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Climate Change Vulnerability and Adaptation in South-Central Oregon

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Cover photos: (clockwise from upper left) Sparks Lake and South Sister Mountain, Oregon; ponderosa pine (*Pinus ponderosa*); Broken Top Mountain, Oregon; Crooked River, Ochoco National Forest, Oregon.

Climate Change Vulnerability and Adaptation in South-Central Oregon

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Abstract

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The South-Central Oregon Adaptation Partnership (SCOAP) was developed to identify climate change issues relevant for resource management on federal lands in south-central Oregon (Deschutes National Forest, Fremont-Winema National Forest, Ochoco National Forest, Crooked River National Grassland, Crater Lake National Park). This science-management partnership assessed the vulnerability of natural resources to climate change and developed adaptation options that minimize negative impacts of climate change and facilitate transition of diverse ecosystems to a warmer climate. The vulnerability assessment focused on water resources and infrastructure, fisheries and aquatic organisms, vegetation, wildlife, recreation, and ecosystem services.

The vulnerability assessment shows that the effects of climate change on hydrology in south-central Oregon will be highly significant. Decreased snowpack and earlier snowmelt will shift the timing and magnitude of streamflow; peak flows will be higher, and summer low flows will be lower. Projected changes in climate and hydrology will have far-reaching effects on aquatic and terrestrial ecosystems, especially as frequency of extreme climate events (drought, low snowpack) and ecological disturbances (flooding, wildfire, insect outbreaks) increase.

Distribution and abundance of cold-water fish species are expected to decrease in response to higher water temperature, although effects will vary as a function of local habitat and competition with nonnative fish. Higher air temperature, through its influence on soil moisture, is expected to cause gradual changes in the distribution and abundance of plant species, with drought-tolerant species becoming more dominant. Increased frequency and extent of wildfire and insect outbreaks will be the primary facilitator of vegetation change, in some cases leading to altered structure and function of ecosystems (e.g., more forest area in younger age classes). Vegetation change will alter wildlife habitat, with both positive and negative effects depending on animal species and ecosystem. Animal species with a narrow range of preferred habitats (e.g., sagebrush, riparian, old forest) will be the most vulnerable to large-scale species shifts and more disturbance.

The effects of climate change on recreation activities are more difficult to project, although warmer temperatures are expected to create more opportunities for warm-weather activities (e.g., hiking, camping) and fewer opportunities for

snow-based activities (e.g., skiing, snowmobiling). Recreationists modify their activities according to current conditions, but recreation management by federal agencies has generally not been so flexible. Of the ecosystem services considered in the assessment, timber supply and carbon sequestration may be affected by increasing frequency and extent of disturbances, and native pollinators may be affected by altered vegetation distribution and phenological mismatches between insects and plants.

Resource managers in the SCOAP developed adaptation options in response to the vulnerabilities of each resource, including high-level strategies and on-the-ground tactics. Many adaptation options are intended to increase the resilience of aquatic and terrestrial ecosystems, or to reduce the effects of existing stressors (e.g., removal of nonnative species). In terrestrial systems, a dominant theme of adaptation in south-central Oregon is to accelerate restoration and fuel treatments in dry forests to reduce the undesirable effects of extreme events and high-severity disturbances (wildfire, insects). In aquatic systems, a dominant theme is to restore the structure and function of streams to retain cold water for fish and other aquatic organisms. Many adaptation options can accomplish multiple outcomes; for example, fuel treatments in dry forests reduce fire intensity, which in turn reduces erosion that would degrade water quality and fish habitat. Many existing management practices are already "climate smart" or require minor adjustment to make them so. Long-term monitoring is needed to detect climate change effects on natural resources, and evaluate the effectiveness of adaptation options.

Keywords: Adaptation, aquatic ecosystems, climate change, ecosystem services, fire, fish, forest ecosystems, hydrology, infrastructure, recreation, roads, science-management partnership, south-central Oregon, terrestrial ecosystems, vegetation, wildlife.

Summary

The South-Central Oregon Adaptation Partnership (SCOAP) is a science-management partnership consisting of the Deschutes, Fremont-Winema, and Ochoco National Forests; Crooked River National Grassland; Crater Lake National Park; U.S. Forest Service Pacific Northwest Research Station, Rocky Mountain Research Station, and Pacific Northwest Region; and the University of Washington. These organizations worked together for more than 2 years to identify climate change issues relevant to resource management in south-central Oregon and to find solutions that can minimize the undesirable effects of climate change and facilitate the transition of diverse ecosystems to a warmer climate. The SCOAP provided education, conducted a climate change vulnerability assessment, and developed adaptation options for federal agencies that manage more than 2 million ha in the assessment area.

Mean annual temperature in south-central Oregon has increased by 0.05 °C per decade since 1895, while annual precipitation has not changed. Global climate models for a high-end greenhouse gas emission scenario (RCP 8.5, comparable to current emissions) project that warming will continue throughout the 21st century. Compared to observed historical temperatures, average warming is projected to increase from 1.3 to 4.0 °C by 2050, and from 2.7 to 4.8 °C by 2080. Precipitation may increase slightly in the winter, although the magnitude is uncertain.

The effects of climate change on hydrology will be highly significant. Decreased snowpack and earlier snowmelt will shift the timing and magnitude of streamflow: peak flows will be higher and summer low flows will be lower. Snowpack in the Oregon Cascade Range will be especially sensitive, and snow residence time is expected to decrease by 7 to 8 weeks, with minimal snow remaining by April 1 at many sites. The largest reductions in summer streamflows are projected for the eastern slopes of the Cascade Range, where earlier snowmelt timing will potentially result in summer streamflow losses of 40 to 60 percent by 2040 and 60 to 80 percent by 2080.

Projected changes in climate and hydrology will have far-reaching effects on aquatic and terrestrial ecosystems, especially as frequency of extreme climate events (drought, low snowpack) and associated effects on ecological disturbance (flooding, wildfire, insect outbreaks) increase. Vulnerability assessment and adaptation development for the SCOAP assessment area conclude the following:

Water Resources and Infrastructure

- **Effects**: Decreasing snowpack and declining summer streamflows will alter timing and availability of water supply, affecting municipal and public uses downstream from public lands, as well as wildlife, recreation, firefighting, road maintenance, instream fishery flows, and livestock grazing. Lower low flows will affect water availability during late summer, the period of peak demand (e.g., for irrigation and power supply). Increased magnitude of peak streamflows in winter will potentially damage roads near perennial streams, ranging from minor erosion to complete loss of the road, thus affecting public safety, access for recreation and resource management, water quality, and aquatic habitat. Bridges, campgrounds, and facilities near streams and floodplains will be especially vulnerable, reducing access by the public.
- **Adaptation options**: Primary adaptation strategies for water use include improving water conservation, aligning water availability with demand, diversifying water sources, and reducing user expectations for water availability. Fuel treatments in low-elevation coniferous forest reduce the risk of high-severity fire and associated effects on soils, erosion, and water quality. Restoration techniques that maintain or modify biophysical properties of hydrological systems can increase climate change resilience. Reintroducing populations of American beaver helps to slow water movement and increase water storage. Primary adaptation strategies for infrastructure include increasing resilience of roads to floods, protecting roads and structures from landslides, reducing activities that increase landslides, increasing resilience of stream conditions to low flows at stream crossings, and increasing the resilience of recreation facilities and other developed sites. Tactics include increasing the size of drainage structures, reducing hydrologic connectivity of roads to the stream system, and decommissioning or rerouting vulnerable roads.

Fisheries and Aquatic Habitat

- **Effects**: Decreased summer streamflows and warmer water temperature will reduce habitat quality for coldwater fish species, especially at lower elevations. Based on projections of stream temperature in a warmer climate, optimal stream habitat for redband trout, which currently have limited distribution and abundance, will decrease from 67 percent (current) to 40 percent (2080). Steelhead trout streams within the optimal range will decrease from 58 percent (current) to 31 percent (2080). Bull trout, which require very cold water, live in fragmented habitats, and have small populations, are expected to have their optimal habitat decrease 31 percent by the 2040s and 52 percent by the 2080s. Nearly 80 percent of current stream habitats used by Lost River and shortnose suckers will have summer temperatures higher than 20 °C by 2080; these species will also be affected by low summer flows and declining water quality. Increased summer water temperatures and decreased summer flows are also expected to alter macroinvertebrate and mollusk populations in streams, lakes, and wetlands.

- **Adaptation options**: Primary adaptation strategies for fisheries and aquatic habitat focus on storing more water on the landscape, increasing resilience to disturbance, maintaining and restoring riparian and wetland vegetation complexity, and maintaining and restoring natural thermal conditions in streams. Specifically, managers can protect springs, increase shallow groundwater storage, increase soil water storage by maintaining or restoring riparian vegetation, and encourage beaver populations. Minimizing the impacts of roads and grazing may help offset increases in sediment yield, and increasing water conservation can help maintain summer flows. Implementing fuel treatments across the landscape may help reduce fire severity, in turn reducing erosion that degrades aquatic systems. Adaptation tactics will be most efficient if they are coordinated with existing stream management and restoration efforts conducted by the Forest Service, other agencies, and private landowners.

Vegetation—

- **Effects**: Higher air temperature, through its influence on soil moisture, is expected to cause gradual changes in the abundance and distribution of tree and shrub species, with drought-tolerant species being more competitive. Ecological disturbance, including wildfire and insect outbreaks, will be the primary facilitator of vegetation change, and future forest landscapes may be dominated by younger age classes and smaller trees. Riparian and groundwater-dependent ecosystems (GDEs), which are interspersed in all vegetation types, will be especially vulnerable to higher air temperature, reduced snowpack, and altered hydrology.

Subalpine forest—Lower snowpack may lead to increased growth and productivity in the short term, but competitors from lower elevations are expected to move into some subalpine habitats. Tree seedling establishment may be a challenge for some species in a warmer climate. Increased frequency and extent of wildfire and insects would have a significant negative effect on most species, especially whitebark pine.

Moist forest—Higher temperature may increase growth in some locations, although drought stress could limit expansion of moist forest and favor species that tolerate low soil moisture. Most species are long lived, so changes may not be realized for many decades or even centuries. Increased wildfire and insects may lead to a more fragmented landscape of moist forest in younger age classes.

Mesic forest—Higher temperature may increase growth in some locations, especially if precipitation increases, although drought stress could limit expansion of mesic forest and favor species that tolerate low soil moisture. Pumice soils could limit expansion in some areas. Severe wildfires are possible in areas with high fuel loading.

Dry forest—These forests are less sensitive to warming than other forest types, and may be able to expand into more suitable habitat (e.g., higher elevation). Establishment and growth will be affected by water availability, and compounding stresses could lead to widespread mortality in the current range of dry forests. Increased frequency and extent of wildfire will tend to favor dominant species in these forests except where fuel loads are high.

Woodland—This vegetation type is limited by precipitation and soil moisture, but facilitated by grazing and fire suppression. Higher temperature may increase mortality in some woodlands, although expansion of juniper may continue. Frequent wildfire and nonnative annual grasses are stressors and may combine to reduce the distribution and abundance of woodlands.

Shrubland and grassland—Continued loss of snowpack may accelerate the loss of some shrublands, especially big sagebrush, which could be replaced by more drought-tolerant species in some locations. Land use conversion, grazing, and nonnative species will compound the effects of climate change on shrubland and grassland. Increased frequency and extent of wildfire would reduce the distribution of sagebrush and some other shrub species.

- **Adaptation options**: Minimizing the incidence of high-severity, stand-replacing disturbance events will help increase the resilience of most forests. Reducing stand density with thinning in dry forests can decrease forest drought stress and increase tree growth and vigor by reducing competition. Expanding fuel treatments in appropriate locations may help prevent stand-replacement fires over large areas. Favoring species and genotypes more tolerant of drought and defoliating insects may also help increase survival following disturbances. Adaptation strategies for rangelands include rapid removal or control of nonnative plants, and collaboration among landowners to effectively control nonnatives. Mechanical treatments, and in some cases prescribed fire, can be used to control expansion of juniper in some locations. Promoting early-season native species, implementation of appropriate postfire actions (e.g., effective seed mixtures), and development of flexible grazing management plans will improve resilience of shrubland and grassland. To minimize negative effects of climate change on riparian areas and GDEs, managers can plan for more frequent flooding, increase upland water storage, and manage water to maintain springs and wetlands.

Wildlife—

- **Effects**: Ecosystem responses to climate change are expected to affect wildlife through changes in food availability, competition, predator-prey dynamics, and availability of key habitat features, such as nesting or resting structures and ephemeral water sources. Despite the flexibility and adaptive capacity of many species, widespread shifts in animal ranges and local extirpation of some species may result from climate change in combination with other stressors. Potential effects of climate change on different focal habitats include the following:

Low-elevation grass/shrub/woodland—Most plant and animal species are adapted to dry conditions, but extreme temperature may exceed physiological thresholds, water may be more limiting, and increased wildfire will alter vegetation structure (especially shrubs). Greater sage-grouse and other sagebrush-obligate species will be sensitive.

Open, large ponderosa pine—Although big trees are resilient to disturbance and dry soils, high-severity fire and long-term drought may convert some areas to grass and shrubs, thus greatly altering habitat. Some woodpecker and owl species will be sensitive.

Wetlands/riparian/open water—These habitats are sensitive to altered hydrology, and extreme flooding events can damage habitat structure for amphibians.

Cold moving water—Distribution of this habitat will decrease as water temperatures increase and summer flows decrease, resulting in loss of riparian vegetation. Amphibians, American dippers, and water shrews will be sensitive.

Mid-elevation old forest—Fuel loadings are often high in this habitat, and increased frequency and extent of high-intensity wildfire would alter forest structure and spatial heterogeneity. Fishers, northern goshawks, northern spotted owls, northern flying squirrels, and olive-sided flycatchers will be sensitive.

Mid-elevation early seral—The lower-elevation portion of this habitat is expected to have increased drought stress, potentially transitioning to grass-shrub following disturbance. Pocket gophers and several bird species will be sensitive.

High-elevation cold forest—Lower elevations may transition to mid-elevation mixed conifer, high-intensity wildfire could reduce structural diversity, and drought stress could reduce resistance to insect outbreaks. Great gray owls, varied thrushes, Vaux's swifts, and American martens will be sensitive.

High-elevation woodlands—Increased drought, white pine blister rust, and mountain pine beetles are expected to increase whitebark pine mortality. Clark's nutcrackers, Townsend's solitaires, and ermine will be sensitive.

Alpine meadow/barren—Increased summer temperature and drought may alter the distribution and abundance of some herbaceous species, and tree encroachment will reduce meadow extent. American pikas, yellow-bellied marmots, and gray-crowned rosy finches will be sensitive.

- **Adaptation options**: Primary adaptation strategies include: (1) reducing repeat disturbances that can result in a habitat type conversion; (2) providing thermal refugia and opportunities for wildlife movement; (3) increasing resilience of late-successional habitat and structure (shrub and forest); (4) maintaining spatial patterns that are resilient to disturbance, providing habitat diversity, and maintaining landscape permeability; (5) identifying, retaining, and restoring riparian and wetland habitat; and (6) developing mitigation strategies to compensate for loss of snowpack location and duration.

In **low-elevation shrub-steppe**, control of nonnative species will be critical, as will management of other stressors (e.g., motorized recreation, grazing).

In **open large-tree ponderosa pine forest**, thinning and prescribed fire can be used to facilitate transition from mixed conifer to open pine structure in appropriate settings, thus reducing the likelihood of high-intensity wildfire. Diverse understory plants are an important component of this habitat type, and control of nonnative plants can maintain diversity.

In **wetland, riparian, and open-water habitat**, reducing stressors will help increase resilience (e.g., limiting impacts from road construction and recreation sites). Relocating roads and recreation developments away from floodplains would also reduce impacts. Promoting connectivity along stream networks can assist animal movement, and beaver colonization can increase water retention.

In **mid-elevation, old, structurally complex forest**, restoration of sustainable landscape patterns may require a combination of mechanical treatments, prescribed fire, and opportunistic use of wildfire under appropriate conditions. It will be important to develop strategies that balance reduction of disturbance risk with conservation of old forests under intensifying disturbance regimes.

In **mid-elevation, early-seral habitat**, planting tree species that will be vigorous in a warmer climate, recruiting and retaining biological legacies, and ensuring habitat connectivity will increase resilience for multiple animal species.

In **high-elevation habitats** (cold forests, woodlands, whitebark pine, meadows), prescribed fire and wildfire can be used in appropriate settings to reduce the risk of large-scale, high-intensity fire moving from adjacent lower elevation locations. Protecting climate and disturbance refugia can also help maintain habitats.

Recreation—

- **Effects**: Summer recreation (hiking, camping, bicycling) will benefit from a longer period of suitable weather without snow, especially during the spring and autumn shoulder seasons. Snow-based recreation (downhill skiing, cross-country skiing, snowmobiling) will be negatively affected by a warmer climate because of less and more transient snow. Ski areas and other facilities at lower elevations will be especially vulnerable. Hunting may be sensitive to temperature and timing and amount of snow during the designated hunting season. Fishing will be sensitive to streamflows and stream temperatures associated with target species; if summer flows are very low, some streams may be closed to fishing. Water-based recreation (swimming, boating, rafting) will be sensitive to lower water levels during drought years. Gathering forest products for personal and commercial use (e.g., huckleberries, mushrooms) will be somewhat sensitive to the climatic conditions that support the distribution and abundance of items being collected.
- **Adaptation options**: Capacity of recreation sites may need to be adjusted to meet increased demand in shoulder and summer seasons (e.g., bigger campgrounds). Increased demand for water-based recreation can be accommodated by managing lake and river access capacity and managing public expectations for site availability. Recreation management will need to transition to shorter winter recreation seasons and changing use patterns. The Sno-Park system could be based on snow levels, and some management units may want to divest in low-elevation Sno-Parks and ski areas that are unlikely to have consistent snow in the future. Engineering transportation systems for wet weather movement (e.g., graveled trails) will ensure access

and protect roads and trails. Managing for increased use in the shoulder seasons will be critical, including adjusting openings and closings for roads, trails, and campgrounds. A sustainable recreation plan would help managers strategically invest and divest in sites based on changing use patterns and ecological carrying capacity.

Ecosystem services—

- **Effects**: Higher temperature and increased frequency and extent of disturbances will alter forest structure and growth, thus affecting both timber supply and carbon sequestration. Mortality associated with drought and multiple stressors may also increase in drier locations. Livestock foraging will likely be affected by altered plant species composition and productivity, especially if nonnative annual grasses spread as expected. Livestock access to water sources and grazing effects on riparian areas may become more prominent issues as water becomes scarcer. Minerals and geological resources are unlikely to be affected by increased temperatures. The ability of forests to sequester carbon will likely decrease if warmer climate increases physiological stress in trees and increases the frequency and extent of disturbances. A warmer climate may also affect the physiology and behavior of some insect pollinators, possibly creating a phenological mismatch in timing of flowering and pollinator emergence. Some pollinators may shift their range to find new food sources, depending on habitat connectivity. Climate change may also affect biophysical structures, processes, and functions related to cultural resources, including first foods (e.g., huckleberries, salmon) valued by Americans Indians and others.

Adaptation options: The primary adaptation strategy for timber is to create resilience in forest ecosystems by thinning to reduce competition and fuel ladders, and removing surface fuels to prevent high-intensity wildfires. Long-term stability of carbon sequestration can be maintained using this same approach. Productive grazing can be ensured by promoting early-season native species, implementing appropriate postfire actions (e.g., effective seed mixtures), and developing flexible grazing management plans. Adaptation options for native pollinators include protecting pollinator habitat, maintaining a diversity of native species with overlapping flowering phenology, and taking pollinators into consideration when developing vegetation management plans. Sustainability of cultural resources can be improved by reducing nonclimate stressors, reducing conflicts between commercial and recreational use versus tribal use, and by considering first foods in vegetation management.

The SCOAP facilitated one of the largest climate change adaptation efforts in the Pacific Northwest to date, including participants from stakeholder organizations interested in a broad range of resource issues. It achieved specific elements of national climate change strategies for federal agencies, providing a new scientific context for resource management, planning, and ecological restoration in south-central Oregon. The large number of adaptation options, many of which are a component of current management practice, provides a pathway for slowing the rate of deleterious change in resource conditions. Rapid implementation of adaptation in resource planning and management will help maintain critical structure and function of aquatic and terrestrial ecosystems in south-central Oregon. Long-term monitoring will help detect potential climate change effects on natural resources and evaluate the effectiveness of adaptation options that have been implemented.

Contents

Chapter 1: Introduction

Joanne J. Ho[1]

The South-Central Oregon Adaptation Partnership (SCOAP) is a science-management partnership that includes the U.S. Forest Service (USFS) Pacific Northwest Region, Pacific Northwest Research Station, and Rocky Mountain Research Station; Deschutes, Fremont-Winema, and Ochoco National Forests; Crooked River National Grassland; Crater Lake National Park; and the University of Washington. Initiated in 2015, SCOAP is a collaborative project with the goals of increasing climate change awareness, assessing vulnerability, and developing science-based adaptation strategies to reduce adverse effects of climate change and ease the transition to new climate conditions (see http://adaptationpartners.org/scoap). Developed in response to proactive climate change strategies of the USFS (USDA FS 2008, 2010a, 2010c), and building on previous efforts in national forests (Halofsky et al. 2011; Littell et al. 2012; Raymond et al. 2013, 2014; Rice et al. 2012; Swanston et al. 2011, 2016), the partnership brings together resource managers, research scientists, and stakeholders to plan for climate change in south-central Oregon.

Climate Change Response in the Forest Service and National Park Service

Climate change is an agencywide priority for the USFS, which has issued direction to administrative units for responding to climate change (USDA FS 2008) (table 1.1). In 2010, the USFS provided specific direction to the National Forest System in the form of the *National Roadmap for Responding to Climate Change* (USDA FS 2010a) and the *Performance Scorecard for Implementing the Forest Service Climate Change Strategy* (USDA FS 2010a). The goal of the agency's climate change strategy is to "ensure our national forests and private working lands are conserved, restored, and made more resilient to climate change, while enhancing our water resources" (USDA FS 2010a). To achieve this goal, starting in 2011, each national forest and grassland began using a 10-point scorecard system to report accomplishments on 10 elements in four dimensions: (1) increasing organizational capacity; (2) partnerships, engagement, and education; (3) adaptation; and (4) mitigation and sustainable consumption. Progress toward accomplishing elements of the scorecard must be reported annually by each national forest and grassland; all units were expected to accomplish 7 of 10 criteria by 2015, with at least one "yes" in each dimension.

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Table 1.1—U.S. Forest Service policies related to climate change

Policy	Description
Forest Service Strategic Framework for Responding to Climate Change (USDA FS 2008)	Developed in 2008, the *Strategic Framework* is based on seven strategic goals in three broad categories: foundational, structural, and action. The seven goals are science, education, policy, alliances, adaptation, mitigation, and sustainable operations. Like the challenges themselves, the goals are interconnected; actions that achieve one goal tend to help meet other goals. The key is to coordinate approaches to each goal as complementary parts of a coherent response to climate change. All seven goals are ultimately designed to achieve the same end (the Forest Service mission): to ensure that Americans continue to benefit from ecosystem services from national forests and grasslands.
USDA 2010–2015 Strategic Plan (USDA FS 2010c)	In June 2010, the U.S. Department of Agriculture released its *Strategic Plan*, which guides its agencies toward achieving several goals, including Strategic Goal 2: "Ensure our national forests and private working lands are conserved, restored, and made more resilient to climate change, while enhancing our water resources." This goal has several objectives. Objective 2.2 is to lead efforts to mitigate and adapt to climate change. The performance measures under this objective seek to reduce greenhouse gas emissions by the U.S. agricultural sector, increase the amount of carbon sequestered on U.S. lands, and bring all national forests into compliance with a climate change adaptation and mitigation strategy. The Forest Service response to this goal includes the *National Roadmap for Responding to Climate Change* and *Performance Scorecard*.
National Roadmap for Responding to Climate Change (USDA FS 2010b)	Developed in 2011, the Roadmap integrates land management, outreach, and sustainable operations accounting. It focuses on three kinds of activities: assessing current risks, vulnerabilities, policies, and gaps in knowledge; engaging partners in seeking solutions and learning from as well as educating the public and employees on climate change issues; and managing for resilience in ecosystems and human communities through adaptation, mitigation, and sustainable consumption strategies.
Climate Change Performance Scorecard (USDA FS 2010a)	To implement the Roadmap, starting in 2011, each national forest and grassland began using a 10-point scorecard to report accomplishments and plans for improvement on 10 questions in four dimensions: organizational capacity, engagement, adaptation, and mitigation. By 2015, each was expected to answer "yes" to at least seven of the scorecard questions, with at least one "yes" in each dimension. The goal was to create a balanced approach to climate change that includes managing forests and grasslands to adapt to changing conditions, mitigating climate change, building partnerships across boundaries, and preparing employees to understand and apply emerging science.
2012 Planning Rule (USDA FS 2012)	The *2012 Planning Rule* is based on a planning framework that will facilitate adaptation to changing conditions and improve management based on new information and monitoring. There are specific requirements for addressing climate change in each phase of the planning framework, including in the assessment and monitoring phases, and in developing, revising, or amending plans. The new planning rule emphasizes restoring the function, structure, composition, and connectivity of ecosystems and watersheds to adapt to the effects of a changing climate and other ecosystem drivers and stressors, such as wildfire and insect outbreaks. A baseline assessment of carbon stocks required in assessment and monitoring will check for measurable changes in the plan area related to climate change and other stressors. Requirements of the Roadmap and Scorecard and requirements of the 2012 Planning Rule are mutually supportive and provide a framework for responding to changing conditions over time.

Similarly, the National Park Service (NPS) Climate Change Response Strategy (CCRS) provides direction for addressing the impacts of climate change on National Park System lands (USDI NPS 2010) (table 1.2). The strategy has four components to guide NPS actions: science, adaptation, mitigation, and communication. The science component involves conducting and synthesizing research at various scales, monitoring trends and conditions, and delivering information to resource managers and partners. It also provides the scientific basis for adaptation, mitigation, and communication. Adaptation involves developing capacity within the agency to assess climate change scenarios and risks and implementing actions to better manage natural and cultural resources and infrastructure for a changing climate. Mitigation efforts focus on reducing the agency carbon footprint and enhancing carbon sequestration. Finally, the strategy requires the NPS to take advantage of agency capacity for education and interpretation to communicate the effects of climate change to NPS employees and to the public. Park rangers and other employees are encouraged to engage visitors about climate change, because national parks are visible examples of how climate change can affect natural and cultural resources. The similarity of USFS and NPS climate response strategies facilitated coordination between the two agencies.

The SCOAP built on previous efforts in ecosystem-based management and ecological restoration in the Pacific Northwest to address climate change and put these efforts in a broader regional context in south-central Oregon. Starting in 2008, Halofsky et al. (2011) conducted a climate change assessment for Olympic National Forest and Olympic National Park (630 000 ha), a science-management collaboration initiated to develop climate adaptation strategies. In 2010, the North Cascadia Adaptation Partnership (Raymond et al. 2014) began a similar effort with an expanded geographical scope of two national forests and two national parks. These organizations worked with stakeholders for more than 2 years to identify climate change issues relevant to resource management in the North Cascades Range in order to transition diverse ecosystems of the region toward a warmer climate. The North Cascadia Adaptation Partnership provided education, conducted a climate change vulnerability assessment, and developed adaptation options for federal agencies that manage 2.4 million ha in north-central Washington. In 2013, the Pacific Northwest Research Station; Pacific Northwest Region; and Malheur, Umatilla, and Wallowa-Whitman National Forests (2.14 million ha in Oregon and Washington) initiated the Blue Mountains Adaptation Partnership (Halofsky and Peterson 2017). This science-management collaboration aimed to increase climate change awareness, assessing vulnerability and developing science-based adaptation strategies to reduce adverse effects of climate change and ease transition to new climate states and conditions. The SCOAP is a continuation of these efforts to develop science-based adaptation strategies.

Table 1.2—National Park Service (NPS) policies related to climate change

Policy	Description
National Park Service Climate Change Response Strategy (USDI NPS 2010)	Developed in 2010, the *Climate Change Response Strategy* was designed to guide management actions and collaboration, from the national to park levels, to address the effects of climate change. The Response Strategy was based on four components: science, mitigation, adaptation, and communication. These components provide a framework for consistent, legal, and appropriate management decisions. The Response Strategy called for a scientific approach to updating interpretations of previous policy and mandates in order to uphold the mission of the NPS in the face of new conditions created by climate change.
A Call to Action: Preparing for a Second Century of Stewardship and Engagement (USDI NPS 2011)	The *Call to Action* outlined themes and goals for the second century of stewardship and engagement of the NPS. The plan provided actions for the achievement of each goal before the NPS centennial in 2016. Under the theme of preserving America's special places, the plan set the goal for management of resources to increase resilience to climate change stressors. Specific actions included revised management objectives, increased sustainability, and changes in investments.
Green Parks Plan (USDI NPS 2012b)	The *Green Parks Plan* (GPP) outlined how the NPS will achieve the commitment set in *A Call to Action*, to "go green." An overarching vision and strategy for sustainable management in the future, the GPP was based on nine strategic goals that focus on the effects of park operations on the environment and human welfare. These goals are to continually improve environmental performance; be climate friendly and climate ready; be energy smart; be water wise; develop a green NPS transportation system, buy green and reduce, reuse, and recycle; preserve outdoor values; adopt best practices; and foster sustainability beyond NPS boundaries.
Revisiting Leopold: Resource Stewardship in the National Parks (USDI NPS 2012c)	In August 2012, the NPS released *Revisiting Leopold* as an updated interpretation of the guiding document, The Leopold Report (Leopold et al. 1963). Members of the current NPS science committee were tasked with revisiting three questions: (1) What should be the goals of resource management in the national parks? (2) Which policies for resource management are necessary to achieve these goals? (3) Which actions are required to implement these policies? The interpretation presents general principles and guidance for all natural and cultural resources of the NPS. The committee stresses that the NPS needs to act quickly on structural changes and long-term investments in management in order to preserve resources through the uncertainties of environmental change.
Climate Change Action Plan 2012–2014 (USDI NPS 2012a)	The 2012 *Climate Change Action Plan* builds on the 2010 NPS Climate Change Response Strategy to communicate how the NPS can respond to climate change at different geographic scales. The plan outlined parameters for introducing science, adaptation, mitigation, and communication actions to address climate change. The plan also identified high-priority actions for addressing climate change in NPS operations, and described how to anticipate and prepare for future changes.

Science-Management Partnerships

Previous efforts in the Pacific Northwest and beyond have demonstrated the success of science-management partnerships for increasing climate change awareness among resource managers and adaptation planning on federal lands. In addition to the assessments described above, Tahoe National Forest, Inyo National Forest, and Devils Postpile National Monument worked with the Pacific Southwest Research Station to develop climate change vulnerability assessments (Littell et al. 2012) and the Climate Project Screening Tool to incorporate adaptation into project planning (Morelli et al. 2012). In response to requests from Shoshone National Forest in northern Wyoming, the USFS Rocky Mountain Research Station synthesized information on past climate, future climate projections, and potential effects of climate change on multiple ecosystems within the forest (Rice et al. 2012). In the largest effort to date in the Western United States, the Northern Rockies Adaptation Partnership developed a vulnerability assessment and adaptation options for 15 national forests and 3 national parks in Montana, northern Idaho, North Dakota, and parts of South Dakota and Wyoming (Halofsky et al. 2018)

In the largest effort to date in the Eastern United States, the USFS Northern Research Station, in collaboration with Chequamegon-Nicolet National Forest in northern Wisconsin and numerous other partners, conducted a vulnerability assessment for natural resources (Swanston et al. 2011) and developed adaptation options (Swanston et al. 2016). Another joint national forest and USFS research vulnerability assessment effort focused on the vulnerability of watersheds to climate change (Furniss et al. 2013). 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 reaction to climate change, watershed condition, and landscape sensitivity. The assessments were intended to help national forest managers identify where limited resources could be best invested to increase watershed resilience to climate change.

The processes, products, and techniques used for several studies and other climate change efforts on national forests have been compiled in a guidebook for developing adaptation options for national forests (Peterson et al. 2011). The guidebook outlines four key steps to facilitate adaption in national forests: (1) become aware of basic climate change science and integrate that understanding with knowledge of local conditions and issues (review), (2) evaluate sensitivity of natural resources to climate change (rank), (3) develop and implement options for adapting resources to climate change (resolve), and (4) monitor the effectiveness of on-the-ground management (observe) and adjust as needed. The SCOAP is focused on implementation of the principles and practices in the guidebook.

The South-Central Oregon Adaptation Partnership Process

The SCOAP geographic area includes Deschutes National Forest (646 200 ha), Fremont-Winema National Forest (911 700 ha), Ochoco National Forest (344 500 ha), Crooked River National Grassland (70 200 ha), and Crater Lake National Park (74 100 ha) (fig. 1.1).

The SCOAP process includes (1) a vulnerability assessment of the effects of climate change on hydrology and roads, fisheries, forest and nonforest vegetation and disturbance, wildlife, recreation, and ecosystem services; (2) development of adaptation options that will help reduce negative effects of climate change and assist the transition of biological systems and management to a changing climate; and (3) development of an enduring science-management partnership to facilitate ongoing dialogue and activities related to climate change in the south-central Oregon region. These resource sectors were selected based on their importance in the region and current management concerns and challenges.

Vulnerability assessments typically involve exposure, sensitivity, and adaptive capacity (Parry et al. 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 and focus on whole systems or individual species or resources (Glick et al. 2011). Several tools and databases are available for systematically assessing sensitivity of species and resources (e.g., Case and Lawler 2016, Luce et al. 2014, Potter and Crane 2010).

We used scientific literature and expert knowledge to assess exposure, sensitivity, and adaptive capacity and to identify key vulnerabilities for the SCOAP assessment area. The assessment process took place over 16 months and involved monthly phone meetings for each of the resource-specific assessment teams. Each assessment team refined key questions that the assessment needed to address, selected values to assess, and determined which climate change impact models best informed the assessment. In some cases, assessment teams conducted spatial analyses, ran and interpreted models, selected criteria in which to evaluate model outputs, and developed maps of model output and resource sensitivities. To the greatest extent possible, teams focused on effects and projections specific to the region and used the finest scale projections that are scientifically valid (Littell et al. 2011).

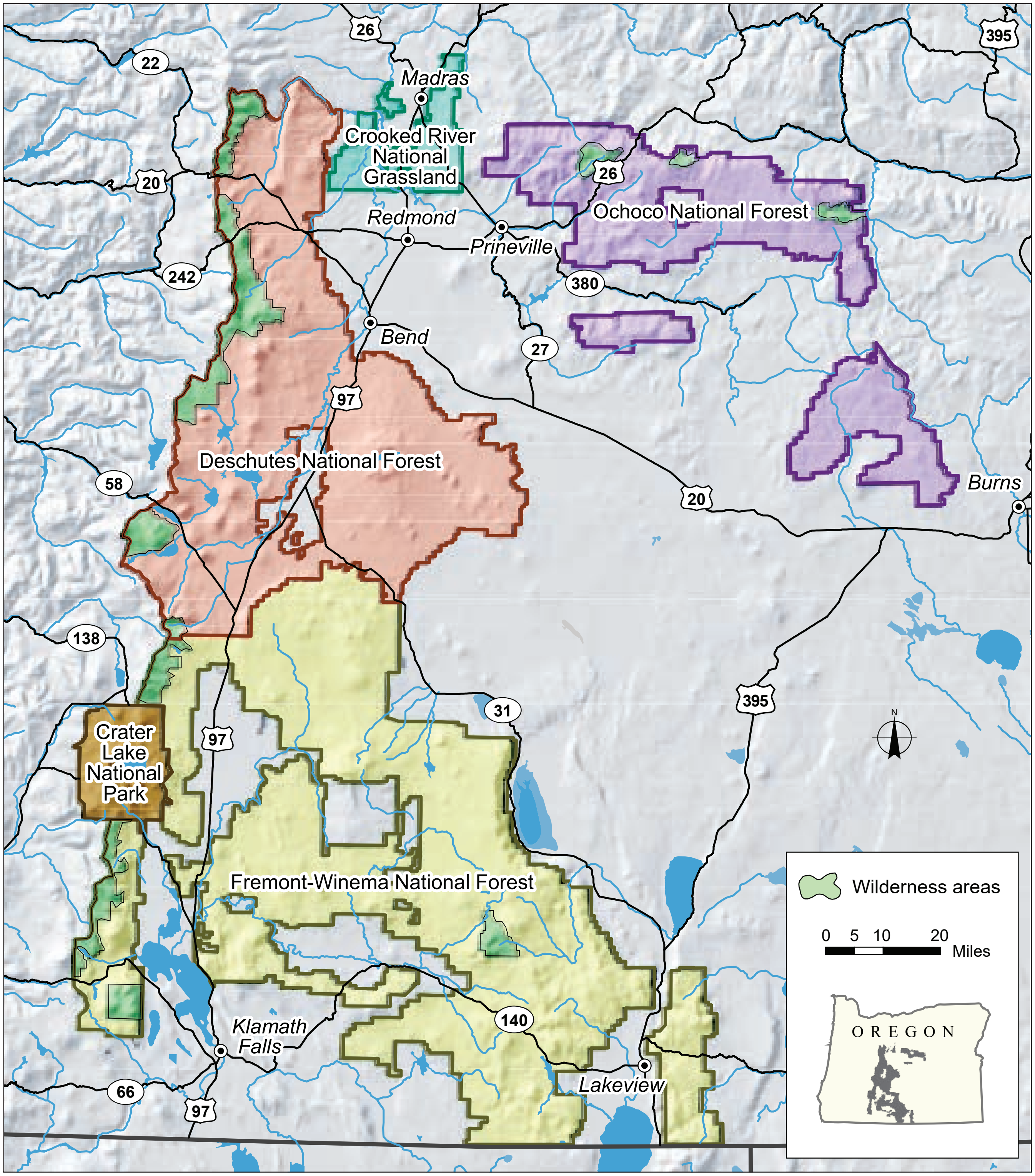

Figure 1.1—Project area for the South-Central Oregon Adaptation Partnership. (Map by Robert Norheim.)

By working collaboratively with scientists and resource managers and focusing on a specific region, the goal of SCOAP participants was to provide the scientific foundation for operationalizing climate change in planning, ecological restoration, and project management (Peterson et al. 2011; Raymond et al. 2013, 2014; Swanston et al. 2016). After identifying key vulnerabilities for each resource sector, scientists, land managers, and stakeholders convened at a workshop in Redmond, Oregon, in March 2016 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 of the resources. 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 generally 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 practices. Information from the assessment was also downscaled to identify the most significant vulnerabilities to climate change for priority resources in each management unit where appropriate. 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.

This publication contains a chapter on expected climatological changes in south-central Oregon, and one chapter for each of the resource sectors covered in the vulnerability assessment (water resources, fisheries, forest and nonforest vegetation, wildlife, recreation, and ecosystem services). Each of the resource chapters includes a review of climate change effects, sensitivities, and current management practices. Results of the adaptation strategies and tactics discussions are described in chapter 10.

Resource managers and other decisionmakers can use this report in several ways. First, the vulnerability assessment will provide information on climate change effects needed for national forest and national park plans, project plans, conservation strategies, restoration, and environmental effects analysis. The assessment will be particularly useful for national forest and national park planning and management. Second, climate change sensitivities and adaptation options developed at the broad scale provide the scientific foundation for finer scale 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. Third, we 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 NPS, but this report provides information that can be used by other land management agencies as well. Just as the SCOAP process has been adapted from previous vulnerability assessments and adaptation planning, it can be further adapted by other national forests and organizations, thus propagating climate-smart management across larger landscapes.

Toward an All-Lands Approach for Climate Change Adaptation

The USFS and NPS climate change strategies identify the need to build partnerships and work across jurisdictional boundaries when planning for adaptation. This concept of responding to the challenge of climate change with an "all-lands" approach is frequently mentioned, but a process for doing so is rarely defined. In addition to representatives from 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. The SCOAP also provides a venue for agencies to learn from the practices of others so that the most effective adaptation strategies can be identified.

Risks and vulnerabilities resulting from climate change and gaps in scientific knowledge and policy need to be assessed. Adaptation is a prominent focus of the SCOAP, with emphasis on creating resilience in human and natural systems. 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. The need for partnerships and collaborations on climate change issues was also identified in the SCOAP. Sharing climate change information, vulnerability assessments, and adaptation strategies across administrative boundaries will contribute to the success of climate change responses in the Pacific Northwest.

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Chapter 2: Biogeographical, Ecological, and Historical Setting for South-Central Oregon

Robin S. Vora and Joanne J. Ho[1]

Introduction

The South-Central Oregon Adaptation Partnership (SCOAP) project area includes Deschutes, Ochoco, and Fremont-Winema National Forests; Crooked River National Grassland; and Crater Lake National Park in central and south-central Oregon (fig. 1.1). Deschutes National Forest (647 145 ha) lies to the east of the Cascade Range crest from Mount Jefferson to Fort Rock and includes Three Sisters Wilderness and Newberry Volcanic National Monument. Ochoco National Forest (248 468 ha) is east of Prineville, and Crooked River National Grassland (47 264 ha), a subunit of the Ochoco, is primarily to the south of the town of Madras. Fremont-Winema National Forest (910 339 ha) abuts the Deschutes between the communities of Crescent and Chemult, extending south along the Cascade Range crest to just west of Upper Klamath Lake, and southeast to Lakeview, Oregon. Crater Lake National Park is located along a relatively small portion (40 575 ha) of the Cascade crest, west of Fremont-Winema National Forest and east and south of Umpqua National Forest. Bend is the largest city within the SCOAP assessment area with a population of 87,000. The SCOAP project area falls within the boundaries of Crook, Jefferson, Deschutes, Klamath, Lake, Douglas, Jackson, Wheeler, and Grant Counties.

Physiography

Summers are warm and winters cold, typical of the interior Western United States. In a typical summer, high pressure off the coast deflects storms, resulting in dry summers (Agee 1993). In winter, the North Pacific High moves south and the Aleutian Low brings in winter storms. Temperature fluctuations are relatively high both diurnally and annually, resulting in cold, snowy winters and hot, dry summers (Aikens 1993). A summer day may have a high of 38 °C during the day and drop to 10 °C at night. Cool highlands collect most of the water and hold it the longest.

Landforms are primarily volcanic in origin, ranging in age from 54 million years before present (BP) to present day. The southeast corner of Ochoco National Forest is underlain by marine sedimentary rocks and accreted terrains from 60

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to 250 million years BP. The eruption of Mount Mazama 7,600 years BP greatly affected the landscape in central Oregon and beyond by depositing a large amount of ash and pumice (fig. 2.1). Anderson et al. (1998) divided the area into several ecological provinces. Cascade Province, the higher elevations and crest of the Cascade Range, is characterized by andesitic or basaltic mountainous terrain. High points within the province include Mount Jefferson (3171 m) and Mount McLoughlin (2895 m), with typical elevations of 1500 to 1800 m. Annual average precipitation is 1500 mm, and snowpacks are long lasting at higher elevations.

Mazama Province, formed by the eruption of Mount Mazama, is characterized by sloping and undulating plateaus in the northern and northeastern portions and by hilly to mountainous topography interspersed with basins throughout most of its interior and western portion. Innumerable large and small buttes, cones, ridges, and mountains formed by volcanism are interspersed across the landscape. Fields of raw lava and pumice are common. Most of the province lies at 1200 to 1500 m elevation. Peaks in the Cascade Range exceed 2400 m.

Klamath Province, the basaltic mountainous part of south-central Oregon, is characterized by large basins consisting of lakebeds surrounded by extensive ancient lake terraces interspersed with basaltic terrain. Drainage is south, mainly through the Klamath River system. Elevations range from 1234 m at Malin to 2562 m at Drake Peak northeast of Lakeview.

John Day Province, the rugged north-central portion of the assessment area, is characterized by extensive, geologically eroded, steeply dissected hills of thick, ancient volcanic sedimentary materials interspersed with buttes and plateaus capped with basalt or tuffaceous rock. Elevations range from 480 m in the northwest corner to 2112 m at Lookout Mountain in the Ochoco Mountains. It includes virtually the entire watersheds of Crooked River, the South Fork of John Day River, and headwaters of Trout Creek.

High Desert Province, the northernmost extent of the Great Basin of North America, is characterized by numerous large and small closed basins surrounded by extensive terraces formed in ancient lakes. Interspersed are low basaltic ridges, hilly uplands, isolated buttes, mountains, and block-faulted igneous formations. Elevations of basins and terraces are between 1230 and 1370 m. Soils in the terraces and basins were formed from parent materials derived through water action. They range from deep loam to deep clayey soils in basins, and from deep sandy to shallow clayey soils on terraces and fans where weak to strong hardpans are common. Average annual precipitation for the province is 250 mm.

Most lower elevation soils in the SCOAP assessment area are xeric or aridic (dry for at least 60 to 90 days in summer) (Clarke and Bryce 1997). Early moisture stress effectively shortens the growing season. Many soils are derived from parent

National Park Service, Crater Lake National Park Museum and Archive Collections

Figure 2.1—The eruption of Mount Mazama 7,700 years BP in what is now Crater Lake National Park (depicted in this painting by Paul Rockwood) produced an enormous amount of pumice and ash that helped shape the landscape and soils of south-central Oregon.

material and rock fragments that contribute to high porosity and low soil moisture. Productivity in xeric areas is dependent on a thin surficial organic layer or on regular fires to release nutrients accumulated in woody debris and dried grasses. At elevations above 1500 m, conditions are cooler, wetter, and more productive, with fewer than 45 days of dryness in the 120 days following June 20. Ash deposits from Glacier Peak (12,000 years BP) and Mount Mazama are as thick as 3 m in some places. Much of the ash has eroded away on lower elevation grasslands and on south-facing slopes. Fine silt loam ash soils have a high water-holding capacity, high water infiltration rate, and largely rock-free growing medium. Most nutrients are near the surface.

Rivers drain into the Columbia and Klamath Rivers, or into inland lakes with no outlets in the high desert (Aikens 1993). The Sacramento River basin headwaters are formed in the Goose Lake watershed that drains the ancestral Cascades and the South Warner basin. The high Cascades have abundant winter snow, whereas arid, lowland areas may have only 200 mm of annual precipitation. Many valleys have wetlands fed by mountain runoff, and wetlands are generally small where upland catchments are small. Today's lakes are remnants of large Pleistocene water bodies. The presence of springs is determined by geomorphology, lithic and sedimentary bedding, and faulting. A large portion of the precipitation that falls in the Cascades seeps into groundwater basins (Gannett et al. 2001). Steady flows of the Deschutes River are a function of an extensive groundwater system fed by precipitation in the Cascades (Grant and O'Connor 2003).

