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Jessica E. Halofsky
David L. Peterson *Editors*

Climate Change and Rocky Mountain Ecosystems

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To Milo, Noah, Christina, and the next generation.

Foreword

Although earth scientists have been studying and discussing climatic variability for decades, climate change as a household phrase spread into public consciousness only recently. Awareness erupted in response to wake-up calls such as Al Gore's film, *An Inconvenient Truth*, produced in 2006, and the first United Nations Climate Change Conference in Copenhagen in 2009. Within land-managing agencies, such as the U.S. Forest Service and National Park Service, attention spread similarly. Hunger to learn about this emergent issue cycled a demand from resource managers on the ground back to scientists. The editors of this book, *Climate Change and Rocky Mountain Ecosystems*, as well as many of the chapter authors, responded by setting out on what turned into multiyear lecture circuits to field offices around the national forests, grasslands, and parks of the country.

What the scientists learned through those visits was as important as what they taught. They brought to the field audiences basic knowledge about weather and climate, interactions of climate and disturbances such as wildfire and insect epidemics, impacts of climate change on vegetation and wildlife, and the role of human actions in changing climates. What they heard resounded around one big question: What do we do now? In other words, how should land managers translate basic scientific information into relevant and practical actions on the ground? In those early years of discussion among scientists and managers about climate, the manual for addressing this fundamental question was unwritten and the toolkit empty.

Less than a decade later and the rich content of the current volume emerges, full of details on how to implement climate-smart resource management under the range of natural and institutional conditions encountered across landscapes of the Northern Rocky Mountains. Embracing aquatic to terrestrial ecosystems, plants to animals, and cultural resources to recreation, the 12 chapters elaborate strategies and tactics that connect the dots between science and practice in this vast ecoregion. Significantly, those early sessions of the lecture-circuit years set the stage for the underlying philosophy of effective climate adaptation promoted herein: the pivotal role of science-management partnerships. Then as now, teaching and learning reveal themselves as a multi-way process, with ideas flowing weblike among resource managers of different staff areas, among scientists of different disciplines, and among scientists and managers. Novel understanding, approaches, and tools emerged as a result of these interactions. If you want to know how to operationalize climate planning and practice in the Northern Rockies, read this book.

But wait! The stories and successes explained in this volume apply widely to other bioregions and institutional settings. The framework presented here, the lessons learned, and the library of climate-adaptation practices compiled are readily propagated elsewhere. The Northern Rockies Adaptation Partnership—the basic unit for experimentation and learning here—took an all-lands approach that spanned natural and social ecosystems from the cool-mesic western Rocky Mountains to the hot-dry rangelands and prairies of the eastern part of the region. With these partners came decades of collective experience for tackling and surmounting the many real challenges of resource management, as well as for innovating and implementing creative solutions. In the end, the reward for thinking and acting in climate-smart ways will be the heightened capacity of our wildlands, watersheds, and airsheds and those who live, play, and depend on them to effectively confront the climate challenges coming at them.

U.S. Forest Service
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Connie Millar

Preface

Climate Change and Rocky Mountain Ecosystems describes the results of a cutting--edge effort to assess climate change vulnerabilities and develop adaptation options for ecosystems in the Northern Rocky Mountains region of the United States, focusing on national forests, grasslands, and parks in Northern Idaho, Montana, North Dakota, Northern South Dakota, and the Greater Yellowstone Ecosystem. Building on a framework developed in previous subregional climate change efforts, the Northern Rockies Adaptation Partnership (NRAP) was the first regional-scale, multi-resource climate change assessment in the United States. The NRAP was unprecedented in scale, scope, and breadth of the partnership, demonstrating the value of using a diverse science-management partnership and a consistent framework to assess climate change effects and identify on-the-ground adaptation options.

This book provides concise descriptions of state-of-science climate change vulnerability assessments for water, fisheries, vegetation, disturbance, wildlife, recreation, ecosystem services, and cultural resources in the Northern Rockies. Adaptation strategies and tactics, including both familiar and novel ecosystem management approaches, are described for all resource areas. Lessons learned and next steps are also described in a concluding chapter.

