer social resources (e.g., hospitals) than urban areas. The oldest mean age in the region is in Prairie County, Montana, where the mean age is 56, and the average median age among the counties is 43.4. 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 in the Northern Rockies is $45,235, considerably lower than the national average of $53,046. High-income counties tend to be in the eastern part of the region with ties to the oil and gas industry, and areas with recreation-based businesses; low-income counties often depend on grazing and timber. Unemployment and poverty are relatively widespread in the region (Fig. 10.1), although the region as a whole had an average unemployment rate in 2012 of 5.4%, lower than the national average of 9.3%. Spatially, unemployment follows median incomes closely, with counties in the east having low unemployment and counties in the west having high unemployment. 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 (Fothergill and Peek 2004).

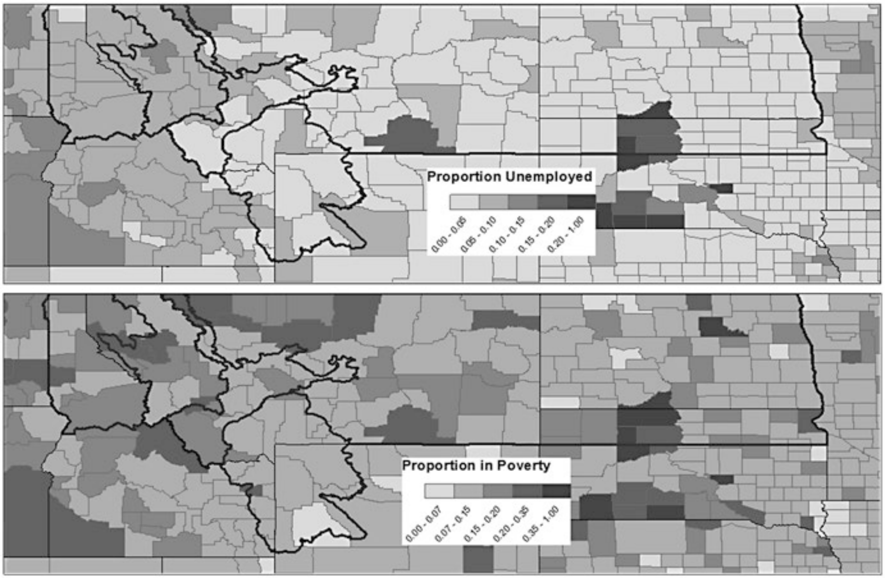


**Fig. 10.1** Demographic information for unemployment (upper) and poverty (lower) in the Northern Rockies

## 10.4 Assessing the Effects of Climate Change on Ecosystem Services

### *10.4.1 Water Quantity*

Major consumptive uses of water in the Northern Rockies include domestic and municipal water supply, industrial use of water, and water for oil and gas development (drilling and hydraulic fracturing). Non-consumptive uses of water 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 that can be exercised only during high-flow years. Any new uses of water require a transfer of water rights, increased water supply through reservoir storage, or mining of ground water.

A recent draft of the Montana State Water Plan details water use in Montana (Tables 10.1 and 10.2) and is representative of most of the Northern Rockies. Hydroelectric power generation (hydropower) accounts for 86% of total water

**Table 10.1** Total water use in Montana

| Planning basin | Hydropower | Irrigation | Reservoir evaporation | Municipal, industrial, livestock | Instream flow |
|---|---|---|---|---|---|
| | | | *Percent* | | |
| Statewide | 85.9 | 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 | 39.2 | 19.5 | 6.0 | 0.3 | 35.0 |
| Yellowstone River | 24.5 | 23.0 | 0.4 | 1.4 | 50.7 |

From Montana DNRC (2014)

**Table 10.2** Consumptive water use in Montana

| 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 | 66.4 | 27.0 | 3.9 | 0.5 | 1.2 | 0 |
| Upper Missouri | 82.3 | 13.7 | 3.0 | 0.9 | <0.1 | 0 |
| Lower Missouri | 42.0 | 56.2 | 0.4 | 1.4 | <0.1 | 0 |
| Yellowstone River | 83.4 | 7.2 | 2.8 | 2.1 | 0.3 | 4.2 |