Geomorphology

South-central Oregon has diverse geology influenced by volcanic activity. Crater Lake National Park is centered on the remnants of Mount Mazama. The eruption covered south-central Oregon with ashfall composed of thick pumice blankets closer to the mountain and sand-silt sized ash that drifted over the crest of the Ochoco Mountains toward Idaho and Montana.

Pumice and ash deposits from Mount Mazama also affected portions of Fremont-Winema National Forest, located in the Eastern Cascades Slopes and Foothills ecoregion. Most of the forest is characterized by fault-block mountains and interspersed depressions. The complex network of faults, tilted raised mountains, and associated volcanic activities produced volcanic eruption centers associated with Gearhart Mountain, Yamsay Mountain, and dozens of smaller volcanoes, domes, and spatter cones. Interspersed between the volcanic flows and peaks, the topography ranges from flat to gently rolling lava plateaus and tablelands to occasional steep highly dissected landforms and massive landslide areas, such as Winter Rim. The extensive basalt flows of Steens Mountain influence the eastern portion of the forest, adding to the dramatic landscape around the Warner Mountains and Abert Rim. More recent large pluvial lakes formed during the cooler Pleistocene and occupied what is now the Klamath River basin, Goose Valley, Summer Lake, and others. Although mineral deposits associated with faulting, fissures, and hot water are present, much of the mineral activity on the forest has been limited to gold exploration, geothermal resources, and uranium mining in the Lakeview District.

Deschutes National Forest lies east of the volcanic Cascade Range crest in central Oregon. The modern High Cascade Range is a north-south trending volcanic eruptive center that extends from southern British Columbia to northern California and has been very active for the past 4 million years. The eruptive centers that comprise the central Oregon Cascades are numerous Quaternary Period stratovolcanoes, shield volcanoes, cinder cones, silicic domes, tuya volcanoes, and maar volcanoes. South Sister in Three Sisters Wilderness is an active volcano with 2,000-year-old rhyolite flows. Over the past 1.8 million years, the High Cascades have experienced a dozen major periods of glaciation. The last major period was the Suttle Lake advance of Cabot Creek glaciation, which culminated about 22,000 to 18,000 years BP. The glaciers sculpted cirques and U-shaped valleys into the volcanic terrain and deposited outwash plains, moraines, kettles, and kames. A minor neoglacial advance culminated in the late 19^{th} century and rapidly retreated during the early 20^{th} century. Currently, there are 17 named glaciers in the central Oregon Cascade Range that cover approximately 750 ha.

Newberry Volcano is located east of the Cascade Range at the edge of the High Lava Plains geologic province. Newberry is the largest volcano in the Cascade Range and was formed by repeated eruptions for 400,000 years. It is a giant shield-shaped composite volcano with lava flows that cover almost 310 000 ha and rises 1220 m from the surrounding area. It was formed by several diverse styles of eruptions and has as many as 400 cinder cones across its slopes. A large eruption 78,000 years BP produced a caldera at its summit that contains two lakes with hot springs. About 7,000 years BP, a 32-km-long fissure system erupted, forming the Northwest Rift Zone with numerous vents. Resulting lava flows dammed the Deschutes River. The most recent eruption is the 1,300-year-old Big Obsidian Flow, which is the youngest lava flow in Oregon. The volcanic activity at Newberry has created a unique landscape, and in 1990, the Newberry National Volcanic Monument was established. The monument covers 22 000 ha of Deschutes National Forest and encompasses the volcano's upper slopes, caldera, and northwest rift zone.

Ochoco National Forest and Crooked River National Grassland extend from the east slope of the Cascades to the South Fork of the John Day River, encompassing the Ochoco and Maury Mountains. The grassland is on the eastern edge of the East Cascades Ecoregion and is underlain by young 7 to 5 million-year-old basalt flows and ashflow tuffs. Ochoco National Forest is situated on the western edge of the Blue Mountains ecoregion. It is underlain by clay-rich volcanic mudflows and andesites of the 44 to 39 million-year-old Clarno Formation; welded tuff, rhyolites, and landslides of the 36 to 25 million-year-old John Day Formation; and the thick 17 million-year-old Picture Gorge Basalts.

These highly weathered andesites, basalts, rhyolites, and ashflow tuffs form the dissected ridges with moderately steep side slopes. Landslides played a major role in the shaping of the Ochoco and Maury Mountains. Caught in the center of the North American Plate clockwise rotation, the mountains compressed, lifted, deformed, and fractured the brittle tuffs and basalts, forming a network of faults across the landscape. On Ochoco National Forest, Steins Pillar, an erosional remnant of the 40 million-year-old eruption of the Wildcat Mountain Caldera, sits on the southern rim, while Twin Pillars, a volcanic neck in the middle of Mill Creek Wilderness, rises above the north rim of the caldera.

Mercury and gold deposits resulting from historical volcanic activity are still mined today. The silica-rich hydrothermal waters associated with volcanic activity disseminated out in the fractures and air pockets to become the agate and thunder eggs sought by the public.

The minerals resource is extensive, encompassing geothermal potential at Newberry on the Deschutes National Forest; oil and gas leases on Crooked River National Grassland; gold, thunder egg, opal, and sunstone mines on the Deschutes, Fremont-Winema, and Ochoco National Forests; and numerous mineral material permits across the four national forests and the grassland.

Ecology

The Columbia Plateau was shaped 6 to 17 million years BP by about 200 separate lava flows from vents in southeastern Washington and northeastern Oregon that filled the basin with lava up to 3 km thick (Clarke and Bryce 1997). Water became a limiting factor with the rise of the Cascade Range 20 to 30 million years BP, which formed a barrier to the eastward flow of weather systems off the Pacific Ocean. Vegetation in south-central Oregon is affected by the rain shadow created by the Cascade Range, transitioning from mountain hemlock (*Tsuga mertensiana* [Bong.] Carrière) and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) near the Cascade crest to dry ponderosa pine (*Pinus ponderosa* Douglas ex P. Lawson & C. Lawson), woodlands, and shrublands along the drier eastern front. Periodic disturbances by wildfire and bark beetles are important ecological processes that greatly influence plant species distribution and abundance, small-scale vegetation structure, and large-scale vegetation pattern.

Vegetation is dominated by grasslands at the lowest elevations, and at higher elevations transitioning to shrublands, ponderosa pine woodlands, true fir mesic forest, subalpine forest and parkland, and alpine meadows. Grasslands include bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] Á. Löve) and Sandberg's bluegrass (*Poa secunda* J. Presl) in the warmest areas, and Idaho fescue (*Festuca idahoensis* Elmer) in deeper, moister soils. Shrublands and western juniper (*Juniperus occidentalis* Hook.) grassland savanna form the transition from grassland to forested slopes. Common shrubs include antelope bitterbrush (*Purshia tridentata* [Pursh] DC.), curl-leaf mountain-mahogany (*Cercocarpus ledifolius* Nutt.) and big sagebrush (*Artemisia tridentata* Nutt.), as well as greenleaf manzanita (*Arctostaphylos patula* Greene) and snowbrush (*Ceanothus velutinus* Douglas ex. Hook.) in the east Cascades. Lodgepole pine (*Pinus contorta* var. *latifolia* Engelm. ex S. Watson) is found on well-drained pumice soils and encroaches into ponderosa pine forests following several decades of fire exclusion.

The paleoecological literature demonstrates that periods of warm weather, accompanied by high levels of wildfire, tend to increase shade-intolerant tree species and decrease shade-tolerant, late-seral species. For example, fire was common during the warm climate of 7,000 to 10,000 years BP. Modern species assemblages have appeared only in the past 5,000 years. Fire regimes in south-central Oregon during the past several centuries have varied greatly geographically and by dominant vegetation. Prior to 1900, mean fire return interval was approximately 15 years in ponderosa pine (fig. 2.2), 25 years in juniper-sagebrush steppe, 30 to 50 years in mixed-conifer, 80 years in lodgepole pine, and 300 years in subalpine forest (Agee 1993). The central Cascade Range has a relatively high occurrence of convective storms and lightning, the primary ignition source for wildfires in this area. Prior to Euro-American settlement, lower elevation forests were burned frequently by American Indians. Fire exclusion since the early 20th century has increased the abundance of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), grand fir (*Abies grandis* [Douglas ex D. Don] Lindl.), white fir (*A. concolor* [Gordon & Glend.] Lindl. ex Hildebr.), and Engelmann spruce (*Picea engelmannii* Parry ex. Engelm.) at lower elevations (Clarke and Bryce 1997).


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Figure 2.2—Dry forest dominated by ponderosa pine (shown here in Deschutes National Forest) is common at low to mid elevations in south-central Oregon. The open stand structure was prevalent prior to 1900 when low-intensity fires occurred frequently.

Terrestrial vegetation communities that have decreased the most since historical times include late-seral, lower montane (including ponderosa pine), single-layer forest (-81 percent change); early-seral, lower montane forest (-77 percent); upland herb (-67 percent); and late-seral, subalpine, multilayer forest (-64 percent) (Marcot et al. 1998). Communities increasing the most include mid-seral, lower montane forest (+53 percent) and mid-seral, montane forest (+59 percent). Urban areas, nonnative species, and agricultural areas have increased greatly over the past century, displacing mostly native upland grassland, herbland, and shrubland communities (fig. 2.3). Rangeland communities have also been altered by increased fire frequency associated with proliferation of nonnative grasses, especially cheatgrass (*Bromus tectorum* L.).

Expansion of western juniper into neighboring plant communities during the past 130 years (fig. 2.4) has been the source of extensive scientific inquiry because of (1) increased soil erosion; (2) lower streamflows; (3) reduced forage production; (4) altered wildlife habitat; (5) altered plant community composition, structure, and biodiversity; and (6) replacement of mesic and semiarid plant communities with woodlands (Miller et al. 2005). Prior to Euro-American settlement, changes in

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Figure 2.3—An increasing number of homes and other structures in the wildland-urban interface fragment habitat for vegetation and wildlife, and create challenges for wildfire suppression.

woodland abundance and distribution were mostly caused by long-term variability in temperature, precipitation, and wildfire.

Climatic variability has also affected animal assemblages, with a large number of species going extinct at the end of the last glaciation (Aikens 1993), including the North American natives giant ground sloth (*Megatherium americanum* Cuvier), giant bison (*Bison latifrons* Harlan), camel (*Camelops* spp.), and horse (*Equus* spp.). Modern-day mammals of interest for conservation and hunting include pronghorn (*Antilocapra americana* Ord), mule deer (*Odocoileus hemionus* Rafinesque), bighorn sheep (*Ovis canadensis* Shaw), black bear (*Ursus americanus* Pallas), mountain lion (*Puma concolor* L.), bobcat (*Lynx rufus* Schreber), coyote (*Canis latrans* Say), and white-tailed jackrabbit (*Lepus townsendi* Bachman). Bird diversity is high, including many passerine species, as well as raptors and migratory waterfowl. Many fish species, both native and nonnative, live in streams and lakes of the region, including coldwater-obligate steelhead/redband trout (*Oncorhynchus mykiss* Walbaum) and bull trout (*Salvelinus confluentus* Suckley).

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Figure 2.4—Encroachment of western juniper into sagebrush-steppe vegetation is a significant challenge for restoration of mature sagebrush habitat for greater sage-grouse (*Centrocercus urophasianus* Bonaparte) and other wildlife species.

Federally listed threatened and endangered species within the SCOAP assessment area include gray wolf (*Canis lupus* L.), northern spotted owl (*Strix occidentalis caurina* Merriam), steelhead, bull trout, Lost River sucker (*Deltistes luxatus* Cope), shortnose sucker (*Chasmistes brevirostris* Cope), and Oregon spotted frog (*Rana pretiosa* Baird and Girard). Invasive and nonnative species, altered (fire) disturbance regimes, reduced water quality and quantity, and land use changes are significant stressors that affect the integrity and conservation of current terrestrial and aquatic ecosystems (ODFW 2006).

Human History, Culture, and Land Use

Traditional cultures were closely adapted to the landscapes of south-central Oregon, with a variety of lifeways that corresponded to the availability of food and other resources (Aikens 1993). Landscape characteristics such as elevation, slope, aspect, and water sources influenced the distribution of settlements and camps during different seasons, and people shifted to more favorable sites during droughts. Salmon and plant roots were harvested in May and June; crickets and grass in July; berries and seeds in August; elk and chokecherries in September; deer, antelope, and rabbits in October and November; and fish in lakes in December and January. Other important food plants included biscuitroot (*Lomatium* spp.), common camas (*Camassia quamash* [Pursh] Greene), bitterroot (*Lewisia rediviva* Pursh), and common yampah (*Perideridia gairdneri* [Hook. & Arn.] Mathias) (Connolly 1999) (fig. 2.5).

American Indian tribes have lived in south-central Oregon for at least 12,000 years, including the Northern Paiute, Tenino (Tygh), Molalla, Klamath, and Modoc (Houser 1996). The Northern Paiute had low population density, lived in small camps, wintered in willow frame houses, and traveled mostly on foot until horses were introduced in the mid-1800s. The Tenino (Tygh) traditionally occupied lands adjacent to the Columbia River until they were moved to the Warm Springs Reservation in 1855. They lived on salmon and other fish, small birds, small mammals, and roots. The Molalla lived in the central Cascade Range, mostly on the west side, but ventured east for hunting and berry picking until pushed west over the Cascades by the Tenino and Northern Paiute. The Klamath occupied the Upper Klamath Basin and surrounding uplands, subsisting on plants and animals found in marsh, river, and lake environments. They lived in large semi-subterranean lodges in winter. The closely related Modoc lived near lakes and rivers in the Lower Klamath Basin.

The Northern Paiute occupied large territories in the northwestern portion of the Great Basin in Oregon (Minor et al. 1979). The general scarcity of foods resulted in an average population density of one person for every 2500 to 5000 ha. Small family bands moved frequently in search of a wide range of plant and animal foods. Klamath settlements centered around Upper Klamath Lake and Klamath

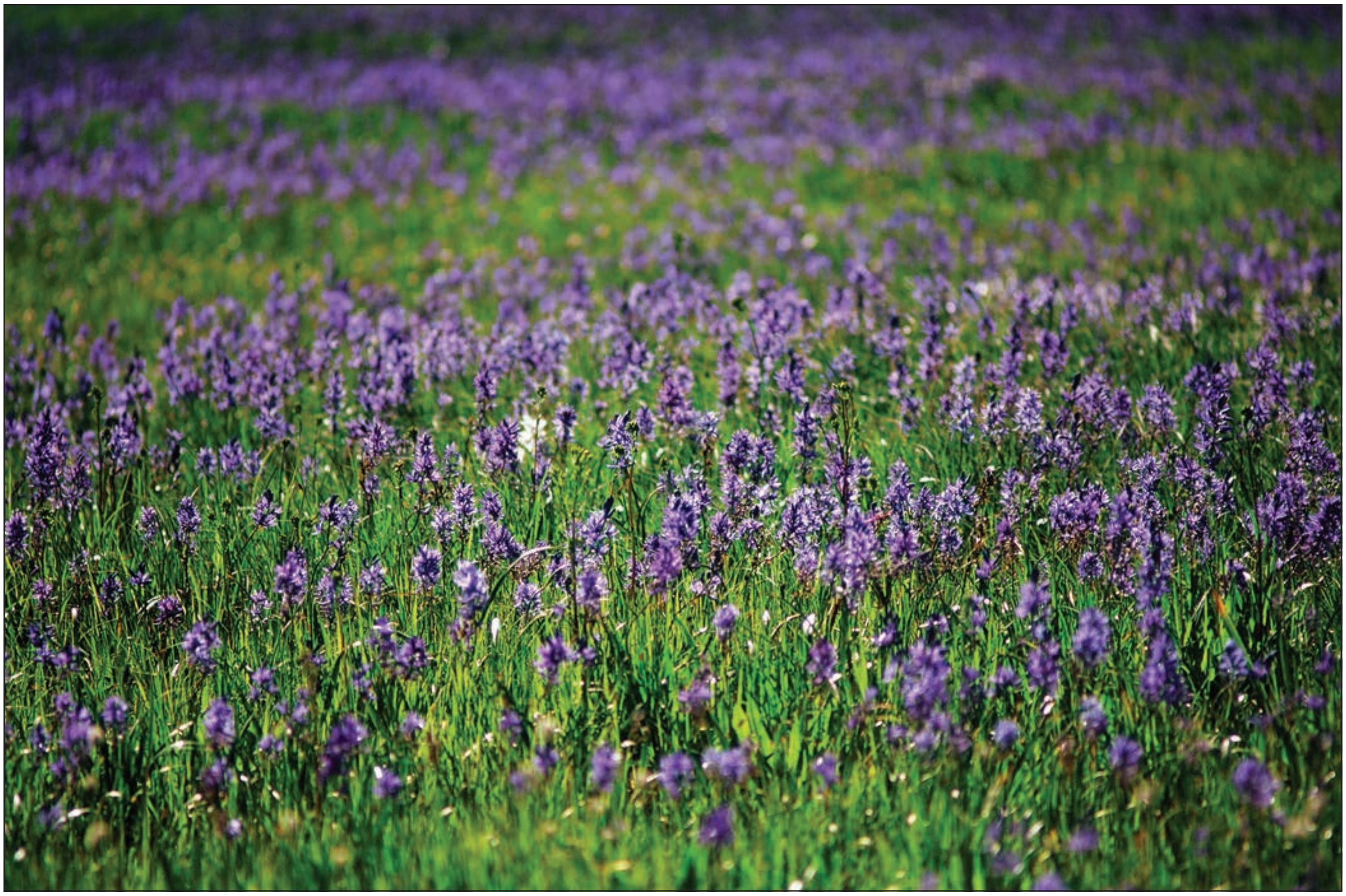

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Figure 2.5—Common camas root has been used by American Indians in south-central Oregon for thousands of years. The roots are collected in early summer, then baked slowly to produce a sweet, high-protein food.

Marsh, as well as along the Williamson River and its tributaries. They ventured farther east in the summer for resources near Sycan River, Sycan Marsh, and Yamsay Mountain. They had more resources than the Paiute, including spring fish runs. Baskets were twined from tule (*Schoenoplectus acutus* var. *occidentalis* [S. Watson] S.G. Sm.), cattail (*Typha latifolia* L.), and swamp grasses. Cradleboards were constructed of willow and tule. Because of differences in environments, the Northern Paiute emphasized hunting and seed gathering, whereas the Klamath-Modoc relied more on fishing, and gathering of roots and yellow pond-lily (*Nuphar advena* [Alton] W.T. Alton).

Euro-American settlement of south-central Oregon began in earnest in the mid 1800s, with settler activities determined by water availability, length of growing season, and temperature. Livestock grazing, mining, logging, farming, road building, and irrigation were common early land uses (Clarke and Bryce 1997). By 1860, two main lines of communication were established—Applegate Road (now State Highway 66) and a north-south route to the The Dalles (now U.S. Highway 97)—and the first livestock were brought to the area at this time (Dicken and Dicken

1985). The coming of the railroad and automobile in the early 1900s, and work by the U.S. Reclamation Service (currently the U.S. Bureau of Reclamation) were the chief elements accelerating population and economic growth. Paved roads, modern logging machinery, large-scale irrigation, hydroelectric energy, and airplanes transformed local economies. Recreation use started in the 1920s and has increased steadily since, with central Oregon developing into a major recreation destination.

The 1930s were characterized by a long, severe drought and a crippling economic depression. The end of the drought and World War II stimulated the growth of agriculture and logging. What was once a sea of sagebrush, grass, and marsh vegetation is now (in season) a checkerboard of alfalfa, potatoes, grain, and other crops. Nonnative species were introduced in rangelands. Logging road construction, wildfire, fire exclusion, plant diseases, livestock grazing, and nonnative plants changed the structure and function of forest vegetation.

A large portion of the SCOAP assessment area remains in federal ownership in lands administered by the U.S. Forest Service (USFS), Bureau of Land Management, U.S. Fish and Wildlife Service, and National Park Service. State forests, private commercial and noncommercial forests, and tribal lands also occupy a large portion of the area and are managed for timber and other resources. Agriculture and urban development have converted lower lying valleys and some river basins from natural systems to intensively managed and settled areas. Continued settlement in the wildland-urban interface is a growing concern with respect to wildfires and loss of wildlife habitat.

Demographic and Economic Trends

Human populations continue to increase slightly in the SCOAP area as it transitions from an economy dominated by timber and agriculture to retail, service, information technology, small manufacturing, and recreation businesses. Most of the population growth is concentrated in Deschutes County (fig. 2.6). Central Oregon was hit harder than much of the rest of the state during the 2008–2012 recession and had high unemployment, but unemployment rates in central Oregon have returned to pre-recession levels (Oregon Employment Department 2017). It is noteworthy that Deschutes County's unemployment rate was above the state average before the recession, and in its recovery has fallen below 5 percent. Within the SCOAP assessment area, Deschutes County is more prosperous in the new economy than other counties and, along with Jefferson County, has returned to or surpassed pre-recession levels. Generally, the more rural communities and those more dependent on wood products have not recovered.[2]

[2] D. Runberg, personal communication. Economist, Oregon Employment Department, 875 Union Street, NE, Salem, OR 97311

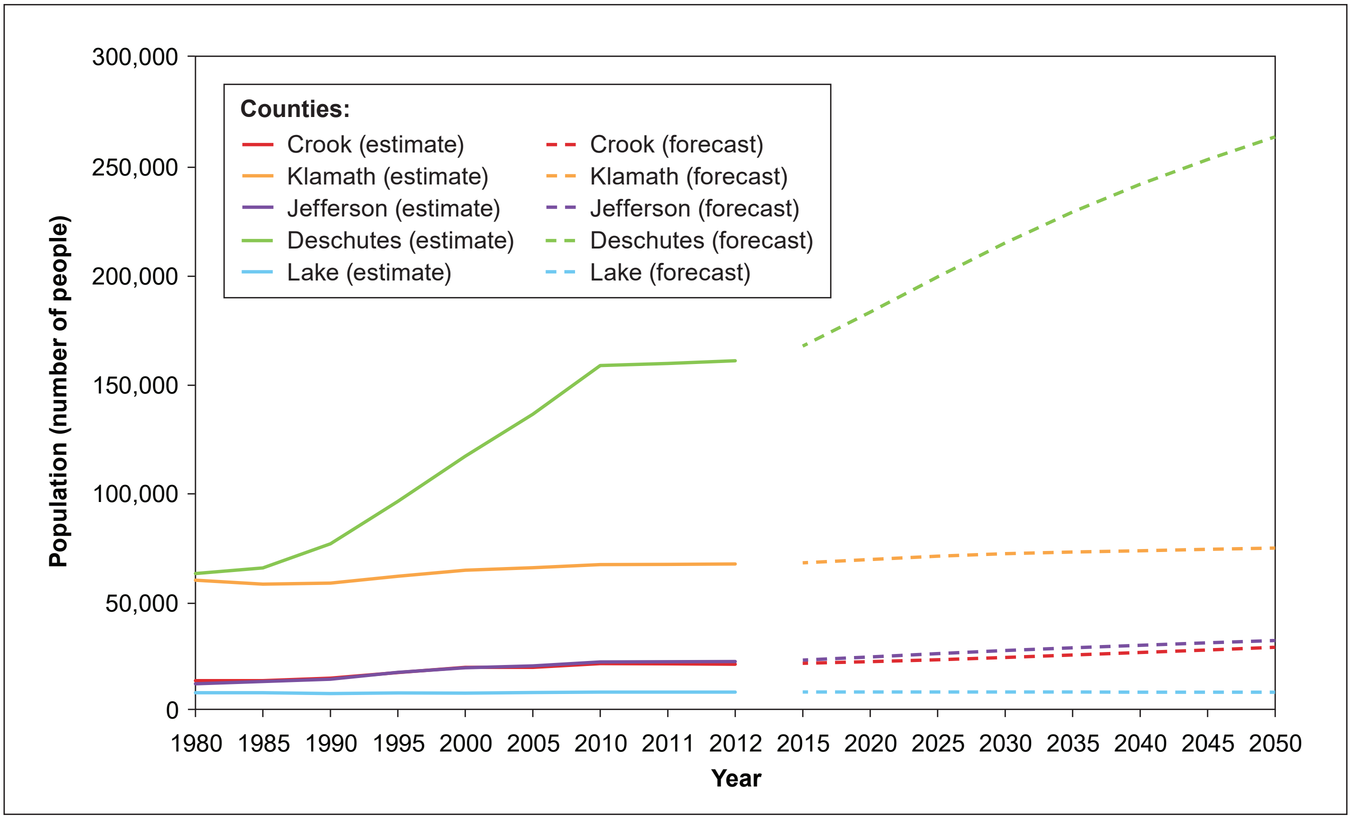

Figure 2.6—South-central Oregon population trends, by county (2010–2050). Data for 1980–2012 are estimates; data for 2013–2014 are missing; data since 2015 are modeled forecasts. Data source: State of Oregon, Department of Administrative Services, Office of Economic Analysis.

Employment in the forestry and logging sector has declined in all counties since 2001, in absolute terms and as a proportion of the total employment within county (figs. 2.7 and 2.8). Nonfederal employee wages earned followed a similar trend until 2014 (figs. 2.9 and 2.10). Outdoor recreation and tourism grew during the 2008–2012 recession and economic expansion that followed, especially in Deschutes County, but more recently appears to have peaked (see footnote 2). In 2008, estimated total travel and local recreation expenditures for fishing, hunting, and wildlife viewing were $146 million for Crook, Deschutes, Jefferson, Klamath, and Lake Counties, with about half of that related to Deschutes County (Dean Runyan Associates 2009). Statewide, fishing and hunting have declined since the 1980s but have stabilized since around 2000, with about half the percentage participating in those activities compared to the 1980s. Socioeconomic trends related to ranching, water, and other resources on the national forests and grassland in the region are more difficult to assess and are not readily available.

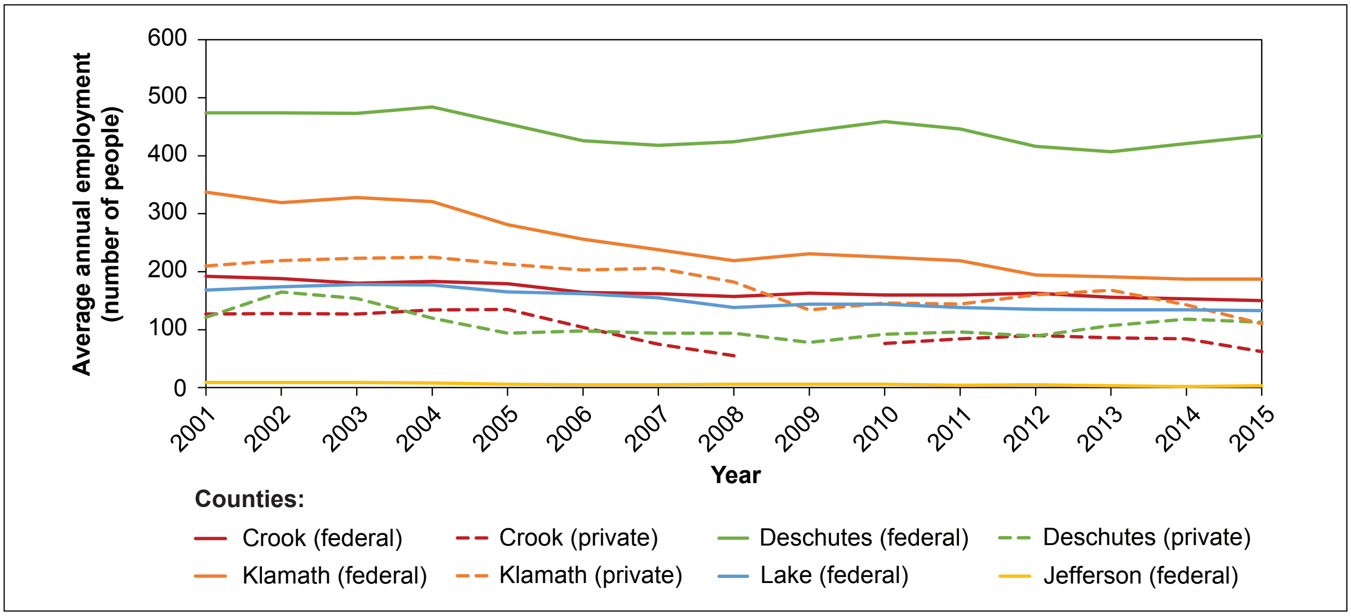

Figure 2.7—Average annual employment level in the forestry and logging sector by county. Data for Crook (private) for 2009 are missing. Data source is Oregon Employment Department 2017.

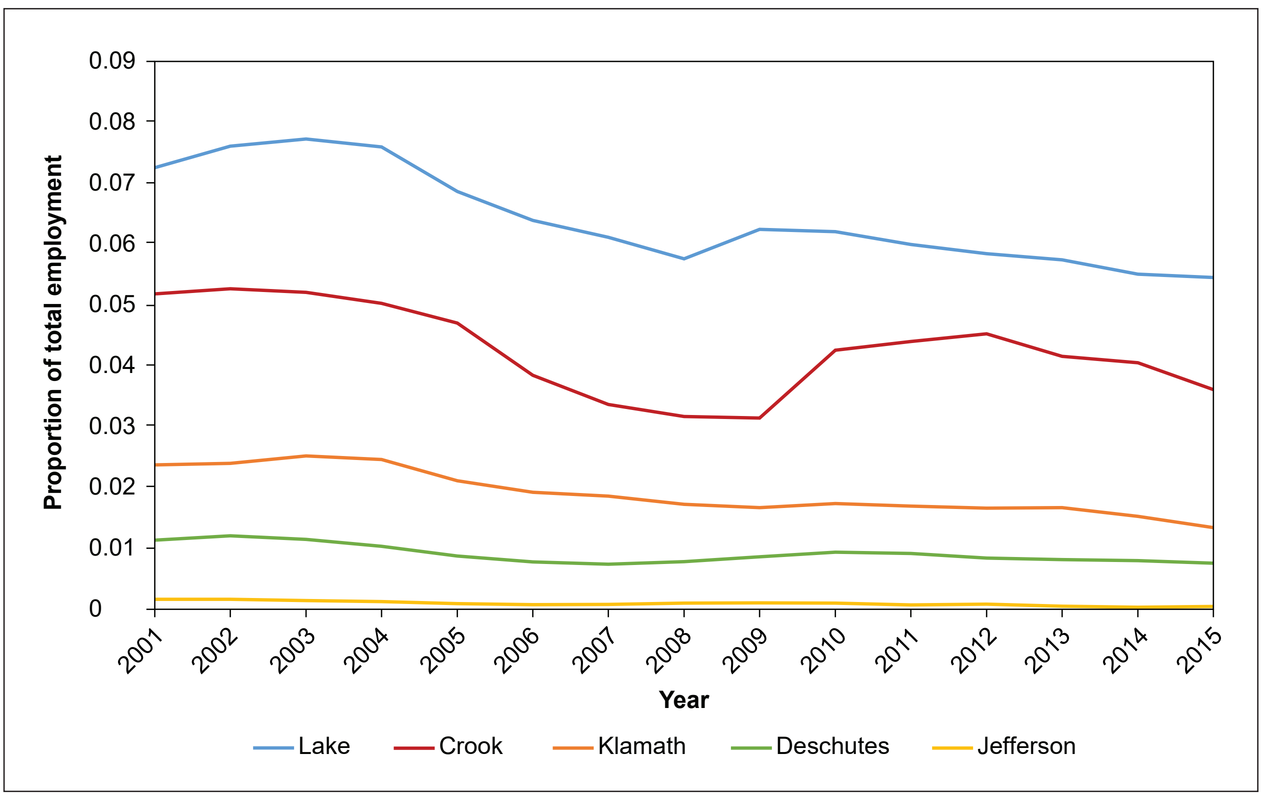

Figure 2.8—Employment in forestry and logging sector as proportion of total employment in county. Data source is Oregon Employment Department 2017.

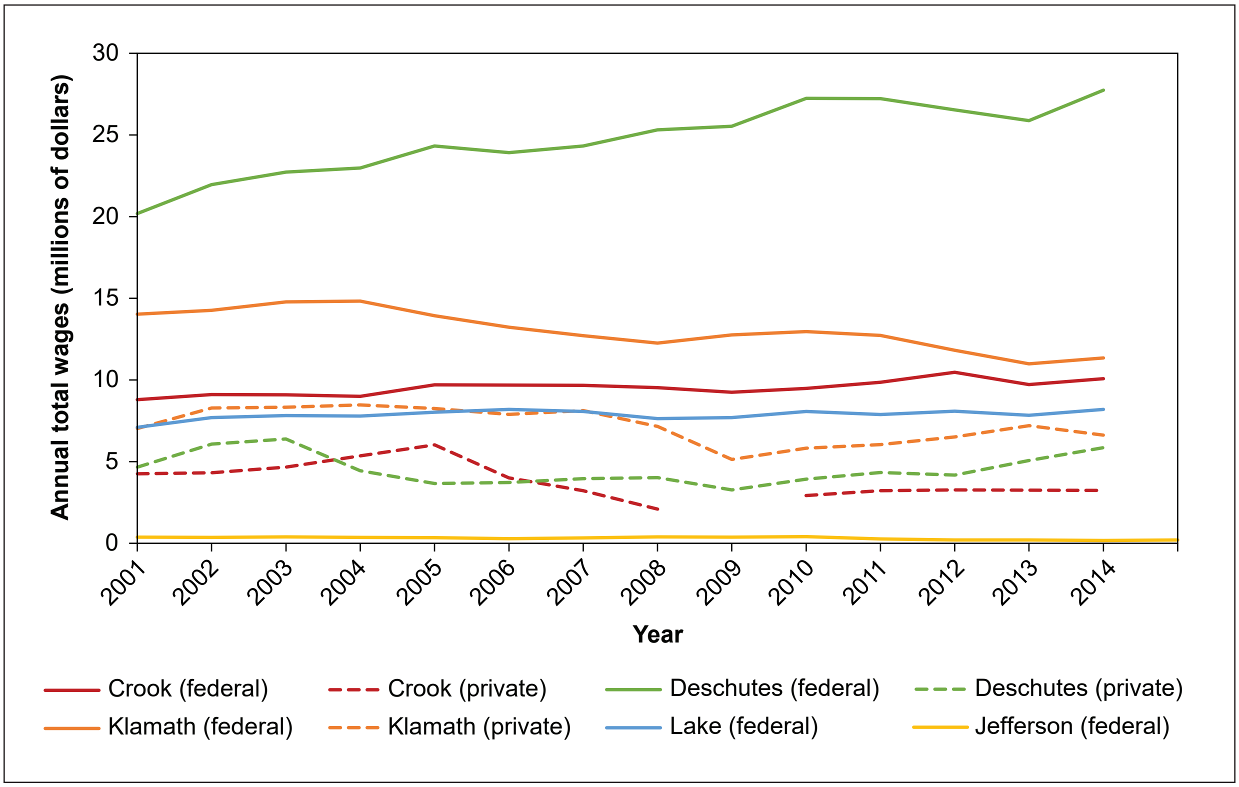

Figure 2.9—Annual total wages in forestry and logging sector by county. Data for Crook (private) for 2009 are missing. Data source is Oregon Employment Department 2017.

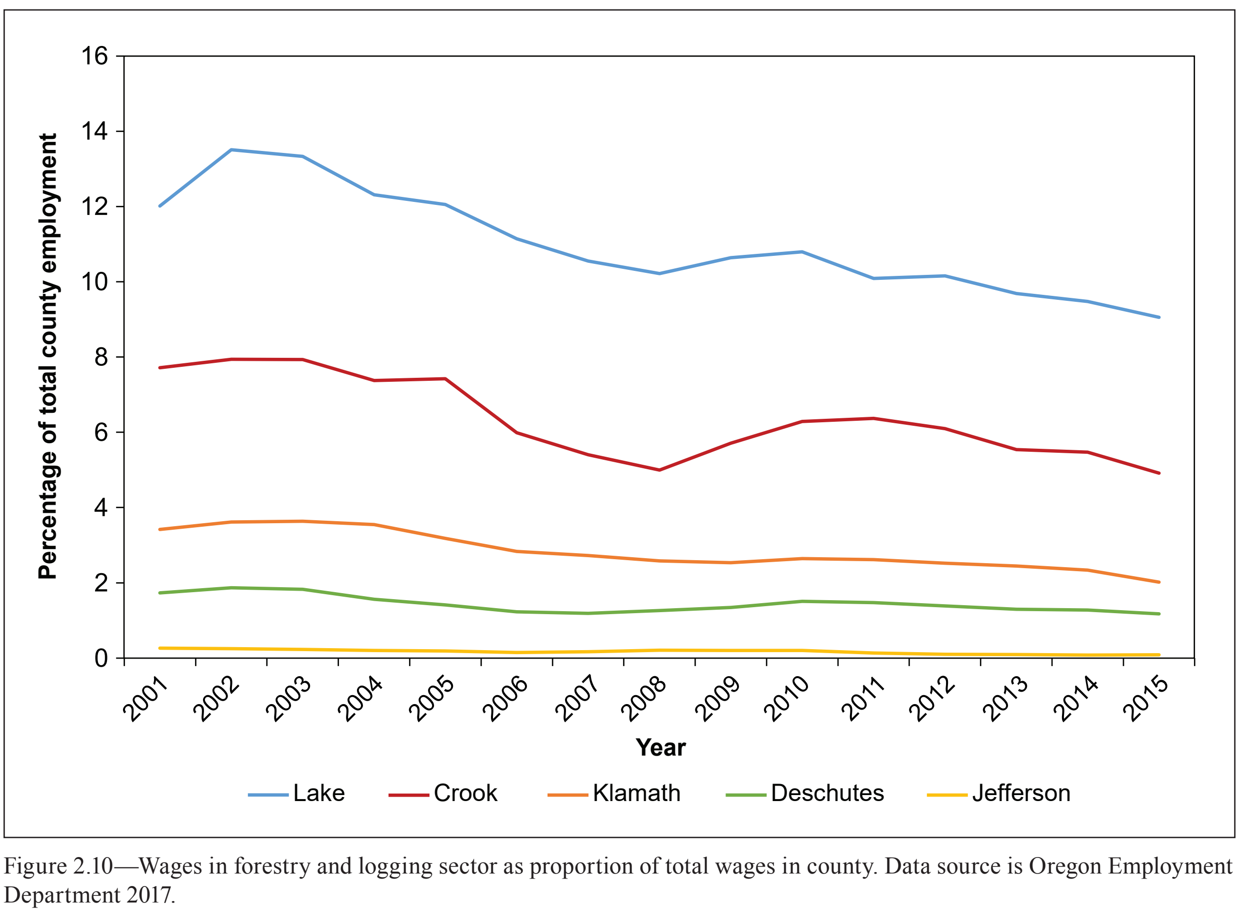

Figure 2.10—Wages in forestry and logging sector as proportion of total wages in county. Data source is Oregon Employment Department 2017.

Natural Resource Management Issues

Multiple-use management is the overarching directive in national forests and national grasslands, where programs focus on forest products, range, wildlife habitat, stream restoration and fisheries, recreation, and wilderness. Resource preservation and visitor enjoyment are the primary focus at Crater Lake National Park.

Many environmental and economic issues related to management of natural resources exist in south-central Oregon. The decline of a formerly strong timber economy has led to the closure of many wood processing mills and the loss of jobs; further mill closures would make it difficult to continue to use logging as a forest restoration tool. At the same time, protection of remaining old forests and old trees for ecological values and habitat for species such as the northern spotted owl has gained regional and national attention. The Northwest Forest Plan (USDA FS and USDI BLM 1994) and the USFS "Eastside Screens" (USDA FS 1994) provide guidance for management of forests in this region, with a focus on maintaining and restoring late-seral structure, including restrictions in areas that can be actively managed for timber, and limits on tree size for harvest.

Several large wildfires have occurred in Oregon in the 2000s, their severity enhanced by fuel accumulations after several decades of fire exclusion. These fires have threatened local communities, degraded air quality, and damaged habitat quality for northern spotted owls and other species. Large fires have often been accompanied by high suppression costs for federal and state agencies. Use of thinning and fuels treatments have been used to begin restoration of low-severity fire regimes in dry forests, a major goal of federal forest resource management. The spread of nonnative species has altered the structure and function of shrub-steppe systems and some open forests, making restoration more difficult, especially at lower elevations (more arid).

Restoration of aquatic and riparian systems has also been a significant management challenge in the SCOAP assessment area, because many streams have degraded riparian areas and barriers to native fish passage, making it difficult to recover populations of native salmonids and other species (fig. 2.11). Overallocation of water, especially in the Klamath Basin, has been a major sociopolitical issue during the past 20 or more years, creating competition and conflict over water between agriculture and fisheries interests. Maintenance of mule deer populations has been difficult because of increased highway mortality and poaching. Increased recreation throughout the region, especially in Deschutes National Forest, is placing additional stress on facilities for which carrying capacity has not been quantified. Collaboration between federal agencies and a wide range of stakeholders has become common practice in recent years, facilitating long-term solutions for many of these issues.

U.S. Forest Service, Ochoco National Forest

Figure 2.11—Stream restoration, shown here in Ochoco National Forest, is helping to improve fish habitat and maintain water within riparian systems for a longer period of time.

Acknowledgments

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Chapter 3: Climate Change in South-Central Oregon

John B. Kim, Becky K. Kerns, Jessica E. Halofsky, and Michelle Day[1]

Historical and Current Climate in South-Central Oregon

The South-Central Oregon Adaptation Partnership (SCOAP) region contains highly varied topography and climate. The region extends from the high elevations west of the crest of the Cascade Range (typical elevations of 1500 to 1800 m, with Mount Jefferson at 3171 m), eastward to the John Day basin (typical elevations <500 m), with several smaller mountain ranges in the south and east (fig. 3.1A) (see chapter 2 for detailed physiographic descriptions). The SCOAP assessment area spans two climate divisions defined by the National Climatic Data Center (fig. 3.1). The heart of the assessment area coincides with the High Plateau climate division, which encompasses the majority of Fremont-Winema National Forest and Crater Lake National Park. The remaining SCOAP assessment area (the northern half of Deschutes National Forest and the southern lobe of Fremont-Winema National Forest) is located in the South Central climate division.

The High Plateau climate division has generally cold winters and warm summers. On average (1970–1999), the daily minimum temperature is below freezing from October to April, whereas the daily maximum temperature can reach well above 20 °C in summer months (figs. 3.1C and 3.2A). The mean annual temperature across the entire climate division is 6.2 °C, but temperatures in the climate division vary widely. The highest elevation and coolest weather station is Crater Lake, with average maximum temperatures ranging from a high of about 20 °C in summer to lows below 0 °C in winter. Summer Lake and Fremont are the warmest weather stations during the summer, with mean maximum July temperatures of 29.6 and 29.1 °C, respectively (Taylor and Bartlett 1993).

Precipitation in the High Plateau climate division follows a typical Mediterranean pattern, with dry summers and wet winters (fig. 3.2B). The mean annual precipitation (1970–1999) of the division is 686 mm, and given the generally high elevation and cold winters, a large amount of precipitation falls as snow. The Cascade crest is lower in elevation in the High Plateau region compared to most

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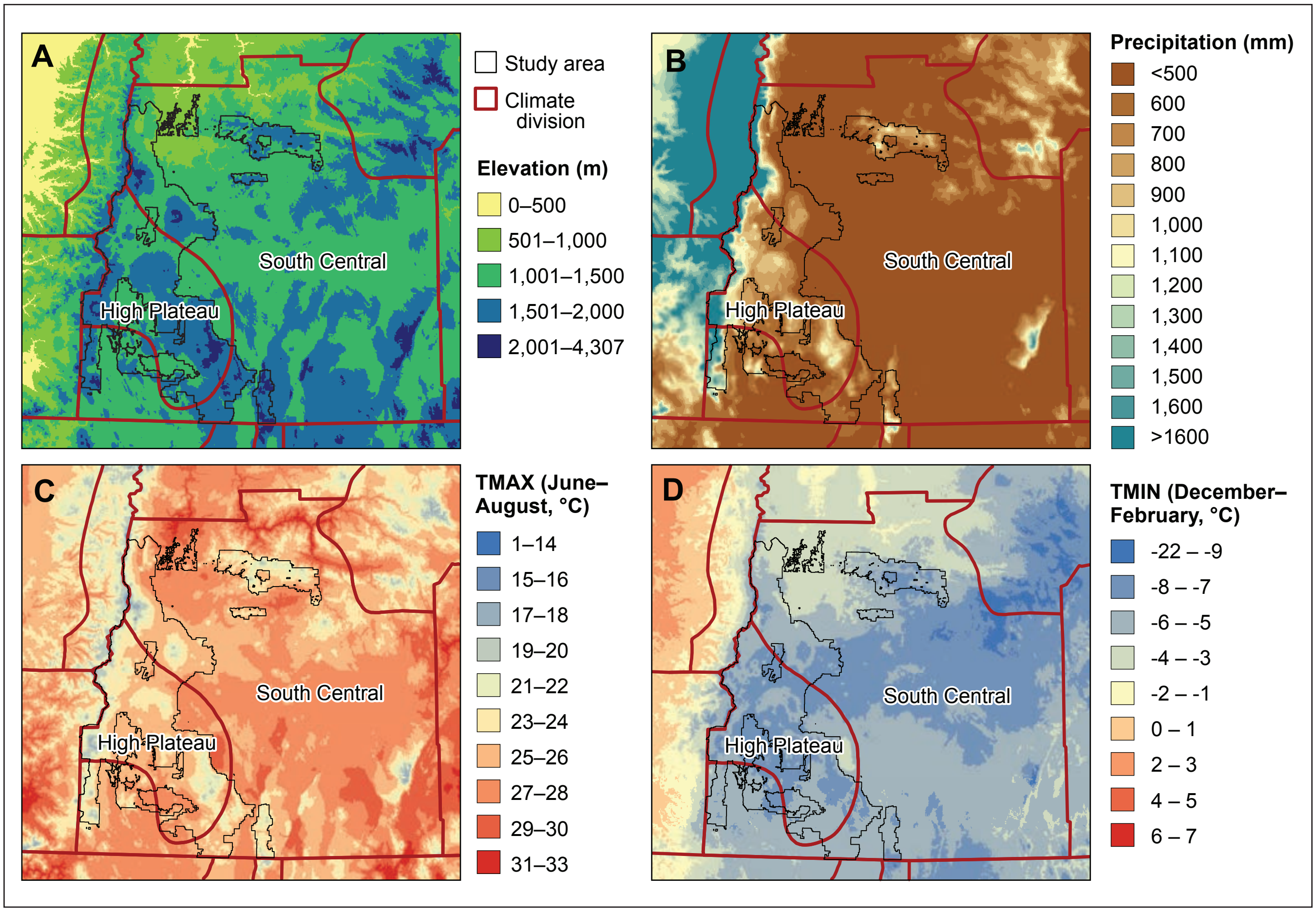

Figure 3.1—Elevation and climate for south-central Oregon: (A) PRISM data (Daly et al. 2001) were used to plot elevation (m), (B) mean annual precipitation, (C) mean daily maximum temperature (TMAX) for June–August, and (D) mean daily minimum temperature (TMIN) for December–February for the 1970–1999 period. The South-Central Oregon Adaptation Partnership assessment area and National Climatic Data Center climate division boundaries are overlaid.

parts of Oregon, so the rain shadow effect is less pronounced (Taylor and Bartlett 1993). As the name implies, the High Plateau is also higher in elevation than other typical areas of the northern and central Oregon Cascades; lower elevations of the High Plateau average 1675 m, whereas comparable areas farther north are typically 600 to 1200 m (Taylor and Bartlett 1993). For these reasons, average annual precipitation is generally higher on the plateau than the surrounding lower elevation areas (figs. 3.1A and 3.1B). However, precipitation depends on elevation and west-east orientation. Crater Lake, in the west, receives an average of 1650 mm per year, whereas Summer Lake and Fremont to the east receive only 300 mm (Taylor and Bartlett 1993).