Chapter 1 provides an overview of ecosystems in the Northern Rockies region and outlines the NRAP vulnerability assessment and adaptation process. Chapter 2 describes historical climate and future climate projections for the Northern Rockies region and five subregions within. Chapters 3, 4, 5, 6, 7 and 8 provide detailed physical and ecological climate change vulnerability assessments for hydrology, fisheries, forest and rangeland vegetation, ecological disturbance, and wildlife. Chapters 9, 10 and 11 focus on climate change vulnerabilities for social values and resources including recreation, cultural heritage, and other ecosystem services. Far more than literature reviews, these assessments synthesize the best available science, evaluate the quality and relevance of the science for each application, and identify geographic locations where sensitivity is high. For several assessments, new climate impact model analyses were conducted. Related adaptation strategies and tactics are described in each chapter, except for disturbance and ecosystem services, for which adaptation options are integrated in other chapters. Finally, Chap. 12 describes potential applications of the vulnerability assessment and opportunities for implementing adaptation options.

We are optimistic that the vulnerability assessments and adaptation options developed through the NRAP will result in revised management approaches on the ground. Follow-up projects are already developing in the region, and information on potential climate change effects and adaptation is being integrated in national forest plan revisions, which will help national forests comply with the U.S. Forest Service 2012 Planning Rule. These projects and applications demonstrate the value of enduring relationships built during the course of the NRAP that have increased the capability of federal agencies to incorporate climate change in resource management and planning.

Only 5 years ago, climate change readiness was barely visible in the western United States. Now, organizational capacity of federal land management is accelerating as a result of science-management partnerships such as the one described here. Addressing the effects of climate change on natural resources will be one of the great challenges for society in future decades. It is our hope that this book will help improve our understanding of how humans are affecting nature and motivate timely implementation of adaptation in the years ahead.

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Chapter 1
Assessing Climate Change Effects in the Northern Rockies

S. Karen Dante-Wood, David L. Peterson, and Jessica E. Halofsky

Abstract The Northern Adaptation Partnership (NRAP) identified climate change issues relevant to resource management in the Northern Rockies (USA) region, and developed solutions that minimize negative effects of climate change and facilitate transition of diverse ecosystems to a warmer climate. The NRAP region covers 74 million hectares, spanning northern Idaho, Montana, northwest Wyoming, North Dakota, and northern South Dakota, and includes 15 national forests and 3 national parks across the U.S. Forest Service Northern Region and adjacent Greater Yellowstone Area. U.S. Forest Service scientists, resource managers, and stakeholders worked together over a two-year period to conduct a state-of-science climate change vulnerability assessment and develop adaptation options for national forests and national parks in the Northern Rockies region. The vulnerability assessment emphasized key resource areas—water, fisheries, wildlife, forest and rangeland vegetation and disturbance, recreation, cultural heritage, and ecosystem services—regarded as the most important for local ecosystems and communities. Resource managers used the assessment to develop a detailed list of ways to address climate change vulnerabilities through management actions. The large number of adaptation strategies and tactics, many of which are a component of current management practice, provide a pathway for slowing the rate of deleterious change in resource conditions.

Keywords Vulnerability assessment • Adaptation options • Northern Rockies • Climate change

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1.1 Introduction

The Northern Rocky Mountains—in this case, the portion within the United States—contain some of the most magnificent landscapes on Earth, stretching from high mountains to grasslands, from alpine glaciers to broad rivers (Fig. 1.1). Once inhabited solely by Native Americans, the region has been altered by two centuries of settlement by Euro-Americans, including extractive activities such as timber harvest, grazing, mining, and water diversions. A significant portion of the Northern Rockies is managed by federal agencies, including 15 national forests, 3 national parks, and the largest contiguous area of wilderness in the continental United States.