From Montana DNRC (2014)

demand in Montana (Montana DNRC 2014), although hydropower is considered a non-consumptive use because it does not affect instream flow or total water downstream. However, reservoirs needed for hydropower experience high rates of water loss to evaporation. Fort Peck Reservoir, in the Lower Missouri River Basin, annually loses 754,000 megaliters of water to evaporation. The largest consumptive use of water in Montana is irrigated agriculture, which accounts for 96% of all water diversions and 67% of all consumptive use. The marginal value of water in agriculture is an order of magnitude lower than the marginal value of water for municipal uses (Montana DNRC 2014).

Compared to more arid regions of the western United States, changes in water yield in the Northern Rockies are expected to be modest, although they may be disproportionately large for local residents who experience them (Foti et al. 2012). Climate and hydrologic models consistently project changes in timing of runoff, making the likelihood of these effects high. Warmer temperatures will make drought more frequent, despite small increases in precipitation shown in some climate models, increasing overall competition for water. 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.

Timing of snowmelt is a major concern in the Columbia and Missouri Basin headwaters. Earlier runoff may be out of sync with many of the demands for water 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. Higher temperatures have already brought a mixture of impacts to agriculture in North Dakota, where 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 either they were not previously grown or where shorter-season varieties dominated.

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. In 2005, heavy rains ruined 400,000 hectares of cropland and prevented another 400,000 from being planted, causing $425 million in damage (Karetinkov et al. 2008). More droughts and intense temperatures may also make plants more susceptible to insect pests (Rosenzweig et al. 2000). More frequent droughts and heavy rain events will stress municipal water supply systems and infrastructure.

Climate change will make it harder to preserve instream flows in the future, with small mountain streams and valued fisheries being particularly vulnerable. Some of the most productive waterfowl breeding grounds in the northern prairie wetlands and pothole region (> 50% of North America's ducks breed here) will be threatened in a warmer climate, and unless these wetlands are maintained, bird populations will be significantly reduced (Sorenson et al. 1998; Johnson et al. 2005).

Transfer of water rights from one use to another is legally possible within the Northern Rockies but 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 so high, these transfers are likely to occur if demand is high enough.

Re-use of effluent and other conservation methods will be important tools for adaptation. Groundwater pumping is 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 they are junior in priority and not reliable for municipal uses. A drier climate in prairie pothole habitats of the Grassland subregion will make it desirable to preserve and restore waterfowl habitat along the wetter fringes (Johnson et al. 2005).

### *10.4.2 Water Quality, Aquatic Habitats, and Fish*

Headwater streams in the Northern Rockies generally provide safe, clean drinking water to downstream communities, and water is important to cultural practices of Native Americans, including the ability to exercise their fishing rights. However, many of the region's streams and lakes are already threatened or impaired according to U.S. Environmental Protection Agency standards, with impairment being caused by grazing, feedlots, and fertilizer runoff. Runoff from roads and bridges are a problem in Idaho, leading to high levels of phosphorous and mercury.

Disturbances such as wildfires and mudslides are a major concern for municipal water supplies (Chap. 3). Sudden increases in sediment or other pollutants often cause water treatment plants to shut down or incur high costs to 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 oil field (Thamke and Smith 2014). Oil spills in the Yellowstone River (2011, 2015) and a pipeline leak near Tioga, North Dakota (2014) highlight the dangers to watersheds surrounding oil and gas fields.

Climate change will potentially affect fishing, water-based recreation, and drinking water, amplifying the effects of development on water quality already occurring in the region. Increased number and severity of wildfires will deposit 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.