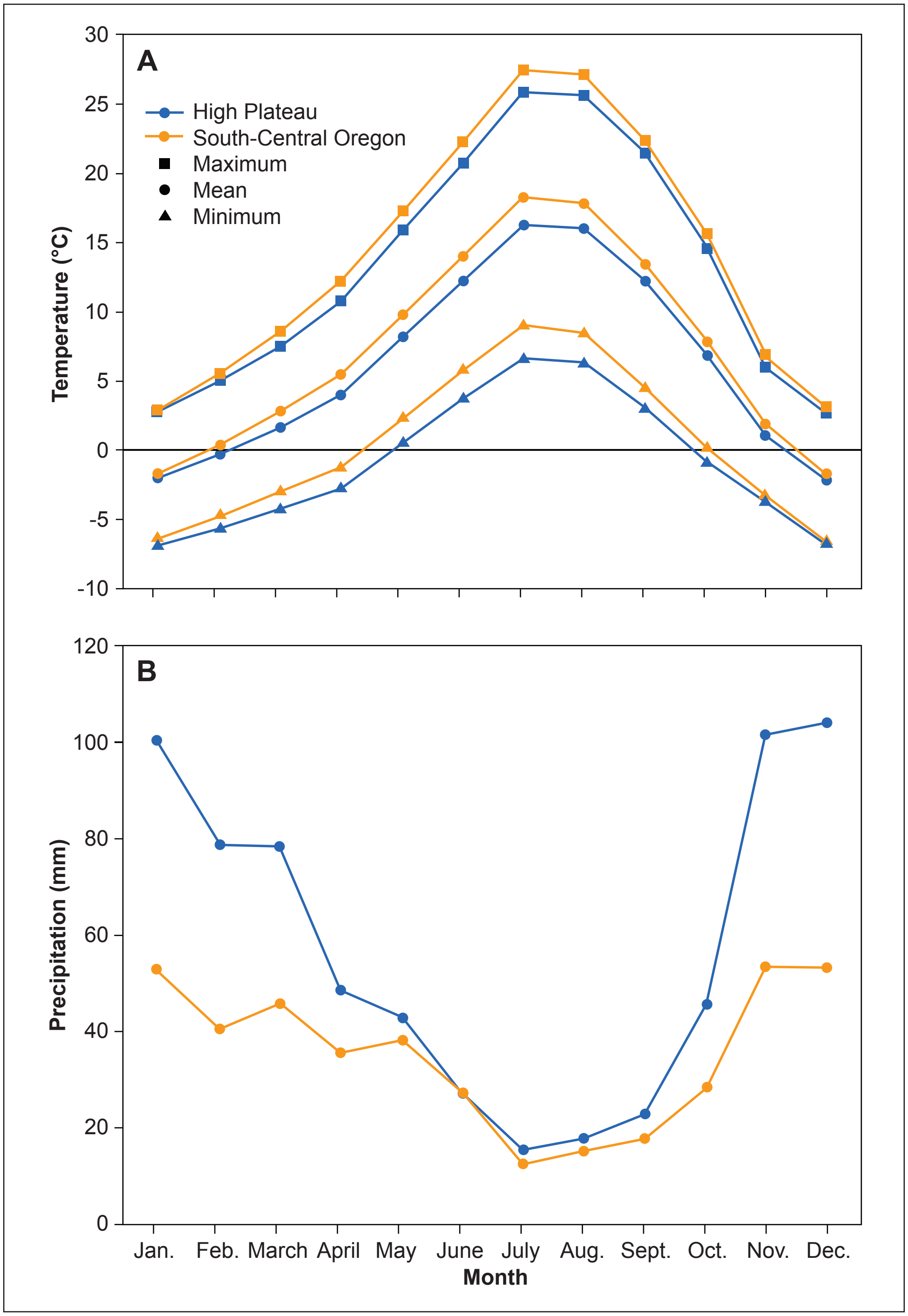

Figure 3.2—Mean monthly (A) temperature and (B) precipitation of the High Plateau and South Central climate divisions, 1970–1999. Climate divisions are defined by the National Climatic Data Center, and the two climate divisions encompass all of the South-Central Oregon Adaptation Partnership assessment area.

The South Central climate division, which includes parts of Deschutes National Forest, Crooked River National Grassland, and Ochoco National Forest, is somewhat warmer than the High Plateau climate division, with a mean annual temperature of 7.4 °C. The average daily minimum temperature in the climate division is below freezing from November to April (figs. 3.1D and 3.2A), whereas the average daily maximum temperature reaches well above 20 °C in the summer months (figs. 3.1C and 3.2A).

The South Central climate division is significantly drier than the High Plateau because of its position in the rain shadow of the Cascade Range. The mean annual precipitation of the South Central climate division is only 418 mm. The winter (December–February) precipitation in this climate division is about half of that in the High Plateau (fig. 3.2B). However, there is a sharp precipitation gradient, and high-elevation sites receive significantly more precipitation, up to 1900 mm (Western Regional Climate Center 2016) (fig. 3.1B). As with the High Plateau climate division, summers are dry, with only 10 percent of total annual precipitation falling in the summer months (Western Regional Climate Center 2016) (fig. 3.2B). Thunderstorms occur an average of 12 to 15 days a year in the region, most frequently in the mountain areas, where the accompanying lightning can ignite forest fires (Western Regional Climate Center 2016).

We used PRISM data (Daly et al. 2001) to explore trends in historical temperature and precipitation in the SCOAP assessment area. PRISM data are gridded, allowing climate estimates for points some distance from weather stations and for regional summaries and maps to be produced. For large basins, PRISM and U.S. Historical Climatology Network station analysis produce similar trends (Small et al. 2006). PRISM data may show artificial increases in minimum temperature at high elevations for the 1981–2010 period (Oyler et al. 2015). Thus, some of our analysis for high-elevation bands should be interpreted with caution. However, we use other metrics to explore historical trends (e.g., maximum and mean annual temperature in figs. 3.1 and 3.2).

Temperatures in the SCOAP assessment area have increased since 1895. Mean annual temperature for the region, based on PRISM data, has increased by 0.053 °C per decade between 1895 and 2012 (fig. 3.3A, blue line), a rate lower than the temperature trend for the Pacific Northwest region (Mote et al. 2013). There is some uncertainty associated with the drivers of historical trends in temperature, specifically the degree to which they are driven by natural climatic variation versus anthropogenic causes (Johnstone and Mantua 2014).

In contrast to temperature, trends in mean annual precipitation have been negligible since 1895 (fig. 3.3B, blue line). Interannual variability in precipitation is

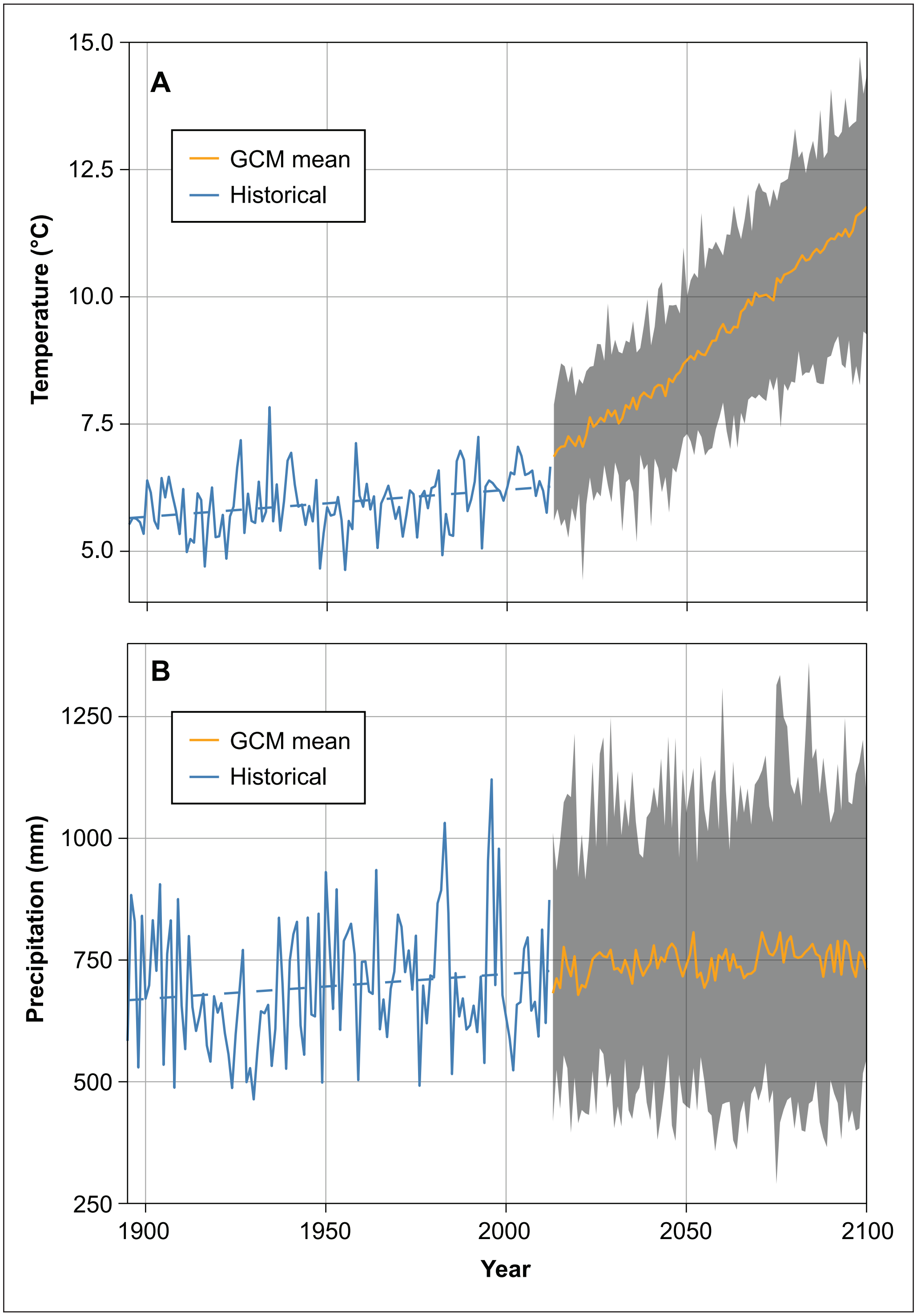

Figure 3.3—Historical and projected annual temperature (A) and precipitation (B) under the RCP 8.5 climate change scenario for the South-Central Oregon Adaptation Partnership assessment area. Historical values were calculated from PRISM (Daly et al. 2001). Dashed lines are fitted to the historical time series, and have a slope of 0.0053 for temperature (R2 = 0.10) and 0.5132 for precipitation (R2 = 0.02). Future projections were calculated from 31 global climate models (GCMs) in the NASA NEX-DCP30 downscaled climate dataset (Thrasher et al. 2013). Gray areas show the range of future projections, and the orange lines represent the mean of the 31 GCMs.

high, driven by synoptic or global-scale mechanisms such as the El Niño Southern Oscillation (ENSO) (Mote et al. 2013). Climate datasets, including PRISM, rely on weather stations, more of which are located at low rather than high elevations. Luce et al. (2013) documented that precipitation in many high-elevation areas of the Pacific Northwest has decreased since 1950, potentially because decreased winter westerly winds have reduced orographically enhanced rainfall. The analysis by Luce et al. (2013) suggests that these trends may apply in some parts of the SCOAP assessment area.

Projected Future Climate in South-Central Oregon

To explore a range of possible future climate for the SCOAP assessment area, we used the NASA NEX-DCP30 dataset. The NEX-DCP30 dataset comprises future climate projections produced by 31 global climate models (GCMs) downscaled to 30 arc-second resolution (approximately 800 m) for the conterminous United States by using a statistical downscaling method (Thrasher et al. 2013). The 31 GCM outputs that comprise NEX-DCP30 are from the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al. 2012), and includes Representative Concentration Pathways (RCPs) 4.5 and 8.5 (van Vuuren et al. 2011), a subset of the most recent set of climate change scenarios published by the Intergovernmental Panel on Climate Change (IPCC). RCP 4.5 represents a future with significant reduction in global greenhouse gases and climate stabilization by year 2100, whereas RCP 8.5 represents a future without a coordinated climate change mitigation policy in place, and population and greenhouse gas emissions continue to increase to the end of the 21st century.

Statistical downscaling methods require an observational climate dataset to calibrate the future projections. The NEX-DCP30 dataset used the PRISM gridded climate dataset (Daly et al. 2001) as the reference dataset in the downscaling process. In this chapter, we also used PRISM to characterize the climate of the SCOAP assessment area during the recent past (see previous section). For future projections, we show the projected change between historical and future climate (the "delta" method), and thus these projections are not affected by the warming bias in PRISM (Oyler et al. 2015).

For the SCOAP assessment area, the downscaled climate projections under RCP 8.5 portray a significant departure in mean annual temperature from the recent historical range of values (fig. 3.3A). PRISM data show a mean annual temperature of 6.0 °C for the 1970–1999 period. Under RCP 8.5, the mean annual temperature of the SCOAP assessment area is projected to range from 8.7 to 12.2 °C for the 2070–2099 period, with 10.8 °C as the mean of all the projections.

Past and future trends for precipitation in the SCOAP assessment area are less clear. PRISM data show that mean annual precipitation is 741 mm for 1970–1999. There is no clear consensus among the GCMs on the direction of change for future precipitation; 22 of the 31 GCMs project an increase in precipitation, and 9 project a decrease. Mean annual precipitation is projected to range from 616 mm to 945 mm under RCP 8.5, with an ensemble average of 765 mm.

For the remainder of this report, we limit our analysis to the RCP 8.5 emission scenario. This scenario serves as a "business as usual" benchmark, a future with no globally coordinated greenhouse gas mitigation. Although temperature projections under RCP 4.5 initially track closely to RCP 8.5 (fig. 3.4), the projected warming diverges from the RCP 8.5 emission scenario around the year 2040, with significantly less warming than the RCP 8.5 scenario by the end of the century. Characteristics of projected changes in precipitation are similar under RCP 4.5 and RCP 8.5, with high interannual variability and a negligible long-term trend.

Projections from the 31 GCMs in the NEX-DCP30 dataset display a significant amount of variability. To examine this variability, we plotted the projected change in mean annual temperature and mean annual precipitation by the end of the century (2070–2099) relative to a recent historical period (1970–1999) (fig. 3.5). Thirty of the 31 GCMs that comprise NEX-DCP30 were evaluated and ranked by Rupp et al. (2013) for their ability to reproduce various characteristics of the recently observed climate of the Pacific Northwest (table 3.1). Although there is high variability in the projected climates, the GCMs ranked higher by Rupp et al. (2013) generally project warmer and wetter climates under RCP 8.5 (fig. 3.5). The GCMs in the lowest quartile of the rankings projected less warming by the end of the century, or relatively high warming but with a greater than 10 percent reduction in precipitation.

Although there are some benefits to considering all 31 GCMs as an ensemble, the high number of projections in the ensemble makes it challenging to explore the possible effects of future climate. Therefore, we selected projections from five GCMs as case studies (table 3.2), spanning the range of potential future climate conditions in terms of mean annual temperature and precipitation, while favoring GCMs ranked high for their model skills (Rupp et al. 2013).

The CESM1(CAM5) model was selected because the future change in annual precipitation and temperature is nearest the mean of the entire ensemble. It was also ranked as having the best performance in the Northwest (Rupp et al. 2013). BNU-ESM simulated future climate is hotter than the ensemble mean, without a significantly different mean annual precipitation (termed the "hot" model). CanESM2 simulated future climate is hotter and wetter than the ensemble mean (termed the

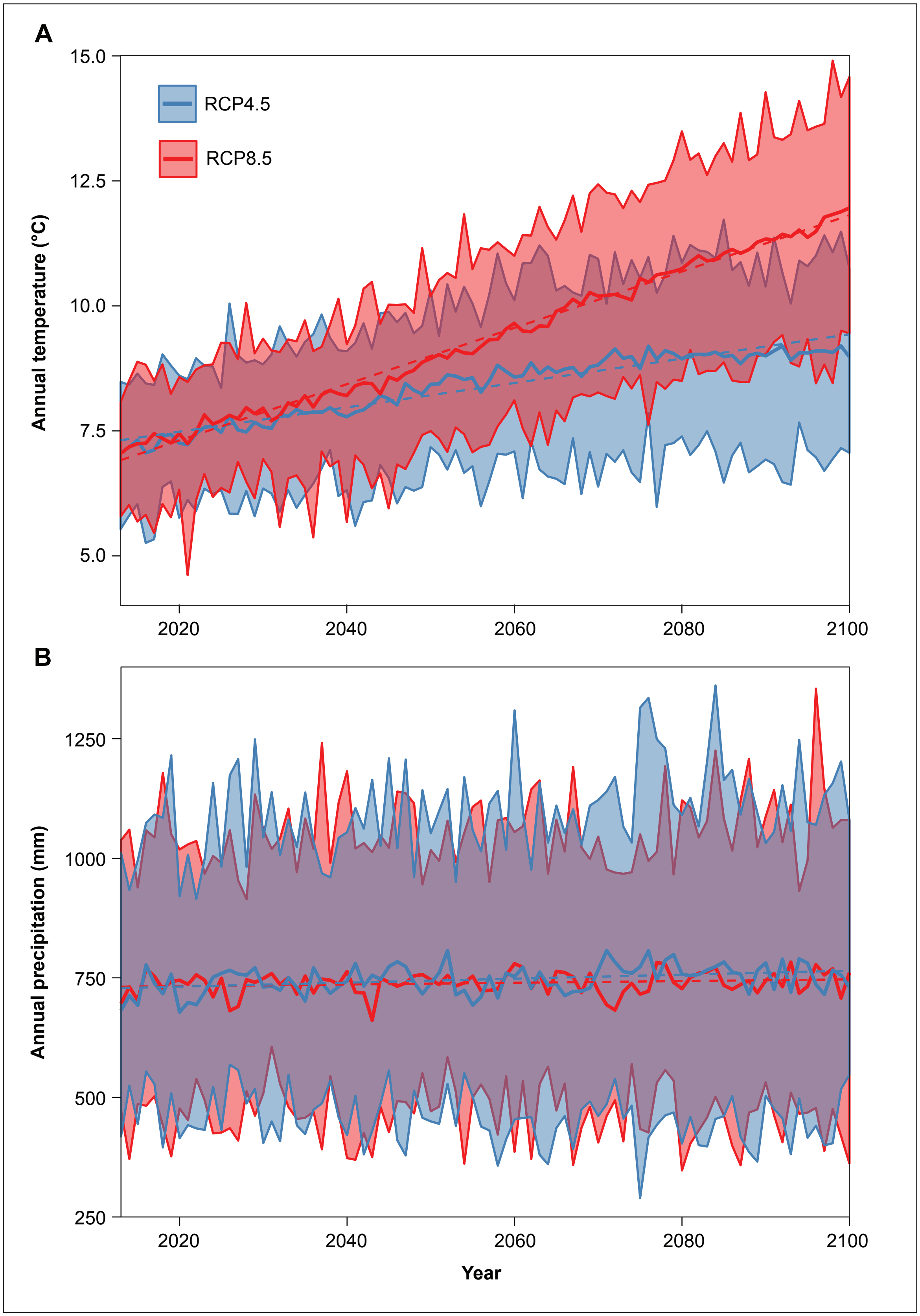

Figure 3.4—A comparison of RCP 4.5 and RCP 8.5 emission scenarios for the South-Central Oregon Adaptation Partnership assessment area. Projected annual temperature (A) and precipitation (B) were calculated from 31 global climate models in the NASA NEX-DCP30 downscaled climate dataset (Thrasher et al. 2013, van Vuuren et al. 2011). Dashed lines are fitted to the annual time series.

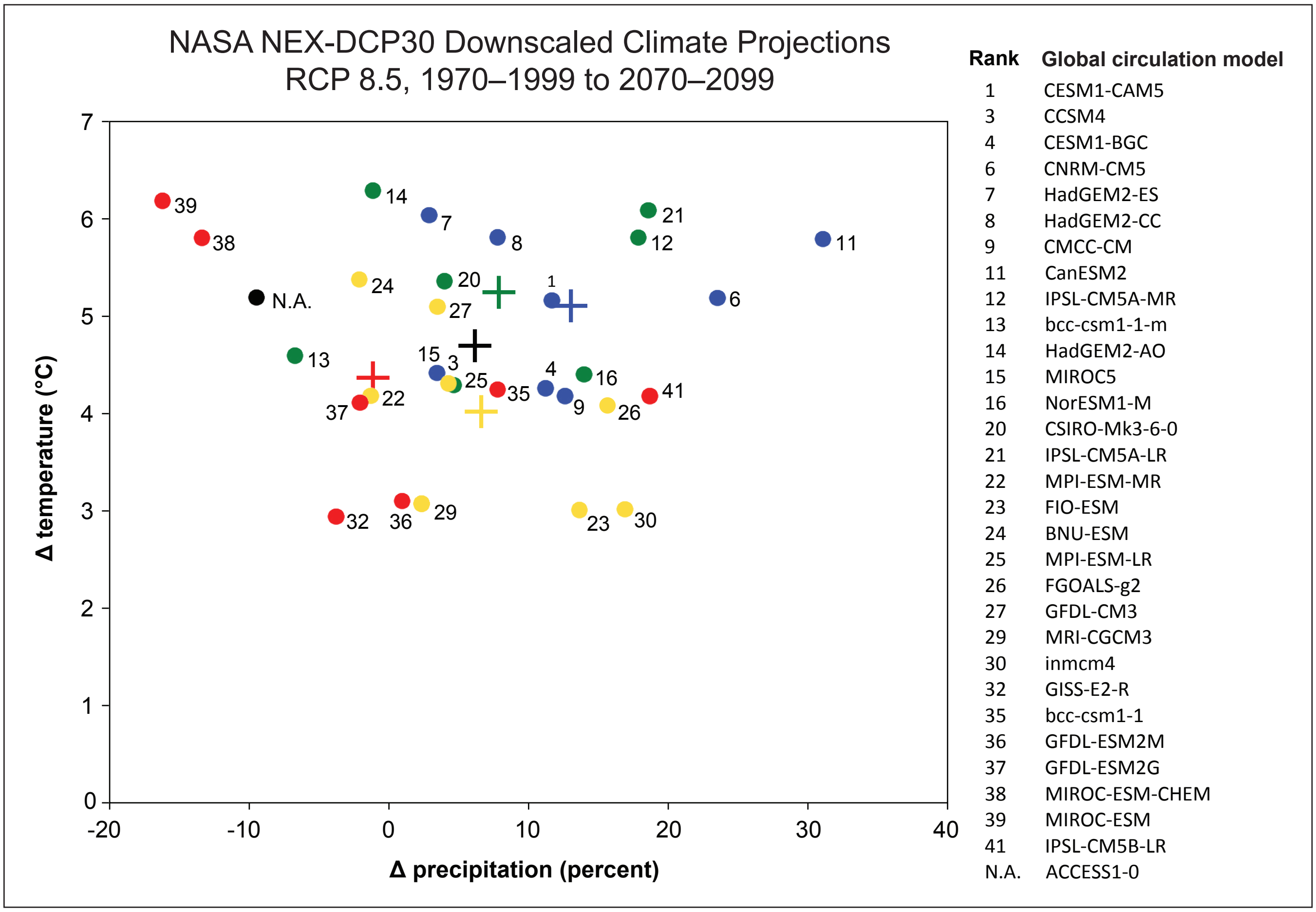

Figure 3.5—Projected change in average annual temperature (ΔT) and average annual precipitation (ΔP) from 31 global climate models (GCMs) between the 2070–2099 and the 1970–1999 periods for the Pacific Northwest (Oregon and Washington); ΔT and ΔP were calculated using the NASA NEX-DCP30 climate dataset (Thrasher et al. 2013). GCMs are ranked according to model skill for simulating historical climate of the Pacific Northwest region (Rupp et al. 2013). The circles representing GCMs are colored per quartile of model skill: blue, green, yellow, and red circles represent quartiles of ranking from the highest to lowest, respectively. Plus symbols are the means of each quartile group of GCMs. The black plus symbol represents the mean of the entire set. ACCESS1-0 GCM was not evaluated in Rupp et al. (2013).

Table 3.1—Ranking of general circulation models (GCMs) that comprise the NEX-DCP30 dataset

Rank	GCM	Rank	GCM	Rank	GCM
1	CESM1(CAM5)	14	HadGEM2-AO	27	GFDL-CM3
3	CCSM4	15	MIROC5	29	MRI-CGCM3
4	CESM1-BGC	16	NorESM1-M	30	inmcm4
6	CNRM-CM5	20	CSIRO-Mk3-6-0	32	GISS-E2-R
7	HadGEM2-ES	21	IPSL-CM5A-LR	35	bcc-csm1-1
8	HadGEM2-CC	22	MPI-ESM-MR	36	GFDL-ESM2M
9	CMCC-CM	23	FIO-ESM	37	GFDL-ESM2G
11	CanESM2	24	BNU-ESM	38	MIROC-ESM-CHEM
12	IPSL-CM5A-MR	25	MPI-ESM-LR	39	MIROC-ESM
13	bcc-csm1-1-m	26	FGOALS-g2	41	IPSL-CM5B-LR

Note: The GCMs are ranked according to their capacity to simulate the historical climate of the Pacific Northwest region (Rupp et al. 2013). ACCESS1-0 was not evaluated in Rupp et al. (2013). Some GCMs evaluated in Rupp et al. (2013) are not included in NEX-DCP30.

Table 3.2—Five downscaled global climate model (GCM) outputs selected for analysis

GCM	Rank	Average temperature change	Average precipitation change	Representative case
		°C	*Percent*	
CESM1(CAM5)	1	5.2	11.7	Near mean
CanESM2	11	5.8	31.1	Hot-wet
BNU-ESM	24	5.4	-2.1	Hot
MIROC-ESM-CHEM	38	5.8	-13.4	Hot-dry
MRI-CGCM3	29	3.1	2.3	Warm

Note: ranking of models is from Rupp et al. (2013), and reflects overall model performance for simulating historical climate of the Pacific Northwest. Projected average change in temperature and precipitation were calculated as the difference between the climate of 2070–2099 and 1970–1999 for the South-Central Oregon Adaptation Partnership region under the RCP 8.5 climate change scenario. Representative case indicates the relative characteristics of the GCM among the 31 GCMs.

“hot and wet” model). MIROC-ESM-CHEM simulated future climate is hotter and drier (i.e., there is significantly lower mean annual precipitation) than the ensemble mean (termed the “hot and dry” model). This is the only model selected that was in the bottom rankings according to Rupp et al. (2013), but it does represent a very dry future that we wanted to explore. MRI-CGCM3 simulated future climate is approximately 2 °C cooler than the ensemble mean, projecting the least amount of warming of all the models selected, with little change in precipitation (termed the “warm” model).

Focusing on five GCMs allows us to contemplate a possible future climate in some level of detail, rather than focusing on the average characteristics of the ensemble of GCMs. The five GCMs are not necessarily the **probable** future climate projections, because the evaluation of the GCMs does not provide probabilities of correctness. Furthermore, the IPCC does not assign probabilities to the RCP scenarios, because future socioeconomic pathways of energy use and mitigation activities are unknown.

Seasonal Patterns of Climate Change

By the end of the century, all five of the selected GCMs project warming in every month of the year (fig. 3.6A). Mean monthly temperatures are projected to rise significantly, with most of the GCMs projecting the most warming in June and July. For example, CESM1(CAM5), the “near mean” GCM, projects the average July temperature to increase from a historical mean of 15.9 to 22.5 °C by the end of the century. The average daily maximum temperature is projected to increase from an average of 22.4 to 26.8 °C by the end of the century. The “warm” GCM, the MRI-CGCM3, projects less warming than the other four GCMs, with summer (June-July-August) average temperatures warming only about half as much as projected by the “hotter” GCMs.

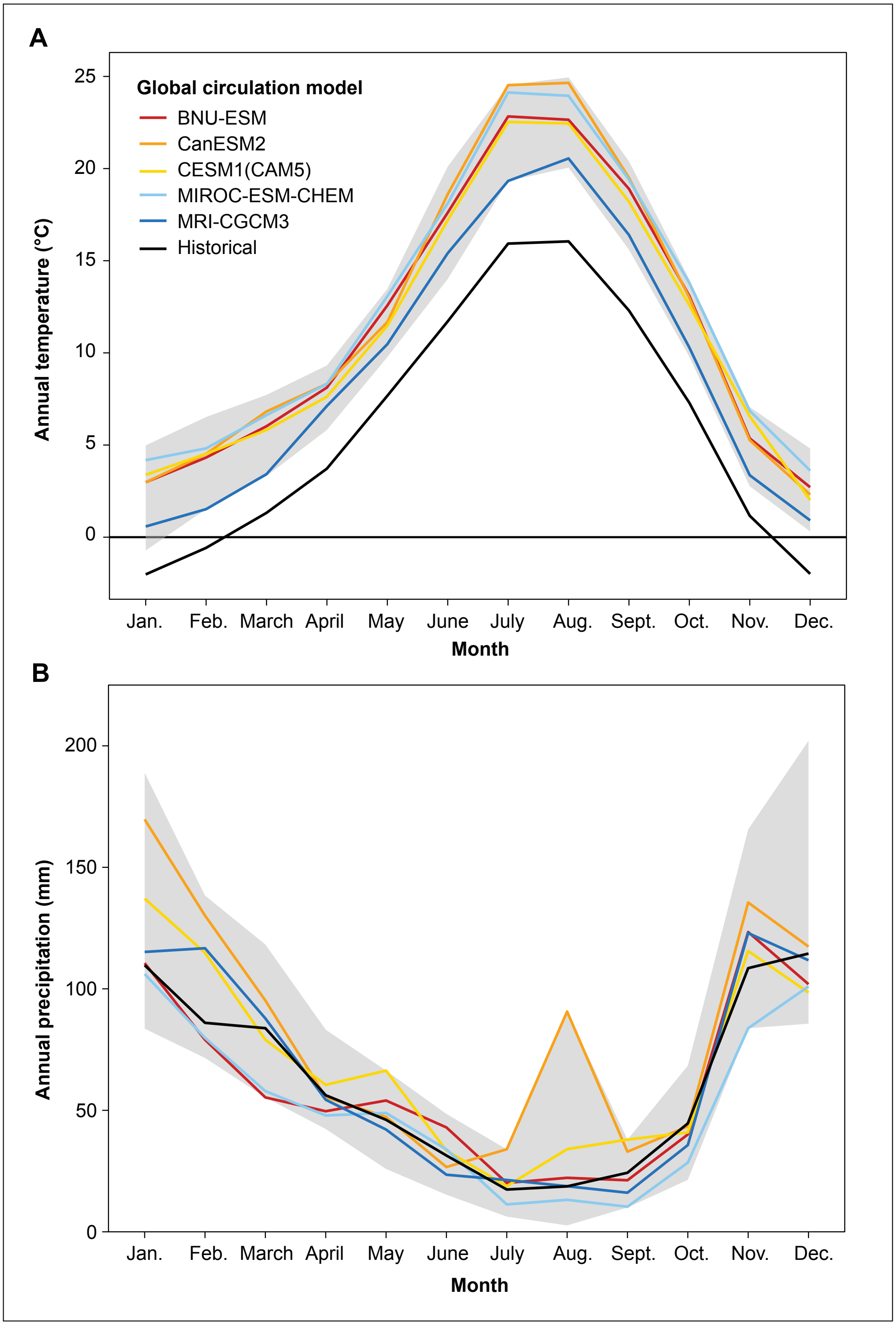

Figure 3.6—Historical and projected monthly mean temperature (A) and mean precipitation (B) patterns under the RCP 8.5 climate change scenario. Black lines represent historical values, calculated from PRISM (Daly et al. 2001). Future projections were calculated from 31 global climate models (GCMs) that comprise the NASA NEX-DCP30 climate dataset (Thrasher et al. 2013). Gray bands represent the minimum and maximum values across all 31 GCMs (listed in table 3.1). The five selected GCMs explored in this chapter are shown as colored lines.

All GCMs project an increase in the seasonal amplitude of precipitation, with more precipitation during December through March, and less precipitation during the growing season (April through October) (fig. 3.6B). This is similar to projections for the entire Pacific Northwest region under RCP 8.5, in which models simulate decreases in summer precipitation (Mote et al. 2013). For the SCOAP assessment area, winter (December–February) precipitation is projected to increase 10 percent under the "near mean" CESM1(CAM5) GCM, and as much as 40 percent under the "hot-wet" CanESM2 GCM, by the end of the century. For summer (June–August), the "near mean" CESM1(CAM5) GCM projects insignificant change (0.7 mm) by the end of the century (2070–2099), whereas the "hot-dry" MIROC-ESM-CHEM GCM projects 10 mm (15 percent) reduction. The "hot-wet" CanESM2 GCM also projects a strong increase in August precipitation (fig. 3.6B); it projects 74.1 mm average precipitation for August, in contrast to 18.7 mm for the other models, suggesting that the GCM is simulating a unique synoptic-scale moisture transport mechanism for the region. This projection may be an outlier, although Rupp et al. (2013) rated this GCM as the eleventh best of 31 models for the Pacific Northwest.

Elevation-Based Differences in Climate Change

Elevation within the SCOAP assessment area varies widely, from less than 500 m in the John Day Basin to 3171 m at the top of Mount Jefferson. Historical climate varied according to elevation, and climate change is also projected to vary with elevation (fig. 3.7). Historical (1970–1999) temperature and precipitation data from PRISM (Daly et al. 2001) agree with the historical portions (1970–1999) of the five selected downscaled GCM climate projections (figs. 3.7A and 3.7C), with the GCM-based data underestimating both mean annual temperature and precipitation at high elevations (2400 to 3000 m) relative to PRISM. However, when the temperature data are converted into growing season length, in which any month with a positive mean temperature is included in the growing season, growing season-length estimates at the two highest elevations diverge significantly between PRISM and the five selected GCMs (fig. 3.7E).

Projected change in mean annual temperature varies little among the elevation bands for a given GCM, with differences less than 0.2 °C (fig. 3.7B). However, projected changes in mean annual precipitation vary widely among the five selected GCMs (fig. 3.7D). Where the GCMs have a "wet" or a "dry" bias, the biases are accentuated in the middle-elevation bands. For example, with the "hot-wet" GCM (CanESM2), mean annual precipitation is projected to increase 12 to 16 percent by the end of the century at elevations between 1200 and 2700 m, whereas the projected increase is only 9 percent at lower and higher elevations. In other words, the uncertainty of precipitation change brought by climate change is particularly high

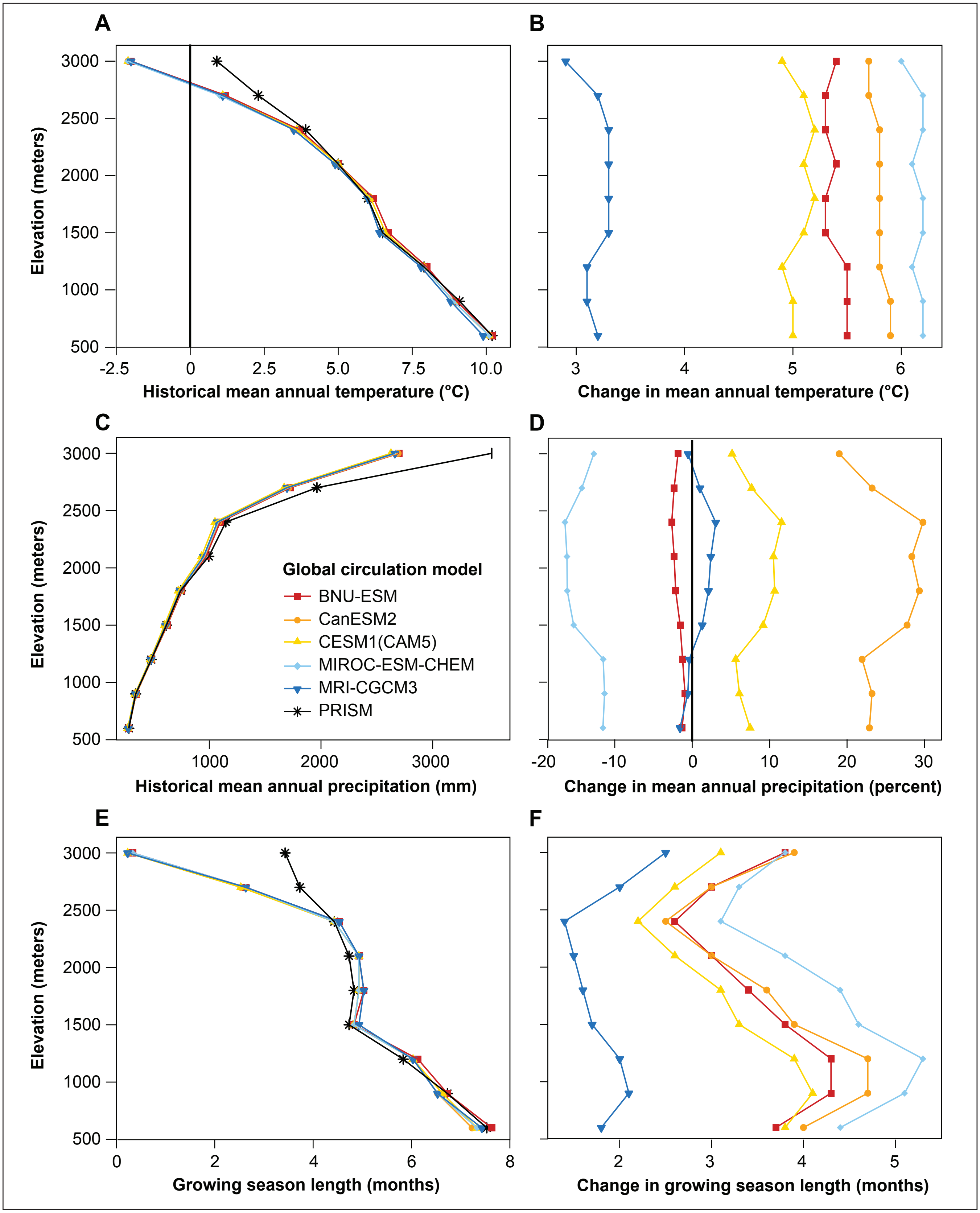

Figure 3.7—(A) Historical mean annual temperature and (B) projected change; (C) historical mean annual precipitation and (D) projected change; (E) historical growing season length and (F) projected change for the South-Central Oregon Adaptation Partnership (SCOAP) assessment area for five selected global climate models. The historical period is 1970–1999, and changes were calculated for 2070–2099 relative to the historical period. Historical values were calculated from PRISM (Daly et al. 2001), and future projections were calculated from the NASA NEX-DCP30 downscaled climate dataset (Thrasher et al. 2013) for the RCP 8.5 climate change scenario (van Vuuren et al. 2013). The SCOAP assessment area was divided into elevation bands in 300-m increments.

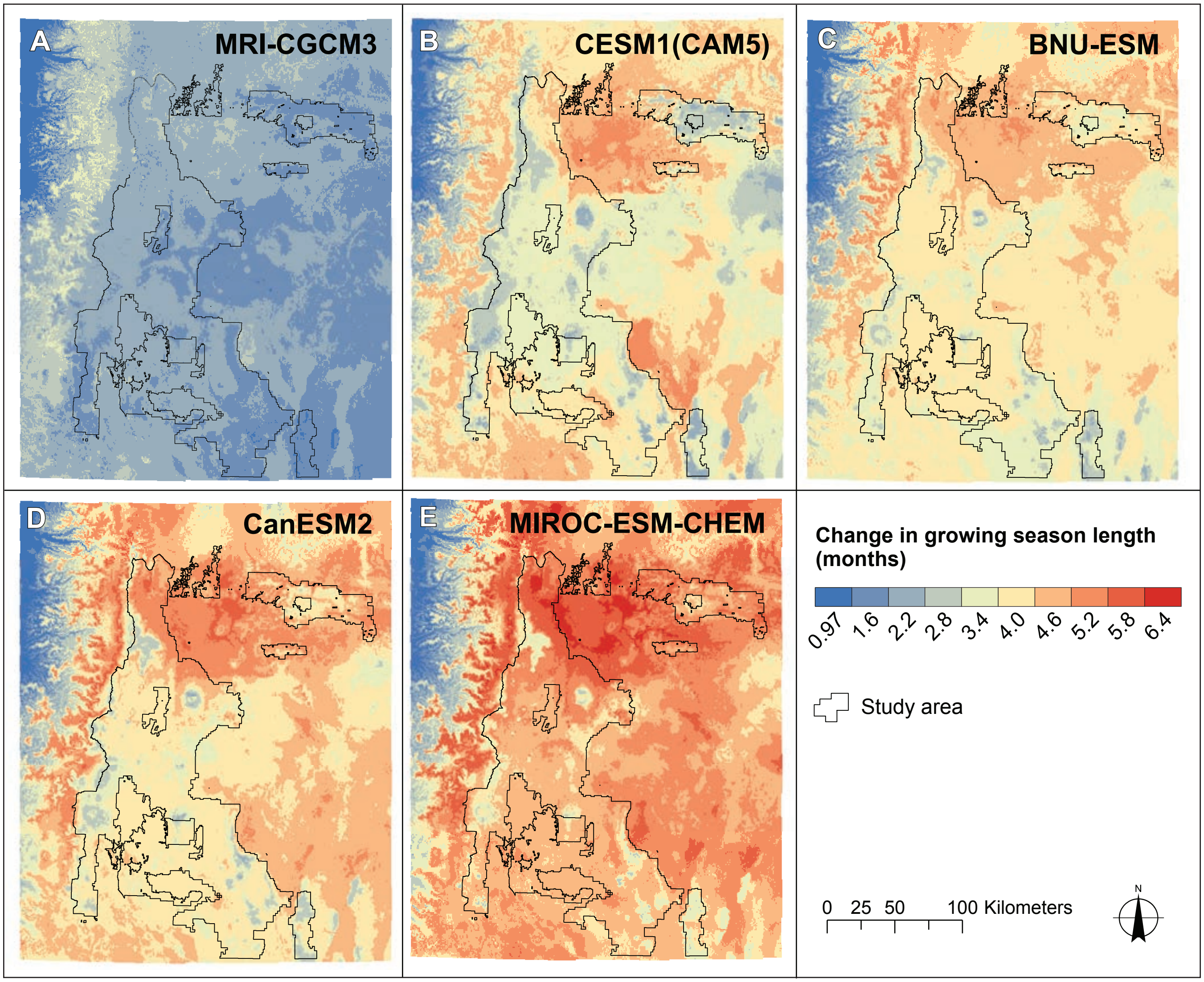

Figure 3.8—Change in growing season length (GSL) from the historical period (1970–1999) to the end of the century (2070–2099) under the RCP 8.5 climate change scenario for five selected global climate models for the South-Central Oregon Adaptation Partnership assessment area. Growing season includes all months with mean daily minimum temperatures greater than 0 °C.

at these middle elevations. About 91 percent of the SCOAP assessment area lies between 1200 and 2100 m elevation.

The projected changes in temperature under the RCP 8.5 scenario are particularly striking when interpreted as changes in growing season length, for which the largest increases are projected for lower elevations and the Cascade Crest, with growing season extending as much as 4 months (figs. 3.7F and 3.8). At middle elevation ranges (1200 to 2100 m), growing season length is projected to increase by 2.6 to 3.8 months, according to data based on the "near-mean," "hot," and "hot-wet" GCMs (CESM1[CAM5], BNU-ESM, and CanESM2, respectively). The "hot-dry" GCM (MIROC-ESM-CHEM) and the "warm" GCM (BNU-ESM) project changes that are significantly higher and lower, respectively.