As "wild" as this region may seem, it is of course not immune to the effects of climate change. An increase in wildfire extent and large insect outbreaks, and their relationship to a warmer climate, have captured the attention of both natural resource managers and the general public. Federal agencies in the region have recognized that climate change will affect their ability to manage for the ecosystem services and values to which the public are accustomed. Federal leadership and resource managers in this region realize that timely adjustment of planning and management—through a "climate change lens"—will be needed to accomplish sustainable resource management in the future.

Recent focus on climate change in the Northern Rockies builds on prior assessment, and adaptation efforts in the western United States have demonstrated the value of science-management partnerships for increasing climate change awareness and facilitating adaptation on federal lands:

- Olympic National Forest and Olympic National Park (Washington) produced the first multi-resource assessment of climate change effects on federal lands, as well as adaptation options that are now being implemented (Halofsky et al. 2011; Littell et al. 2012).
- Tahoe National Forest, Inyo National Forest, and Devils Postpile National Monument held workshops and developed the Climate Project Screening Tool in order to incorporate adaptation into project planning (Morelli et al. 2012).
- Shoshone National Forest (Wyoming) synthesized information on past climate, future climate projections, and potential effects of climate change for multiple ecosystems (Rice et al. 2012).
- The North Cascadia Adaptation Partnership assessed resource vulnerabilities and developed adaptation options for two national forests and two national parks in Washington (Raymond et al. 2013, 2014).

In the largest effort to date in the eastern United States, Chequamegon-Nicolet National Forest (Wisconsin) conducted a vulnerability assessment for forest resources and developed adaptation options (Swanston et al. 2011; Swanston and Janowiak 2012). Finally, watershed vulnerability assessments, conducted on 11 national forests throughout the United States, were locally focused (at a national forest scale) and included water resource values, hydrologic response to climate change, watershed condition and landscape sensitivity (Furniss et al. 2013).