Warming air temperature will cause stream temperatures to increase. Some native fish species, such as bull trout (*Salvelinus confluentus*) and cutthroat trout (*Oncorhynchus clarkii*), are extremely sensitive to warm water, whereas some nonnative species can tolerate higher temperatures (Chap. 4). Fish habitats at lower elevations are likely to experience the biggest, near-term temperature increases, making them vulnerable to shifts in species composition and distribution. 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 (Chap. 4 ). Culturally important fisheries, such as those of the Nez Perce tribe, will be affected within the boundaries of their reservation and traditional fishing grounds, already stressed by hydropower and stream modification (Wagner et al. 2004).

Warming has already led to expansion of agriculture in some areas of the Northern Rockies. Continued expansion will generally decrease water quality, but the net effects of flooding and drought are uncertain (Warziniack 2014). Lower water flows have also been linked to increased water temperature, eutrophication, and content of nutrients and metals (Murdoch et al. 2000; van Vliet et al. 2011), especially in nutrient-rich bodies of water (Schindler et al. 2008).

Restoration of streams, wetlands, and riparian areas may help stabilize water 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 future. Other adaptation strategies are described in Chaps. 4 and 9.

### *10.4.3 Building Materials and Wood Products*

Timber and forest products are dominant economic forces in the Northern Rockies, with forest products comprising 23% of direct manufacturing employment in Montana (McIver et al. 2013) (Table 10.3). Because much of the timber in the Northern Rockies is exported from the region, the most important aspect of timber is providing jobs, particularly in rural communities. The timber industry also provides a labor force capable of doing forest restoration work. In 2011, Idaho and Montana contained 160 timber processing facilities including 73 saw mills. Over 97% of timber is processed in sawmills, up from 80% (Keegan et al. 2005).

Historically, much of the timber in the area has come from national forests, although that share has decreased greatly. In 1979, 46% of timber harvested in Idaho came from national forests, declining to only 7% in 2006 (Brandt et al. 2012). 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 (Table 10.3). Between 2005 and 2009, employment in the wood products industry declined 29% in Idaho and 24% in Montana (Keegan et al. 2012). Mills in the region are the major employer for some small communities, making the effects of mill closures particularly pronounced in a few places. Although timber jobs have been declining in the Northern Rockies, non-timber jobs have been increasing.

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 sensitivities of timber resources associated with climate change are wildfire, insects,

**Table 10.3** Sold timber volume from national forests in the U.S. Forest Service Northern Region and Greater Yellowstone Area subregion

| National Forest | 1980 | | | 2013 | | |
|---|---|---|---|---|---|---|
| | Sales | Sold volume | Inflation adjusted sold value | Sales | Sold volume | Inflation adjusted sold value |
| | | *Thousands of $m^3$* | *US dollars* | | *Thousands of $m^3$* | *US dollars* |
| Beaverhead-Deerlodge | 630 | 111 | 1,971,012 | 845 | 19 | 59,067 |
| Bitterroot | 268 | 101 | 3,883,685 | 266 | 19 | 459,684 |
| Bridger-Teton | 425 | 48 | 885,087 | 627 | 23 | 150,834 |
| Caribou-Targhee | 7347 | 232 | 7,726,627 | 743 | 17 | 93,922 |
| Custer | 127 | 4 | 81,794 | 292 | 4 | 18,088 |
| Flathead | 289 | 459 | 22,504,836 | 334 | 35 | 963,163 |
| Gallatin | 310 | 56 | 628,518 | 551 | 11 | 44,820 |
| Helena | 113 | 52 | 1,451,979 | 393 | 8 | 34,000 |
| Idaho Panhandle | 669 | 748 | 64,207,103 | 866 | 95 | 3,562,340 |
| Kootenai | 616 | 415 | 36,705,744 | 820 | 84 | 1,820,020 |
| Lewis and Clark | 277 | 29 | 134,615 | 387 | 5 | 21,160 |
| Lolo | 367 | 96 | 2,281,829 | 597 | 15 | 298,537 |
| Nez Perce-Clearwater | 414 | 603 | 18,881,743 | 699 | 105 | 6,567,655 |
| Shoshone | 307 | 28 | 198,089 | 415 | 18 | 225,075 |

Data from U.S. Forest Service, via Headwater Economics; http://headwaterseconomics.org/interactive/national-forests-timber-cut-sold

and disease (Ryan et al. 2008; Chaps. 6, 7). In addition, warmer winters and associated freezing and thawing may increase forest road erosion and landslides, making winter harvest more difficult and expensive. Climate change will result in larger, more frequent fires and a longer fire season. Increased fires may increase demand for fuel 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.