Growing Degree-Days and Climatic Water Deficit

The magnitude of increased growing season under the RCP 8.5 scenario can be seen in the increases in growing degree-days (GDDs) and wet growing degree-days (WGDDs) (fig. 3.9). GDDs are defined as the mean daily temperature above a threshold-based temperature (0 °C in this case) accumulated on a daily basis over time (McMaster and Wilhelm 1997). GDDs are calculated as the product of temperature (above the threshold) and number of days. For example, if every day of the month were 10 °C, then GDDs would be 10 degrees × 31 days (310 degree-days). GDD values for the historical period (1970–1999) have good agreement for most months of the year when calculated from PRISM (Daly et al. 2001) and from the five selected GCMs (fig. 3.9A). Large increases in GDDs are projected for the future (fig. 3.9B). The "near-mean"

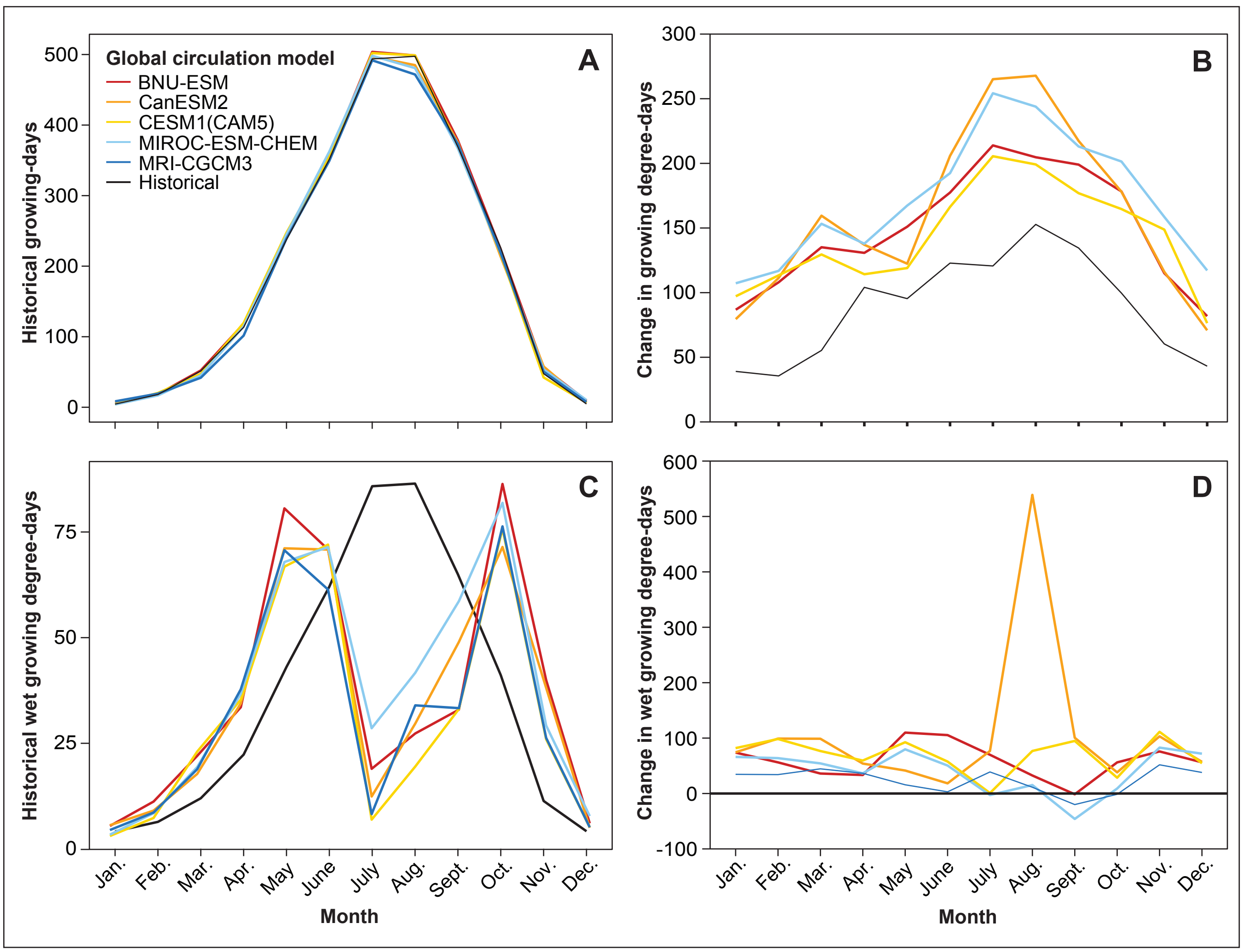

Figure 3.9—(A) Monthly growing degree-days (GDDs) and (C) wet GDDs (WGDD); (B) GDDs by elevation and (D) WGDD by elevation for five selected global climate models (GCMs) for the South-Central Oregon Adaptation Partnership assessment area. Historical values (A and C) for GDDs and WGDDs were calculated from PRISM data (Daly et al. 2001) and from MC2 dynamic global vegetation model simulations for 1970–1999. Future projections (B and D) represent the RCP 8.5 climate change scenario (van Vuuren et al. 2013) for 2070–2099.

GCM (CESM1[CAM5]) projects 76 to 113 more GDDs per month in winter (December–February), 114 to 130 more in spring (March–May), 166 to 206 more in summer (June–August), and 149 to 177 more in autumn (September–November).

Wet growing degree-days may be a better metric for locations where plant growth is limited by both temperature and moisture (figs. 3.9C and 3.9D). WGDDs are calculated the same way as GDDs, except only months with precipitation greater than 46 mm are included. The threshold of 46 mm is the average precipitation for May from 1970 to 1999 based on PRISM data. This is an arbitrary threshold, but the seasonal patterns of WGDDs and relations among the GCMs are not sensitive to this threshold. That is, the curves in figures 3-9C and 3-9D would not change their shape or positions relative to each other if a different precipitation threshold were used.

For WGDD estimates for the historical period (1970–1999), there is a disagreement between PRISM and the five selected GCMs, logically arising from the variability of precipitation estimates among the GCMs (fig. 3.9C). Historical WGDD estimates based on GCMs are significantly lower than those based on PRISM for July, August, and September. For example, the “near-mean” GCM (CESM1[CAM5]) estimates a WGDD of just 6.9 in July, whereas WGDD for July based on PRISM is 27.1. In other words, GCMs have a significant bias for simulating drier summers relative to PRISM. In any case, with the exception of the “hot-wet” GCM (CanESM2), the projected changes to WGDDs are generally consistent throughout the year, ranging between 33 and 100 more WGDDs each month (fig. 3.9D). Warmer temperature generally drives increased WGDDs, although there are some exceptions among the GCMs.

Seasonal patterns of GDDs and WGDDs under RCP 8.5 suggest that climatic conditions for plant growth may be more favorable in some locations by the end of the century. However, the warmer temperatures projected to drive these changes may also cause drought stress in plants in the summer. Climatic water deficit (CWD) represents the amount by which potential evapotranspiration (PET) exceeds actual evapotranspiration (AET), an indicator of drought stress (Stephenson 1988). We obtained PET and AET estimates for the SCOAP assessment area from MC2 dynamic global vegetation model simulations performed with PRISM and the five selected GCMs (see chapter 6), and calculated CWD as an annual value, averaged by elevation bands (fig. 3.10). As with GDDs, there was good agreement between CWD values based on PRISM and those based on the five selected GCMs at all elevations (fig. 3.9A). Under the RCP 8.5 scenario, CWD is projected to nearly double by the end of the century at most elevations (fig. 3.9B). For example, for the “near-mean” GCM (CESM1[CAM5]), CWD is projected to increase 86 to 106 percent relative to historical (1970–1999) values for elevations between 1,200 and 2,100 m. The increase in CWD may be as much as 128 to 164 percent for this same elevation band according to the “hot-dry” GCM (MIROC-ESM-CHEM).

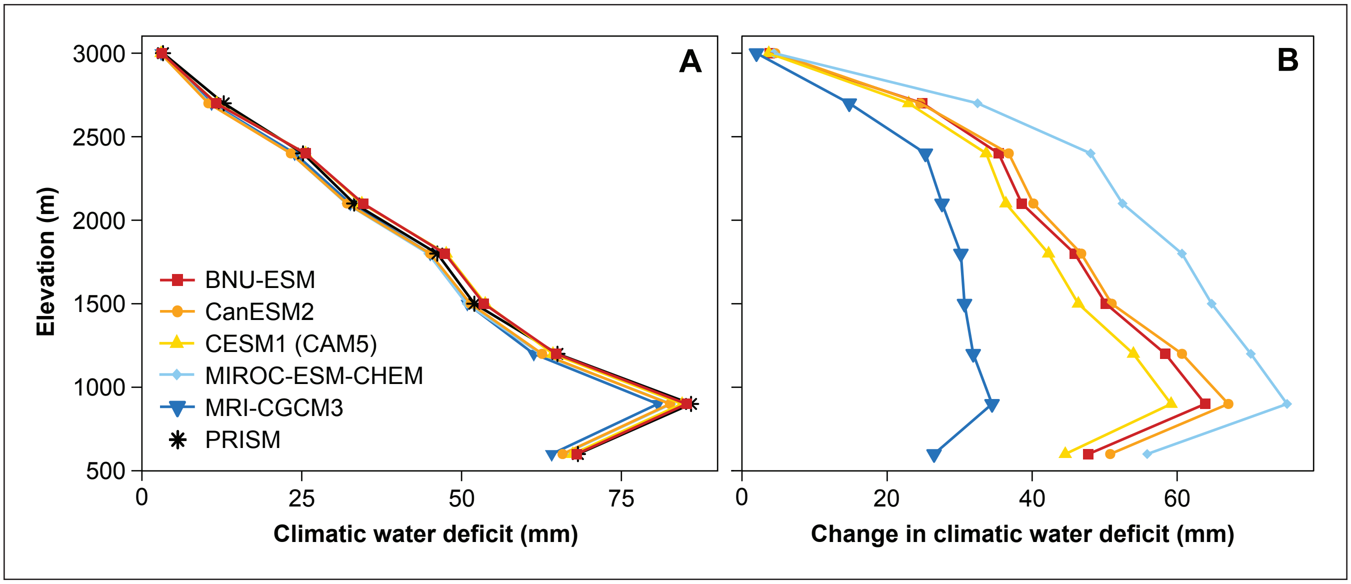

Figure 3.10—Climatic water deficit (CWD) for (A) 1970–1999 and (B) projected change in CWD based on the five selected global climate models for the South-Central Oregon Adaptation Partnership assessment area. Data for the historical period were calculated from PRISM (Daly et al. 2001) and from the MC2 dynamic global vegetation model output for 1970–1999. Future projections (B) represent the RCP 8.5 climate change scenario (van Vuuren et al. 2013) for 2070–2099.

Summary

Climate has warmed in the SCOAP assessment area over the past century, and under a no-mitigation ("business-as-usual") emission scenario (RCP 8.5), the region is projected to warm 4.7 °C by the end of the century (2070–2099) relative to a recent historical period (1970–1999). There is uncertainty in the climate change projections in terms of both the degree of warming and in the changes to precipitation, but there are no scenarios that project future cooling. Precipitation may increase modestly (~6 percent) with wetter winters and drier summers, but some GCMs project drier winters and wetter summers. Although projected changes in precipitation vary by elevation, warming temperatures are expected to extend the growing season at all elevations.

Warmer springs, autumns, and winters result in climate favorable for plant growth, with more GDDs during the year. When only WGDDs are considered, the increases are consistent throughout the year, although some GCMs that project more precipitation in historically dry months project spikes of WGDDs in those dry months. Increases in GDDs and WGDDs will be offset by increased drought stress in plants, as represented by CWD. Climate water deficit is projected to nearly double by the end of the century for most elevations in the region. These changes will affect vegetation and disturbance (chapter 6) and wildlife (chapter 7) in the SCOAP assessment area.

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Chapter 4: Climate Change, Water, and Roads in South-Central Oregon

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Introduction

Water is a critical resource in forest and rangeland environments of western North America, largely determining the distribution of plant and animal species across a broad range of elevations and ecosystems. Water is also essential for human endeavors, directly affecting where and how human communities and local economies have developed. The higher elevations of the South-Central Oregon Adaptation Partnership (SCOAP) region are an important source of water for forest ecosystems and numerous human uses, including private and municipal water supplies, industry, irrigation, livestock watering, and recreation.

Climate change will likely affect physical hydrological processes and resource values influenced by hydrological processes, including water use, infrastructure, and fish. Specifically, climate change will alter the amount, timing, and type of precipitation, and timing and rate of snowmelt (Luce et al. 2012, 2013, 2014a; Safeeq et al. 2013), which in turn, will reduce snowpack volumes (Hamlet et al. 2005) and streamflows (Hidalgo et al. 2009, Mantua et al. 2010), and increase stream temperatures (Isaak et al. 2012, Luce et al. 2014b). Changes in the amount and timing of precipitation will also affect vegetation, which will further alter water supplies (Adams et al. 2011). Reduced or less reliable water supply affects local economic activities, planning, and resource management.

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Changes in peak streamflows will likely affect roads and other infrastructure (Strauch et al. 2014), and access to national forest lands in south-central Oregon. Flooding can damage roads, bridges, and culverts, creating safety hazards, affecting aquatic resources, and incurring high repair costs. Reduced access to public lands decreases many different uses (recreation, timber harvest, livestock grazing, etc.), as well as land management functions (maintenance, fire suppression, etc.). Understanding vulnerabilities and the processes through which climate change affects hydrology will help federal land managers identify how to maintain ecosystem function, a sustainable water supply, and a sustainable road system in the face of climate change.

This chapter describes hydrologic processes and regimes in the SCOAP assessment area, historical trends in hydrologic parameters (snowpack, peak streamflow, and low streamflow), and projected effects of climate change on these hydrologic parameters. Although climate change will likely also affect vegetation with consequent changes to evapotranspiration and water availability, we do not include these cascading consequences here but focus on direct effects of climate on streamflow. The second half of the chapter describes how water supply, roads, and infrastructure may be affected by altered hydrology with climate change, in the context of current and emerging management priorities across the SCOAP landscape.

Hydrogeological Setting

The SCOAP assessment area encompasses a large and diverse landscape with a varied geological history. Ultimately, the interplay between climatic processes expressed along topographic and elevational gradients and the underlying structure and hydrologic properties of the terrain is what determines modern streamflow regimes and their likely changes in the future. Understanding how future climate could change streamflow requires an appreciation of how geology interacts with precipitation patterns to determine the rate and timing of the transformation of water from rain or snowmelt into streamflow.

The SCOAP assessment area can be divided into four distinct geological provinces having different hydrological properties: (1) the southeastern section of the Oregon High Cascades; (2) the western region of the High Lava Plains; (3) the northwestern section of the Basin and Range; and (4) the Ochoco Mountain–Blue Mountain complex. Briefly, the Oregon High Cascades represent the western margin of the assessment area and are a north-south trending range of volcanic peaks, centers, and highlands. These are young volcanic mountains composed primarily of basalt and basaltic andesite with some minor silicic centers. Most of the range is less than 8 million years old; the highest peaks are less than 2 million years old, and some of the youngest volcanoes have erupted in the past 10,000 years. Mount Mazama, whose cataclysmic eruption 7,700 years ago created the caldera that was later filled by Crater Lake, falls in this latter category, and ash from this eruptive episode blankets much of the analysis area. The Basin and Range is composed of older (10 to 20 million years old) volcanic rocks that have been deformed by north-south-trending normal faulting, leading to a varied topography of north-south mountains separated by lower elevation basins, many of which were lakes during the latest Pleistocene ice age. The High Lava Plains are generally composed of Miocene (5 to 23 million years old) flood basalts from various volcanic centers, along with more silicic rhyolite domes and ash flows. The High Lava Plains are also faulted, but generally in a more northwest-southeastern orientation. The Ochoco Mountain–Blue Mountain complex is a much older part of the landscape, with a mixed lithology of volcanic and sedimentary rocks mostly dating back 17 to 55 million years, but with some dating back 200 to 300 million years.

Understanding the geological setting is important because the geology directly influences the landscape permeability and porosity and thereby the rate that water moves through the subsurface typically through fractures. This has bearing on interpreting climate change, because the geology controls the rate that precipitation and snowmelt (recharge) is converted to streamflow (discharge) and also the ratio of surface to subsurface flow that reaches streams. In general, the older the rocks the lower the subsurface permeability and thus the more rapid transformation from recharge to discharge and the greater the proportion of surface to subsurface (groundwater) flow. This is typically reflected in the greater degree of dissection and higher stream densities in older landscapes, such as the Ochoco Mountains and Fremont-Winema uplands, where streams typically run very low by the end of summer because of a lack of groundwater. In contrast, the much younger rocks of the High Cascades are highly permeable because of voluminous fragmented, blocky lava flows, and much of the precipitation and snowmelt in this region ends up moving vertically downward into very large groundwater aquifers that drain slowly and support large spring systems. The landscape is relatively undissected, and high streamflows are extended late into summer.

With these perspectives in mind, the streamflow response to climate change across the SCOAP assessment area is easier to understand. Our analysis brings together both the climate-induced changes in precipitation regime and the underlying geology to map sensitivity to climate change across the landscape.

Streamflow Response Calculations

Climate-induced changes are estimated using the variable infiltration capacity model (VIC) (Liang et al. 1994), which calculates snow accumulation and melt, runoff generation, and evaporation on large grid cells (1/16th degree) using elevation bands and discretization across vegetation types to describe the heterogeneity within cells. The data used in this assessment are derived from VIC projections at https://cig.uw.edu/datasets/wus/. The runoff generated within VIC cells was apportioned to streams based on fractional contributions in each catchment, following Wenger et al. (2010).

The VIC model was calibrated to large watersheds, and although the groundwater parameters are some of the most important to VIC calibration (Matheussen et al. 2000), the large calibration units do little to inform local watershed groundwater behavior. Given the importance of groundwater in portions of the SCOAP assessment area to low flows, the catchment scale routing process used by Wenger et al. (2010) was modified to account for local information on groundwater storage and discharge based on the recession constant (k) of Safeeq et al. (2013, 2014). Specifically, their k values were applied to generate a unit hydrograph routing kernel by each unit for which k was calibrated. The groundwater recession properties explained in Tague and Grant (2009) and Safeeq et al. (2013, 2014) are fully consistent with the unit hydrograph approach, so the k estimates from the long summer recessions are appropriate for direct application. Mathematically, each day's runoff from VIC was apportioned as outflow timing based on each basin's k value, and the flow apportionments from each preceding day were summed to obtain the current day's streamflow.

Two approaches were used to model potential peak flow increases. First, we used a technique developed by Safeeq et al. (2015) that relies on developing statistical empirical relationships that control peak flows at the regional scale. Key predictors of peak flows include drainage area and metrics for climate, land cover, soil, and topography that were extracted using principal components analysis. Among the climate variables, a measure of the variability in the snow fraction (the proportion of total precipitation falling as snow) was used to explore how a warming climate might change the proportion of snow versus rain, hence susceptibility to rain-on-snow events. This analysis was then used to paint the landscape "wall-to-wall" in terms of likely increases to peak flows ranging from a 2- to 100-year event.

We also used the estimates of peak flow from the VIC model, which explicitly models the effects of the key variables (windspeed, air temperature, absolute humidity, intensity of precipitation) at short time scales to estimate high melt and runoff rates. For peak flows, we used the VIC outputs without benefit of considering geologic differences, as was done for low flows. Although geologically mediated flow paths do affect peak flows, the influence is reduced for peak flows in contrast to low flows, and the relationship is therefore less direct than for the relationship between low flows and the recession constant, and not easily characterized or calibrated. However, VIC outputs are informative as a measure of the degree to which rain-on-snow events are increasing midwinter flooding. Earlier use of these data showed reasonable correlations to fish distributions (Wenger et al. 2011a, 2011b) and historical flood observations (Goode et al. 2013).

Snowpack Trends

One of the principal changes expected in the hydrology of Western U.S. mountains is less snow accumulation and faster snowmelt (Barnett et al. 2008). Snowpack storage can be quantified in terms of depth and duration. The "depth" is represented as snow-water equivalence (SWE), and duration as snow residence time (SRT) (Luce et al. 2014a). The SWE on April 1 is considered a useful metric of storage for the coming spring runoff and irrigation season, and we focused on this metric (fig. 4.1). The snow residence time was examined in two ways, first as the mean residence time shift (in days and as a fraction) (fig. 4.2). The second was based on sensitivity of snow in remote sensing imagery, depending on historical temperature and precipitation variations that provides a classification of snowpack behavior with four classes: "no snow," "ephemeral snow," "persistent, more sensitive," and "persistent, least sensitive"[2] (fig. 4.2). The no snow and ephemeral snow classes are expected to be relatively insensitive with respect to timing because snow does not last long (days to weeks) in these places normally. The other two classes refer to places where snow cover usually persists through the season, and they describe relative degrees of change expected based on temperature and moisture of the locations.

The different snow metrics yielded coherent but strongly contrasting expectations of snow changes in the eastern versus western portions of the study area. In low-elevation eastern portions, snow is already absent or ephemeral, and warming temperatures will change average snow residence times to a small degree (fig. 4.2). At higher elevations in the western portion, the average residence time of snow declines on the order of 3 to 4 weeks (fig. 4.2). In the Oregon Cascades, the predominantly low elevations (<2000 m) and stronger maritime influence yield warm snowpacks that are very sensitive to changing temperature (Cooper et al. 2016, Luce et al. 2014b, Mote 2003), and changes on the order of 7 to 8 weeks in snow residence timing are likely, coupled with a near complete loss of April 1 SWE expected at several sites (fig. 4.1). The sheer volume of water loss in the Cascades compared to the more eastern areas is also noteworthy, with 3 to 4 times as much SWE loss in the Cascades as farther east. This is mostly because of much deeper initial snowpacks related to strong orographic enhancement in the Cascades, whereas snowpacks to the east are in the rain shadow. In short, precipitation will spend less time as snow before continuing on its way through the hydrologic cycle.

[2] Kramer, M.G. Unpublished data. On file with: M.G. Kramer, Washington State University, 14204 NE Salmon Creek Avenue, Vancouver, WA 98686.

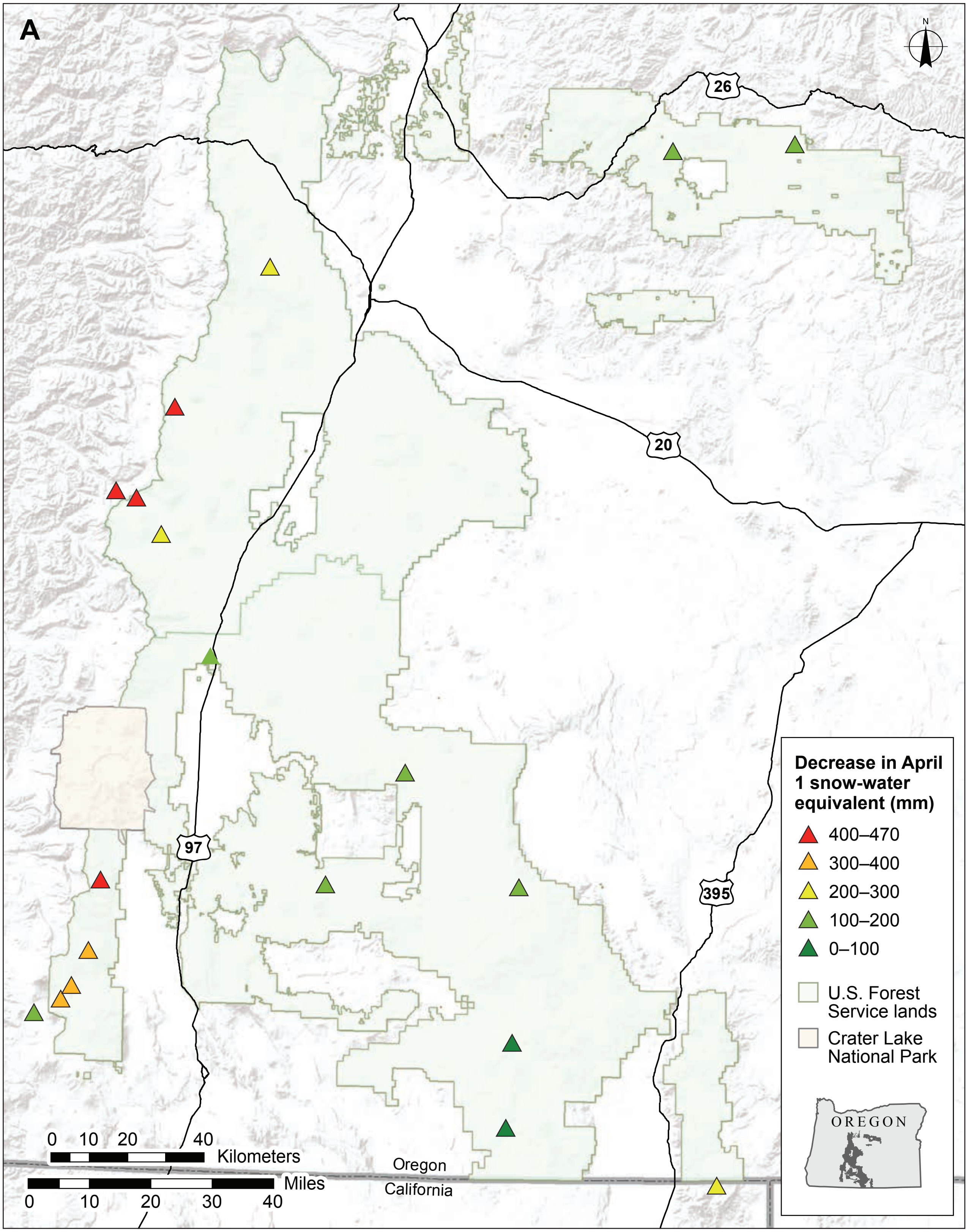


Figure 4.1—(A) Decrease in April 1 snow-water equivalent in millimeters and (B) percentage change for a 3 °C increase in December through March average temperature at SNOTEL stations in the South-Central Oregon Adaptation Partnership assessment area (from Luce et al. 2014).

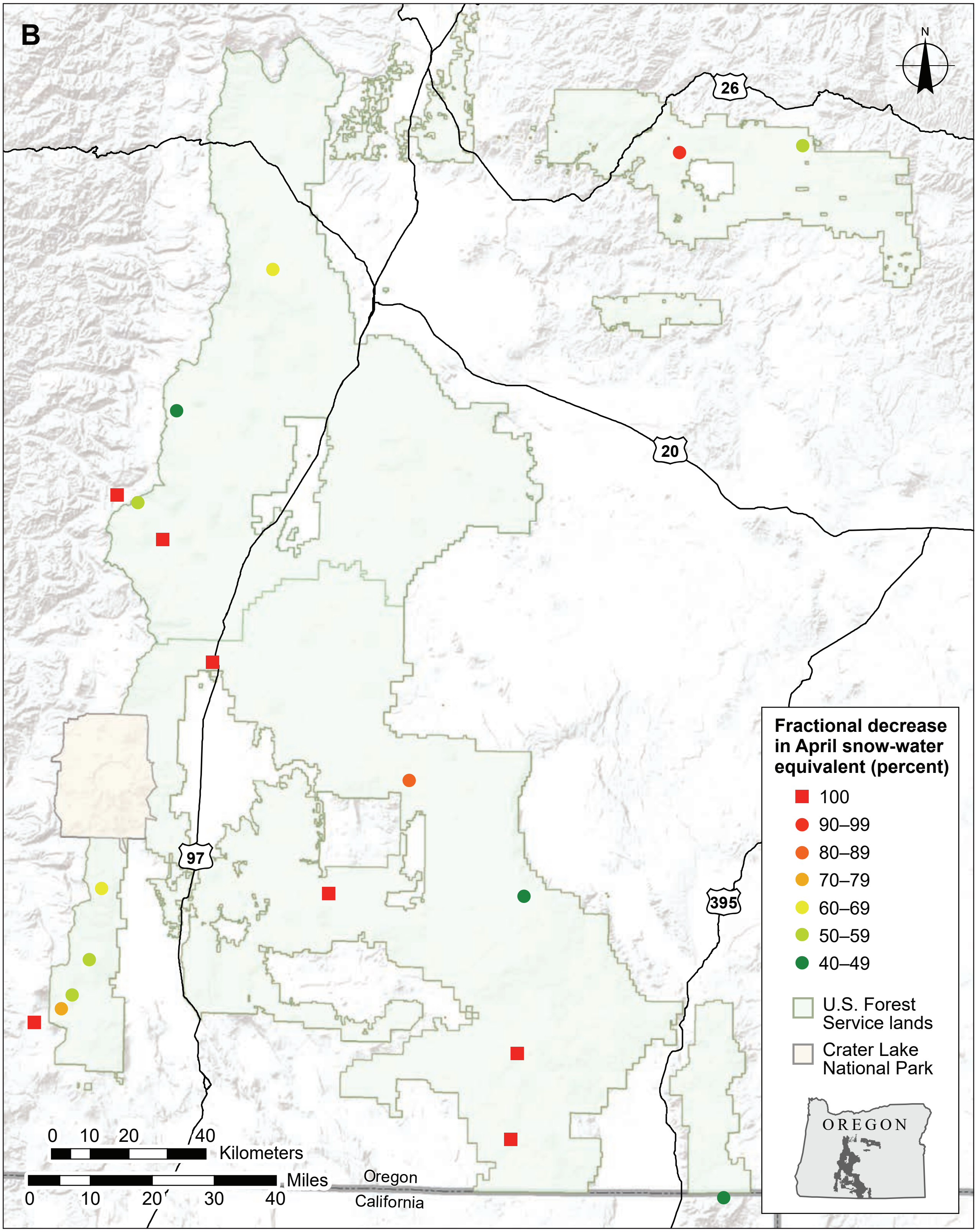


Figure 4.1 continued—(A) Decrease in April 1 snow-water equivalent in millimeters and (B) percentage change for a 3 °C increase in December through March average temperature at SNOTEL stations in the South-Central Oregon Adaptation Partnership assessment area (from Luce et al. 2014).

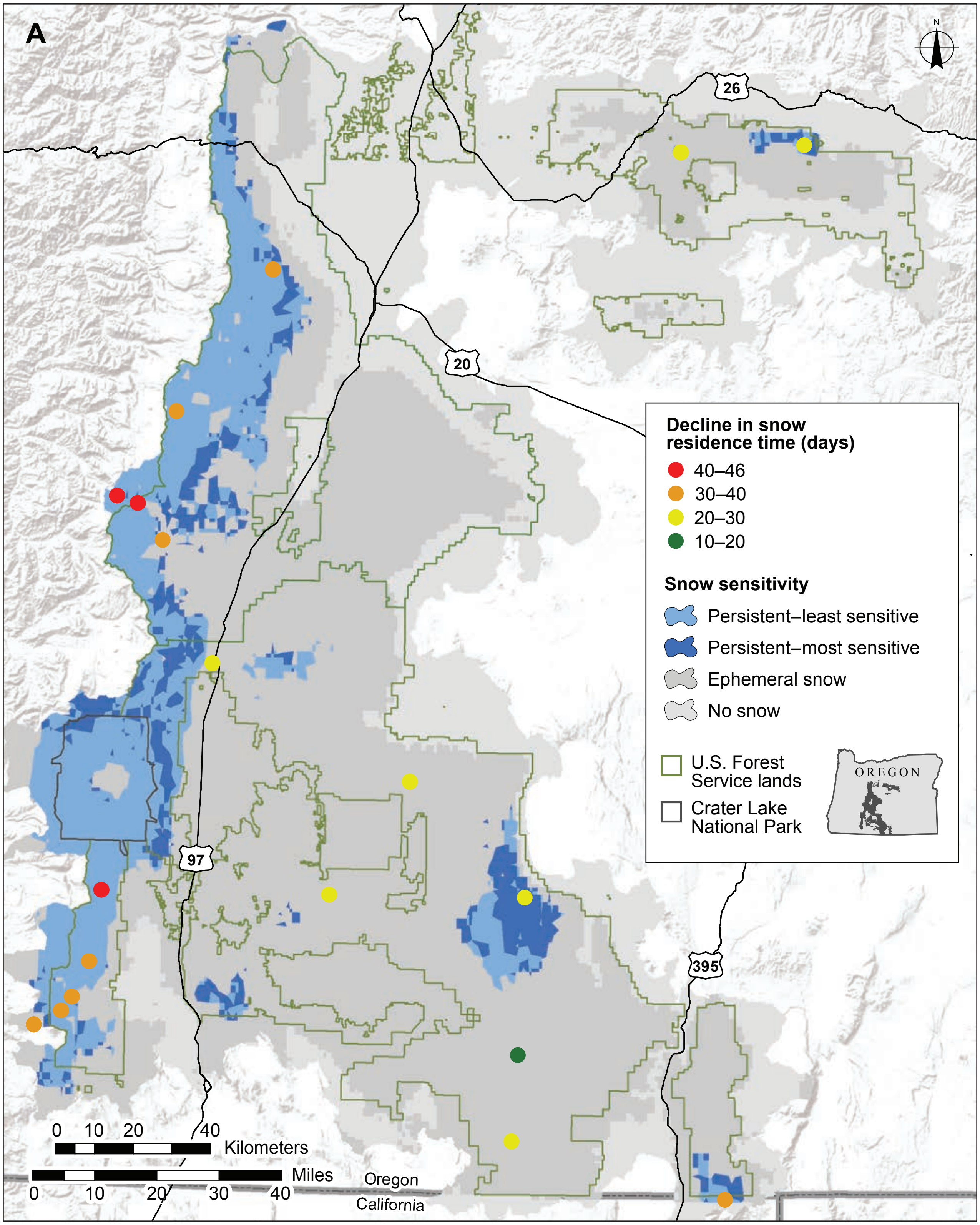


Figure 4.2—(A) Reduction in mean snow residence time in days and (B) percentage change given a 3 °C increase in December through March average temperature at SNOTEL stations in the South-Central Oregon Adaptation Partnership assessment area (from Luce et al. 2014), superimposed on a snow sensitivity classification derived from remote sensing in contrasting years (unpublished data on file with: M.G. Kramer, Washington State University, 14204 NE Salmon Creek Avenue, Vancouver, WA 98686).

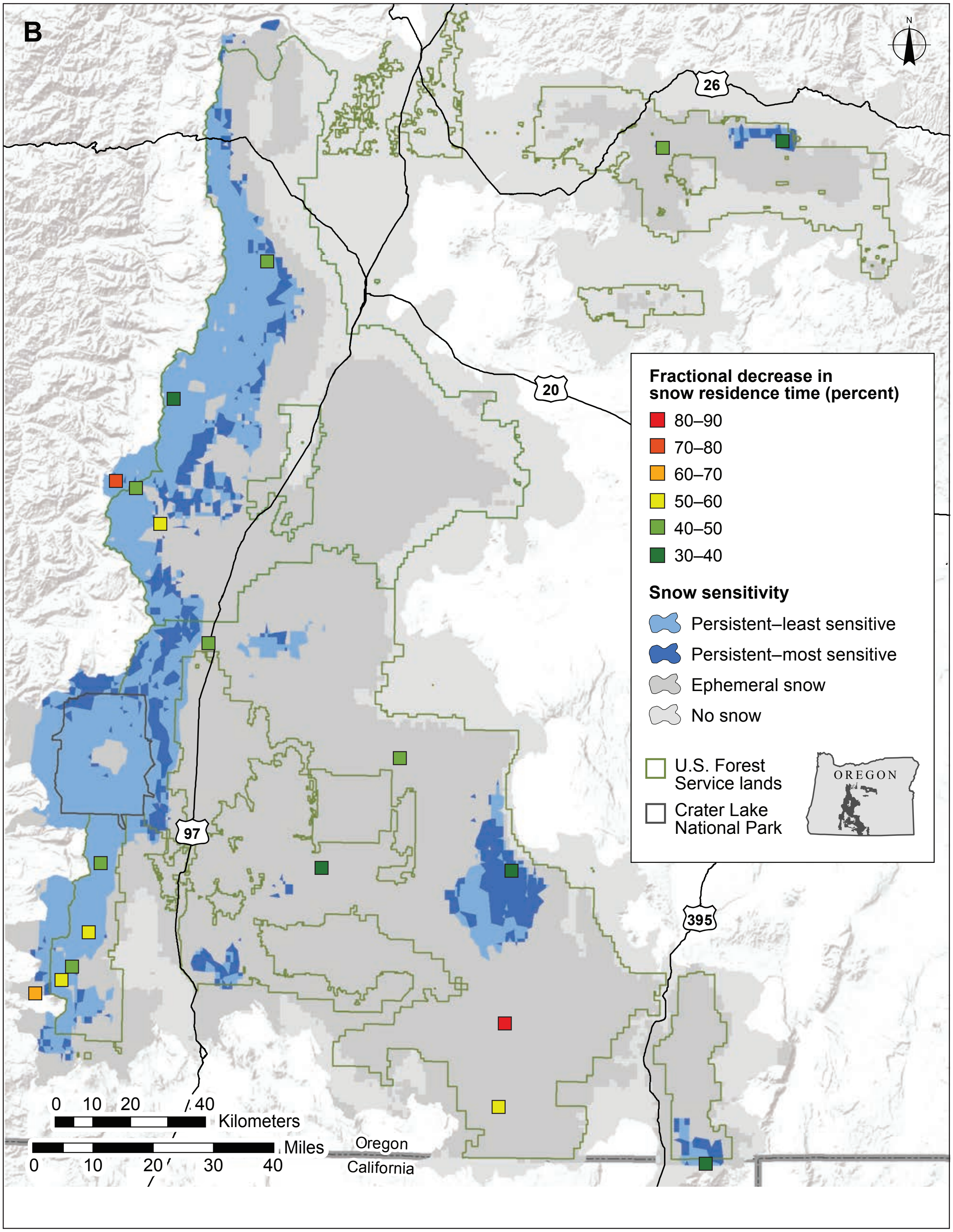


Figure 4.2—Continued.

Low-Flow Changes

In general, climate in the Pacific Northwest has warmed since 1895 (see chapter 3), and precipitation has declined in the mountains (Luce et al. 2013), resulting in smaller snowpacks (Hamlet et al. 2005, Mote et al. 2005), although snowpack trends differ across the region and with period of reference (e.g., see Stoelinga et al. 2010). Smaller snowpacks melt out earlier in the year. As a result, spring, early summer, and late summer flows have been decreasing, and the fraction of annual flow occurring earlier in the water year has been increasing (Kormos et al. 2016, Leppi et al. 2011, Luce and Holden 2009, Safeeq et al. 2013, Stewart et al. 2005). An analysis by Stewart et al. (2005) in eastern Oregon showed some of the largest trends toward decreasing fractional flows from March through June, a conclusion further supported by Safeeq et al. (2013). In addition to decreased summer flows, Luce and Holden (2009) showed declines in some annual streamflow quantiles in the Pacific Northwest between 1948 and 2006. For example, they found decreases in the 25th-percentile flow (drought-year flows) over the study period, meaning that the driest 25 percent of years have become drier across the Pacific Northwest.

As indicated above, however, summer low flows are influenced not only by the timing of snowmelt, but also by landscape drainage efficiency, or the inherent geologically mediated efficiency of landscapes in converting recharge (precipitation) into discharge (Safeeq et al. 2013, Tague and Grant 2009). Although climate dictates both the form of precipitation (snow versus rain) and when precipitation is converted to recharge (i.e., when rain falls or snowpacks melt), geology and topography dictate how long it takes for this recharge to be converted into streamflow. Our analysis of sensitivity to climate warming takes both of these factors into account. Summer streamflows might be reduced compared to the present because snowpacks are smaller or melt out earlier, but those climate effects may be expressed differently in regions with different geologically mediated flowpaths and groundwater storage.

These processes are clearly visible in the SCOAP assessment area, where streamflow sensitivities to future climate warming vary widely (fig. 4.3). The largest reductions in summer streamflows are projected for the eastern slopes of the High Cascades, where the earlier snowmelt timing will potentially result in summer streamflow losses of 40 to 60 percent by 2040 (fig. 4.3A) and 60 to 80 percent by 2080 (fig. 4.3B). These areas are expected to see some of the greatest shifts in snowmelt volume in the Western United States (Luce et al. 2014a), which is the primary driver behind such large fractional changes in summer streamflow. A few watersheds are more buffered than others and show lesser fractional low-flow changes because of slow, deep groundwater reservoirs (lower k values, fig. 4.4). Other focal areas of reduced summer streamflow are the uplands of the Fremont-Winema National Forest, with projected reductions of 20 to 30 percent by the

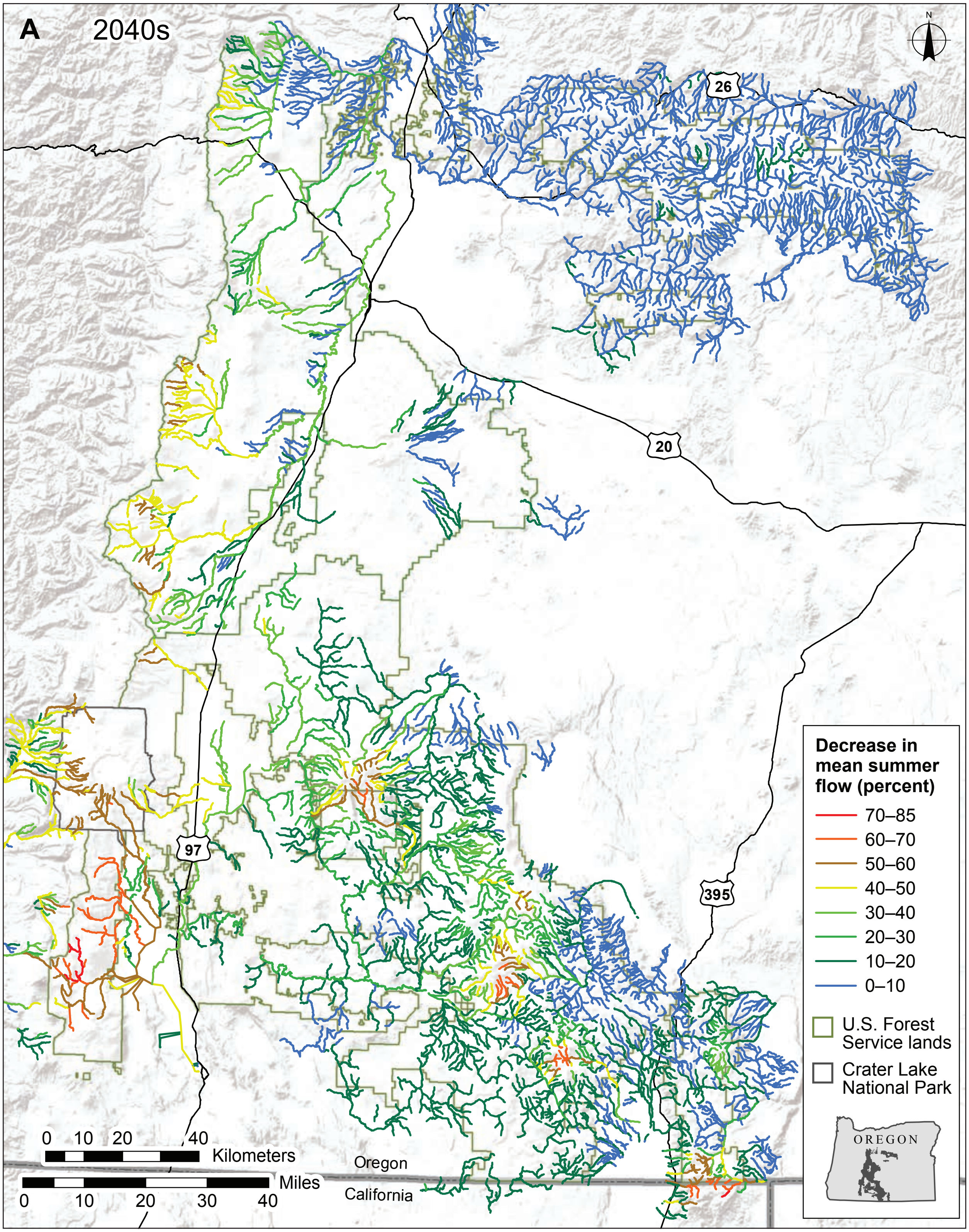


Figure 4.3—Projected low-flow declines in the South-Central Oregon Adaptation Partnership assessment area based on variable infiltration capacity model projections of surface water input changes filtered by geologically based unit hydrograph for (A) the 2040s and (B) the 2080s under the A1B greenhouse gas emission scenario.

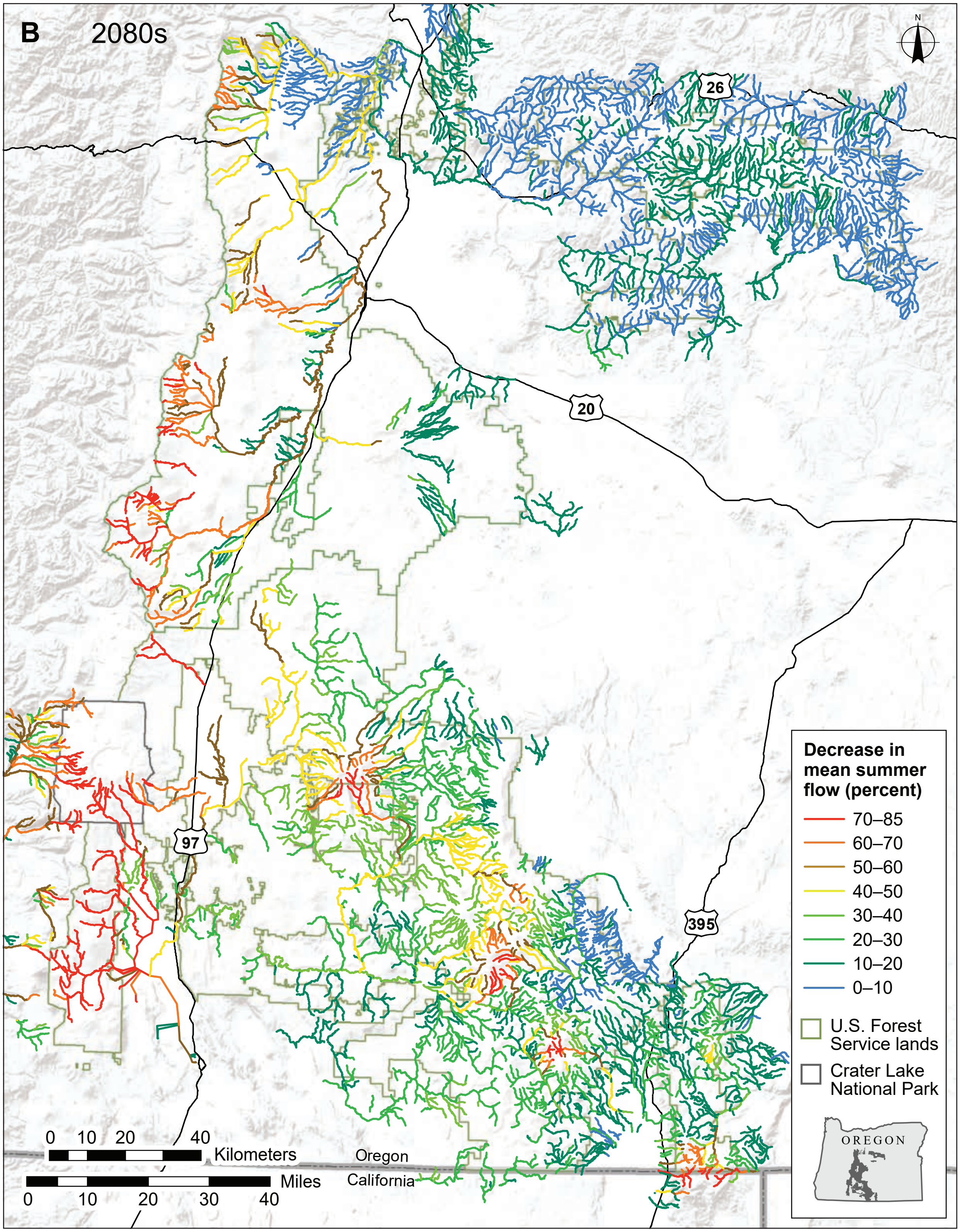


Figure 4.3 (continued)—Projected low-flow declines in the South-Central Oregon Adaptation Partnership assessment area based on variable infiltration capacity model projections of surface water input changes filtered by geologically based unit hydrograph for (A) the 2040s and (B) the 2080s under the A1B greenhouse gas emission scenario.