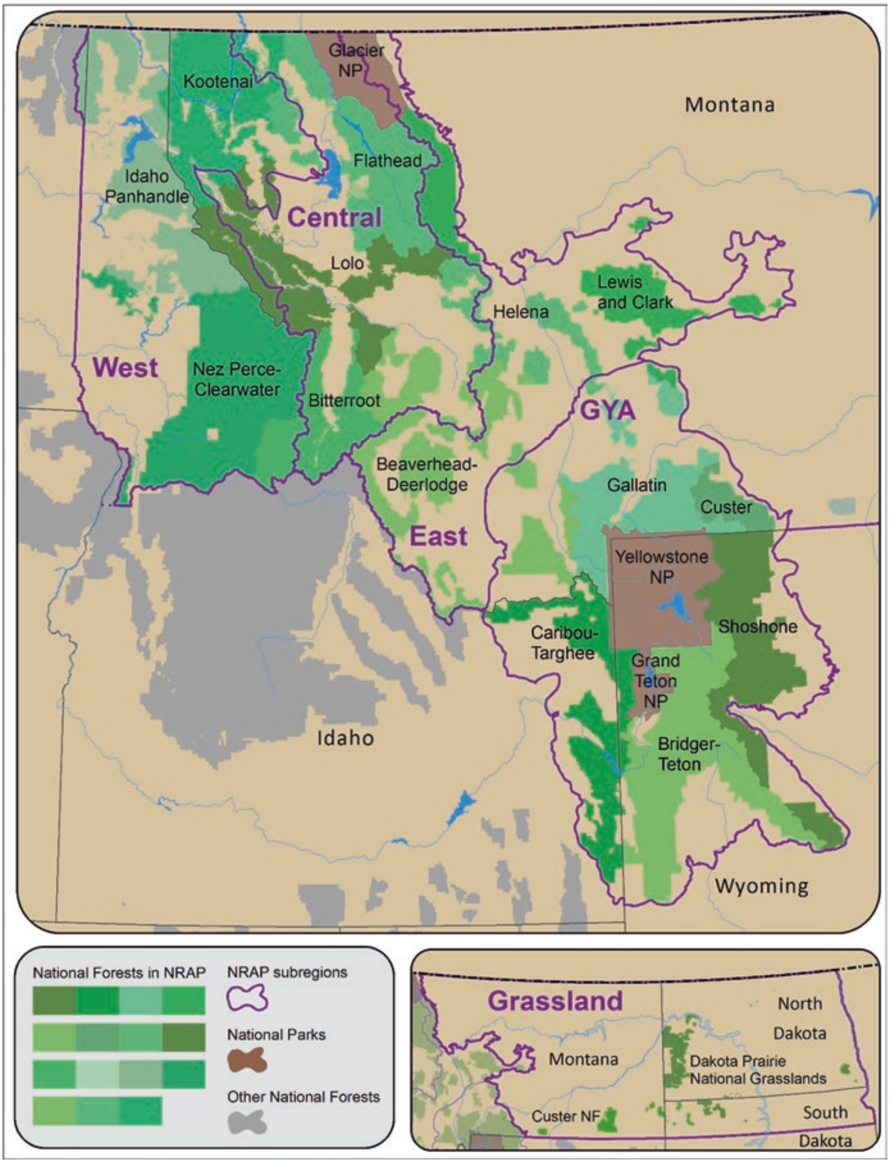

Fig. 1.1 National forests and national parks included in the climate change assessment for the Northern Rockies Adaptation Partnership (NRAP) (Map by R. Norheim)

A conceptual framework and process for conducting assessments and developing adaptation options on national forests have been well documented (Peterson et al. 2011; Swanston and Janowiak 2012). Five key steps guide this process:

1. Educate: Ensure that resource managers are aware of basic climate change science, integrating that understanding with knowledge of local conditions and issues.
2. Assess: Evaluate the sensitivity and adaptive capacity of natural and cultural resources to climate change.
3. Adapt: Develop management options for adapting resources and organizations to climate change.
4. Implement: Incorporate adaptation options and climate-smart thinking into planning and management.
5. Monitor: Evaluate the effectiveness of on-the-ground management and adjust as needed.

1.2 Northern Rockies Adaptation Partnership Process

The Northern Rockies Adaptation Partnership (NRAP) was created to address the potential effects of climate change in the context of ongoing ecosystem-based management and ecological restoration. Restoration is a priority in national forests, especially related to hazardous fuel reduction in dry forests (stand density reduction plus surface fuel removal), and restoration of riparian areas to improve hydrological and biological function. Restoration must be integrated with climate change assessment and adaptation to ensure long-term sustainability of ecosystems.

Initiated in 2013, the NRAP is a science-management partnership that includes U.S. Forest Service (USFS) regional offices and national forests; USFS Pacific Northwest and Rocky Mountain Research Stations; Glacier, Yellowstone, and Grand Teton National Parks; Great Northern and Plains and Prairie Potholes Landscape Conservation Cooperatives; Department of the Interior North Central Climate Science Center; Greater Yellowstone Coordinating Committee; Oregon State University; and EcoAdapt. By working collaboratively with scientists and resource managers and focusing on a specific region, the goal of NRAP was to provide the scientific foundation for operationalizing climate change in planning, ecological restoration, and project management in the Northern Rockies (Peterson et al. 2011; Swanston and Janowiak 2012; Raymond et al. 2013, 2014). Specific objectives were:

- Conduct a vulnerability assessment of the effects of climate change on hydrology, fisheries, wildlife, forested and non-forested vegetation and disturbance, recreation, cultural resources, and ecosystem services.
- Develop adaptation options that help reduce negative effects of climate change and assist the transition of biological systems and management to a changing climate.
- Develop an enduring science-management partnership to facilitate ongoing dialogue and activities related to climate change in the Northern Rockies.