Management actions may be able to mitigate drought stress and soil water deficits. Land managers also have the option to conduct fuel treatments, which help decrease the probability of large, severe wildfires and to salvage burned or insect-killed timber before it loses market value. However, timber management cannot respond quickly to potential threats. The wood products industry may 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). The most resilient communities will be those that diversify their economic bases, effectively reducing their exposure to adverse impacts to the timber industry.

### *10.4.4 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. The main stressors from oil and gas development are effects on other ecosystem services, such as water quality. Traffic from trucks and heavy machinery also increase the risk of introducing nonnative species to surrounding rangelands.

Climate will not directly affect minerals industries, although 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 co-located 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 oil fields causes wages in all other sectors of regional economics, 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 non-climatic drivers will be more important, including international prices for oil and gas, national climate policy, and regional concerns about threats to watersheds.

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. The most successful mineral-based economies are those that are able to collect some of the resource rents from drilling and invest them in the community, extending prospects for long-term economic growth (Kunce and Shogren 2005).

### *10.4.5 Forage for Livestock*

The area contained within the Northern Rockies Adaptation Partnership contains 64 million hectares of rangeland, of which 85% are privately held. Of the federal rangeland, 3.4 million hectares are Bureau of Land Management lands, of which 3.2 million hectares are in Montana. Most counties in the region have a significant share of total income derived from cattle.

Cheatgrass (*Bromus tectorum*) and other nonnative plants have become a major nuisance in Western rangelands, significantly reducing usable forage. Human modification has also converted rangeland to other uses, dominated by agricultural development, resource extraction, and residential development (Reeves and Mitchell 2012). Human modification and fragmentation of rangelands have potential consequences for socio-economic sustainability of rural communities, including loss of rural character, loss of biodiversity, difficulty in managing interconnected lands for grazing, threats to watershed health, compromised viewscapes, loss of native species, and changes in disturbance regimes.

Warmer temperatures carbon dioxide fertilization are expected to increase productivity of rangelands (Reeves and Mitchell 2012; Chap. 6), and increased regional population will lead to fragmentation of rangelands. Arid grasslands are likely to experience short-term response in species richness because of the prevalence of annual species (Cleland et al. 2013). Carbon dioxide 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 species (Polley et al. 2012).

Cattle stocking rates in the Northern Rockies 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. The biggest threat to rangeland from climate change may be increasing rates of spread of nonnative weeds and changes in fire regime (Maher 2007). Fire makes ranch planning difficult. Loss of access to grazing areas requires emergency measures like the use of hay, requiring increased investments by ranchers. Increased fire will facilitate conversion of more lands to domination by nonnative plants. Fire also kills shrubs, especially sagebrush (*Artemisia* spp.), increasing the prevalence of grasses and herbs, thus reducing structural and floristic diversity.

Human modification of rangelands and associated fragmentation are driven by opportunities for economic growth, as land is converted to higher value uses. Rangeland conversion 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). Natural amenities in and near the Rocky Mountains are often touted as an economic asset (Power 1998; Rasker 1993), and during the 1990s, 67% of counties in the Rocky Mountains grew faster than the national average (Beyers and Nelson 2000). The effects of demographic and socioeconomic factors may affect rangeland quantity and quality more than climate change in some areas.