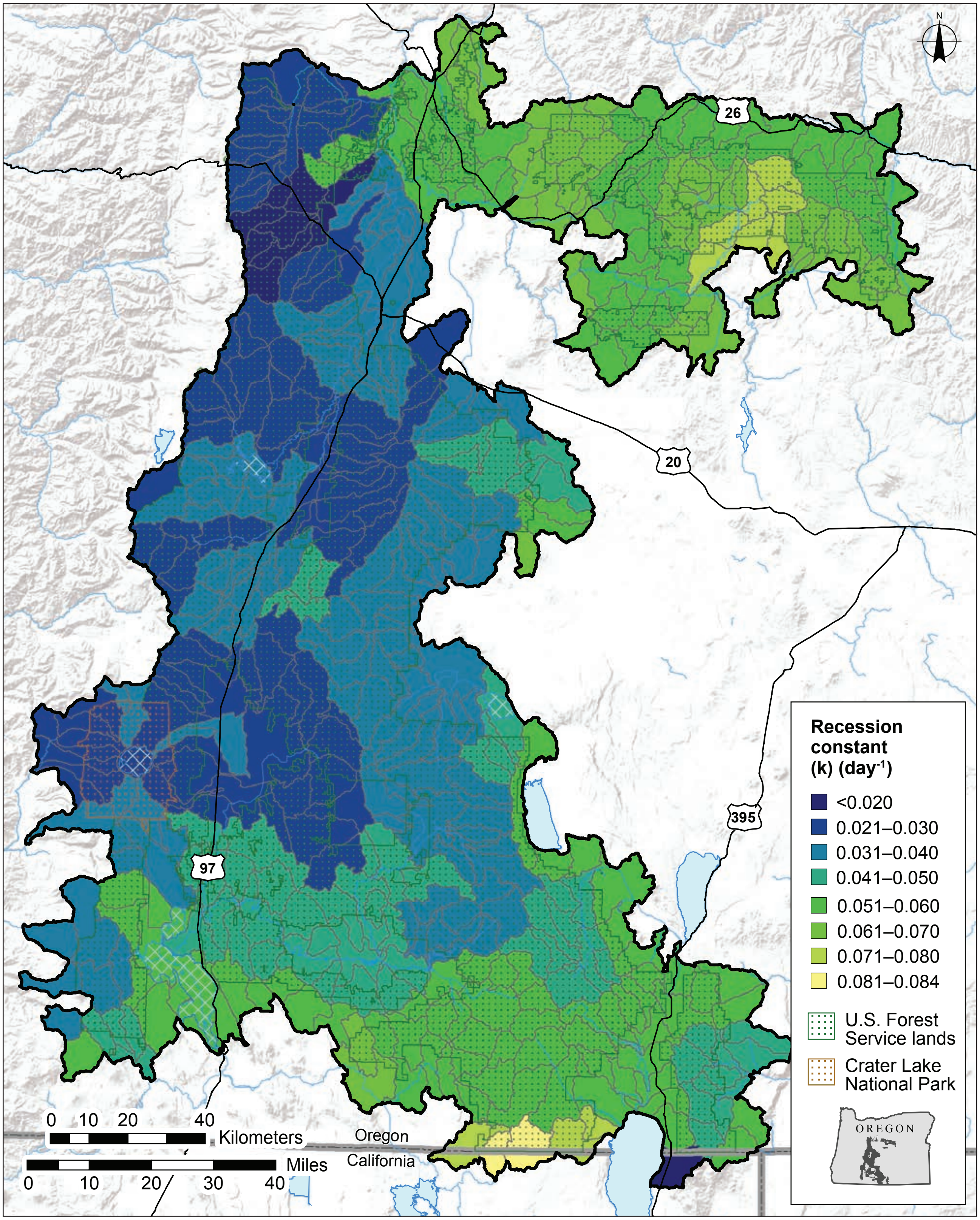


Figure 4.4—Recession constant (k) for the South-Central Oregon Adaptation Partnership assessment area (data from Safeeq et al. 2014). Lower k values represent deep groundwater-dominated systems; higher k values represent surface-flow-dominated systems.

2040s (fig. 4-3A) and 40 to 50 percent by the 2080s (fig. 4.3B). Much lower summer streamflow sensitivity to climate warming is projected for the Ochoco Mountains and Crooked River National Grassland. There, lower elevations limit the current influence of snowpack storage on flow timing, and summer flows are not expected to recede below current levels of late summer streamflow. In these areas, summer streamflow is more likely to decrease 10 to 20 percent over the next 50 years.

Peak-Flow Changes

Flooding regimes in the Pacific Northwest are sensitive to precipitation intensity, temperature effects on freezing elevation (which determines whether precipitation falls as rain or snow), and the effects of temperature and precipitation change on seasonal snow dynamics (Hamlet and Lettenmaier 2007, Tohver et al. 2014). Floods typically occur during the autumn and winter because of heavy rainfall (sometimes combined with melting snow), or less commonly, in spring because of unusually heavy snowpack and rapid snowmelt (Hamlet and Lettenmaier 2007, Sumioka et al. 1998). Summer thunderstorms can also cause local flooding and mass wasting, particularly after wildfire (e.g., Cannon et al. 2010, Istanbulluoglu et al. 2004, Luce et al. 2012, Moody and Martin 2009).

Flooding can be exacerbated by rain-on-snow events because rainfall runoff is augmented by rapid snowmelt (e.g., Harr 1986), and the snowpack can move water to channels faster (Eiriksson et al. 2013, Rössler et al. 2014). The physical dynamics of rain-on-snow events are more complex than just warm rain falling on and melting a cold snowpack. Much of the energy for melting snow is derived from the latent heat of condensation released when warm moist air condenses on cold snowpacks (Marks et al. 1998). Thus, rain-on-snow-driven melting and subsequent peak flows are contingent on windspeed, air temperature, absolute humidity, intensity of precipitation, elevation of the freezing line, and antecedent snow cover distributions (Eiriksson et al. 2013, Harr 1986, Marks et al. 1998, McCabe et al. 2007, Wayand et al. 2015).

Warming affects future flood risk from rain-on-snow events differently depending on the importance of these events as a driver of flooding in different basins under the current climate. In general, as temperatures warm, the rain-on-snow zone, an elevation band below which there is rarely snow and above which there is rarely rain, will likely shift upward in elevation. This upward shift will tend to strongly increase flooding in basins where the current rain-on-snow zone is low in the basin (with a large snow collection area above). In contrast, in basins in which the rain-on-snow zone is higher in the basin, the upward shift may only modestly increase the fractional contributing basin area, or potentially shrink the total area available for rain-on-snow-driven melting as the upper part of the basin transitions into the rain-dominated zone.

In the latter half of the 20th century, increased temperatures led to earlier run-off timing in snowmelt-dominated and mixed rain-and-snow watersheds across the Western United States (Cayan et al. 2001, Hamlet et al. 2007, Safeeq et al. 2013, Stewart et al. 2005). With future increases in temperature, and potentially more precipitation in winter months, common floods are expected to increase in magnitude (e.g., Goode et al. 2013), and extreme hydrologic events (e.g., those currently rated as having 100-year recurrence intervals) may become more frequent (Hamlet et al. 2013). Heavy precipitation events may be associated with less warming than light precipitation days (Rupp and Li 2017), which may affect future snowpack and runoff.

Results from our two complementary analyses show many similarities and some differences in projections of future increases in peak flows across the SCOAP landscape. The Safeeq et al. (2015) approach identifies the eastern slopes of the Cascades as being particularly vulnerable to increasing peak flows (fig. 4.5), primarily as the result of areas that now see mostly snowfall in winter transitioning to areas where rain-on-snow events are more common. These areas are projected to have peak-flow increases on the order of 20 to 40 percent by mid century, with progressively more areas showing increased peak flows by 2080 (fig. 4.5). By 2080, other areas, including Fremont-Winema and Ochoco National Forests, are also projected to have increased peak flows of 20 to 30 percent by 2080. These percentage increases are expected across the full range of peak flows, from 2-year to 100-year events.

The VIC analysis yields a similar overall pattern (fig. 4.6), although it projects that peak flow increases in Fremont-Winema National Forest will be sooner and larger, while those in the eastern Cascades will be less extensive. Differences between the two approaches reflect different methods and assumptions. In particular, the Safeeq et al. (2015) approach relies entirely on changes in peak flows resulting from the increasing probability of rain-on-snow events, whereas the VIC approach incorporates both this effect and potential changes in precipitation across the region, as expressed in global climate models.

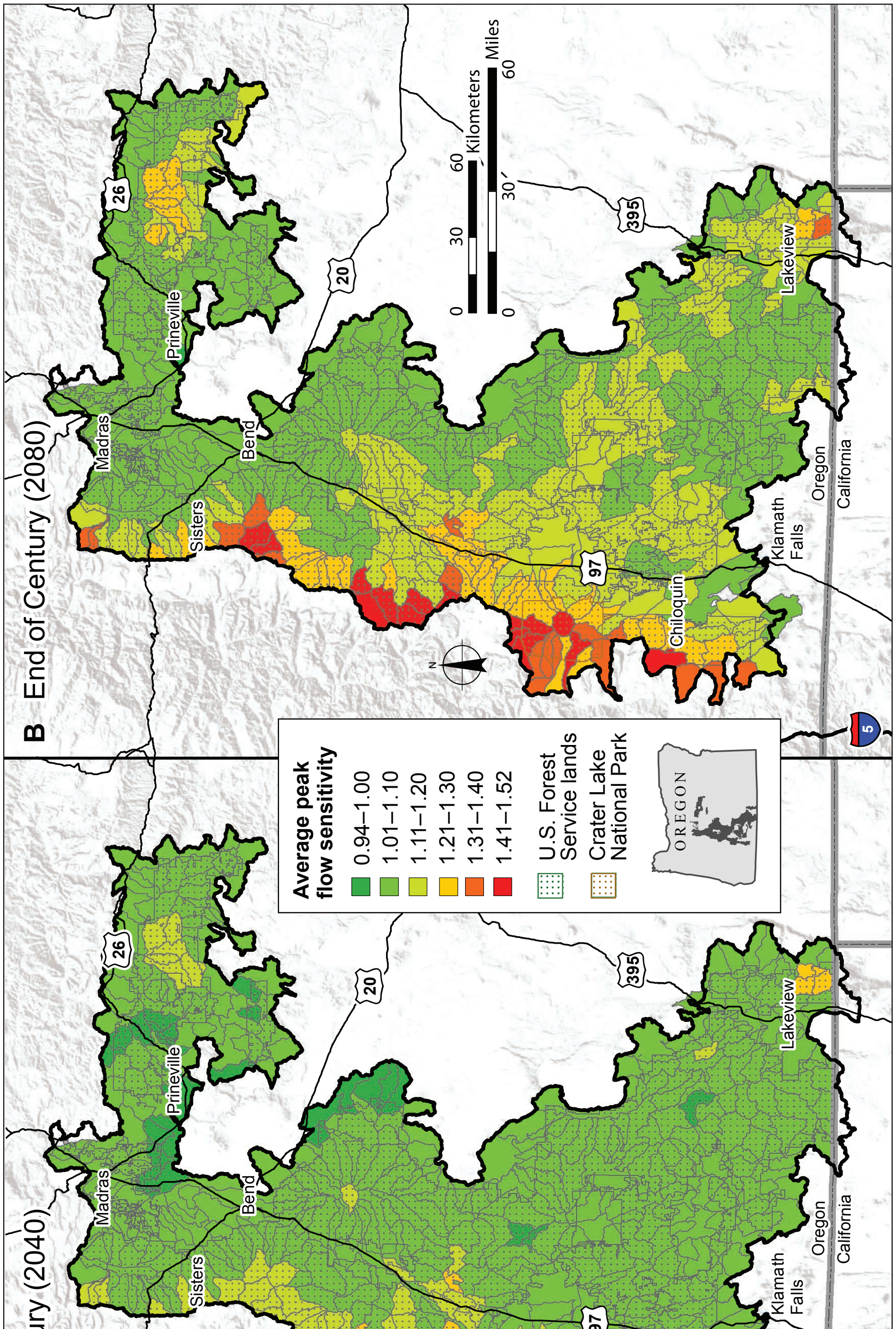
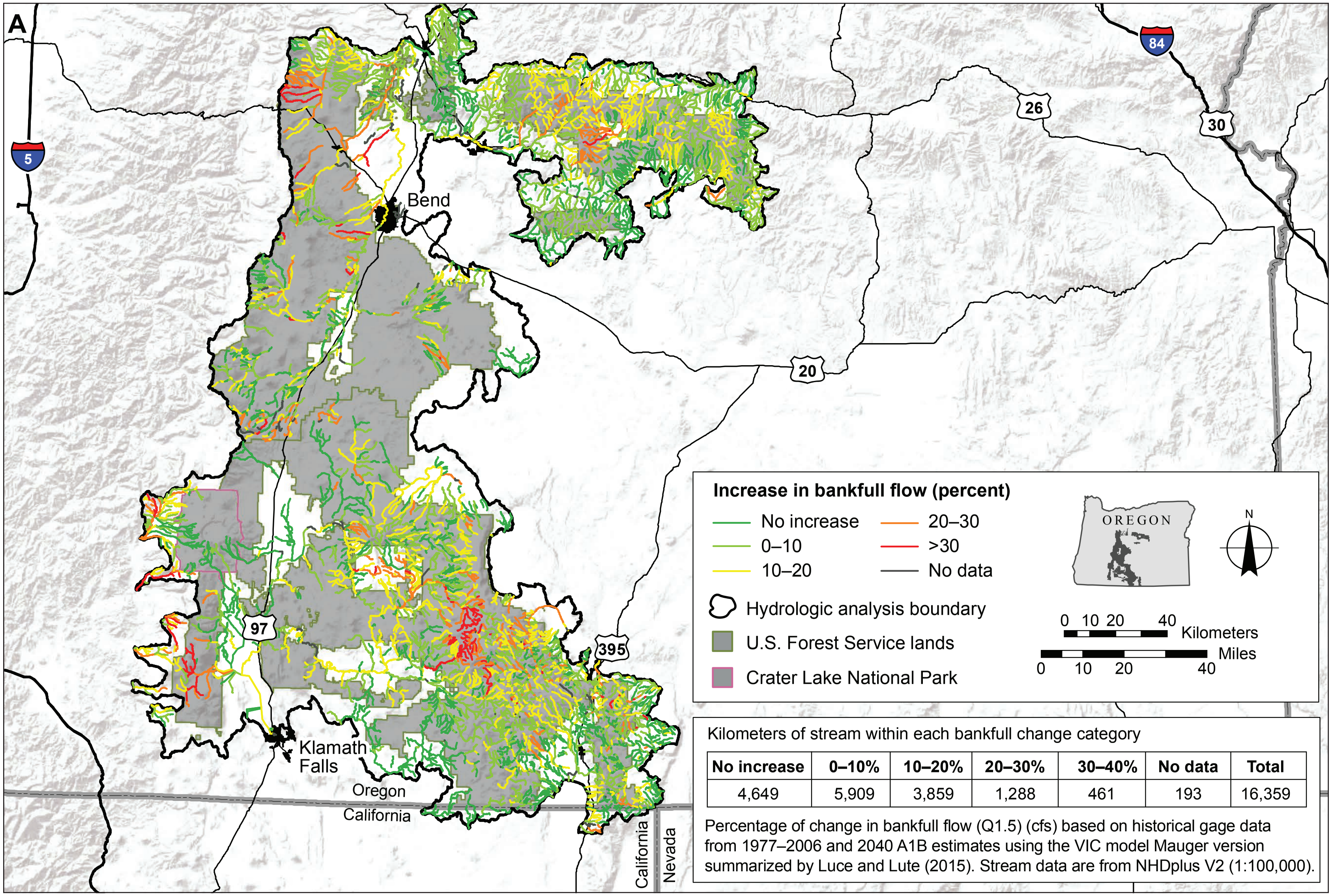
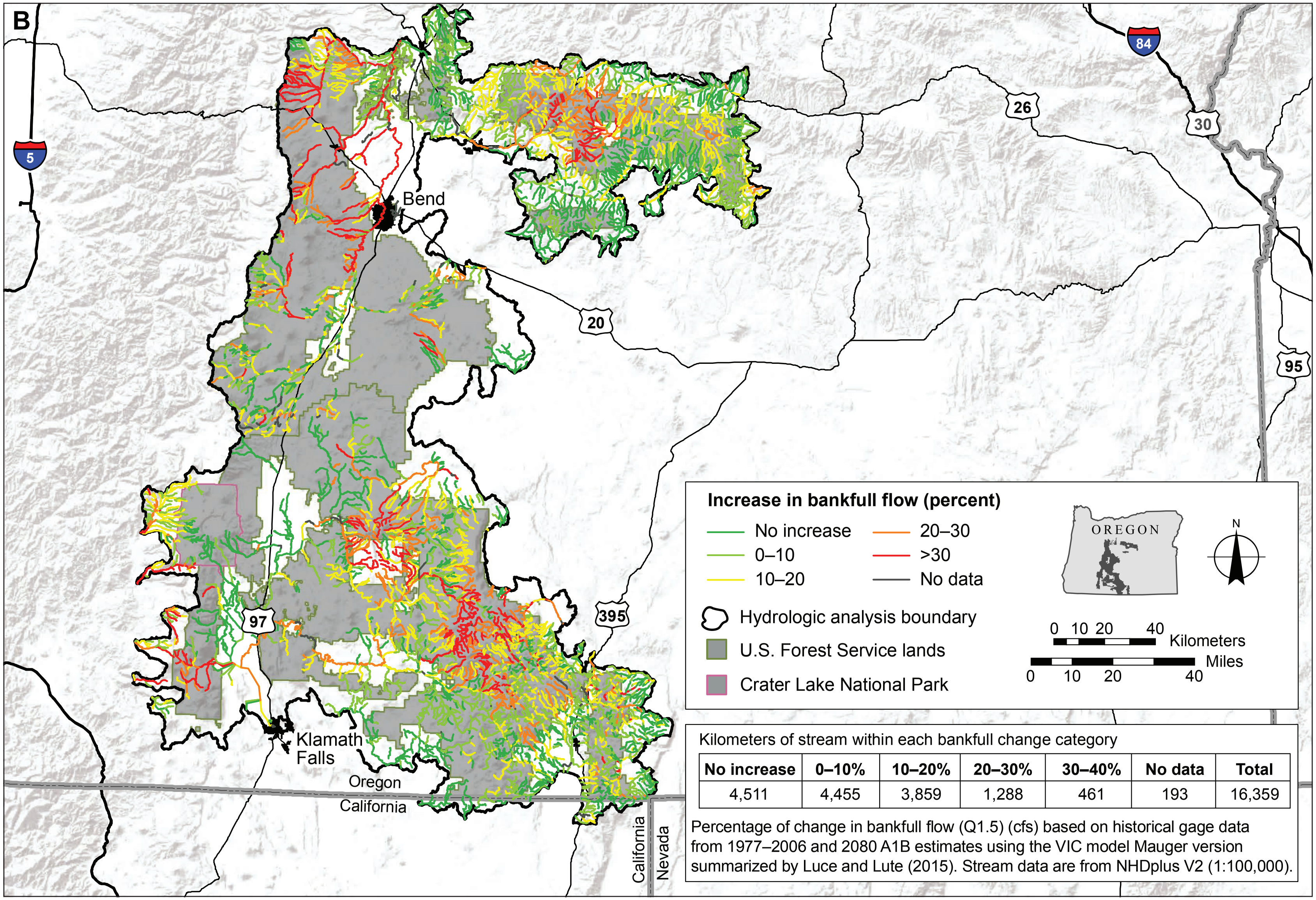


Figure 4.5—Average empirically derived (from Safeeq et al. 2015) peak flow ratio change projections (e.g., 1.1 means a 10 percent increase) for (A) the 2040s and (B) the 2080s under the A1B greenhouse gas emission scenario.



No increase	0–10%	10–20%	20–30%	30–40%	No data	Total
4,649	5,909	3,859	1,288	461	193	16,359

Figure 4.6—Projected percentage change in bankfull flow (1.5-year event) in the South-Central Oregon Adaptation Partnership assessment area based on variable infiltration capacity model projections for (A) the 2040s and (B) the 2080s under the A1B greenhouse gas emissions scenario.



No increase	0–10%	10–20%	20–30%	30–40%	No data	Total
4,511	4,455	3,859	1,288	461	193	16,359

Percentage of change in bankfull flow (Q1.5) (cfs) based on historical gage data from 1977–2006 and 2080 A1B estimates using the VIC model Mauger version summarized by Luce and Lute (2015). Stream data are from NHDplus V2 (1:100,000).

Figure 4.6 (continued)—Projected percentage change in bankfull flow (1.5-year event) in the South-Central Oregon Adaptation Partnership assessment area based on variable infiltration capacity model projections for (A) the 2040s and (B) the 2080s under the A1B greenhouse gas emission scenario.

Water Resources and Uses

In the predominantly dry climate of south-central Oregon, water availability is critical for human habitation and enterprises (chapters 2 and 3). Many streams and groundwater systems surrounding the SCOAP assessment area originate from Deschutes, Fremont-Winema, and Ochoco National Forests, Crooked River National Grassland, and Crater Lake National Park, thus providing valued ecosystem services to local communities and economies. There are about 1,400 water rights on national forest lands in the SCOAP assessment area; 63 percent provide water for domestic livestock, 12 percent for industrial uses and road construction, 9 percent for recreation and domestic uses, 8 percent for wildlife, and the remainder for other uses. Twelve municipalities (Ashland, Bend, Dayville, Lakeview, La Pine, Madras, Mitchell, Paisley, Prineville, Redmond, Sisters, and Terrebonne) rely directly on national forests for their municipal water supply (fig. 4.7). About 100 points of diversion (PODs) (under a certificated water right) are located within the boundaries of national forests in the SCOAP assessment area that provide water for domestic use (fig. 4.8).

Water is critical for livestock on national forests and surrounding lands, and consumption for this purpose is broadly dispersed across different ecosystems. Water for livestock is the largest permitted water use on national forest land by number of certificated water rights in the SCOAP assessment area. Fremont-Winema National Forest has the largest number (612) and percentage of water rights whose beneficial use is livestock watering (74 percent of its PODs). Ochoco National Forest and Crooked River National Grassland also have a high number of livestock-watering PODs—69 percent and 50 percent of its certificated water rights for livestock watering, respectively. Only 10 percent of PODs on Deschutes National Forest are identified for livestock uses. All PODs within Crater Lake National Park are reserved for municipal, domestic, and recreation uses.

Most basins in national forests in the SCOAP assessment area are fully allocated in terms of water available for appropriation under state law in the dry summer season. In national forests, water is generally available for campgrounds and administrative sites and for other appropriated uses (e.g., livestock and wildlife), although in dry years, availability may be limited at some sites, especially in late summer. Dams for storage facilities, stream diversions, and development of springs and ponds for livestock on national forests affect hydrological and ecological functions of streams, wetlands, and groundwater-dependent ecosystems (chapter 6). In drought years, although water users with senior rights (primary, long-term claims to water) may continue to receive water, downstream users with junior rights (secondary and later claims, subsidiary to senior rights) may not receive water for various purposes, primarily irrigation. To date, this has not been a major issue, but if water usage changes in the future, partitioning of water among users could affect allocation during severe droughts.

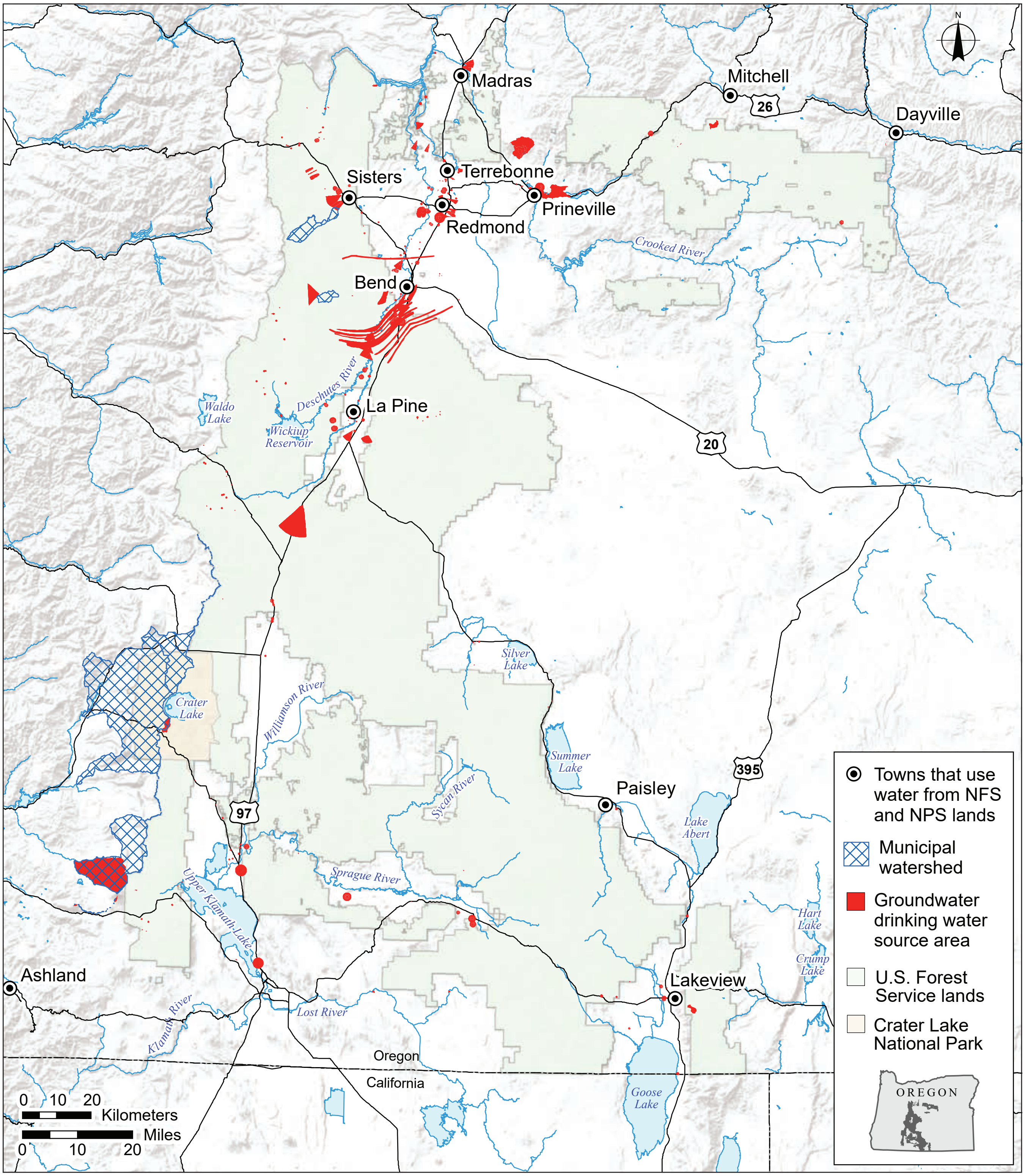


Figure 4.7—Public water systems that obtain water from National Forest System (NFS) and National Park Service (NPS) lands.

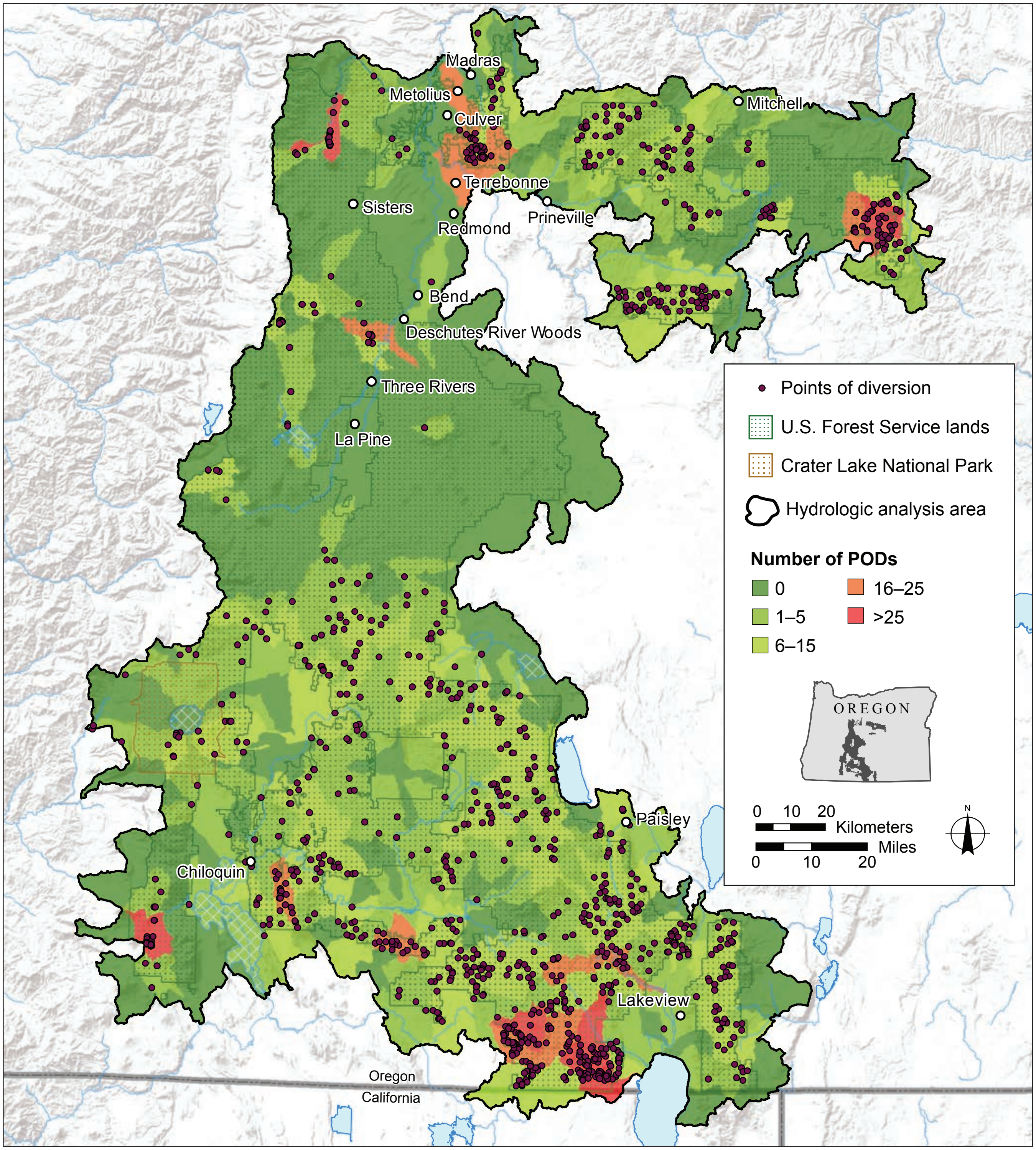


Figure 4.8—Water uses and points of diversions (PODs) for subwatersheds in the South-Central Oregon Adaptation Partnership assessment area.

Climate Change Effects on Water Availability

Warming temperatures from climate change will lead to decreased snowpack and earlier snowmelt, resulting in shifts in timing and magnitude of streamflow (Mote et al. 2005). Across most of the SCOAP assessment area, the majority of precipitation occurs during October through March, when consumptive demand is lowest. In summer, when demand is highest, rain is infrequent and streams are dependent on groundwater to maintain low or baseflows. Because water supply in the SCOAP assessment area is limited, climate change may reduce water available for current demands in summer months, especially during extreme drought years and after multiple consecutive drought years.

The 2014–2015 winter in the SCOAP assessment area was similar to what has been projected by climate models for around 2060. For example, the April 1 snowpack in Lake County and Klamath County was less than 9 percent and 12 percent of the historical average, respectively. As a result, calls for water were made by senior water users much earlier than normal, particularly in the Klamath Basin. The town of Lakeview, which normally draws water for municipal supply from Bullard Canyon Spring in the Warner Mountains during winter and spring, had a cumulative spring flow of 1.14 million L per day at the end of April 2014, compared to a normal 3.79 million L per day into early summertime. This placed more pressure on the town's use of Goose Lake Valley groundwater well sources.

Historical snowpack sensitivity and projections of summer streamflow (fig. 4.9) across the SCOAP assessment area identify areas that may be particularly sensitive with respect to water supply. Lower elevation locations with mixed snow and rain during winter will be the most vulnerable to reduced spring snowpack, but even the most persistent snowpacks at higher elevation are expected to decline by the 2080s. The VIC hydrologic model projections (for natural flows, not accounting for withdrawals, use, and storage) suggest that the Goose Lake, Lake Abert, Middle Deschutes, Sprague, Upper Deschutes, Upper Klamath Lake, Upper Rogue, and Warner Lakes subbasins (a subbasin is around 180 000 ha) are at highest risk for summer water shortage associated with low streamflow by 2080 (fig. 4.9). Decreased summer low flows in these areas have the greatest potential to affect agricultural irrigation and municipal uses.

Water diversions and dams can also affect resilience to climate change. Although dams increase water storage during low flow, they also increase water extraction and evaporation. Aging and inefficient diversion infrastructure can increase water loss. Engaging users in areas in which water shortages can occur is critical for addressing climate change effects on water and resolving water distribution issues. This could be done through public meetings and other forums in which federal resource manag-

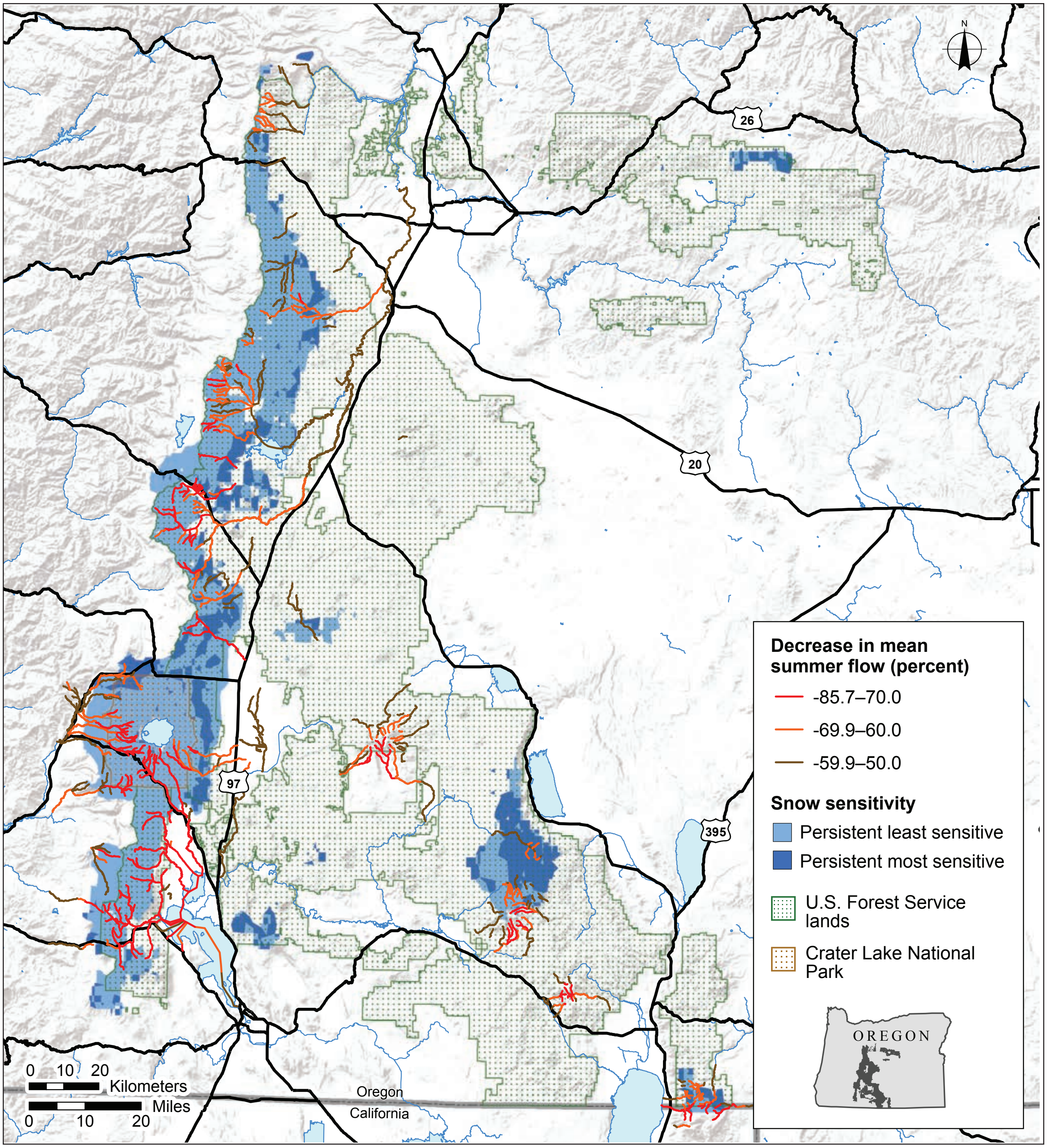


Figure 4.9—Snowpack sensitivity and projections for mean summer low streamflow. Percentage change calculated from historical data (1977–2006) and the A1B emission scenario for 2080, using the variable infiltration capacity model. Persistent least sensitive = timing of peak snowmelt differed by >30 days between the warmest, driest year and coldest, wettest year in >30 percent of the watershed; persistent most sensitive = timing of peak snowmelt in the warmest, driest year occurred >30 days earlier than the coldest, wettest year in >50 percent of the subwatershed.

ers and other stakeholders jointly identify issues and develop potential solutions. Clarifying water demand, negotiating water allocations, ensuring environmental flows (e.g., for fisheries) in the water rights process, adjudicating overallocated basins, and monitoring compliance can help reduce susceptibility to climate stresses.

Water quantity is an important attribute of the Watershed Condition Framework (WCF) classification system used by national forests to rate overall watershed condition (Potyondy and Geier 2011). Most subwatersheds (around 5000 to 15 000 ha) across the SCOAP assessment area were rated as "functioning" or "functioning at risk" for this attribute, based on the magnitude of existing flow alterations from dams, diversions, and withdrawals relative to natural streamflows and groundwater storage. The Goose Lake, Upper Klamath Lake, Little Deschutes, Lower Crooked River and Upper and Lower Deschutes River subbasins contain the highest number of subwatersheds rated as having "impaired function" for water quantity on national forest lands, according to the 2015 WCF forest assessments. Most of these areas are among those expected to experience the largest changes in summer flows (fig. 4.9), indicating they are the most vulnerable to climate change from a water-use perspective. The magnitude of existing water diversions and presence or absence of backup water systems affect vulnerability of water supplies for human uses. Systems with redundant supplies will generally be less vulnerable during droughts.

Peak stream discharge is expected to increase throughout a significant portion of the SCOAP assessment area as a result of more winter precipitation falling as rain relative to snow, as well as more rain-on-snow events (McCabe et al. 2007). Application of the method developed by Safeeq et al. (2015) (fig. 4.5) suggests that the Lake Abert, Middle Deschutes, Sprague, Summer Lake, Upper Crooked, and Upper Klamath Lake subbasins will experience substantial changes in bankfull flow (>30 percent increase in magnitude) by 2080. With increases in frequency and magnitude of peak discharge, some stream diversions could experience adverse impacts, such as flood debris accumulation and damage to infrastructure (fig. 4.10).

Roads, Infrastructure, and Access

Historically, the primary purpose of the road system on national forests was timber harvest. Reduced harvesting during the past 30 years has decreased the need for roads for timber purposes. However, local population growth and tourism have increased demand for access for recreational activities. For example, recreation demand on Deschutes National Forest is now more than double the demand predicted in the 1990 forest land management plan. Trail use and camping are the most popular activities, but visitors are staying for a shorter duration than in the past. More than 60 percent of trips to national forests last 6 hours or less, and short visits

Figure 4.10—Brown Diversion on Cherry Creek, Fremont-Winema National Forest, (upstream view), inundated with flood debris as a result of a rain-on-snow storm event, December 2014.

concentrate human impacts on areas that are easily accessible (USDA FS 2010, chapter 8). Demand is predicted to continue to increase for trail use by mountain bikes, motorized vehicles, and off-highway vehicles, as well as for winter recreation, based on the Statewide Comprehensive Outdoor Recreation Plan (OPRD 2013).

Roads, trails, bridges, and other infrastructure that were built over the past century throughout the eastern Cascade Range and the Ochoco and Warner Mountains provide access to public lands for loggers, mineral prospectors, hunters, and tourists. National forests and national parks in the SCOAP assessment area were specifically created to protect the land and resources of the area, including water, timber, range, wildlife, and cultural resources. Providing access to accomplish objectives of protection and management largely determined where these activities historically occurred. Today, reliable and strategic access is critical for people to recreate, extract resources, and monitor and manage resources, as well as to respond to emergencies (Louter 2006). Access management balances these benefits with a wide range of other ecosystem services.

The three national forests and Crooked River National Grassland contain a combined 39 107 km of roads and 940 km of trails. Of the existing transportation system, the majority consists of native-surfaced roads and trails. Road densities across this landscape tend to be higher at (1) middle to lower elevations in areas that are more regularly managed for timber, (2) valley bottoms that facilitate recreational access to streams and rivers, and (3) where road and trail building was facilitated by flatter ground. Because of the rugged topography in much of this area, roads and trails are forced to cross many waterways. Most known road/water crossings use culverts installed decades ago. Some crossings are being replaced, but many have not been inventoried, and conditions are unknown.

In 2015, Crater Lake National Park saw record visitation with 614,000 visitors (chapter 8). More than 16 percent of visits were overnight stays, which is more than five times the national average for national parks. With this increase in visitation, short-duration trips are also increasing, which increases demand for easy access and parking. Because road building was minimized during park development, higher visitation has led to traffic congestion, especially between June and September when 75 percent of visitation occurs. High seasonal visitation stresses transportation management at the park. Although all federal units in the SCOAP assessment area maintain some year-round access, many roads and facilities are closed in winter where snow cover is high, especially in Crater Lake National Park where roads are at high elevation.

Road Classification, Maintenance, and Effects on Water Resources

Road designs and conditions, which affect water runoff and erosion, differ widely across the SCOAP assessment area. The condition of roads varies substantially, as do the interaction and impact roads have on the condition and processes of watersheds and aquatic ecosystems. Although some roads are paved and designed to provide a high degree of comfort for passenger car use, much of the road system (especially in national forests), was designed to lower standards to facilitate timber extraction, mining, or recreational access for four-wheel-drive vehicles (table 4.1). Most roads were developed when engineering standards for road/stream crossings were required to withstand a 25-year flood event (pre-1990), rather than a 100-year event that is the construction standard today.

Roads can intercept precipitation, surface runoff, and shallow groundwater; reduce infiltration capacity of the land; concentrate and accelerate runoff; and increase rates of erosion and the potential for sediment delivery to stream systems. These processes tend to increase peak flows, channel erosion, and sedimentation in stream systems and can alter low flows in summer and autumn. Roads near rivers and streams (table 4.1) generally have a greater direct impact on the fluvial system. However, roads in the uplands also affect these processes and can increase slope instability in some locations (Trombulak and Frissell 2000).

Table 4.1—Road resources, maintenance levels (ML), and stream associations

Code description	Operation maintenance level	Fremont-Winema National Forest	Ochoco National Forest	Deschutes National Forest	Crooked River National Grassland	Total
				Kilometers		
ML 0	Decommissioned	0[a]	887	525	136	1,548
ML 1	Basic custodial care (closed)	10 822	2 133	3 847	94	16 896
ML 2	High clearance cars/trucks	7 839	1 934	8 546	360	18 678
ML 3	Suitable for passenger cars	572	99	333	0	1 003
ML 4	Passenger car (moderate comfort)	210	26	102	3	340
ML 5	Passenger car (high comfort)	0	43	41	0	84
Total		19 443	5 121	13 393	593	38 549
Road length within 90 m of streams		1 881	1 297	740	114	4 032[b]

[a] Fremont-Winema National Forest reports decommissioned roads as ML1.
[b] Crater Lake National Park has an additional 13 km of roads within 90 m of streams.

National forests develop prioritized annual road maintenance plans based on operational maintenance level and category. Maintenance of forest roads subject to Highway Safety Act standards receive priority for appropriated capital maintenance, road maintenance, or improvement funds over roads maintained for high-clearance vehicles. Activities that are critical to health and safety generally receive priority, but these investment decisions are balanced with demands for access and protection of aquatic habitat.

Given current and projected funding levels, federal agencies balance benefits of access with costs of maintaining a sustainable transportation system that is safe, affordable, and responsive to public needs and that causes minimal environmental impact. Management actions that promote sustainability include storm-proofing roads (management activities that decrease erosion of sediments from roads), upgrading drainage structures and stream crossings, reconstructing and upgrading roads, decommissioning roads, converting roads to alternative travel routes such as trails, and developing comprehensive access and travel management plans.

Planning for transportation and access on national forests is included in forest land management plans. The 2001 Road Management Rule (RMR) (36 CFR 212, 261, and 295) requires national forests to use science-based analysis to identify a minimum road system that is ecologically and fiscally sustainable. This transportation analysis process increases the ability of forests to acquire funding for road improvement and decommissioning, establish a framework to set annual maintenance costs, meet terms of agreement with regulatory agencies, and operate a financially sustainable transportation system, while maintaining flexibility in management options. Ochoco, Deschutes, and Fremont-Winema National Forests have identified a sustainable road and trail network in accordance with the RMR. The transportation analysis process was science based and focused on sustainability, but did not specifically consider the effects of climate change.

As forests continue to implement the RMR, road projects on national forest lands, such as reconstruction of roads and trails or decommissioning, must comply with the National Environmental Policy Act (NEPA 1969), requiring environmental assessment and public involvement. Decommissioning roads is a process of restoring areas with roads to a more natural condition by decompacting road prisms, reestablishing drainage patterns, fully or partially recontouring and stabilizing slopes, restoring vegetation, providing ground cover with slash or mulch, blocking vehicular access, installing water bars, removing culverts and bridges, and removing fill material from stream crossings (36 CFR 212.5; Road System Management; 23 U.S.C. 101).

Process-driven spatial and terrain analysis tools that assess road risks—the Water Erosion Prediction Project (Flanagan and Nearing 1995), Geomorphic Road Analysis and Inventory Package (Black et al. 2012, Cissel et al. 2012), and NetMap (Benda et al. 2007)—are often used to identify hydrologic impacts and guide management decisions on projects. Climate and runoff variables that drive the modeling process with these tools are intended to capture future climatic conditions and contribute to management decisions.

Climate Change Effects on Transportation Systems

Changes in the magnitude and timing of runoff events and snowpack will manifest differently across the SCOAP assessment area, affecting the transportation system and driving changes in management. The primary effects will occur through (1) reduced snowpack and earlier runoff, (2) higher peak flows and flood risk in winter and early spring, (3) reduced low flows in the summer, and (4) increased landslide risk associated with elevated soil moisture through the winter (Strauch et al. 2014).