Vulnerability assessments typically involve assessing exposure, sensitivity, and adaptive capacity (IPCC 2007), where exposure is the degree to which the system is exposed to changes in climate, sensitivity is an inherent quality of the system that indicates the degree to which it could be affected by climate change, and adaptive capacity is the ability of a system to respond and adjust to the exogenous influence of climate. Vulnerability assessments can be both qualitative and quantitative, focusing on whole systems or individual species or resources (Glick et al. 2011; Hansen et al. 2016). For the NRAP, we used scientific literature and expert knowledge to assess exposure, sensitivity, and adaptive capacity relative to key vulnerabilities in each resource area. The assessment process took place over 16 months, including monthly phone meetings for each of the resource-specific assessment teams. Each assessment team identified key questions, selected values to assess, and determined which climate change models best informed the assessment. In some cases, assessment teams conducted spatial analyses and/or ran and interpreted models, selected criteria in which to evaluate model outputs, and developed maps of model output and resource sensitivities.

After identifying key vulnerabilities for each resource sector, workshops were convened in October and November 2014 in Bismarck, North Dakota; Bozeman, Montana; Coeur d'Alene, Idaho; Helena, Montana; and Missoula, Montana to present and discuss the vulnerability assessment, and to elicit adaptation options from resource managers. During these workshops, scientists and resource specialists presented information on climate change effects and current management practices for each resource area. Information from the region-wide assessment was also downscaled to identify the most significant vulnerabilities to climate change for priority resources in each subregion. Facilitated dialogue was used to identify key sensitivities and adaptation options. Participants identified strategies (general approaches) and tactics (on-the-ground actions) for adapting resources and management practices to climate change, as well as opportunities and barriers for implementing these adaptation actions into projects, management plans, partnerships and policies. Participants focused on adaptation options that can be implemented given our current scientific understanding of climate change effects, but they also identified research and monitoring that would benefit future efforts to assess vulnerability and guide management. Facilitators captured information generated during the workshops with a set of spreadsheets adapted from Swanston and Janowiak (2012). Initial results from the workshops were augmented with continued dialogue with federal agency resource specialists. Detailed vulnerability assessment and adaptation results are described in a technical report (Halofsky et al. 2017).

1.3 Toward Implementation of Climate-Smart Management

The NRAP vulnerability assessment provides information on climate change effects needed for national forest and national park plans, project plans, conservation strategies, restoration, and environmental effects analysis. Climate change sensitivities and adaptation options developed at the regional scale provide the scientific foundation for subregional and national forest and national park vulnerability assessments, adaptation planning, and resource monitoring. We expect that over time, and as needs and funding align, appropriate adaptation options will be incorporated into plans and programs of federal management units. We also anticipate that resource specialists will apply this assessment in land management throughout the region, thus operationalizing climate-smart resource management and planning.

Adaptation planning is an ongoing and iterative process. Implementation may occur at critical times in the planning process, such as when managers revise USFS land management plans and other planning documents, or after the occurrence of extreme events and ecological disturbances (e.g., wildfire). We focus on adaptation options for the USFS and National Park Service (NPS), but this information can be used by other land management agencies as well. Furthermore, the approach used here can be emulated by agencies and organizations outside the Northern Rockies, thus propagating climate-smart management across larger areas.

The USFS and NPS climate change strategies identify the need to build partnerships and work across jurisdictional boundaries when planning for adaptation, that is, an "all-lands" approach. The NRAP is an inclusive partnership of multiple agencies and organizations with an interest in managing natural resources in a changing climate. In addition to representatives from the national forests, grasslands, and parks, several other agencies and organizations participated in the resource sector workshops. This type of partnership enables a coordinated and complementary approach to adaptation that crosses jurisdictional boundaries (Olliff and Hansen 2016). Communicating climate change information and engaging employees, partners, and the general public in productive discussions is also an integral part of successfully responding to climate change. Sharing climate change vulnerability assessments and adaptation strategies across administrative boundaries will contribute to the success of climate change responses throughout the Northern Rockies.