### *10.4.6 Viewsheds and Clean Air*

Air quality is an ecosystem service that can be altered by changes in vegetation composition and tree responses to climate change. Tropospheric ozone, air pollution episodes, plant sensitivity to air pollutants, and release of pollen all affect the provision of air quality by forests. The Northern Rockies generally have 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 inversions, wood-burning stoves become a major source of air pollution. In summer, smoke from wildfires settles in valleys, leading to poor air quality. Some areas in Idaho are 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, oil-field emissions, and vehicle traffic in mineral-rich areas of the state.

A large percentage of Northern Rockies residents are in demographic groups that are sensitive to poor air quality (e.g., elderly, poor), and nearly 1 in 10 adults have asthma (Center for Disease Control 2009). As more young people leave rural communities, sensitive populations remain in rural areas without health facilities that can accommodate an aging population.

Air quality can deteriorate 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 (Bedsworth 2011). Climate change may affect distribution patterns and mixtures of air pollutants through altered wind patterns and amount and intensity of precipitation. By 2050, summertime organic aerosol concentration over the western United States is projected to increase by 40% and elemental carbon by 20%. Higher temperatures accelerate chemical reactions that, in combination with reactive hydrocarbons, form ozone and secondary particles (Kinney 2008).

Systems are already in place to alert residents when air quality deteriorates. 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 fuel treatments can reduce wildfire risk and smoke production. As noted above, the effects of poor air quality are greater for vulnerable populations like the elderly, young, and poor, who have little capacity to adapt.

### *10.4.7 Regulation of Soil Erosion*

A U.S. Forest Service (USFS) soil management directive identifies six soil functions: soil biology, soil hydrology, nutrient cycling, carbon storage, soil stability and support, and filtering and buffering (USFS 2009). 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. Resource management practices are designed to limit erosion and soil compaction, but landslides and erosion are still a common problem, with roads and other human activities serving as a large source of sediment in many watersheds. Loss of soil from agricultural fields is a problem in the eastern part of the Northern Rockies, 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 this area, and may continue with further expansion of agriculture.

Soil erosion interacts with other landscape processes 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 may lead to greater erosion and more landslides. A combination of increased drought and flooding could exacerbate erosion in some areas. Erosion is also a significant concern for cultural sites (Chap. 11).

One of the key impacts of soil erosion in mountains is its effect on water quality and water treatment costs. Without expensive dredging, the usable life of dams and reservoirs will decrease, and capital investments will be necessary to remove sediment (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. Accelerating fuel treatments to make forests more resilient to wildfire can limit erosion by reducing fire severity.

### *10.4.8 Carbon Sequestration*

Forests provide an important ecosystem service in the form of carbon sequestration—the uptake and storage of carbon in forests and wood products. Carbon sequestration is considered a regulating ecosystem service because it mitigates greenhouse gas emissions by offsetting losses through removal and storage of carbon. Carbon storage in forests is becoming more valuable as the impacts of greenhouse gas emissions manifest in different ways (USFS 2015).

The National Forest System includes 22% of the total U.S. forest area and 24% of total carbon stored in U.S. forests (excluding interior Alaska). Carbon sequestration can be enhanced by preventing conversion of forest land to non-forest uses, restoring and maintaining resilient forests better adapted to a changing climate and other stressors, and reforesting lands disturbed by wildfires. Federal agencies balance carbon stewardship with a wide range of ecosystem services by maintaining and enhancing net sequestration in existing ecosystems.

Although disturbances are the predominant drivers of forest carbon dynamics, biogeochemical cycling and climatic variability influence forest growth rates and consequently the carbon fluxes (Pan et al. 2009, 2011). Changes in carbon stocks and resulting net emissions may be influenced by vegetation management and restoration—fire and fuels management, timber harvest, reforestation, and other practices—that can integrate carbon dynamics across broad landscapes and over many decades, while meeting other resource management objectives. Harvested wood products (HWP), such as lumber, panels, and paper, can account for a significant amount of off-site carbon storage, contributing to national-level accounting and regional reporting (Skog 2008). Products derived from timber harvest from federal lands extend carbon storage and/or substitute for fossil fuel use.