These changes have both direct and indirect effects on infrastructure and access. Direct effects on transportation systems are those that physically alter the operation or integrity of transportation facilities, including effects related to floods, snow, landslides, extreme temperatures, and wind. Hydrologic extremes such as flooding are often induced by individual weather events (e.g., storms); when these events exceed the historical range of intensity and frequency, they may also exceed current design standards for infrastructure.

Peak flow analyses, using VIC (fig. 4.11) and methods by Safeeq et al. (2015) (figs. 4.12 and 4.13), show varied vulnerability of roads to changes in future peak-flow events. Peak flows and road system vulnerability are generally lower in low-elevation drainage systems and spring-fed systems, and higher in mid- to high-elevation drainages, especially where baseflow is less supported by groundwater. Roads in Crater Lake National Park generally show a decrease in vulnerability to peak flows using VIC (fig. 4.11), but subwatersheds in Crater Lake National Park show an increase in peak flows over time using the Safeeq et al. (2015) method (figs. 4.7 and 4.12).

Crooked River National Grassland shows a slight decrease in peak flows and road system vulnerability at lower elevations and a slight increase at higher elevations. Similarly, in Ochoco National Forest, low-elevation areas of the southern and eastern part of the forest show decreasing peak flows and road system vulnerability as precipitation regimes trend to mostly rain. However, the central, northern, and western parts of the forest show increased peak flows and road system vulnerability where increased rain-on-snow activity is anticipated. In Deschutes National Forest, peak flows and road system vulnerability decrease in a few subwatersheds, predominantly associated with groundwater-dominated systems. Most other subwatersheds show increasing vulnerability associated with rain-on-snow activity. Fremont-Winema National Forest is projected to see minor decreases in vulnerability to peak flows in low-elevation drainages and groundwater systems, but increases in vulnerability in mid elevations of southern, central, and eastern parts of the forest that will be increasingly susceptible to rain-on-snow events.

Antecedent moisture conditions, geology, and terrain are good predictors of mass wasting (including landslides and debris flows) (Kim et al. 1991), and elevated soil moisture and rapid changes in soil moisture are important triggers (Crozier 1986). Therefore, portions of the SCOAP assessment area with projected increases in antecedent soil moisture, coupled with more intense winter storms (including high wind) (Buma and Johnson 2015), will have a higher probability of mass wasting. Areas in the eastern Cascade Range of Deschutes and Fremont-Winema National Forests and Crater Lake National Park may see increased slope movement associated with steeply dissected glacial and volcanogenic deposits. In Ochoco National Forest, where geologic conditions have generated a high prevalence of active and dormant landslide terrain, higher winter soil moisture conditions with increased precipitation, more rain than snow, and greater storm intensity (Salathé et al. 2014) will likely increase mass wasting.

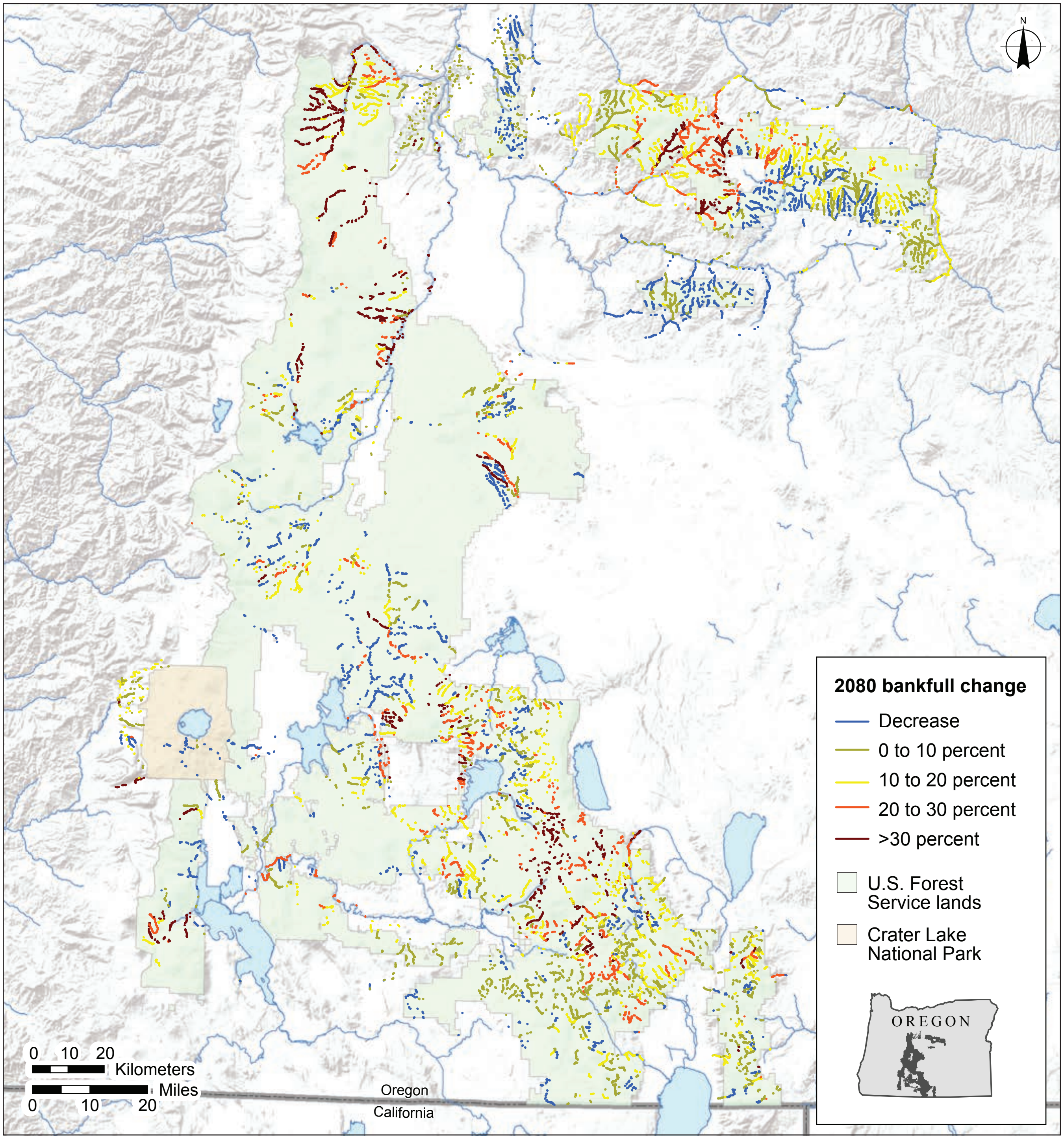


Figure 4.11—Projected winter change in bankfull flow on perennial streams within 90 m of roads (maintenance levels 1–5) administered by the U.S. Forest Service or National Park Service. Percentage change was calculated from historical data (1977–2006) and the A1B emission scenario for 2080, using the variable infiltration capacity model.

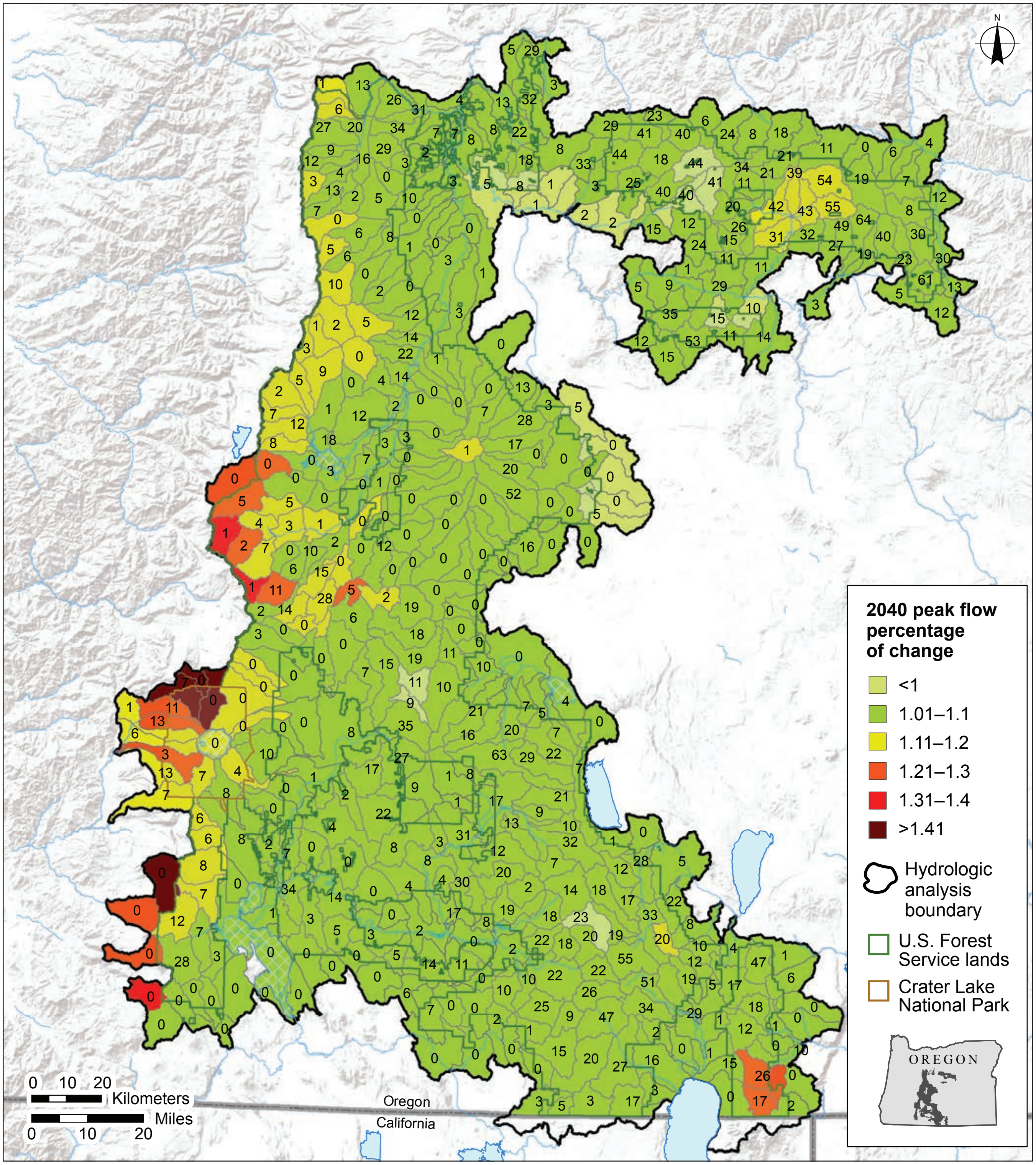


Figure 4.12—Peak-flow sensitivity and kilometers of roads within 90 m of perennial streams for subwatersheds in the South-Central Oregon Adaptation Partnership assessment area in 2040. Peak flow sensitivity is derived from Safeeq et al. (2015) for the A1B emission scenario.

These effects will vary with elevation, because higher elevation areas typically have steeper slopes and more precipitation during storms. Furthermore, reduced snowpack, particularly in mid elevations, is expected to increase antecedent soil moisture conditions in winter (Hamlet et al. 2013). Increasing trends in April 1 soil moisture have been observed in modeling studies as a result of climatic warming, indicating that soil moisture recharge is occurring earlier in spring and is now higher on April 1 than it was prior to 1947 (Hamlet et al. 2007). In areas increasingly predisposed to landslide activity, transportation system infrastructure and access will be at greater risk.

To assess vulnerability of the transportation system, we identified the traits of the transportation system most sensitive to projected climate changes (box 4.1) to inform transportation management and long-range planning. The vulnerability of roads to changes in climate, hydrologic variables, and soil moisture varied based on topography, geology, aspect, slope stability, engineering design, location, and use.

Roads and trails built decades ago have increased in sensitivity because of age and declining condition. Many infrastructure components are at or near the end of their design lifespan. Culverts, by far the most common infrastructure component of the transportation system, are typically designed to last 25 to 75 years, depending on structure and material. Culverts remaining in place beyond their design life are less resilient to high flows and bed load movement and have a higher likelihood of structural failure. As roads and trails age, their surface and subsurface structure deteriorates, leaving them increasingly vulnerable to less-severe storm events. In the face of higher severity storms, aging infrastructure and outdated design standards can lead to increased incidents of road failure. Much of the travel network in the SCOAP assessment area, when originally constructed, did not have the advanced design, materials, alignment, drainage, and subgrade required by today's standards.

New or replaced infrastructure is likely to have increased resilience to climate change, especially if projected runoff characteristics for later in the 21st century are considered in design and materials. New culverts and bridges are typically wider than the original structures to meet agency regulations and current design standards. In the past 15 years, many culverts under federal roads in the SCOAP assessment area have been replaced to improve fish passage and stream function using open-bottomed arch structures or bridges that are less constraining during high flows and support aquatic organism passage at a full range of flows. Natural channel design techniques that mimic the natural stream channel condition upstream and downstream of the crossings are being used at these crossings on fish-bearing streams. Culverts on non-fish-bearing streams are also being upgraded.

Box 4-1

Sensitivities of the Transportation System in National Forests in South-Central Oregon

- Aging and deteriorating infrastructure increases sensitivity to climate impacts; existing infrastructure is not necessarily designed for future conditions (e.g., culverts are not designed for higher peak flows).
- Roads and trails built on steep topography are more sensitive to landslides and washouts.
- A substantial portion of the transportation system is at high elevation, increasing exposure to weather extremes and increasing the cost of repairs and maintenance.
- Roads built across or adjacent to waterways are sensitive to high streamflows, stream migration, and sediment movement.
- Funding constraints, insufficient funds, or both limit the ability of agencies to repair damaged infrastructure or take preemptive actions to create a more resilient transportation system.
- Design standards or operational objectives that are unsustainable in a warmer climate may increase the frequency of infrastructure failure in the future.

Roads and trails may be directly and indirectly affected by climate change, depending on their location. Because of rugged topography in parts of the SCOAP assessment area, roads and trails built to access resources or provide recreational opportunities were built on steep slopes. Large cut slopes and fill material were sometimes required, creating over-steepened hill slopes and increased risk of landslides. Increased soil moisture can further exacerbate slope instability in disturbed areas (e.g., wildfire can reduce root cohesion). Higher runoff and peak flows from disturbed areas can also strain road-stream crossing infrastructure (Croke and Hairsine 2006, Schmidt et al. 2001, Swanston 1971). Roads and trails that were built in valley bottoms near streams to take advantage of gentle gradients are also at greater risk to flooding, channel migration, bank erosion, and shifts in alluvial fans and debris cones.

Management of roads and trails (planning, funding, maintenance, response) will determine how sensitive current and future transportation systems are to climate change effects. Although not immune to these potential effects, highways in the SCOAP assessment area that are built to a higher design standard and regularly maintained will be less sensitive to climate change than unpaved roads on federal lands built to a lower standard. The current lack of funding for most road and trail management activities limits options for responding to infrastructure repair and improvement, which also contributes to the vulnerability of roads and trails.

Indirect effects of climate change on transportation systems include secondary influences on access that can alter visitor-use patterns and increase threats to public safety. Earlier snowmelt allows visitors earlier access to federal lands, which affects the road system and future maintenance by increasing travel on wet roads, which in turn exacerbates road-surface erosion. It also increases the opportunity for the public to be physically present during the time of year that soil moisture conditions and storm events are most likely to cause landslides and flood events.

Current and Near-Term Climate Change Effects

Ongoing changes in climate and hydrologic response in the short term (the next 10 years) are likely to be a mix of natural variability combined with ongoing trends related to climate change. High variability of short-term trends is an expected part of the response of the evolving climate system. Natural climatic variability, in the short term, may exacerbate, compensate for, or even temporarily reverse expected trends in some hydroclimatic variables.

Higher streamflow in winter (October through March) and higher peak flows, in comparison to historical conditions, increase the risk of flooding and impacts to structures, roads, and trails (MacArthur et al. 2012, Walker et al. 2011). Floods also transport logs and sediment that block culverts or are deposited on bridge abutments. Isolated intense storms can overwhelm the capacity of vegetation and soil to retain water, concentrating high-velocity flows into channels that erode soils and remove vegetation. During floods, roads and trails can become preferential paths for floodwaters, reducing operational function and potentially damaging infrastructure not designed to withstand inundation.

In the short term, flooding of roads and trails will likely increase in late autumn and winter, threatening the structural stability of stream crossing infrastructure and subgrade material. Roads near perennial and other major streams are especially vulnerable (figs. 4.11 through 4.14), and are often located in floodplains where they provide recreation access. Increased high flows and winter soil moisture may also increase the amount of large woody debris delivered to streams, further increasing damage to culverts and bridges, and in some cases making roads impassable or requiring road and facility closures. Unpaved roads with limited drainage structures or minimal maintenance are likely to experience increased surface erosion, requiring additional repairs or grading.

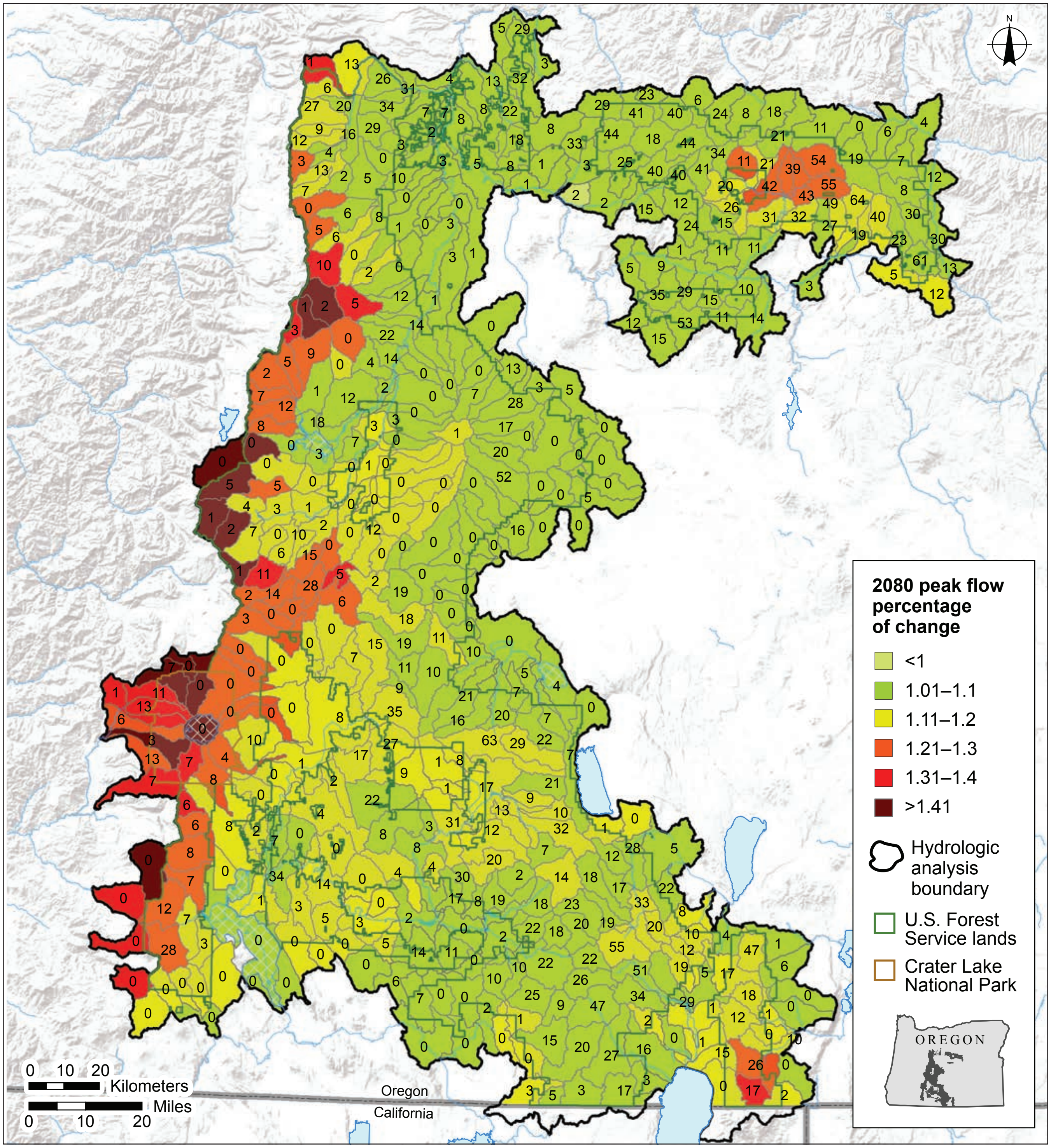


Figure 4.13—Peak flow sensitivity and kilometers of roads within 90 m of perennial streams for subwatersheds in the South-Central Oregon Adaptation Partnership assessment area in 2080. Peak flow sensitivity is derived from Safeeq et al. (2015) for the A1B emission scenario.

U.S. Forest Service

Figure 4.14—Road (also used as a trail) adjacent to Cherry Creek (Fremont-Winema National Forest) inundated with floodwater during a rain-on-snow event, December 2014.

Increasing incidence of more intense precipitation and higher soil moisture in early winter could increase the risk of landslides in some areas, particularly on dormant landslide terrain in Ochoco National Forest and in the Winter Rim area of Fremont-Winema National Forest. In addition, increased wildland fire, coupled with increased rain-on-snow events in winter, could trigger instability of slopes in landslide-prone areas.

Landslides contribute to flooding by diverting water, blocking drainage, and filling channels with debris (Chatwin et al. 1994, Crozier 1986, Schuster and Highland 2003), often elevating flood risk through aggradation of streambeds. Culverts filled with debris can cause flooding, damage, or complete destruction of roads and trails (Halofsky et al. 2011). Landslides that connect with waterways or converging drainages can transform into more destructive flows (Baum et al. 2007). Roads themselves also increase landslide risk, especially if they are built on steep slopes and through erosion-prone drainages (Chatwin et al. 1994, Montgomery 1994, Swanson and Dyrness 1975, Swanston 1971). In the Western United States, development of roads has increased the rate of debris avalanche erosion by 25 to 340 times the rate found in forested areas without roads (Swanston 1976). Consequently, areas with high road or trail density in landscapes that already experience frequent landslides will be especially vulnerable to increased landslide risks in a warmer climate.

Short-term exposures to climatic extremes may affect safety and access in the SCOAP area. Damaged or closed roads also reduce agency capacity to respond to emergencies or provide detour routes during emergencies. Increased flood risk could make conditions more hazardous for river recreation and campers. More wildfires (chapter 6) could reduce safe operation of some roads and require additional emergency response to protect recreationists and communities (Strauch et al. 2014). Damaged and closed roads also reduce agency capacity to respond to wildfires.

Emerging and Intensifying Exposure in the Medium and Long Term

Many of the observed exposures to climate change in the short term are also likely to increase in the medium (10 to 30 years) and long term (more than 30 years). In the medium term, natural climatic variability may continue to affect outcomes in any given decade, whereas in the long term the cumulative effects of climate change may become a dominant factor. Conditions thought to be extreme today may be averages in the future, particularly for temperature-related changes (MacArthur et al. 2012).

Flooding in autumn and early winter is projected to continue to intensify in the medium and long term, particularly in mixed rain-and-snow basins, but direct rain-on-snow events may diminish in importance as a cause of flooding (McCabe et al. 2007). At mid to high elevations, more precipitation falling as rain rather than snow will continue to increase winter streamflow. By the 2080s, peak flows are anticipated to increase in magnitude and frequency (figs. 4.11 through 4.13). In the long term, higher and more frequent peak flows will likely continue to increase sediment and debris transport within waterways. These elevated peak flows could affect stream-crossing structures downstream as well as adjacent structures because of elevated stream channels.

Projected increases in flooding in autumn and early winter will shift the timing of peak flows and affect the timing of maintenance and repair of roads and trails. More repairs may be necessary during the cool, wet, and dark time of year in response to damage from autumn flooding and landslides, challenging crews to complete necessary repairs before snowfall. If increased demand for repairs cannot be met, access may be restricted until conditions are more suitable for construction and repairs.

In the long term, declines in low streamflow in summer may require increased use of more expensive culverts and bridges designed to balance the management of peak flows with providing low-flow channels in fish-bearing streams. Road design regulations for aquatic habitat will become more difficult to meet as warming temperatures hinder recovery of coldwater fish populations, although some streams may be buffered by inputs from snowmelt or groundwater.

Over the long term, landslide risk is expected to increase more in areas with tree mortality caused by wildfire and insect outbreaks, the concurrent effect of tree mortality reducing soil root cohesion and decreased interception and evaporation (Martin 2006, Montgomery et al. 2000, Neary et al. 2005, Schmidt et al. 2001). Thus, soils will likely become more saturated and vulnerable to slippage on steep slopes during the wet season. Although floods and landslides will continue to occur near known hazard areas (e.g., because of high forest road density), they may also occur in new areas (e.g., those areas that are currently covered by deep snowpack in mid-winter) (MacArthur et al. 2012). Thus, more landslides at increasingly higher elevations (with sufficient soil) may be a long-term effect of climate change.

A longer snow-free season may extend visitor use in early spring and late autumn at higher elevations (Rice et al. 2012) (chapter 8). Lower snowpack may lead to fewer snow-related road closures for a longer portion of the year, allowing visitors to reach trails and campsites earlier in the season. As noted earlier, roads that were historically frozen during winter months will be subject to more flowing water and increased exposure to erosion.

Warmer temperatures and earlier snowmelt may encourage use of roads and trails before they are cleared. Trailheads, which are located at lower elevations, may be snow-free earlier, but hazards associated with melting snow bridges, avalanche chutes, or frozen snowfields in shaded areas may persist at higher elevations. Early-season visitors may be exposed to more extreme weather than they have encountered historically (Hamlet and Lettenmaier 2007), creating potential risks to visitors. Whitewater rafters may encounter unfavorable conditions from lower streamflows in late summer (Mickelson 2009) and hazards associated with sediment deposition and woody debris from high winter flows. Warmer winters may shift river recreation to times of year when risks of extreme weather and flooding are higher.

Climate change may also benefit access and some aspects of transportation operations over the long term. Lower snow cover will reduce the need for and cost of snow removal, and earlier snow-free dates projected for the 2040s suggest that low- and mid-elevation areas will be accessible earlier. For example, temporary trail bridges on rivers may be installed earlier in spring as spring flows decline. A longer snow-free season and warmer temperatures may allow for a longer construction season at higher elevations. Although less snow may increase access for summer recreation, it may reduce opportunities for winter recreation at low and moderate elevations (Joyce et al. 2001, Morris and Walls 2009) (chapter 8). The highest elevations in the SCOAP assessment area may retain relatively more snow than other areas, creating higher local demand for winter recreation over the next several decades.

Summary

The results and map products discussed in this chapter represent our understanding of the likely effects of climate change on key hydrologic processes. However, these results should be applied with caution. Key uncertainties include the specific climate trajectories that south-central Oregon will experience in the future, critical assumptions underlying all models used, and the myriad uncertainties and errors attached to the calibration of each of the models. Resource managers wishing to apply the results of this analysis in forest planning are encouraged to read the primary literature in which the strengths and limitations of different modeling and forecasting approaches are described.

In general, projections of future trends in streamflow and related processes are strongest in characterizing relative sensitivities of different parts of the landscape rather than absolute changes. In other words, the spatial pattern of trends is more robust than projections associated with any particular location. Similarly, more confidence applies to the interpretation of relative as opposed to absolute magnitudes of projected changes. Differences in results between modeling approaches, such as the low-flow analysis, should be interpreted as bracketing likely potential changes. However, the general agreement among approaches described here increases confidence in the projections.

The effects of climate change on hydrology in south-central Oregon will be significant. Decreased snowpack and earlier snowmelt will shift the timing and magnitude of streamflow; peak flows will be higher, and summer low flows will be lower. Snowpack in the Oregon Cascades will be especially sensitive to higher temperatures, and changes on the order of 7 to 8 weeks in snow residence timing are likely, coupled with a near-complete loss of April 1 SWE at many sites. The largest reductions in summer streamflows are projected for the eastern slopes of the High Cascades where the earlier snowmelt timing will potentially result in summer streamflow losses of 40 to 60 percent by 2040 and 60 to 80 percent by 2080. Other focal areas of reduced summer streamflow are the uplands of Fremont-Winema National Forest, with projected reductions of 20 to 30 percent by 2040 and 40 to 50 percent by 2080. Areas most vulnerable to increasing peak flows include the eastern slopes of the Cascades and Fremont-Winema and Ochoco National Forests.

Changes in hydrology will affect water availability in south-central Oregon. Water supply in south-central Oregon is limited in summer months, and climate change may reduce water available for current demands in summer, especially during extreme drought years and after multiple consecutive drought years. The Goose Lake, Lake Abert, Middle Deschutes, Sprague, Upper Deschutes, Upper Klamath Lake, Upper Rogue, and Warner Lakes subbasins are at highest risk for summer water shortage associated with low streamflow. Decreased summer low flows in these areas have the greatest potential to affect agricultural irrigation and municipal uses.

Precipitation and snowpack changes will also affect flood and landslide risk in south-central Oregon. In the short term, flooding of roads and trails will likely increase in late autumn and winter, threatening the structural stability of stream-crossing infrastructure. Roads near perennial and other major streams are especially vulnerable. Flood risk and road system vulnerability are generally lower in low-elevation drainages and spring-fed systems, and higher in mid- to high-elevation drainages, especially where baseflow is less supported by groundwater. Increasing incidence of more intense precipitation and higher soil moisture in early winter could increase the risk of landslides in some areas, particularly on dormant landslide terrain in Ochoco National Forest and in the Winter Rim area of Fremont-Winema National Forest.

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Chapter 5: Climate Change, Fisheries, and Aquatic Habitat in South-Central Oregon

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Introduction

Lands administered by Deschutes, Fremont-Winema, and Ochoco National Forests, Crooked River National Grassland, and Crater Lake National Park support a diversity of native aquatic species that will be affected by climate change. Climate change is affecting the aquatic environments of these areas in many ways. Warming air temperatures and changing precipitation patterns are resulting in warmer stream temperatures (Bartholow 2005; Isaak et al. 2010, 2012, 2016a; Petersen and Kitchell 2001), altered stream hydrology (Hamlet and Lettenmaier 2007, Luce et al. 2013), and changes in the frequency, magnitude, and extent of climate-related events such as floods, droughts, and wildfires (Holden et al. 2012, Littell et al. 2010, Luce and Holden 2009, Rieman and Isaak 2010). Fish populations have been adapting by shifting their phenology and migration dates (Crozier et al. 2008, 2011; Keefer et al. 2008), using cold-water refugia during thermally stressful periods (Keefer et al. 2009; Torgersen et al. 1999, 2012), and shifting spatial distributions within river networks (Comte et al. 2013, Eby et al. 2014).

This chapter describes a climate change vulnerability assessment for bull trout (*Salvelinus confluentus* Suckley), summer steelhead (*Oncorhynchus mykiss* Walbaum), interior redband trout (*O. mykiss gibbsi* Suckley), Lost River sucker (*Deltistes luxatus* Cope), and shortnose sucker (*Chasmistes brevirostris* Cope) in south-central Oregon. These species were selected for analysis in consultation with local biologists because of potential sensitivity to climate change, societal importance as listed species under the

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Endangered Species Act (bull trout, steelhead, Lost River sucker, and shortnose sucker), and their occupancy of a broad range of aquatic habitats both within and downstream of the selected national forests, grasslands, and parks. Although habitats for the selected species overlap in places, each species uses a unique set of aquatic habitats and displays a diverse array of life history strategies, including anadromy (steelhead), fluvial and adfluvial movements (bull trout, Lost River sucker, and shortnose sucker), and residency (bull trout and redband trout).

The objective of this chapter is not to provide an exhaustive review of the climate-aquatic-fisheries literature; general reviews already exist for the Pacific Northwest (ISAB 2007; Mantua and Raymond 2014; Mantua et al. 2009, 2011; Mote et al. 2003), and more broadly (Ficke et al. 2007; Furniss et al. 2010, 2013; Isaak et al. 2012; Luce et al. 2012; Poff et al. 2002; Rieman and Isaak 2010; Schindler et al. 2008). Rather, the intent is to assess the specific vulnerabilities to climate change of each of the five selected species in stream networks on national forest and adjacent lands. Aiding this assessment are recently developed, high-resolution stream temperature and flow scenarios that translate outputs from global circulation models (GCMs) to reach-scale habitat factors relevant to aquatic biota.

Analysis Area

There are 18 subbasins within the South-Central Oregon Adaptation Partnership (SCOAP) assessment area that have portions administered by Deschutes, Fremont-Winema, and Ochoco National Forests and by Crater Lake National Park. These subbasins are found within five major hydrological units or basins (6^{th}-field hydrologic unit code), referred to here as river basins (fig. 5.1). The majority of lands within Deschutes and Ochoco National Forests and Crooked River National Grassland lie within the Deschutes River basin. A small portion of southeastern Deschutes National Forest is also within the Oregon closed basin, and the northeastern edge of Ochoco National Forest is within the John Day River basin. Most of the drainages of Fremont-Winema National Forest flow within the Klamath, Oregon, and Upper Sacramento closed basins, with very limited drainage area within the Deschutes basin. The Oregon closed basin, characterized by interior (endorheic) drainage (Lev et al. 2012), has no hydrologic connection to any other river basins. Crater Lake National Park drainages flow into the Klamath River basin and Rogue River basin, although the latter lies outside the SCOAP assessment area.

Approximately 19 000 km of streams occur in the combined river basins in the SCOAP assessment area, of which almost 5000 km are identified as perennial streams on Deschutes, Fremont-Winema, and Ochoco National Forests and Crooked River National Grassland. All watersheds are classified as “functioning properly” or “at risk” based on the Watershed Condition Framework (Potyondy and Geier 2011) (fig. 5.2).

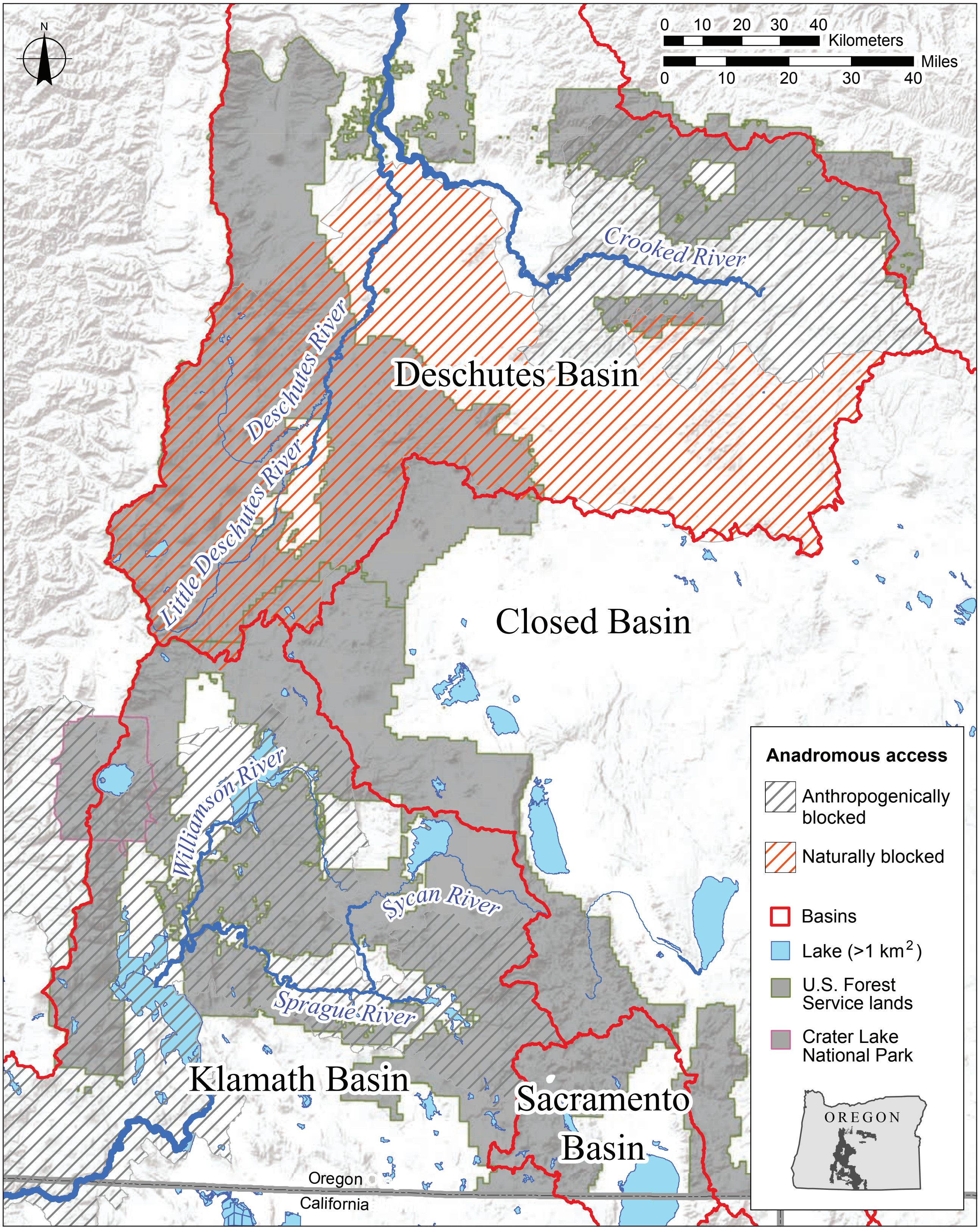

Figure 5.1—The South-Central Oregon Adaptation Partnership assessment area, showing hydrologic subdomains and areas where anadromous fish access is blocked by natural or human-caused factors.

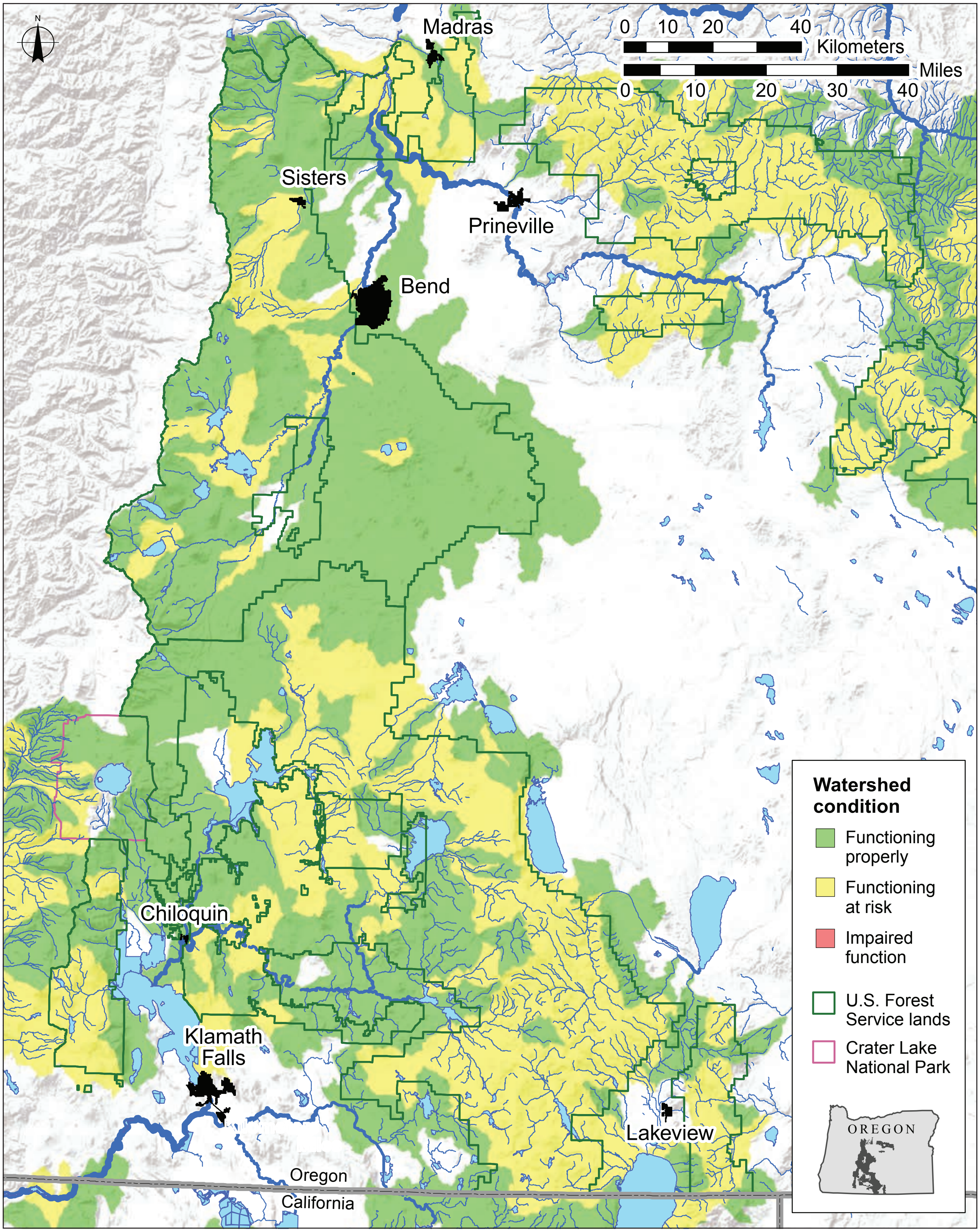

Figure 5.2—Watershed condition framework classifications for national forests within the South-Central Oregon Adaptation Partnership assessment area.

Selected Aquatic Species

Steelhead and Redband Trout

Steelhead and redband trout are alternate life history forms of the same species where they co-occur (Falke et al. 2013, McMillan et al. 2011, Mills et al. 2012). Both steelhead and redband trout spawn at lower elevations and may tolerate relatively warm temperatures in their spawning and rearing habitats. For summer rearing, optimal mean August temperatures are 11 to 16 °C, and the suboptimal range is from 16 to 22.3 °C for maximum weekly maximum temperature (MWMT) (Isaak et al. 2017, Richter and Kolmes 1995, Rodnick et al. 2004). Steelhead trout are a large-bodied anadromous form of *O. mykiss*. They spawn in spring in medium rivers to headwater tributaries and rear in cool medium and small rivers, tributary and headwater streams, and upstream portions of large rivers in the analysis area, within accessible portions of the Middle Columbia River (MCR) basins. The MCR steelhead distinct population segment (DPS) includes all naturally spawned populations in streams within the Columbia River basin, from above the Wind River in Washington and the Hood River in Oregon (exclusive), upstream to and including the Yakima River in Washington, excluding steelhead from the Snake River basin (USDC NOAA 1999, 2006). MCR steelhead do not include resident forms of *O. mykiss* (redband or rainbow trout) co-occurring with these steelhead. Four major population groups (MPG) have been identified within the DPS: Cascades Eastern Slope tributaries; Yakima River; John Day River; and Umatilla and Walla Walla Rivers.

Deschutes and Ochoco National Forests include portions of the John Day River MPG and Cascades Eastern Slope tributaries MPG, either directly inhabited by steelhead or designated as critical habitat (fig. 5.3). Redband trout, a smaller bodied spring-spawning resident life form of the *O. mykiss* species, have different habitat requirements than steelhead. Redband trout occupy small and medium rivers and tributary streams, where they sometimes adopt fluvial life histories, although most populations are residents. On Deschutes and Ochoco National Forests and Crooked River National Grassland, distribution of redband includes all areas across the forests, including those that have steelhead trout (fig. 5.4). Part of this area on Fremont-Winema National Forest includes the Fort Rock species management unit (SMU) (Buck, Bridge, and Silver populations). On Fremont-Winema National Forest, redband also occur within the Chewaucan, Goose Lake, Fort Rock, Upper Klamath Basin, and Warner Lakes SMUs.

The juvenile life stages of the two forms of *O. mykiss* are indistinguishable visually where they co-occur, but juvenile individuals eventually express one or the other of the two life histories, as they either develop physiologically into ocean-going steelhead or remain as freshwater resident redband trout. The likelihood

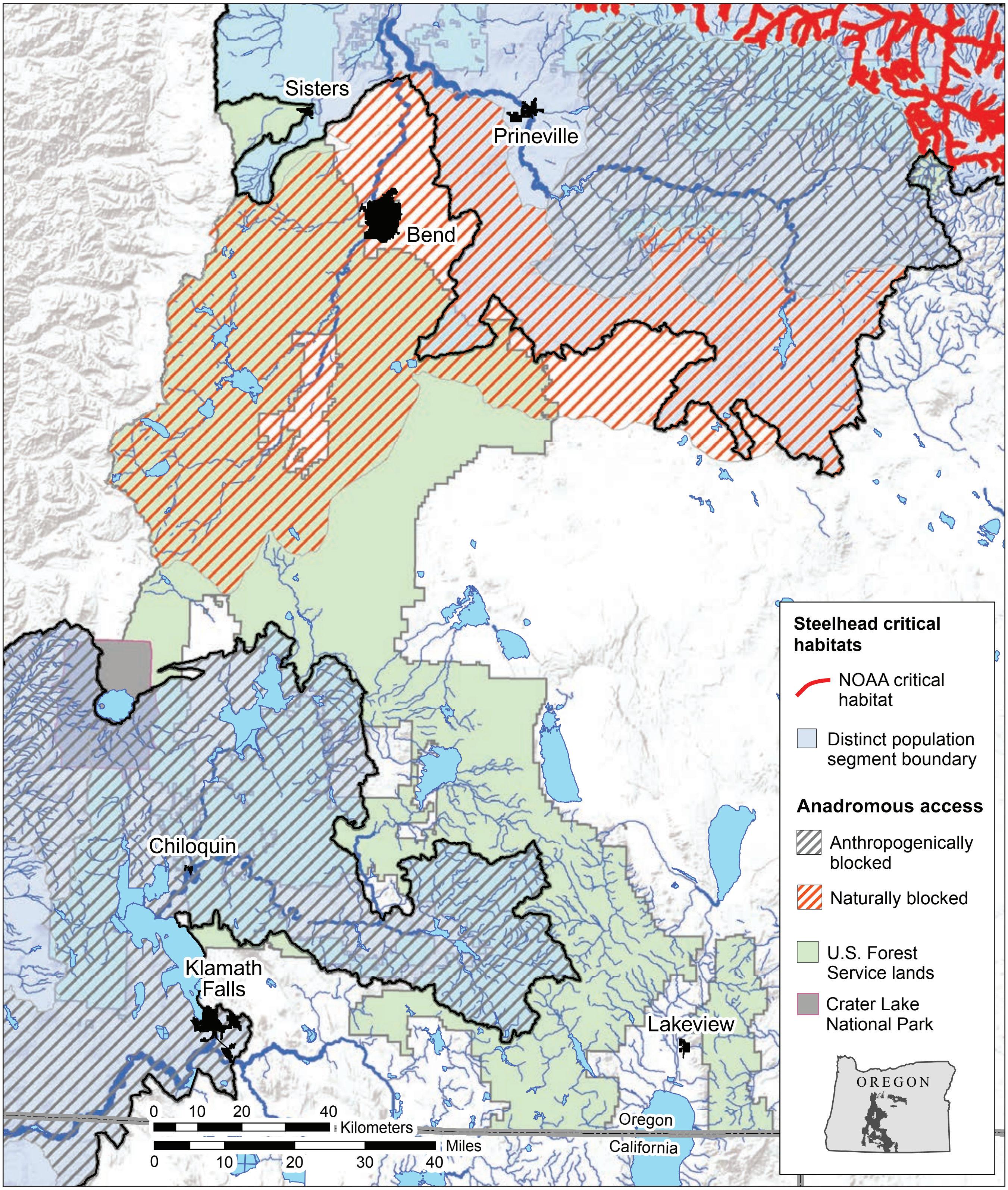

Figure 5.3—Steelhead critical habitats designated by the National Oceanic and Atmospheric Administration (NOAA). Geospatial data were downloaded from http://www.westcoast.fisheries.noaa.gov/maps_data/endangered_species_act_critical_habitat.html.