1.4 A Brief Tour of the Northern Rockies

The NRAP includes 15 national forests, 3.2 million hectares of wilderness, and 3 national parks across the USFS Northern Region and the adjacent Greater Yellowstone Area. The NRAP region covers 74 million hectares (Fig. 1.1), spanning northern Idaho, Montana, northwest Wyoming, North Dakota, and northern South Dakota. In order to capture the diversity of biogeography in this reagion, the NRAP climate change vulnerability assessment and adaptation strategy development process were conducted for five subregions:

- **Western Rockies:** Idaho Panhandle National Forest (NF), Kootenai NF, Nez Perce-Clearwater NF, Glacier National Park (NP)
- **Eastern Rockies:** Beaverhead-Deerlodge NF (eastern portion), Custer NF (eastern portion), Gallatin NF (northern portion), Helena NF, Lewis and Clark NF
- **Central Montana:** Bitterroot NF, Flathead NF, Lolo NF
- **Grassland:** Custer NF (part), Dakota Prairie Grasslands

- **Greater Yellowstone Area:** Bridger-Teton NF, Caribou-Targhee NF, Shoshone NF, Gallatin NF (southern portion), Custer NF (western portion), Beaverhead-Deerlodge NF (western portion), Grand Teton NP, Yellowstone NP

1.4.1 Western Rockies Subregion

The Western Rockies subregion, which occupies 7 million hectares, is extremely mountainous and heavily forested. It contains numerous large rivers, including the Salmon River which winds 680 km through central Idaho and provides habitat for Pacific salmon species. Other major rivers include the Clearwater, Kootenai, Pend Oreille, and Clark Fork of the Columbia (Fig. 1.2). Climate in this region is affected by a maritime atmospheric pattern; summers are hot and dry, and winters are relatively cold due to the high amount of moisture carried through the Columbia River Gorge.

Commercially harvested coniferous species in this area include Douglas-fir (*Pseudotsuga menziesii*), Engelmann spruce (*Picea engelmannii*), grand fir (*Abies grandis*), lodgepole pine (*Pinus contorta* var. *latifolia*), ponderosa pine (*P. ponderosa*), subalpine fir (*A. lasiocarpa*), western hemlock (*Tsuga heterophylla*), western larch (*Larix occidentalis*), western redcedar (*Thuja plicata*), and western white pine (*P. monticola*). Other species not used for wood products include whitebark pine (*P. albicaulis*), limber pine (*P. flexilis*), alpine larch (*Larix lyallii*), mountain hemlock (*Tsuga mertensiana*), and western juniper (*Juniperus occidentalis*). Quaking aspen (*Populus tremuloides*), black cottonwood (*P. nigra*) and paper birch (*Betula papyrifera*) are also commonly found. Common shrub species include serviceberry

Fig. 1.2 The Western Rockies subregion is characterized by complex mountainous topography with mixed conifer forests and streams (Photo by U.S. Forest Service)

(*Amelanchier alnifolia*), redosier dogwood (*Cornus sericea*), oceanspray (*Holodiscus discolor*), Lewis mockorange (*Philadelphus lewisii*), huckleberries (*Vaccinium* spp.) and smooth sumac (*Rhus glabra*) (Sullivan et al. 1986).

The Western Rockies provide habitat for over 300 animal species, including iconic mammals such as black bear (*Ursus americanus*), grizzly bear (*U. arctos*), elk (*Cervus elaphus*), moose (*Alces alces*), and gray wolf (*Canis lupus*). Avian taxa include bald eagle (*Haliaeetus leucocephalus*), golden eagle (*Aquila chrysaetos*), osprey (*Pandion haliaetus*), many species of owls, wild turkey (*Meleagris gallopavo*), California quail (*Callipepla californica*), and greater sage-grouse (*Centrocercus urophasianus)*. Fish species include native cutthroat trout (*Oncorhynchus clarkii*), rainbow trout (*O. mykiss*), and bull trout (*Salvelinus confluentus*), and nonnative brook trout (*S. fontinalis*). The Kootenai River is home to the endangered white sturgeon (*Acipenser transmontanus*) and threatened burbot (*Lota lota*).

Wildfire is a dominant influence on the structure, function, and productivity of forest ecosystems in the Western Rockies, with stand replacement fires occurring at 50–500 year intervals, and surface fires occurring in dry forests at 2–50 year intervals. Frequent fires keep many forests in the early stages of succession as indicated by high numbers of western larch and pine (Schnepf and Davis 2013), although fire exclusion during the past 80 years has reduced fire frequency in lower-elevation dry forests, resulting in dense stands and elevated accumulation of surface fuels.