Estimates of total ecosystem carbon and stock change (flux) have been produced for all national forests in the United States (USFS 2015). Carbon stocks reflect the amount of carbon stored in aboveground live trees, belowground live trees, understory, standing dead trees, down dead wood, forest floor, and soil organic carbon. Carbon stock change (flux) reflects year-to-year balance of carbon (Woodall et al. 2013) and measures interannual variation caused by tree growth, disturbance, and management.

Carbon stock trends for each national forest between the years 1990 and 2013 (Fig. 10.2) indicate that Idaho Panhandle National Forest stored the largest amount of carbon in the region (188 Tg in 1990, 183 Tg in 2013), and some forests had an increase in carbon stocks and others a decrease. Cumulative carbon stored in HWP in the USFS Northern Region increased in 1955, peaking in 1995 with 34 Tg (Fig. 10.3). Since then, the HWP pool has decreased to 32 Tg, illustrating how timber harvest affects HWP.

Many factors affect the sensitivity of forests to sequester carbon, and although the net effect of climate change on carbon storage in forests is uncertain, increased risk of wildfire and insect outbreaks will make it more difficult to retain carbon in biomass. Preliminary results from the Forest Carbon Management Framework (Healey et al. 2014; Raymond et al. 2015) show that fire had a major impact on carbon storage in Flathead National Forest between 1990 and 2012, followed by

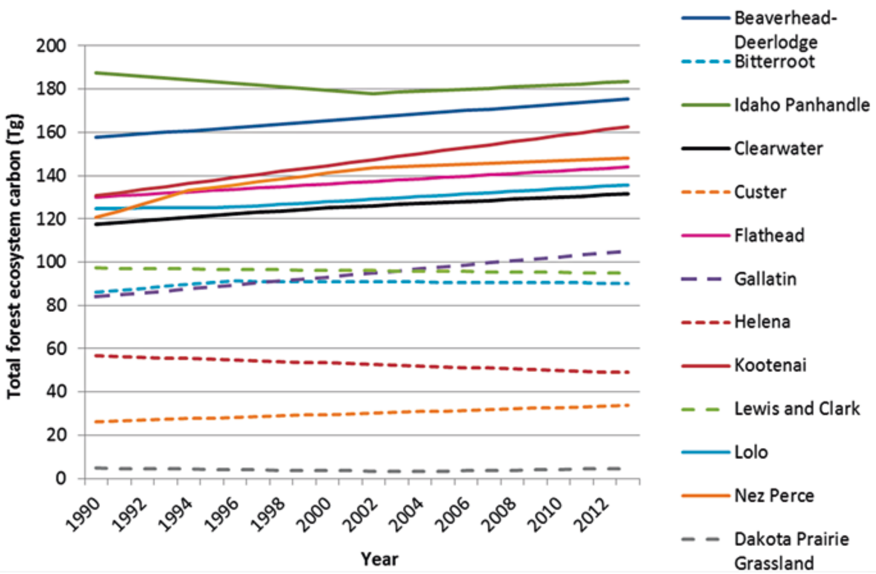


**Fig. 10.2** Total forest ecosystem carbon for national forests and grasslands in the U.S. Forest Service Northern Region, 1990–2013