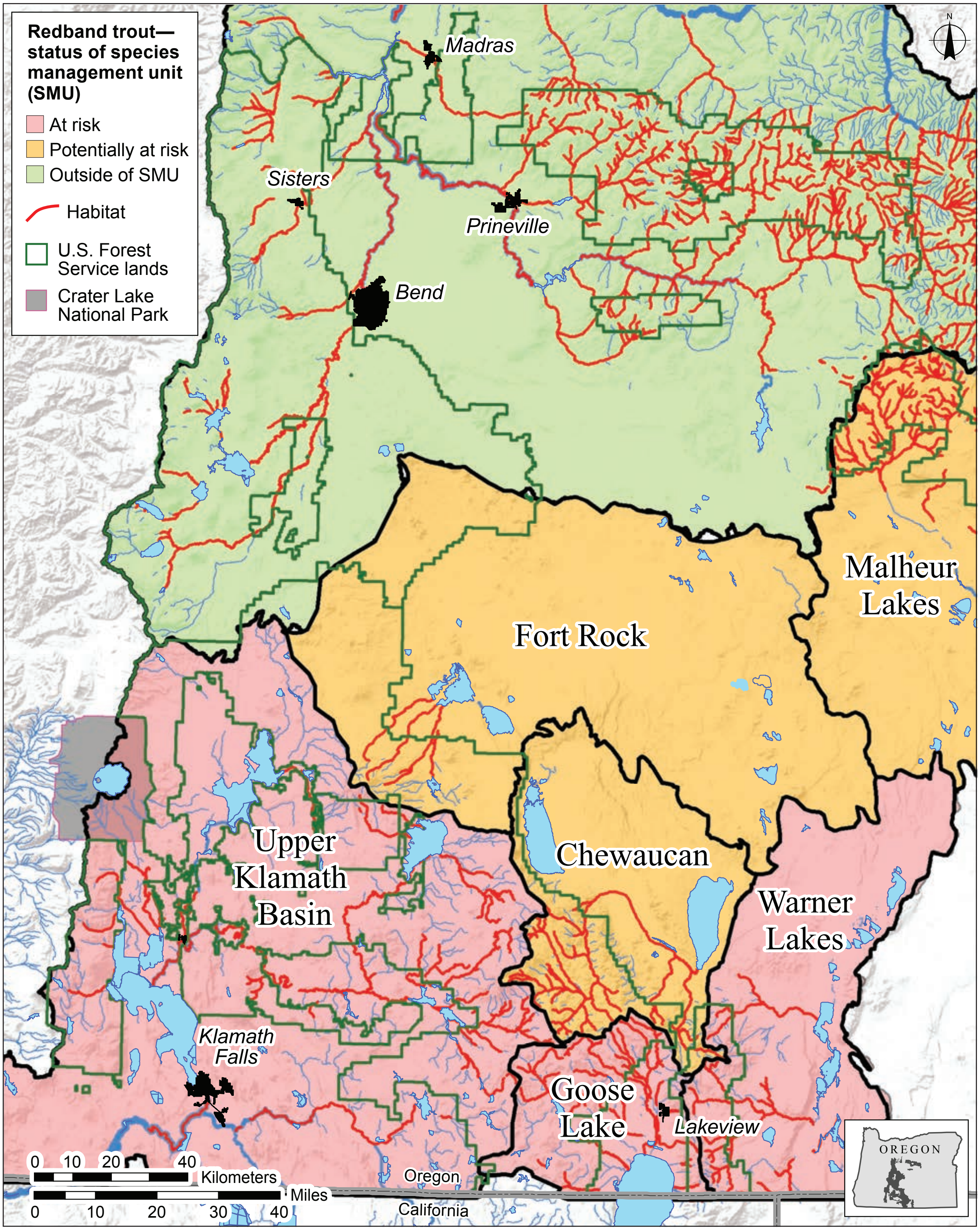

Figure 5.4—Redband trout conservation status within the South-Central Oregon Adaptation Partnership assessment area, derived from geospatial data obtained from the Oregon Department of Fish and Wildlife. Status is shown within and outside of a species management unit.

that a juvenile will express one or the other life history is strongly influenced by environmental and physiological factors, including water temperature, food supply, gender, growth rates, and body fat development, which interact in complex ways to ultimately determine which individuals outmigrate as steelhead smolts and which remain to mature in freshwater (Sloat and Reeves 2014). In addition, where they co-occur, offspring of female steelhead may mature into resident redband trout, and offspring of female redband trout may ultimately outmigrate to the ocean and return to National Forest System streams as adult steelhead (Carmichael et al. 2005).

Bull Trout

Bull trout are fall spawners with eggs that overwinter in the gravels and fry that emerge from redds in late winter and early spring (Dunham et al. 2008, Rieman and McIntyre 1993). Their habitat ranges from medium-size, high-elevation tributaries to very small headwater streams. Migratory individuals are known to winter in larger rivers and tributaries but move upriver toward headwater resident tributaries as migratory corridors begin to warm with advancing spring temperatures (Howell et al. 2010). Optimal habitats for bull trout provide year-round high-quality cold water and high habitat complexity. Optimal temperatures for juvenile bull trout rearing are less than 17 °C MWMT (Dunham et al. 2003), which equates to less than 11 °C August mean temperatures based on extensive field datasets (Isaak et al. 2015, 2017).

Within the analysis area, bull trout exist as a variety of life history forms, freshwater migratory (fluvial and adfluvial) and headwater year-round resident. Migratory bull trout move between their natal streams and larger bodies of fresh water, such as lakes, reservoirs, and mainstem rivers, where they can grow much larger than the year-round residents that rear and mature in small, colder headwaters.

Bull trout populations are often a mix of resident and migratory individuals. This mix of life histories is an adaptation to infrequent but catastrophic natural disturbances in their high-elevation habitats. When such disturbances cause a small resident population to "wink out," migratory individuals that were elsewhere at the time of the event can then found a new population in the vacant habitat, though such recolonization may not occur immediately. The benefits of such disturbances are that they tend to deliver pulses of large wood and streambed material that provide new spawning gravels and increase habitat complexity, providing for resting places and cover to shelter fish from predators and reduce energy demands imposed by fast streamflow. A fresh assortment of large streambed substrate provides spaces in the streambed where juveniles can hide from predators.

Bull trout within the analysis area occur in the Mid-Columbia and Klamath recovery units. Within the Mid-Columbia recovery unit, bull trout are present within the Lower Deschutes River core population that encompasses the Deschutes River and its tributaries and Odell Lake core area (fig. 5.5). The Lower Deschutes core area is generally described as the mainstem Deschutes River and its tributaries from Big Falls downstream to the Columbia River. Current bull trout distribution is limited to the Lower Deschutes core area, which includes five local populations (Shitike Creek, Warm Springs River, and three Metolius River population complexes [First, Jack, Canyon, Roaring, Brush, Abbot, Candle, and Jefferson Creeks, and Whitewater River]).

Within the Klamath recovery unit, bull trout are present in the Upper Klamath Lake, Sycan River, and Upper Sprague River core populations. The Upper Klamath Lake core area includes bull trout in Threemile, Sun, and Lost Creeks. Sun Creek, in Crater Lake National Park, currently supports the largest local population in the Upper Klamath Lake core area. The only bull trout population in the Sycan River core area is found in Long Creek. Finally, the Upper Sprague River core area supports bull trout in Deming, Leonard, Brownsworth, and Boulder-Dixon Creeks. Deming Creek currently supports the largest local population of bull trout in this core area.

Lost River and Shortnose Suckers

Lost River sucker and shortnose sucker are members of a group of suckers (family Catostomidae) that predominantly use lake environments. Both Lost River sucker and shortnose sucker are large, long-lived, lake-dwelling fish that are endemic to the Klamath River basin of southern Oregon and northern California, specifically within the Lost, Upper Klamath Lake, Upper Klamath, and Sprague subbasins. Lost River sucker and shortnose sucker have complex life histories that include stream, lake, marsh, and shoreline habitats (National Research Council 2004). Like most members of the Catostomidae, both sucker species tolerate and prefer relatively warm temperatures (Martin and Saiki 1999). Both spawn during the spring (February through June) in tributary rivers, streams, or springs associated with lake habitats (Buettner and Scoppettone 1990). The fertilized eggs hatch after about 1 week, and after approximately 10 more days the larvae emerge out of the gravel, quickly drifting downstream to lakes (Buettner and Scoppettone 1990, Coleman et al. 1988, USFWS 2012). Larvae transform into juveniles by mid-July. Lost River suckers are generally limited to lake habitats when not spawning, and no large

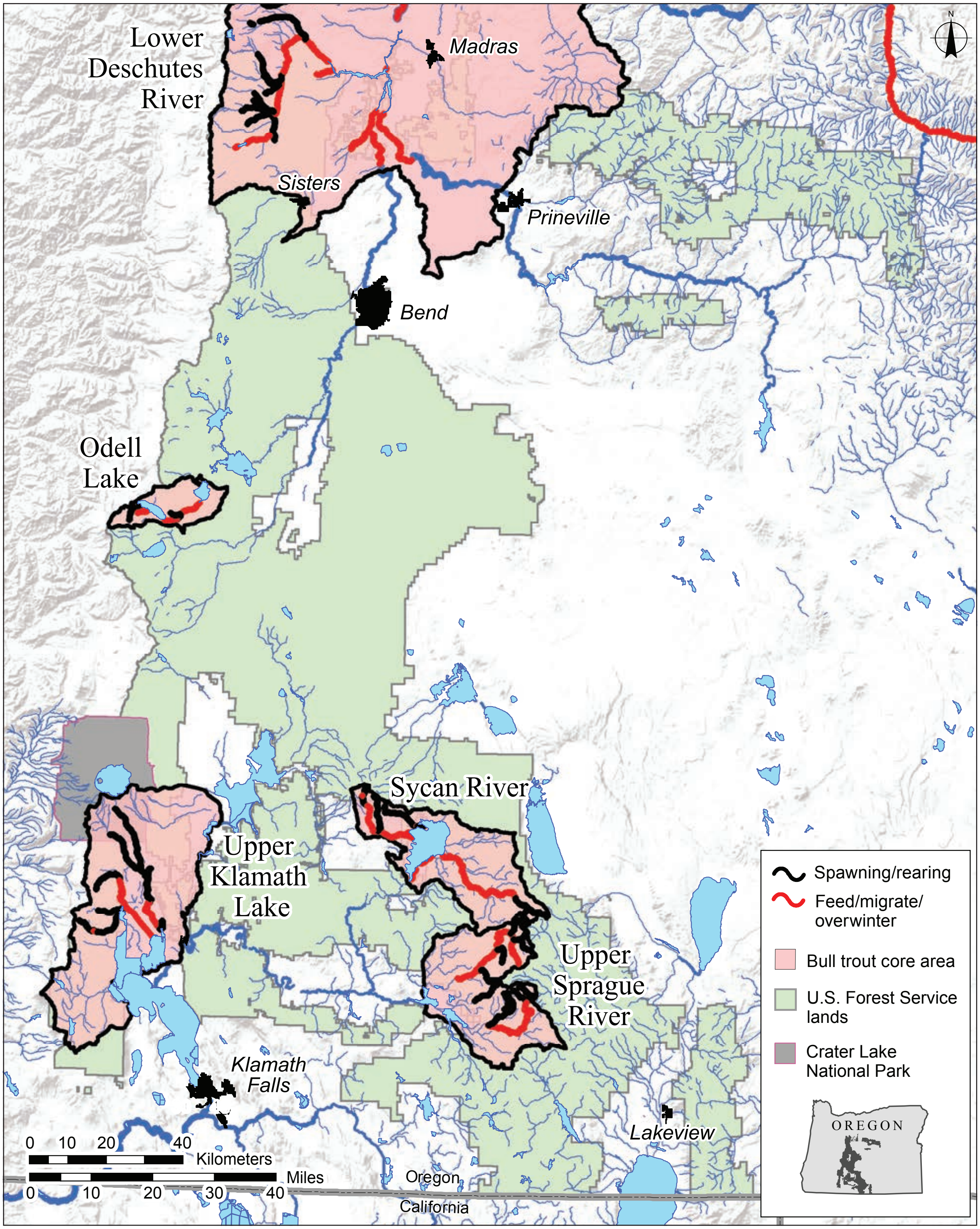

Figure 5.5—Bull trout core areas within the South-Central Oregon Adaptation Partnership assessment area based on U.S. Fish and Wildlife Service critical habitat designations. Geospatial data were downloaded from http://ecos.fws.gov/ecp/report/table/critical-habitat.html.

populations are known to occupy stream habitats. However, there are apparently some shortnose suckers that both live and spawn in streams (Buettner and Scoppettone 1990, Coleman et al. 1988).

Currently, there are two major populations of Lost River sucker in the Klamath Basin, found in Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California, along with a very small population in Tule Lake, California (fig. 5.6). There are three major populations of shortnose sucker in the Klamath basin found in Upper Klamath Lake and Gerber Reservoir in Oregon and Clear Lake Reservoir, California (fig. 5.7). Although Upper Klamath Lake likely contains the largest Lost River sucker and shortnose sucker populations, Gerber Reservoir and Clear Lake Reservoir have self-sustaining sucker populations (Barry et al. 2007). Gerber Reservoir and its tributaries represent the only habitat with a shortnose sucker population that does not also have a Lost River sucker population (USFWS 2012). Populations of suckers in Clear Lake and Gerber Reservoirs are isolated from suckers in the rest of the Klamath basin because the reservoir dams do not provide fish passage.

The recovery units for both species are the Upper Klamath Lake unit and the Lost River Basin unit. Each recovery unit also includes several management units. Upper Klamath Lake unit (designated for each species separately) includes all individuals residing in Upper Klamath Lake, its tributaries, or any of the reservoirs along the Klamath River. This unit is composed of four management units, depending on the species: Upper Klamath Lake and tributaries (river-spawning individuals), Upper Klamath Lake (shoreline spring-spawning individuals), Keno Reservoir, and populations below Keno Reservoir.

The Lost River Basin unit (designated for each species separately) includes all individuals residing in the reservoirs and flowing water in this subbasin. Four specific management units have been designated: Clear Lake Reservoir and tributaries, Tule Lake, Gerber Reservoir and tributaries, and Lost River proper.

The Klamath Basin lakes and reservoirs that provide habitat for Lost River sucker and shortnose sucker are not on national forest lands. Rather, small tributary streams on national forests may provide seasonal habitat that may be accessed from the lakes or reservoirs during spring spawning.

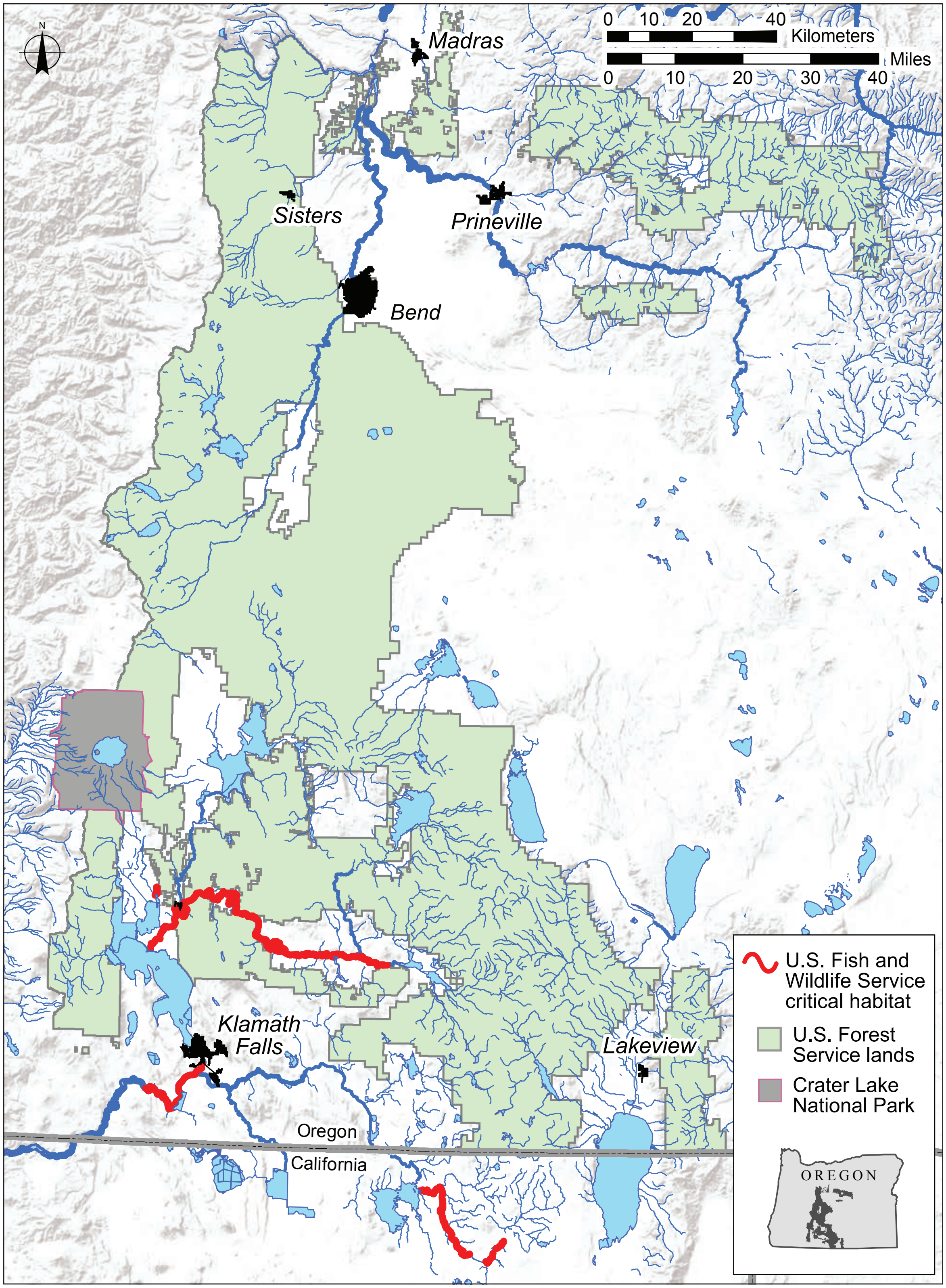

Figure 5.6—Critical habitat for Lost River sucker within the South-Central Oregon Adaptation Partnership assessment area based on U.S. Fish and Wildlife Service designations. Geospatial data were downloaded from http://ecos.fws.gov/ecp/report/table/critical-habitat.html.

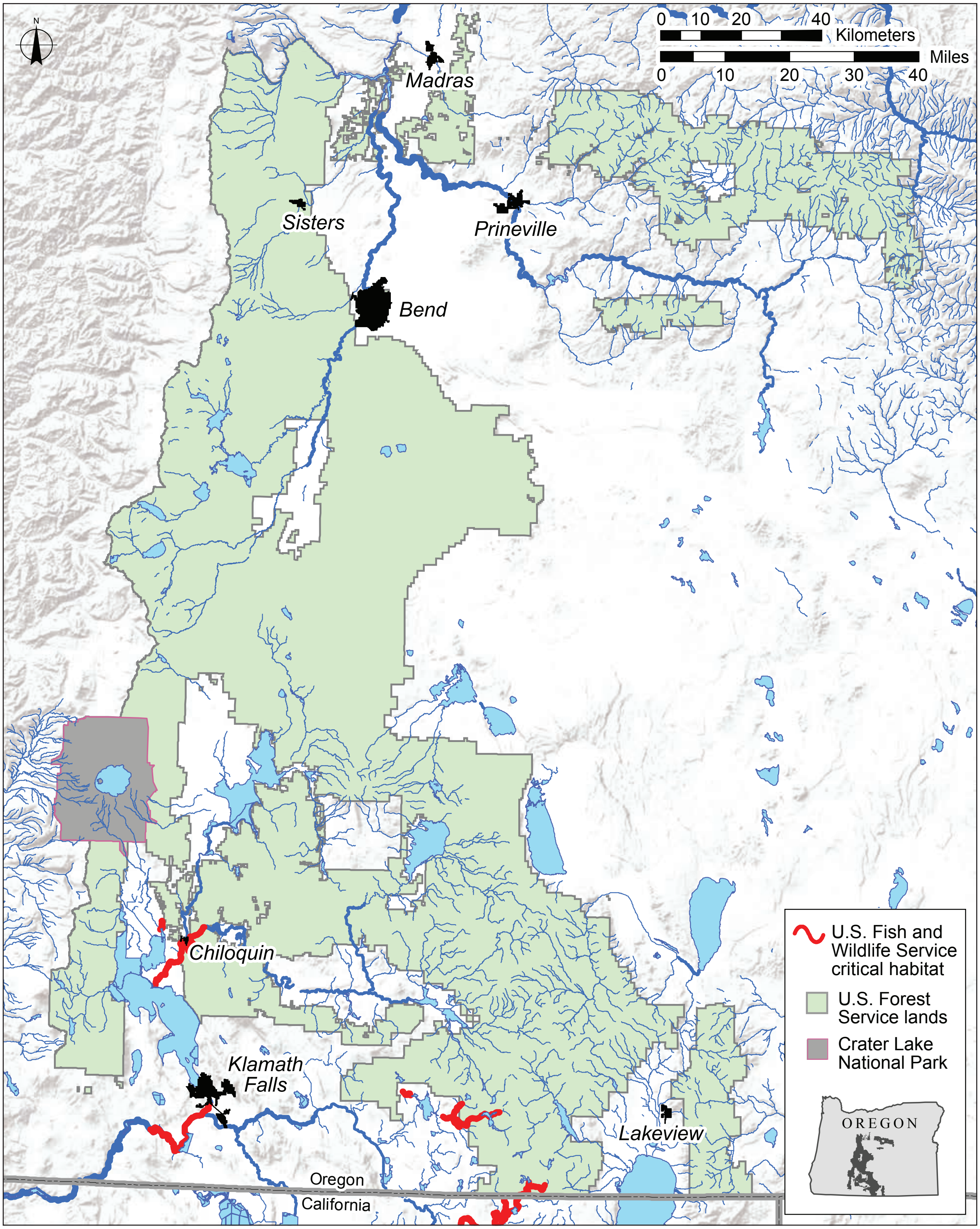

Figure 5.7—Critical habitat for shortnose sucker within the South-Central Oregon Adaptation Partnership assessment area based on U.S. Fish and Wildlife Service designations. Geospatial data were downloaded from http://ecos.fws.gov/ecp/report/table/critical-habitat.html.

Current Status and Trend

Current Population Conditions

Steelhead trout—

Middle Columbia River steelhead populations have declined substantially from their historical numbers. In 2006, Middle Columbia River steelhead were listed as a threatened species under the 1973 Endangered Species Act (ESA) because of overfishing, loss of habitat and connectivity, and hatchery practices. In addition, they are classified as a state critical species (species imperiled with extirpation from a specific geographic area of the state because of small population sizes, habitat loss or degradation) by the Oregon Department of Fish and Wildlife (ODFW). The National Marine Fisheries Service (NMFS) completed a recovery plan in 2009 to protect and restore Middle Columbia River steelhead populations (USDC NOAA 2009). The recovery strategies outlined in the recovery plan are targeted to achieve viable populations with representation of all the major life-history strategies present historically, and with the abundance, productivity, spatial structure, and diversity attributes required for long-term persistence.

Based on the 2009 Middle Columbia River steelhead recovery plan (USDC NOAA 2009), viability assessments have determined populations within the analysis area either meet viability criteria or are considered maintained. The biological review team further stratified Middle Columbia River steelhead into major population groups based on ecoregions characteristics, life history types, and other geographic and genetic considerations. The analysis area includes portions of the Cascade Eastern Slope Tributaries MPG (specifically Deschutes River Eastside and Westside) and John Day River MPG (specifically Lower Mainstem and South Fork John Day River).

Within the Cascades Eastern Slope Tributaries MPG, the Deschutes River Eastside population currently meets recommendations for viable status. However, viability is considered to be at low to moderate risk because of the large confidence interval around the productivity estimate, tributary habitat changes, loss of historical spawning habitat, and out of DPS hatchery spawners.[2] The Deschutes River Westside population does not meet viability criteria and is considered to be at high risk (Carmichael and Taylor 2010). Abundance data for both populations indicate that total spawning abundance is below levels reported in the last status review; however, natural-origin spawner abundance is higher (Carmichael and Taylor 2010).

[2] Rife, D. 2011. Ochoco National Forest and Crooked River National Grassland: aquatic MIS analysis—redband trout. Unpublished report. On file with: John Chatel, U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, 1220 SW 3rd Avenue, Portland, OR 97204.

Most populations within the John Day MPG, with the exception of the North Fork John Day River, are rated as maintained status and stable. Within the John Day MPG, the South Fork John Day River populations are considered to be at moderate risk based on current abundance and productivity (see footnote 2). Natural origin abundance estimates were higher in the current NMFS 5-year status assessment. Estimates of the fraction of natural origin spawners were relatively unchanged for the upstream John Day populations (Ford 2011). Productivity estimates (geometric mean of brood year spawner:spawner ratio at low to moderate parent escapements) were generally lower in the updated data series than the estimates generated for the Interior Columbia River Basin Technical Recovery Team status reviews ending in spawning year 2005. The South Fork John Day River population had higher total and natural origin spawning escapements compared to the 1997–2001 brood cycle.

Redband trout—

Although redband trout are not listed under the ESA, populations within the Oregon closed basins (pluvial lake basins in Oregon) are of particular concern by various state and federal agencies. These populations are outside the current range of steelhead and separated from other redband trout populations in the Columbia and Snake River basins. Many populations have experienced reductions, primarily because of habitat degradation, habitat fragmentation, and introduction of nonnative species. Redband trout populations within the Oregon closed basins are considered viable but believed to be declining. They are therefore listed as a species of special concern by the U.S. Fish and Wildlife Service and classified as a state critical or state vulnerable species by the ODFW. Within the Pacific Northwest Region of the Forest Service, most SMUs are designated as a regional-forester-sensitive species.

Little work has been done in regard to the status of redband trout populations or densities in the Columbia River basin. However, a study done by Stuart et al. (2007) in the Crooked River basin found that strong redband populations were mostly found in the headwater sections of streams on federally owned lands. In addition, even though redband trout occupied an estimated 75 percent of their historical range within the basin, their abundance was depressed.

The ODFW has designed seven SMUs for the redband trout in south-central and southeast Oregon based on several geographic clusters of subbasins. On Fremont-Winema National Forest, redband occur within the Warner Lakes SMU (Honey, Upper Deep, and Twentymile populations); Fort Rock SMU (Buck, Bridge, and Silver populations); Chewaucan SMU (Chewaucan, Foster, Willow, and Crooked populations); Goose Lake SMU (Thomas-Bauers Complex, Upper Drews, Dry, Crane, Cogswell, Tandy, Kelley, Antelope, and Muddy populations); and Upper Klamath Basin SMU (Jenny, Klamath River, Cascade Complex, Wood

River, Lower and Upper Williamson, Lower Sprague, Upper Sycan, Upper Sprague, and Lost River). On Deschutes and Ochoco National Forests and Crooked River National Grassland, distribution of redband includes all areas, including those that have steelhead trout.

Based on the ODFW 2005 status report (ODFW 2005), redband trout populations within the assessment area appear to be either high or moderate in abundance and distribution compared to other eastern Oregon populations. Degraded habitat conditions, barriers to migrations, and introduction of other stocks of rainbow trout (primarily coastal rainbow trout [*O. mykiss irideus* Gibbons]), and nonnative eastern brook trout (*Salvelinus fontinalis* Mitchill) are the most persistent threat to these populations.

Warner Lakes Redband Trout SMU includes four populations in the interior basin of Lake Warner. Three of the four populations are within the assessment area. Distribution of this SMU appears to be widespread in perennial streams and lakes of Warner Valley, as conditions allow. Multiple irrigation diversions and the presence of nonnative warmwater fish in Warner Lakes limit the expression of an adfluvial life history. Redband trout in the Honey and Twentymile populations are able to express multiple life histories because they have access to the Warner Lakes. However, passages to lakes are hindered by numerous irrigation diversions. Therefore, migratory success is highly influenced by water year and climatic conditions.

The Upper Deep Creek population is separated by Deep Creek Falls, which restricts the opportunity for genetic mixing and could increase the possibility of inbreeding depression, although this phenomenon is something to which salmonids are often less vulnerable because of their relatively large genome size (Waples et al. 2008). As a result, small isolated populations are often known to persist for decades or centuries in the absence of catastrophic stochastic events (Peterson et al. 2014, Whiteley et al. 2010). Densities and abundance are relatively high in the headwater and mid-reaches (ODFW 2005). Conversely, densities in the lower reaches may be low and susceptible to extreme environmental fluctuations and degraded habitat (ODFW 2005). Abundance surveys conducted by the ODFW in 2005 showed mean density for the Warner Lakes SMU to be high relative to densities throughout eastern Oregon, although lower reaches in each population unit were underrepresented (ODFW 2005).

The Fort Rock Redband Trout SMU consists of three populations in the Silver Lake Basin, all within the assessment area. All three populations occupy the tributaries of Paulina Marsh, which has been diked, channelized, and drained for agricultural purposes. Historically, this SMU regularly expressed an adfluvial life history. However, since Paulina Marsh has been drained, migratory life history and inter-population mixing is possible only during high water years. Average densities for the SMU were moderate relative to other eastern Oregon streams, according to the 2005 Oregon Native Fish Status Report. In addition, sites with the highest densities were found in narrow canyon reaches, which are protected from the effects of land uses such as grazing (ODFW 2005).

The Chewaucan Redband Trout SMU is composed of four populations, all of which are within the analysis area; three populations are in the Lake Abert basin (Chewaucan, Crooked, and Willow), and the other is within the Summer Lake basin (Foster). The populations within the Lake Abert basin are distributed throughout the basin and are moderately abundant. In Foster Creek, redband trout distribution is less than 2 km, and the population is isolated from other streams and populations. Density and abundance of the Foster Creek population have not been adequately evaluated. However, survey data suggests that density is comparable to populations in the Lake Abert basin (ODFW 2005). Barriers to migration and degraded habitat are the most persistent threats to populations in this SMU.

The Goose Lake SMU consists of 19 populations. Six populations are in California and outside the assessment area. Of the 13 populations within Oregon, 9 are within the assessment area. Redband trout are present in most of the tributaries of Goose Lake, but are fragmented and limited to headwater and some mid-order reaches. Migratory redband trout are present when rearing conditions in Goose Lake are suitable. However, degraded habitat and irrigation activities obstruct movement between the lake and spawning grounds. Abundance of redband trout in the Goose Lake SMU fluctuates with instream flows and habitat quality (ODFW 2005).

The Upper Klamath Basin SMU consists of 10 populations that differ in life history, genetics, disease resistance, and status. Eight of the 10 populations are within the assessment area. This SMU currently supports the largest and most functional adfluvial redband trout populations of the Oregon Interior Basin and are widely distributed throughout the upper Klamath River basin (ODFW 2005). However, some populations are severely limited in distribution and abundance because of habitat quality and nonnative species. The Wood River and Lower Williamson populations are extremely abundant and may be the largest of Oregon's interior basins (ODFW 2005). In addition, long-term redd counts show that these two populations are stable or increasing in abundance. Conversely, Upper Williamson and Upper Sycan populations are low and abundance is depressed. The Upper Williamson population is isolated by a natural barrier to migration and therefore unable to mix with other populations, increasing the risk of extinction if the population becomes very small. Similar to the SMU populations within the Oregon closed basin, abundance within the Upper Klamath Basin SMU fluctuates with water year and habitat quality.

Bull trout—

All populations of bull trout within the coterminous United States were listed as a threatened species under the ESA in 1998. Bull trout are classified by the ODFW as a state critical species or state vulnerable species. Historical habitat loss and fragmentation, interaction with nonnative species, and fish passage issues are regarded as the most significant threat factors that led to listing of the species.

Bull trout core populations are the population units that correspond scalewise to anadromous populations in terms of recovery purposes. Core populations are generally defined at the subbasin scale, but may also be described based on groups of adjoining subbasins depending on the population of interest. Rangewide abundance and trend information for bull trout cannot be estimated because of variation in sampling, methods used to estimate abundance, and in some core areas, a complete lack of data. However, core area assessments completed within the analysis area indicate populations are either increasing or maintaining (USFWS 2005).

Within the SCOAP assessment area, bull trout are present within the Lower Deschutes River core area that encompasses the Deschutes River and its tributaries (specifically Lower Deschutes River and Metolius River–Lake Billy Chinook), and in the Odell Lake core area (Coastal recovery unit). The Klamath recovery unit is also within the assessment area and consists of Upper Klamath Lake, Sycan River, and Upper Sprague River core populations.

The Coastal recovery unit consists of three regions, Puget Sound, Olympic Peninsula, and Lower Columbia River region. Populations with the Lower Columbia River region, specifically Lower Deschutes and Odell Lake core area, are within the assessment area. The status of bull trout across the Lower Columbia River region is highly variable, with one relative stronghold (Lower Deschutes core area). The Odell Lake core area may have the lowest adult abundance, containing fewer than 100 adults. Abundant brook trout populations that compete with, and sometimes exclude, bull trout are an issue in these streams. According to the latest conservation assessment, a decrease in kokanee (*O. nerka* Walbaum in Artedi), which is a significant part of the bull trout prey base, poses as an additional previously unidentified threat (USFWS 2015).

The Klamath Recovery unit consists of three core areas, Sycan River, Upper Klamath Lake, and Upper Sprague River, all of which are within the analysis area. Bull trout within each core area are considered genetically distinct from each other. Populations within the Sycan River and Upper Klamath Lake core area consist of isolated, headwater populations of resident fish. Outside of their headwater refuges, bull trout continue to be subject to competition and hybridization with brook trout. Because of this, bull trout populations within the Sycan and Upper Klamath Lake core area face greater risk of extirpation. Although habitat improvement and concerted conservation efforts have taken place since listing of the species, there are no monitoring data that describe whether population improvements have occurred. The Upper Sprague River core area comprises five bull trout local populations (Boulder, Brownsworth, Deming, Dixon, and Leonard Creeks). Local populations of bull trout in this core area are genetically distinct from those in the other two Klamath recovery unit core areas (USFWS 2008), and may have a higher risk of extirpation because not all are interconnected. Migratory bull trout have occasionally been observed in the North Fork Sprague River (USFWS 2002). Generally, populations within the Upper Sprague River core area continue to survive in fragmented and degraded habitats and are subject to competition and hybridization with brook trout.

Lost River and shortnose suckers—

Lost River sucker and shortnose sucker were both listed as endangered under the ESA in 1988, and in 1991, both species were also listed as endangered by the state of Oregon (USFWS 1988). The motivating factors were range contractions, declines in abundance, and a lack of recent recruitment to adult populations that were driven by water diversions, interactions with nonnative species, habitat fragmentation, and degradation of water quality (Belk et al. 2011, Janney et al. 2008, Rasmussen 2011). Most fish in annual spawning aggregations are 20 to 25 years old (Hewitt et al. 2012), which is strong evidence of ongoing recruitment failure in these populations. Although these sucker species are long-lived, without recruitment in the near future, they may not persist into the next decade. Currently, Clear Lake Reservoir (California), Upper Klamath Lake (Oregon), and their tributaries support the largest populations, ranging in size from 25,000 to 100,000 fish (NMFS and USFWS 2013). Although both lakes are outside the assessment area, approximately 40 km of stream habitat (tributaries of lakes containing Lost River sucker and shortnose sucker) are within Fremont-Winema National Forest.

Both species ascend Upper Klamath Lake and Agency Lake tributaries into the Sprague River, Wood River, and the marshland around Upper Klamath and Agency lakes. These tributaries and marshland have limited habitat on Fremont-Winema National Forest. In Clear Lake Reservoir, both species ascend Willow Creek (Barry et al. 2007), but only shortnose suckers migrate upstream as far as Oregon and use North Fork Willow Creek within the national forest. Gerber Reservoir and its tributaries support only shortnose suckers. Gerber Reservoir is outside of the analysis area, but tributaries Barnes Valley Creek, Lapham Creek, Long Branch Creek, Horse Canyon, and Dry Prairie provide spawning habitat on the forest when annual precipitation timing and flow are adequate and access is not denied by irrigation diversion boards already in place.

Predatory native and introduced fish species have also affected Lost River and shortnose suckers. In Gerber Reservoir, introduced fishes include fathead minnow (*Pimephales promelas* [Rafinesque]) and yellow perch (*Perca flavescens* Mitchill). These fishes are believed to prey on young suckers and compete with them for food or space (Markel and Dunsmoor 2007). Parasites, including anchor worm (*Lernaea* spp.), have been found on shortnose suckers throughout Gerber Reservoir tributaries during forest surveys.

Current Fish Habitat Conditions

Habitat conditions described below were summarized from management indicator reports and project analyses on Deschutes, Fremont-Winema, and Ochoco National Forests, 5-year status review of Middle Columbia River steelhead (NMFS 2011), revised recovery plan for the Lost River sucker and shortnose sucker (USFWS 2012), draft bull trout recovery plans for the Klamath and Coastal recovery units (USFWS 2015), and redband trout species management unit summaries for select populations within major pluvial lake basins of the Great Basin (ODFW 2005).

Steelhead—

Deschutes River steelhead—The Deschutes River Basin is in the north-central part of Oregon and drains an area of more than 2.6 million ha. For Deschutes River steelhead, the analysis area consisted of two areas. The main area is located above the Pelton Round Butte hydroelectric complex, located at approximately river mile (RM) 100. Passage past this three-dam complex was established in 2011, so steelhead now have access to the Metolius River, Deschutes River, and tributaries below the natural barrier at Big Falls (RM 128) and the Crooked River and tributaries below Bowman Dam. The second area is within the Trout Creek watershed that contributes flow to the Deschutes River approximately 18 km below the Pelton Round Butte Dam complex.

The populations above the Pelton Round Butte Dam complex are included in the Deschutes River Westside population, within the Cascade eastern slope MPG, and have six major spawning areas (MaSAs) and nine minor spawning areas (MiSAs). Only the Upper Metolius and Whychus MaSAs are within the assessment area. The Metolius River is a major spring-fed system that contributes abundant cold water to the Deschutes River system at Lake Billy Chinook. Although habitats are of high quality throughout the Metolius and associated tributaries, cold water temperatures will likely limit steelhead production from this system. This has held true with the initial restored runs seeking out the Deschutes and Crooked River systems more than the Metolius. It is unknown at this point what the contribution of the Metolius River system will be to the steelhead population in this MPG.

Whychus Creek is a tributary to the Deschutes River above the Pelton Round Butte Dam complex at Lake Billy Chinook. The lower reaches (3 km) are influenced by cold water from Alder Springs. Habitat within this system has historically been limited by numerous diversions and channeling of the system. In recent years, all but one of the diversions have been either breached or removed to provide passage throughout the mainstem. In addition, restoration work has occurred on the mainstem, and further restoration is planned in the future. Habitat will ultimately be limited by warm summer temperatures downstream of the Three Sisters irrigation diversion. Efforts continue to increase water quantity in Whychus Creek to reduce summer stream temperature.

Habitat in the mainstem Deschutes and Crooked Rivers is in generally good condition, but mean August stream temperatures based on the NorWeST historical scenarios indicate that portions of these rivers regularly exceed 18 °C (MWMT > 25 °C), which may be exacerbated by irrigation withdrawals. Trout Creek within the assessment area is the major supplier of cool water for downstream reaches. The Trout Creek watershed comprises 180 522 ha, and Ochoco National Forest manages 14 100 ha of the watershed. Predominant management actions in this watershed include timber management, recreation, agriculture, and livestock grazing. Much of the agriculture is irrigated, with water diverted from Trout Creek or one of its tributaries. Push-up dams are still in use on lower Trout Creek to divert water for irrigation. On the national forest, Trout Creek is used as spawning and rearing habitat for steelhead. However, it is not the primary spawning area for steelhead, which occurs on flatter, meandering sections beyond the forest boundary.

John Day River steelhead—The John Day River Basin is located east of the Deschutes River basin and drains an area of approximately 1.3 million ha. The John Day River is the longest free-flowing river with wild anadromous salmon and steelhead in the Columbia River basin. The Lower Mainstem John Day River and Upper John Day River is a plateau of nearly level to rolling Columbia River basalt dissected by the John Day River and its tributaries. Vegetation within the lower and upper basins was essentially a bunchgrass climax community with some forest at higher elevations, but the introduction of livestock grazing and agriculture has greatly altered its vegetation composition.

The John Day River MPG has two populations within the assessment area (Lower Mainstem John Day River and South Fork John Day River). The Lower Mainstem John Day River population has 11 MaSAs and 19 MiSAs, but only 4 of the MaSAs are within the assessment area (Bridge Creek, Cottonwood, Mountain Creek, and Upper Rock Creek). The South Fork John Day population has three MaSAs (Upper South Fork John Day, Lower South Fork John Day, and Murderers Creek) and no MiSAs. Only portions of the Lower South Fork John Day River are within the assessment area.

Assessments of Bridge Creek, Mountain Creek, and Rock Creek watersheds by local biologists indicate that overall conditions within the watershed are functioning appropriately. Fish passage continues to be a predominant issue, with passage at culverts and diversions as the main issues. However, the majority of the barriers are outside of the assessment area. Steelhead critical habitat and populations are generally well connected within the assessment area, and the watersheds are providing thermally suitable habitats.

The Lower South Fork John Day River watershed is partially within the assessment area. The ability for fish to freely distribute throughout the watershed is not inhibited by human-made fish passage barriers. The watershed and all critical habitat within the analysis area are contained within both the Black Canyon Wilderness and within the Wind Creek drainage. Overall, steelhead critical habitat and populations within the analysis area of the Lower South Fork John Day watershed are generally well connected and the watershed is providing thermally suitable habitats.

Redband trout—

Redband trout inhabit most major watersheds and tributaries within the Crooked River basin. Habitat conditions were described for the entire basin in the Crooked River Basin Plan (Stuart et al. 1996). Only the North Fork Crooked River, Ochoco Creek, and McKay Creek are within the assessment area. In the North Crooked River, much of the basin has fragmented and isolated populations of redband trout owing to temperature barriers and culverts that block upstream passage. However, redband trout were found to be moderately abundant in tributaries with good habitat and cool water. In Ochoco Creek, habitat was found to vary from good to poor. Habitat stressors include high temperatures, irrigation withdrawals, and channel incision. Up to 65 percent of McKay Creek has been channelized or altered.

These factors have been further compounded by upstream blockages at numerous road crossings, which have isolated populations within and between watersheds. Stuart et al. (2007) have previously noted that on the forest, population abundance was directly tied to quality of habitat. Good quality habitat was found to have more than 1 fish per square meter, whereas poor quality habitat was found to have less than 0.5 fish per square meter. Although no models have been developed to determine viability of redband trout based on habitat, local biologists determined that habitat for redband trout is still available in adequate amounts, distribution, and quality to maintain viability on Ochoco National Forest and Crooked River National Grassland.

An assessment by Muhlfeld et al. (2015) rated habitat quality of redband trout within the Oregon closed basins (including the Chewaucan, Fort Rock, Goose Lake, Upper Klamath Basin, and Warner Lakes SMUs). Of the 32 percent of stream habitat currently occupied by redband trout, 5 percent was rated as excellent condition, 27 percent as good condition, 35 percent as fair condition, and 18 percent as poor condition. No habitat quality rating was done for 16 percent of the lotic habitats. The most common habitat characteristics that led to good to excellent ratings were mean summer water temperatures within the optimum range of 10 to 16 °C, pool habitats comprising of 35 to 60 percent of the total stream habitat area, and adequate streamflow. Habitat characteristics most common for fair to poor quality ratings were mean summer water temperatures exceeding 16 °C, fine sediment composition greater than 25 percent, and lack of stream shading.

Bull trout—

Most bull trout core areas in this region historically supported a fluvial life history form, but many are now adfluvial because of reservoir construction. The exception is Odell Lake, which supports a natural adfluvial life history. Two subpopulations of the Coastal recovery unit exist within the assessment area—Odell Lake on the upper Deschutes River basin and Metolius River–Lake Billy Chinook Complex. The Klamath Recovery unit is also within the assessment area.

Bull trout habitat in the Odell drainage is centered on Odell Lake. The Odell Lake population is in a closed basin separated from the Deschutes River system by a lava flow from about 5,000 years BP. Flows are stable and cold, with peak temperatures staying well below 10 °C. Habitat restoration work on the lower portion of Trapper Creek (tributary of Odell Lake) has occurred in the past decade. Large wood and associated habitat complexity have improved as a result. In addition, passage improvements at the outlet of Odell Lake have increased use in Odell Creek. Odell Creek flows to Davis Lake and provides several kilometers of high-quality spawning, rearing, and foraging habitat.

Habitat in the Metolius River drainage and Upper Deschutes River below Steelhead Falls is generally in good condition. Water temperature in most spawning and rearing streams associated with the Metolius River are below 10 °C during spawning and rarely exceed 12 °C during the peak of summer. Juvenile habitat in the form of undercut banks, overhanging vegetation, aquatic vegetation, and wood is abundant in many of the rearing tributaries of the Metolius River. Wood density is high compared to other basins because the stability of the streams reduces the amount of wood transported during normal spring flows. Fine sediment is a concern and may have increased from past road construction and riparian logging in riparian areas. Low-gradient, spring-fed reaches are particularly sensitive to fine sediment loading because of their low sediment transport rates. The percentage of fine sediment in spawning gravel is moderate to low and has declined as a result of the 1996 flood.[3] The Upper

[3] **Houslet, B.S.; Riehle, M.D. 1998.** Trends in fine sediment in potential bull trout spawning habitat to tributaries of the Metolius River, Oregon. Unpublished report. On file with: U.S. Department of Agriculture, Forest Service, Willamette National Forest, Sisters Ranger District, P.O. Box 249, Highway 20 and Pine Street, Sisters, OR 97759.