Mountain pine beetles (*Dendroctonus ponderosae*) kill large numbers of lodgepole pine, often in outbreaks of thousands of hectares, and they increasingly kill whitebark pine and limber pine (*P. flexilis*) at high elevation as the climate continues to warm. White pine blister rust (*Cronartium ribicola*), a nonnative fungus, causes mortality in five-needle pines (western white pine, whitebark pine, limber pine), and has greatly reduced the dominance of western white pine (Schwandt et al. 2013). Forests dominated by Douglas-fir and grand fir have increased as a result, accelerating forest succession toward shade tolerant, late-successional true firs, western hemlock, and western redcedar (Bollenbacher et al. 2014).

1.4.2 Central Rockies Subregion

The Central Rockies subregion, which occupies 5 million hectares, contains steep mountains, rolling meadows, large rivers, and lakes, and alpine ecosystems throughout its mountain ranges (Fig. 1.3). It also contains the largest contiguous area of designated wilderness in the United States outside of Alaska. The Bitterroot and Missoula Valleys located in west-central Montana experience an inland mountain climate. Air masses that develop over the Pacific Ocean release moisture in the Cascade Range and over the mountains of northern Idaho. West-central Montana occupies the rain-shadow area, receiving dried-out Pacific air and little moisture in the valley bottoms (Lackschewitz 1991). Climate in the Flathead and Glacier region is similar, influenced by the Pacific Maritime atmospheric pattern with warm, dry summers and wet, cold winters.

Fig. 1.3 The Central Rockies subregion is characterized by glacially carved topography, dense coniferous forest, and lakes in high mountain landscapes (Photo by U.S. Forest Service)

Microclimate has a big effect on the distribution and productivity of vegetation. Forests in the Bitterroot and Missoula valleys are drier than those in Idaho and northwestern Montana. Species found here include western redcedar, western white pine, Pacific yew (*Taxus brevifolia*), bride's bonnet (*Clintonia uniflora*), American trail plant (*Adenocaulon bicolor*), and threeleaf foamflower (*Tiarella trifoliata*). Intermountain forest species dominate the west-central Montana landscape, including western larch, alpine larch (*Larix lyallii*), ponderosa pine, mock azalea (*Menziesia ferruginea*), and common beargrass (*Xerophyllum tenax*). Bottomland ponderosa pine and hardwood species are found in moist sites, whereas different types of bunchgrass species (*Agropyron, Festuca*) and a mixture of ponderosa pine and bunchgrasses are found in dry sites. Douglas-fir, grand fir, and subalpine fir dominate at higher elevation (Lackschewitz 1991). In the Flathead Valley and Glacier National Park, lower elevations are dominated by Douglas-fir, ponderosa pine, grand fir, Engelmann spruce, and western redcedar. Douglas-fir, western larch and subalpine fir are common at mid elevation, and whitebark pine is found at high elevation (Newlon and Burns 2009). Black cottonwood and quaking aspen are common deciduous trees at lower elevations.

The Central Rockies contain over 60 species of mammals, with wilderness locations having relatively intact populations, including gray wolf, Canada lynx (*Lynx canadensis*), mountain lion (*Felis concolor*), mountain goat (*Oreamnos americanus*), bighorn sheep (*Ovis canadensis*), and grizzly bear. Hundreds of bird species are found in the Central Rockies, including killdeer (*Charadrius vociferus*) and spotted sandpiper (*Actitis macularius*) in riparian areas, song sparrows (*Melospiza melodia*) in grassland, and willow flycatcher (*Empidonax traillii*) and MacGillivray's warbler (*Geothlypis tolmiei*) in shrubby habitat. Rivers contain populations of native bull trout, westslope cutthroat trout (*Oncorhynchus clarki lewisi*), northern pike minnow (*Ptychocheilus oregonensis*), and largescale sucker (*Catostomus macrocheilus*).