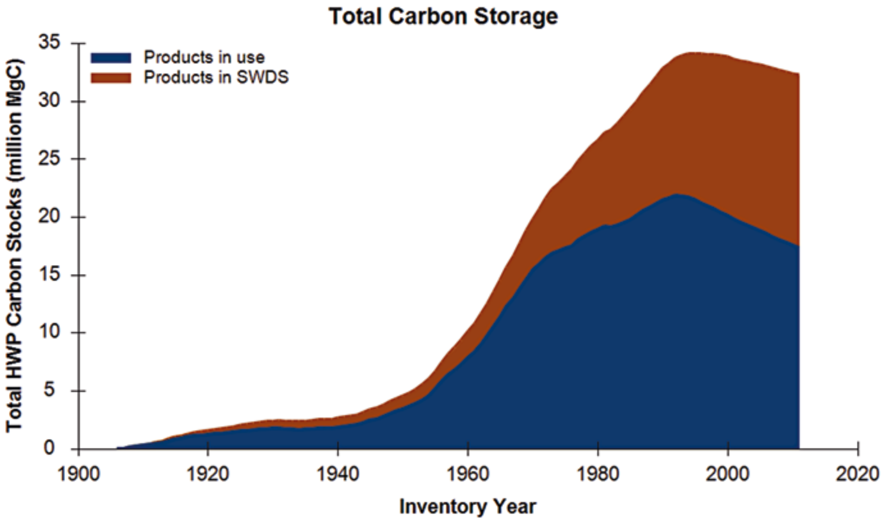


**Fig. 10.3** Cumulative total carbon stored in harvested wood products (HWP) manufactured from national forests in the U.S. Forest Service Northern Region, including carbon in products still in use and stored at solid waste disposal sites (SWDS) (Stockmann et al. 2014)

harvest. The largest impact on carbon storage in Idaho Panhandle National Forest was disease, followed by harvest.

Elevated nitrogen deposition, a phenomenon observed across much of the western United States, may increase wood production and accumulation of soil organic matter, thus increasing carbon sequestration. Carbon uptake in living biomass is often a transitory phenomenon, but carbon accumulation in soil is potentially a long-term sink because belowground carbon has longer turnover times than aboveground carbon (Bytnerowicz et al. 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 some root rots. As more trees die and decompose, forests could switch from carbon sinks to carbon sources.

Adaptive capacity for sequestering carbon depends on the spatial and temporal scales at which this ecosystem service is defined. Carbon storage in any particular forest location may go up or down over time, but analysis of storage should logically occur at very large spatial scales. Adaptive capacity for carbon storage is probably low, because most of the factors affecting carbon sequestration are external, especially wildfire and other disturbances that can override other factors, including management.

### *10.4.9 Summary*

Ecosystem services are the benefits people derive from landscapes and encompass the values that motivate people to live in the Northern Rockies. Ecosystem services are the core of our sense of place. Social (demographic changes, economics, policy) and environmental (e.g., climate change) factors, individually and interactively, can affect ecosystem services both positively and negatively. Opportunities for adaptation to climate change need to consider the broader social context to be successful and to set priorities. In summary:

- **Water yield** is not expected to change significantly, and few communities are likely to experience water shortages and water stress. The biggest effect on water yield will be timing of water availability, although this could potentially be overcome with reservoir storage. Because agriculture is the largest consumer of water and a big economic force, 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 the major source of impairment, leading to degraded riparian and aquatic habitat, increased water temperatures, and high levels of contamination. Climate change is expected to amplify these effects.
- **Wood products** provide jobs in the region. Climate change will cause more wildfires and insect outbreaks, but effects on wood products will be smaller than from economic forces and policies. Timber production has been in steady decline, a trend that will probably continue, with significant effects on economic vitality of small rural towns. Diversification of local economies can help buffer the loss of timber-related jobs.
- **Minerals and mineral extraction** are important economic drivers, and are not vulnerable to climate change. However, mineral and energy extraction are connected to other ecosystem services, particularly water quality. Wildfires, floods, and mudslides all put mineral extraction infrastructure and associated watersheds at risk.
- **Forage for livestock** may benefit from increased productivity in a warmer climate, with minor economic benefits to ranching in small communities. Most stressors on grazing are human induced, including loss of rural population, spread of nonnative plant species, and fragmentation of rangelands.
- **Viewsheds** and **air quality** will be affected by increasing wildfire frequency and length of 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 road construction can mitigate some effects.

- **Carbon sequestration** will be challenged by increasing wildfires and insect outbreaks, especially in the western part of the Northern Rockies. Managing forests for carbon sequestration is likely to become more important in response to national climate policies, but will need to be implemented in the context of other resource objectives. Thinning and fuel treatments can help reduce the magnitude of periodic carbon pulses.

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