Deschutes River below Steelhead Falls has fair to good habitat but does not currently support bull trout because of summer temperatures that exceed 18 °C. Upstream diversions in the city of Bend for irrigation cause this increase. Bull trout use the lower 3 km of the river below Whychus Creek, where cooler water temperatures exist.

Bull trout within the Upper Klamath recovery unit have been isolated from other populations for the past 10,000 years and are recognized as evolutionarily and genetically distinct. Habitat degradation and fragmentation, past and present land use practices, past fisheries management practices, and agricultural water diversions have contributed to the reduction of bull trout distribution within this unit (USFWS 2015). Livestock grazing has led to an increase in sediment and nutrient loading rates by accelerating erosion (McCormick and Campbell 2007, USFWS 2002). Although livestock grazing has been reduced along most stream reaches occupied by bull trout, grazing impacts still occur in some locations that were historically occupied.

Water control structures and agricultural diversions have contributed to the decline of bull trout in the Klamath recovery unit. Unscreened irrigation diversions exist in each of the three core areas (USFWS 2015). Timber harvesting and associated activities, as well as a high density of forest roads within the basin, have resulted in soil erosion and transport of sediment into streams (National Research Council 2004, USFWS 2002). High road density remains in the upper Klamath River basin, and many roads are located near streams where they likely contribute sediment (USDA FS 2010). However, since bull trout were listed in 1998, land and resource agencies have worked together to reverse and stabilize trends in the existing populations. No definitive data have been evaluated to determine whether conservation efforts have had any detectable effects. Populations within this recovery unit continue to survive in fragmented and degraded habitats.

Lost River sucker and shortnose sucker—

Current connectivity and habitat conditions in the assessment area for Lost River sucker and shortnose sucker have been greatly influenced by the arid climate of the Klamath Basin, high demand for irrigation withdrawals, construction of several impassable diversion dams, livestock grazing, timber harvest, and road construction. These land management activities are conducted on both federal and private lands. Loss of habitat was a major factor leading to the listing of both species of sucker. Important habitat areas for spawning, rearing, and other needs were altered for agricultural and other anthropogenic purposes. However, not all adverse effects on sucker habitat are caused solely by anthropogenic factors, because natural climatic variation has always played an important role. A combination of shallow water in Upper Klamath Lake and irrigation diversions during droughts negatively affect water quality for suckers (Martin and Saiki 1999). Clear Lake reservoir is also affected by droughts. Despite the loss or access to important habitats, the general trend of habitat loss and modification has stabilized or is improving. Removal of Chiloquin Dam on the Sprague River and restoration and reconnection of the Williamson River Delta to Klamath Lake have improved sucker habitat.

The Sprague, Lost, and Wood Rivers have year-round perennial flow. However, many other habitats in the analysis area have "interrupted" perennial flow in the summer and early autumn, leaving disconnected pool habitat for several kilometers. Disconnected habitat is particularly prevalent in the North Fork Willow Creek and Gerber Reservoir tributaries. Flow between the isolated pools does not resume until the following season runoff. Fishes that were able to ascend the streams during runoff are often prevented from returning to downstream lakes or reservoir habitats because of low or disconnected flows, the result of low precipitation years, irrigation diversions, or road crossings.

Little is known about the long-term water quality dynamics of much of the range of both sucker species. However, Sprague River, the primary spawning habitat for suckers in the Upper Klamath Lake and the largest tributary to the Williamson River, is listed as water quality impaired for nutrients, temperature, sediment, and dissolved oxygen under section 303d of the Clean Water Act (1977). Although both species are relatively tolerant of water-quality conditions unfavorable for many other fishes (such as high pH, temperature, and lower dissolved oxygen concentrations), conditions in many of the water bodies currently occupied by both species are periodically harmful or fatal to the species. This is caused mostly by significant amounts of dissolved nutrients, which promote biological productivity, such as algal growth. The dynamics of the algal blooms can affect dissolved oxygen levels, pH, and un-ionized ammonia, all of which can affect fish health and survival.

Projected Climate Change Effects

Stream Network and Hydrology Models

To delineate a stream network for the SCOAP assessment, geospatial data for the National Hydrography Dataset (NHD) Plus 1:100,000-scale national stream hydrography layer (McKay et al. 2012) were downloaded from the Horizons Systems website (http://www.horizon-systems.com/NHDPlus/index.php) and clipped to the major watershed boundaries associated with the analysis area. Reaches in the NHDPlus layer coded as "intermittent" were deleted from the network. The network was further filtered to exclude reaches with slope >15 percent and those with minimum summer flows <0.006 $m^3 s^{-1}$, which approximates a low-flow wetted width of 1 m (based on an empirical relationship developed in Peterson et al. [2013]), because fish occurrences are rare in these areas. For purposes of this assessment, the summer flow period was defined as beginning with the recession of the spring flood to September 30, and is considered to be a critical period for many fish populations because it coincides with maximum temperatures.

Summer flow values predicted by the variable infiltration capacity (VIC) hydrologic model (Hamlet et al. 2007, Wenger et al. 2010) were downloaded from the streamflow metrics website (http://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml) and linked to reaches in the hydrography layer. The VIC model is a distributed, physically based model that balances water and energy fluxes at the land surface and takes into account soil moisture, infiltration, runoff, and baseflow processes within vegetation classes (Liang et al. 1994). It has been widely used in the Western United States to study past and potential future changes to flow regimes (Hamlet et al. 2007, 2013), snowpacks (Hamlet et al. 2007), and droughts (Luo and Wood 2007).

Application of the minimum summer flow criteria reduced the original set of blue lines in the NHD-Plus hydrography layer for the SCOAP assessment area to 19 000 stream km, of which 5000 km were on Forest Service lands (fig. 5.8). In addition to summer flows, the VIC model predicts several other flow metrics relevant to fish: center of flow mass (date at which 50 percent of annual flow has occurred); winter 95 percent flow (number of days from December 1 to February 28 when flows are among highest 5 percent of year); and mean annual flow (Wenger et al. 2010) (summarized below). One limitation of the VIC model is that it sometimes predicts poorly in areas with significant groundwater fluxes, like those underlying much of the SCOAP assessment area (fig. 5.9) (Gannett et al. 2012, Waibel et al. 2013). To provide an additional set of hydrologic model results, we included summaries of future changes in summer low flows and peak flows using model results from Safeeq et al. (2014, 2015). In the case of summer low flows, the VIC flow model predictions were modified with the sensitivity parameters developed in Safeeq et al. (2014) to better integrate groundwater effects.

Climate Scenarios

To assess stream responses to climate change, the hydrologic models were forced by an ensemble of 10 GCMs that best represented historical trends in air temperatures and precipitation for the Northwestern United States during the 20th century (Hamlet et al. 2013, Mote and Salathé 2010). We considered changes associated with the A1B emissions scenario (moderate emissions as defined by the Intergovernmental Panel on Climate Change [Solomon et al. 2007]) and summarized flow characteristics during a historical baseline period (1970–1999, hereafter the 1980s)

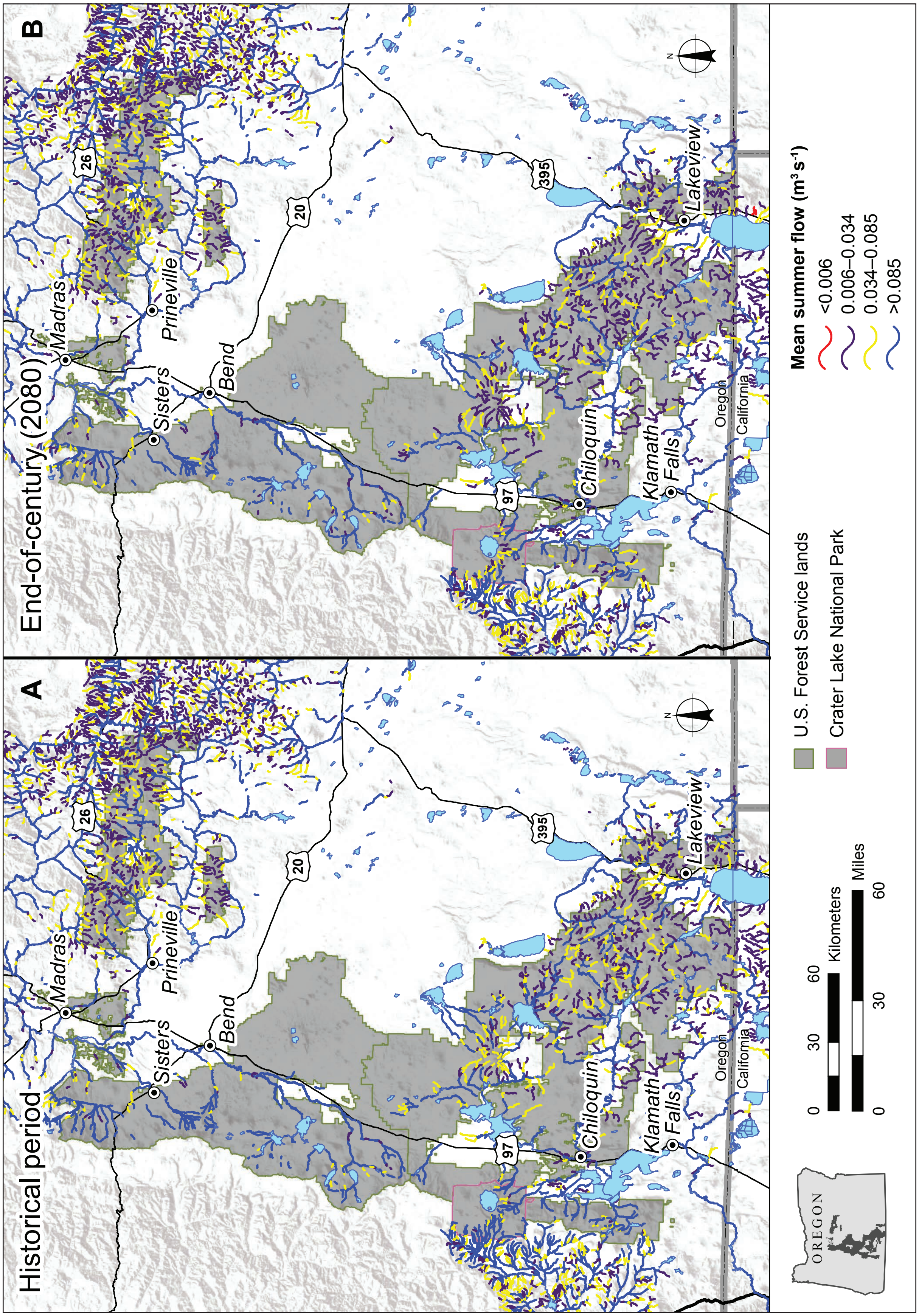

Figure 5.8—Mean summer flows by stream reaches for (A) the 1980s and (B) the 2080s based on the A1B emissions scenario. Red stream reaches depict locations where summer flows are $<0.006\ m^3\ s^{-1}$ and could become intermittent.

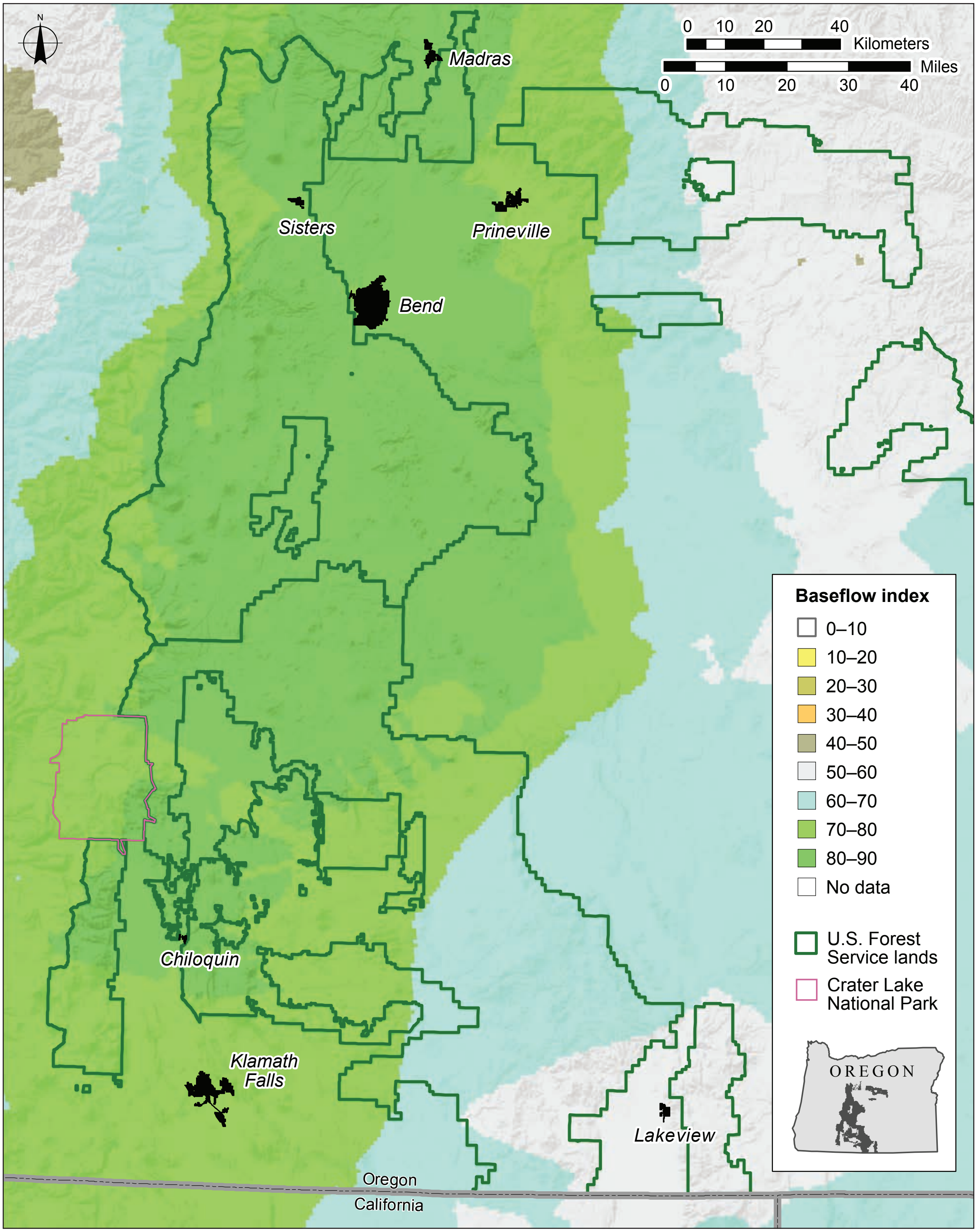

Figure 5.9—Baseflow index values for the south-central Oregon region. These values provide an indication of local groundwater importance to streamflows.

and two future periods (2030–2059 [hereafter 2040s] and 2070–2099 [hereafter 2080s]). Within the SCOAP assessment area, summer air temperatures were projected to increase 3.2 °C by the 2040s and 5.5 °C by the 2080s, with smaller increases during other seasons. Summer precipitation is projected to decrease, but precipitation is projected to increase during other seasons, suggesting that total annual precipitation will remain consistent or increase slightly (Hamlet et al. 2013, Mote and Salathé 2010). These projections are largely consistent with those described in chapter 3.

Most GCM projections are relatively consistent until the mid 21st century and diverge in late century, primarily because of uncertainties about future greenhouse gas emissions (Cox and Stephensen 2007, Stocker et al. 2013). The climatic conditions associated with the A1B emission scenario and historical period bracket that range of possibilities. Given uncertainties about the magnitude and timing of changes, it is reasonable to interpret future projections as a moderate change scenario (2040s) and an extreme change scenario (2080s) relative to the baseline period (1980s).

Stream Temperature Model and Scenarios

To complement the streamflow scenarios, geospatial data for August mean stream temperatures were downloaded for the same A1B emission scenario and climate periods described above from the NorWeST website (http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html). NorWeST scenarios were developed by applying spatial statistical models for data on stream networks (Isaak et al. 2010, Ver Hoef and Peterson 2010) to a crowd-sourced temperature database contributed by resource agencies within the project area. NorWeST scenarios account for differential sensitivity of streams (Luce et al. 2014) to climate forcing through application of basin-specific parameters. NorWeST scenarios are available at 1-km resolution and were modeled in the study area from more than 4,899 summers of measurement with digital sensors at 1,493 unique stream sites. The temperature model used to create the scenario was accurate (r^2 ~0.90; root mean square error ~1.0 °C) and was calibrated to a wide range of historical climatic variation (interannual variation in August air temperatures of 4.0 °C and threefold variation in August flows), which is notable because the warmest and driest years exceeded mean conditions projected to occur by the 2040s.

Analysis for Fish Species and Population Groups

Flow and stream temperature models were also used to characterize potential changes within the subset of habitats specific to each species. All stream kilometers that supported the fish species of interest were summarized for each population according to stream temperature (<8, 8 to 11, 11 to 14, 14 to 17, 17 to 20, >20 °C), winter high flow frequency (<5, 5 to 10, and >10 days), and summer baseflow (<0.03, 0.03 to 0.09, and >0.09 $m^3 s^{-1}$) criteria for the three timeframes (current, 2040, and 2080). In the case of redband trout, summaries were made for SMU streams that contained redband based on the Forest Service Region 6 distribution layer. Streams that support steelhead critical habitat, which may overrepresent current distribution, were used within each MPG to characterize potential changes. Streams that support Lost River and shortnose sucker critical habitat were used to characterize potential changes to these populations. For bull trout, changes were summarized based on core areas designated by the U.S. Fish and Wildlife Service. Within each core area, the Climate Shield model (Isaak et al. 2015) was also used to estimate the probabilities of juvenile bull trout occurrence within individual streams as evidence of local populations.

Climate Cycles and Ocean Effects on Fisheries

The biology of anadromous steelhead trout in the Middle Columbia River demonstrates that anadromous fish populations are heavily influenced by many factors outside and downstream of national forests. For example, population dynamics and abundance of steelhead are strongly affected by conditions in the ocean environment (Mantua et al. 1997). The productivity of that environment for salmon growth and survival varies through time in response to sea surface temperatures and strength of coastal upwelling tied to regional climate cycles like the El Niño Southern Oscillation (ENSO; 5- to 7-year periods) and the Pacific Decadal Oscillation (PDO; 20- to 30-year periods). Although ocean productivity and climate cycles most strongly affect anadromous fishes, these cycles are also relevant to resident species like bull trout and redband trout because of inland effects on temperature, precipitation, and hydrologic regimes that alter the quality and quantity of freshwater habitat (Kiffney et al. 2002). In the Pacific Northwest, cool (wet) phases of ENSO and PDO are more beneficial to fish populations than are warm (dry) phases (Copeland and Meyer 2011, Mote et al. 2003). Research summarized in the recent Intergovernmental Panel on Climate Change report (Stocker et al. 2013) provides little evidence to support concerns about climate change affecting the periodicity or magnitude of ENSO or PDO, either in the historical record or in future climate projections. However, other changes associated with warmer ocean conditions include increased stratification of the water column, acidification, and changes in the intensity and timing of coastal upwelling. These changes can affect the ocean food web because warmer waters are less nutrient-rich, altering the behavior and migration patterns that steelhead travel to ocean feeding areas resulting in reduced steelhead survival.

Climate Change Effects on Fish and Fish Habitat

Future Streamflows

The broad elevation range across the SCOAP assessment area translates to significant spatial heterogeneity in stream hydrology. Streams in low-elevation catchments have rain-dominated hydrographs, with peak flows occurring earlier in the year than high-elevation streams dominated by snowmelt runoff. Relative to the 1980s baseline period, runoff timing (center of flow mass) of all streams is projected to advance 8 to 18 days in the year (table 5.1; fig. 5.10). The number of winter high-flow days is projected to increase slightly, as are peak flows that could increase by 4 to 12 percent (figs. 5.11 and 5.12). Summer flow reductions of 20 to 47 percent are projected, but the linear extent of the perennial network is projected to change little (table 5.1; fig. 5.8). Summer flow reductions are projected to be most prominent in the highest elevation watersheds where flows are most dependent on winter snow accumulation. The projected trends in stream runoff timing and summer flows are similar to observed trends in the historical record during the past 50 years across the Pacific Northwest (Luce and Holden 2009, Luce et al. 2013, Safeeq et al. 2014, Sawaske and Freyberg 2014). Projected trends in flow conditions within the species habitat networks (figs. 5.3 through 5.7) are summarized in tables 5.2 through 5.5. These trends largely parallel the changes projected to occur across the full SCOAP network, but differences in the locations of habitat networks (e.g., headwaters for bull trout, larger rivers for salmon) create locally specific responses.

Winter high-flow frequency—

As air temperatures increase, the rain-on-snow zone will move up in elevation, increasing stream flooding where the current rain-on-snow zone is lower in a subbasin. In contrast, subbasins with an already higher elevation rain-on-snow zone will see only a modest increase in flooding risks (Hamlet and Lettenmaier 2007, Tohver et al. 2014). As rain-on-snow zones move higher over time, the zones themselves will shrink in size, reducing the potential contribution to peak winter runoff in some subbasins. The probability of rain-on-snow events occurring is also expected to decrease with warmer temperatures because of decreased snow occurrence and length of time that snow is on the ground (McCabe et al. 2007), especially in lower elevation subbasins.

Table 5.1—Summary of streamflow statistics relevant to fish populations in the South-Central Oregon Adaptation Partnership assessment area, based on changes associated with the A1B emissions scenario

		All lands		Forest Service lands	
Flow metric	**Climate period**	**Day of year[a]**	**Days advance**	**Day of year**	**Days advance**
Center of flow mass	1980s	173	—	174	—
	2040s	165	-8	163	-11
	2080s	160	-13	156	-18
		Number of days	**Days increase**	**Number of days**	**Days increase**
Winter 95% flow	1980s	10.5	—	9.8	—
	2040s	12.4	1.9	12.6	2.8
	2080s	13.2	2.7	13.8	4.0
		Stream kilometers	**Percentage change**	**Stream kilometers**	**Percentage change**
Stream length[b]	1980s	19 161	—	4968	—
	2040s	19 103	-0.3	4963	-0.1
	2080s	19 064	-0.5	4942	-0.5
Peak flow[c]	1980s	—	—	—	—
	2040s	—	3.7	—	5.5
	2080s	—	9.2	—	12.3
		Cubic meters per second	**Percentage change**	**Cubic meters per second**	**Percentage change**
Mean summer flow[c]	1980s	4.1	—	1.30	—
	2040s	3.3	-20.0	0.89	-31.3
	2080s	2.9	-29.5	0.69	-47.0
Mean annual flow	1980s	5.3	—	1.40	—
	2040s	5.3	1.2	1.42	1.4
	2080s	5.3	-0.1	1.39	-0.8

[a] Refers to day of water year starting October 1.
[b] Stream reaches in network with mean summer flows greater than 0.006 m3 s-1
[c] Average flow across all reaches in the network.
— = no data.

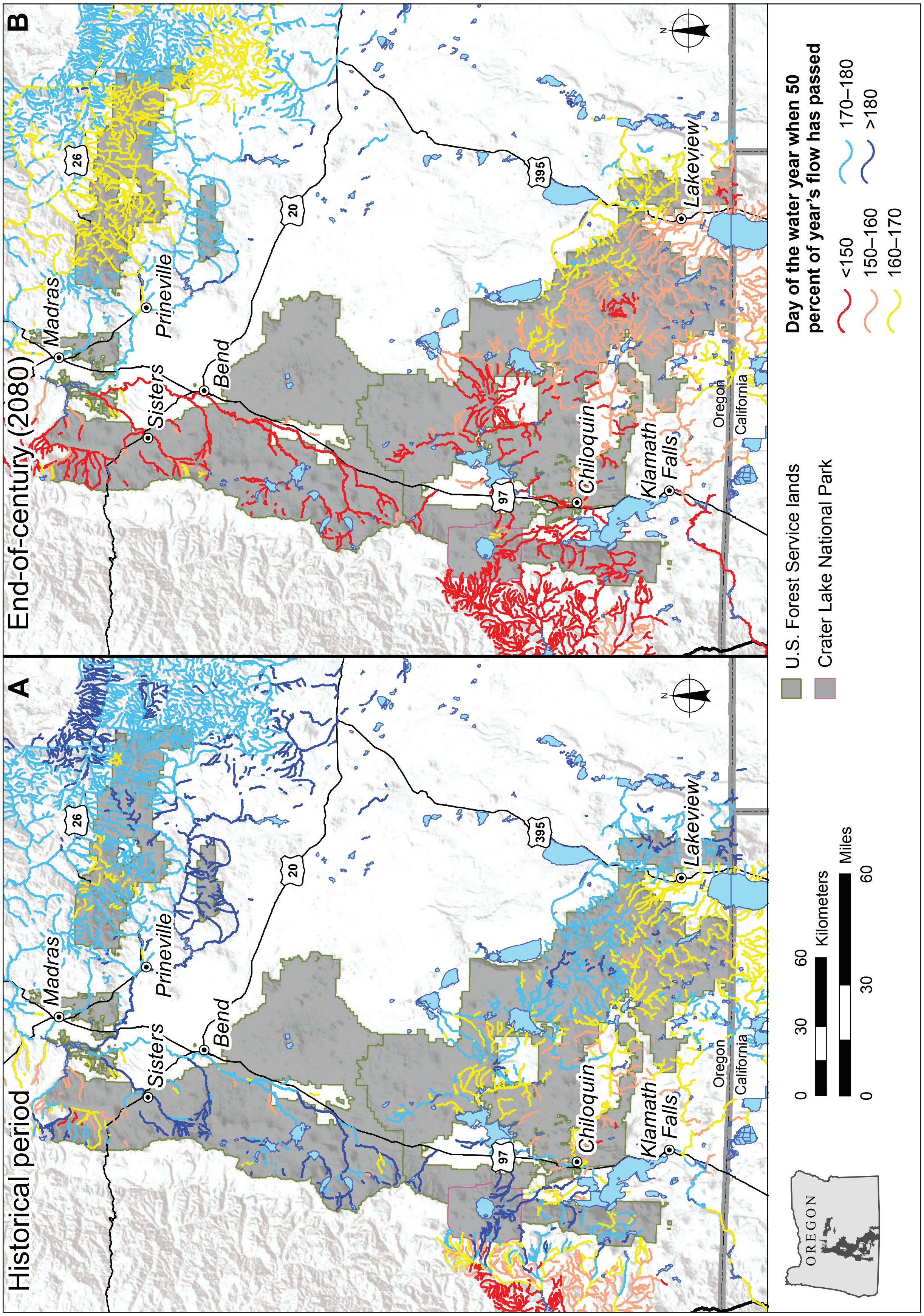

Figure 5.10—Dates of the center of annual flow mass (50 percent of annual flows) for (A) the 1980s and (B) the 2080s based on the A1B emissions scenario. Cool colors indicate streams with snowmelt-dominated hydrographs, and warm colors indicate rainfall-dominated hydrographs.

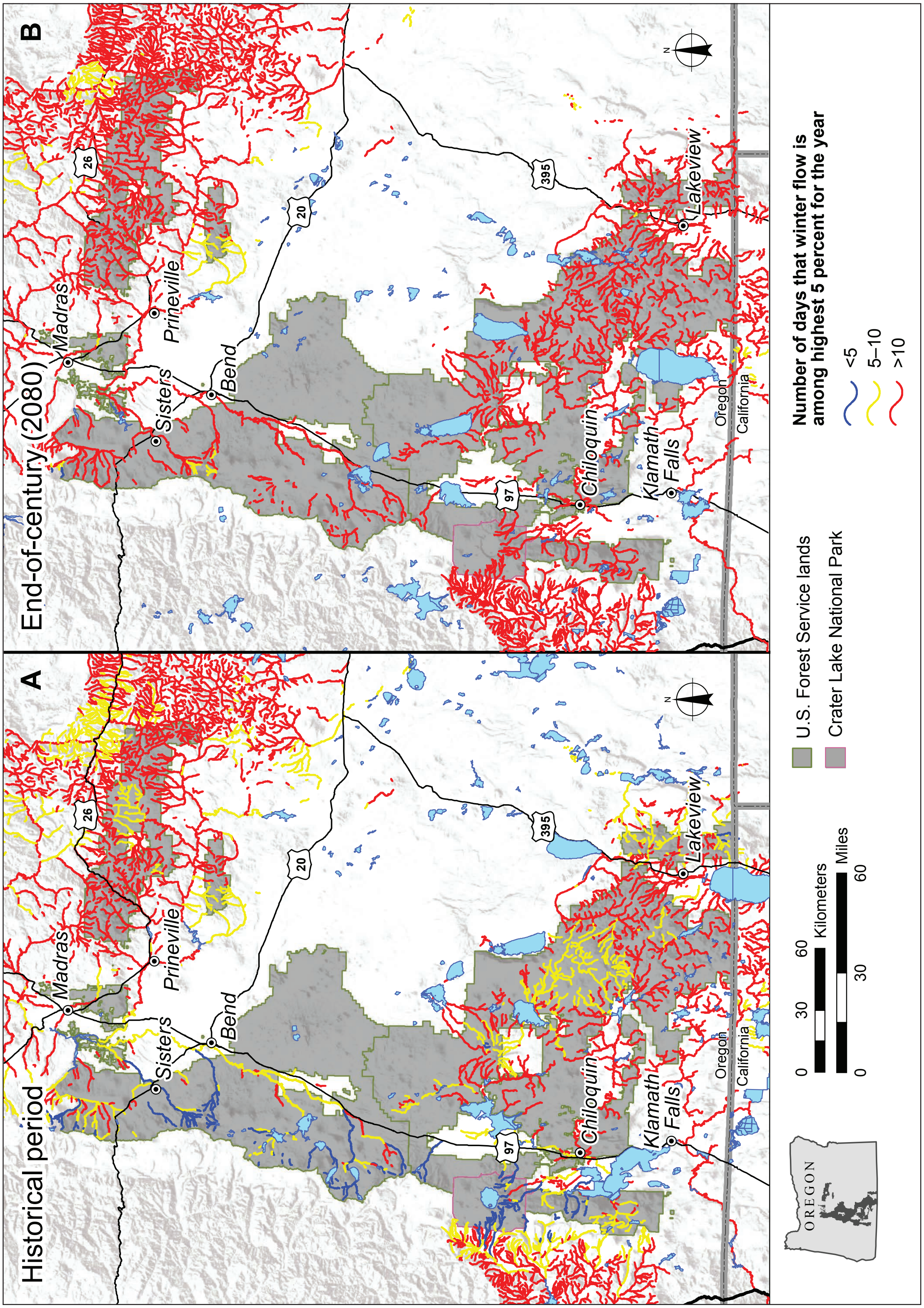

Figure 5.11—Frequency of days when winter high flows are among the highest 5 percent of the year for (A) the 1980s and (B) the 2080s based on the A1B emissions scenario.

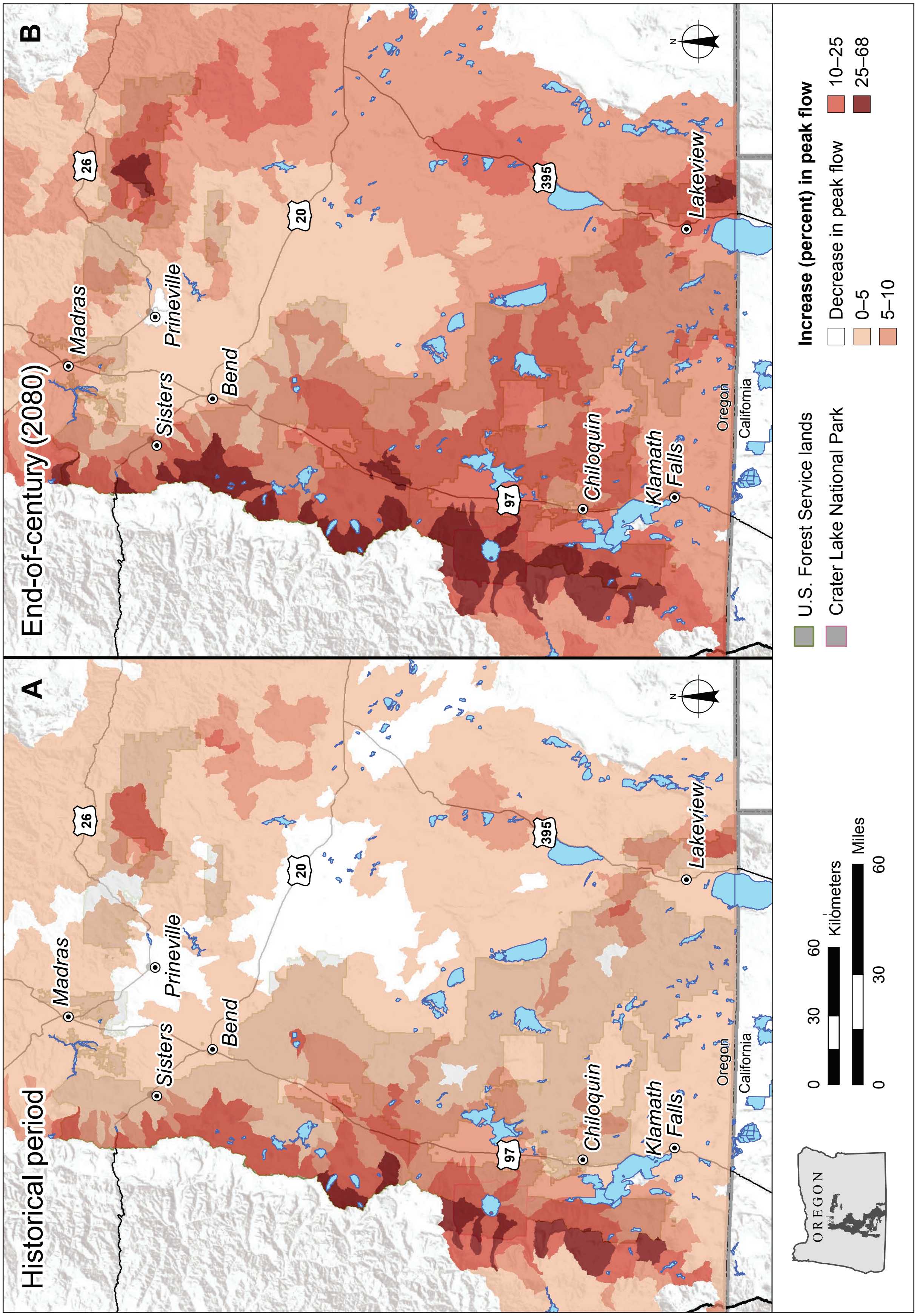

Figure 5.12—Percentage of increase in peak flows projected by Safeeq et al. (2015) during (A) the 2040s and (B) the 2080s relative to the 1980s baseline and the A1B emissions scenario.

Table 5.2—Streamflow and temperature characteristics for the redband trout habitats shown in figure 5.4, based on changes associated with the A1B emissions scenario

Stream metric		Number of high-flow days					
	Period	*<5*	*5–10*	*>10*			
Winter 95% flow	1980s	44 (1)	784 (26)	2216 (73)			
	2040s	0 (0)	52 (2)	2992 (98)			
	2080s	0 (0)	13 (1)	3031 (99)			
		Streamflow in $m^3 s^{-1}$					
		<0.034	*0.034–0.085*	*>0.085*			
Summer flow	1980s	528 (17)	604 (20)	1913 (63)			
	2040s	649 (21)	604 (20)	1792 (59)			
	2080s	709 (23)	618 (20)	1717 (56)			
		Stream kilometers					
		<8	*8–11*	*11–14*	*14–17*	*17–20*	*>20*
August temperature	1980s	17.3 (1)	237 (8)	874 (29)	1150 (38)	644 (21)	122 (4)
	2040s	5.5 (1)	116 (4)	611 (19)	1145 (38)	881 (29)	286 (9)
	2080s	17 (1)	148 (5)	451 (15)	1099 (35)	850 (28)	479 (16)

Note: all values are stream kilometers (those in parentheses are percentages of the total).

Table 5.3—Streamflow and temperature characteristics for the steelhead trout core area habitats shown in figure 5.3, based on changes associated with the A1B emissions scenario

Stream metric		Number of high-flow days					
	Period	*<5*	*5–10*	*>10*			
Winter 95% flow	1980s	2.7 (0.1)	814.7 (24)	2597.5 (76)			
	2040s	0	409.3 (12)	3005.6 (88)			
	2080s	0	307.4 (9)	3107.4 (91)			
		Streamflow in $m^3 s^{-1}$					
		<0.034	*0.034–0.085*	*>0.085*			
Summer flow	1980s	306.6 (9)	461.2 (14)	2647.1 (77)			
	2040s	326.2 (10)	473.6 (14)	2615.1 (76)			
	2080s	338.7 (11)	490.1 (14)	2586.0 (75)			
		Stream kilometers					
		<8	*8–11*	*11–14*	*14–17*	*17–20*	*>20*
August temperature	1980s	12.8 (0.4)	209.9 (6)	661.3 (19)	1286.3 (38)	891.8 (26)	352.8 (10.6)
	2040s	2 (0.1)	75.4 (2)	422.8 (12)	975.6 (29)	1334.8 (39)	604.3 (18)
	2080s	0	31.9 (0.9)	284.0 (8)	789.1 (23)	1339.2 (39)	970.5 (29.1)

Note: all values are stream kilometers (those in parentheses are percentages of the total).

Table 5.4—Streamflow and temperature characteristics for bull trout spawning and rearing core area habitats shown in figure 5.5, based on changes associated with the A1B emissions scenario

		Number of high-flow days					
Stream metric	*Period*	*<5*	*5–10*	*>10*			
Winter 95% flow	1980s	64 (18)	203 (56)	95 (26)			
	2040s	1 (1)	34 (9)	327 (90)			
	2080s	0	0	362 (100)			
		Streamflow in $m^3 s^{-1}$					
		<0.034	*0.034–0.085*	*>0.085*			
Summer flow	1980s	77 (21)	74 (20)	211 (59)			
	2040s	131 (36)	43 (12)	188 (52)			
	2080s	139 (39)	44 (12)	179 (49)			
		Stream kilometers					
		<8	*8–11*	*11–14*	*14–17*	*17–20*	*>20*
August temperature	1980s	63 (18)	203 (56)	91 (25)	5 (1)		
	2040s	32 (8)	151 (42)	150 (42)	28 (8)		
	2080s	20 (6)	109 (30)	179 (49)	53 (15)	1 (0.3)	

Note: all values are stream kilometers (those in parentheses are percentages of the total).

Table 5.5—Streamflow and temperature characteristics for the shortnose and Lost River sucker core area habitats shown in figures 5-6 and 5-7, based on changes associated with the A1B emissions scenario

		Number of high-flow days					
Stream metric	*Period*	*<5*	*5–10*	*>10*			
Winter 95% flow	1980s		15 (5)	301 (95)			
	2040s			316 (100)			
	2080s			316 (100)			
		Streamflow in $m^3 s^{-1}$					
		<0.034	*0.034–0.085*	*>0.085*			
Summer flow	1980s	27 (8.5)	27 (8.5)	262 (83)			
	2040s	34 (11)	24 (8)	258 (82)			
	2080s	41 (13)	20 (7)	255 (80)			
		Stream kilometers					
		<8	8–11	11–14	14–17	17–20	>20
August temperature	1980s			9.5 (3)	25.6 (8)	209 (66)	72 (23)
	2040s			4.5 (1)	143 (45)	143 (45)	155 (49)
	2080s				58 (18)	58 (18)	247 (48)

Note: all values are stream kilometers (those in parentheses are percentages of the total).

Most streams within the SCOAP assessment area average 10 days of winter high flows (under the baseline conditions), and projections indicate that this number could increase slightly by 1 to 4 days at mid and late century, respectively (table 5.1; fig. 5.12). The Safeeq et al. (2015) peak flow analysis also suggests relatively small increases later in the century, with 4 to 12 percent increases anticipated (table 5.1; fig. 5.12).

Where increased frequency and severity of flood flows do occur during winter, it may affect overwintering juvenile fish and eggs incubating in the streambed. Scouring of the streambed can dislodge eggs (Schuett-Hames et al. 2000), and elevated sediment transport caused by high flow can increase sediment deposition in redds, suffocating eggs (Peterson and Quinn 1996). Potential effects on fish from altered winter peak flows are likely to differ by species. Eggs from fall-spawning fish (e.g., bull trout) are likely to be at higher risk from winter channel scour events than spring-spawning fish (e.g., redband and steelhead) because their eggs are incubating in stream substrates during the winter (Bjornn and Reiser 1991, Goode et al. 2013). The risk of egg scour may also be greater for small resident bull trout than for large migratory bull trout that bury their eggs deeper in stream substrates, or in channels with less habitat diversity and off-channel habitats (Shellberg et al. 2010). Winter floods may increase risks to fry that are vulnerable to displacement during the first month after emergence (Fausch et al. 2001, Nehring and Anderson 1993) or to juveniles with poor swimming ability in high-velocity water (Crisp and Hurley 1991, Heggenes and Traaen 1988). The retreat of snow level to higher elevations may lead to earlier fry emergence for some populations (Healey 2006). Earlier emergence may expose the fry to increased mortality because of a lack of food or increased predation (Brannon 1987, Tallman and Healey 1994).

These potential effects are most likely to occur in years with higher rain-on-snow risk. However, they will not occur every year or in every subbasin across the SCOAP assessment area. Risks of winter peak flow to fish habitat will differ by habitat and subbasin condition, valley confinement, and frequency and intensity of each rain-on-snow event. Smaller watersheds with higher road densities may concentrate flows into streams and magnify channel scour. Streams that have less habitat diversity may be more vulnerable to high flows that result in higher fish mortality from winter floods.

Risks from higher and more frequent winter high flows will increase in some SCOAP assessment area subbasins in the future, although risk will differ at different locations. Because salmonids have evolved in a highly dynamic landscape (Benda et al. 1992, Montgomery 2000), they may have sufficient phenotypic plasticity to buffer environmental changes, assuming that such changes are within the historical range of variability (Waples et al. 2008). However, it is unknown if phenotypic adjustment can keep pace with evolving disturbance frequency induced by contemporary climate change (Crozier et al. 2008, 2011).

Summer flows—
As described previously, spring and early summer flows have been decreasing as a result of earlier snowmelt and runoff over the past 50 years (Safeeq et al. 2014, Stewart et al. 2005). Streamflow magnitude in the Pacific Northwest also declined between 1948 and 2006, including decreased 25th percentile flow (Luce and Holden 2009), which means that the driest 25 percent of years have become drier across the majority of the Pacific Northwest. This trend is expected to continue because large portions of the SCOAP assessment area could lose all or significant portions of April 1 snow-water equivalent (SWE) in future periods with reduced snow accumulation and increased rain-on-snow events that reduce snowpack SWE prior to April 1. Snowpack sensitivity differs with elevation, and future decreases at high elevations are expected to cause large decreases in summer flows (fig. 5.8).

Effects on fish and their habitats from altered summer low flows will differ by the intensity and frequency of drought and early-season runoff, as a function of geology, drainage elevation, and fish species across the SCOAP assessment area. Streams more dependent on snowmelt with minimal groundwater contribution will be affected more than streams sustained by groundwater. However, even these groundwater streams will have lower baseflows in sustained droughts.

Fish populations most affected by lower summer flows will likely be in headwater areas inhabited by redband trout or bull trout. However, all fish populations will be stressed as streamflows decrease over the summer. Increased frequency of extreme low flows reduces the probability of survival in rearing juveniles (May and Lee 2004). In some stream reaches, riffles will become shallower and perhaps intermittent (Sando and Blasch 2015). This may result in disconnected stream reaches, isolated pools, overcrowding of fish, increased competition for food and cover, decreasing water quality, local eutrophication, and greater vulnerability to predators in remaining deep water habitat.

Future Stream Temperatures

Considerable thermal heterogeneity exists across streams in the SCOAP assessment area because of the complex topography and range of elevations (table 5.6; fig. 5.13). August stream temperatures in the baseline period averaged 14.4 °C and ranged from 3.5 to 27.5 °C. Temperatures of streams flowing through higher elevation national forest lands were cooler, averaging 12.9 °C. Summer temperatures are projected to increase across the SCOAP assessment area by an average of 1.3 °C in the 2040s

Table 5.6—Summary of August mean stream temperatures across the South-Central Oregon Adaptation Partnership assessment area during a baseline period and two future periods under the A1B emissions scenario

	< 8 °C	8–11 °C	11–14 °C	14–17 °C	17–20 °C	> 20 °C
All lands:						
1980s (1970–1999)	654	2,271	5,138	6,998	3,301	799
2040s (2030–2059)	310	1,454	3,730	6,633	5,459	1,516
2080s (2070–2099)	166	998	2,921	5,862	6,320	2,796
Forest Service lands:						
1980s (1970–1999)	333	866	1,901	1,561	298	9
2040s (2030–2059)	189	557	1,476	2,009	682	50
2080s (2070–2099)	103	440	1,151	2,032	1,069	147

Note: These summaries are for streams in which mean summer flow is greater than 0.006 cms and slope is less than 15 percent.

and 2.2 °C in the 2080s. Larger than average increases are projected to occur in the warmest streams at low elevations, and smaller than average increases are projected for the coldest streams. This differential warming occurs because cold streams are usually more buffered by local groundwater contributions than are warm streams (Isaak et al. 2016b, Luce et al. 2014, Mayer 2012). Projected temperature increases for the SCOAP assessment area are smaller than the 2 to 4 °C increases projected for Pacific Northwest streams for the same A1B emission scenario (Beechie et al. 2012, Mantua et al. 2010, Wu et al. 2012), but previous studies modeled short-term weekly maxima that change at proportionally higher rates than mean temperatures (Meehl and Tebaldi 2004).

Stream warming rates are often greatest during summer because of the combined effects of air temperature increases and flow declines (Abatzoglou et al. 2014, Isaak et al. 2012) but will generally track long-term air temperature trends at slightly slower rates (e.g., 30 to 80 percent as fast). Projected trends in stream temperatures within the species habitat networks (figs. 5.3 through 5.7) are summarized in tables 5.2 through 5.5. These trends largely parallel the changes projected to occur across the stream network in the SCOAP assessment area, but differences in the locations of habitat networks and species ecology create locally variable responses. For example, temperature increases in headwater spawning and rearing habitats for bull trout may be smaller than increases in lower elevation, warmer rivers. But because bull trout distributions are strongly constrained by temperatures, a small increase could cause a significant habitat loss.

In most cases, stream temperature increases will cause fish species to gradually adjust their spatial distributions and phenologies to the evolving thermal environment. Adjustments in spatial distributions will be most pronounced near distributional boundaries that are currently mediated by temperature. Range

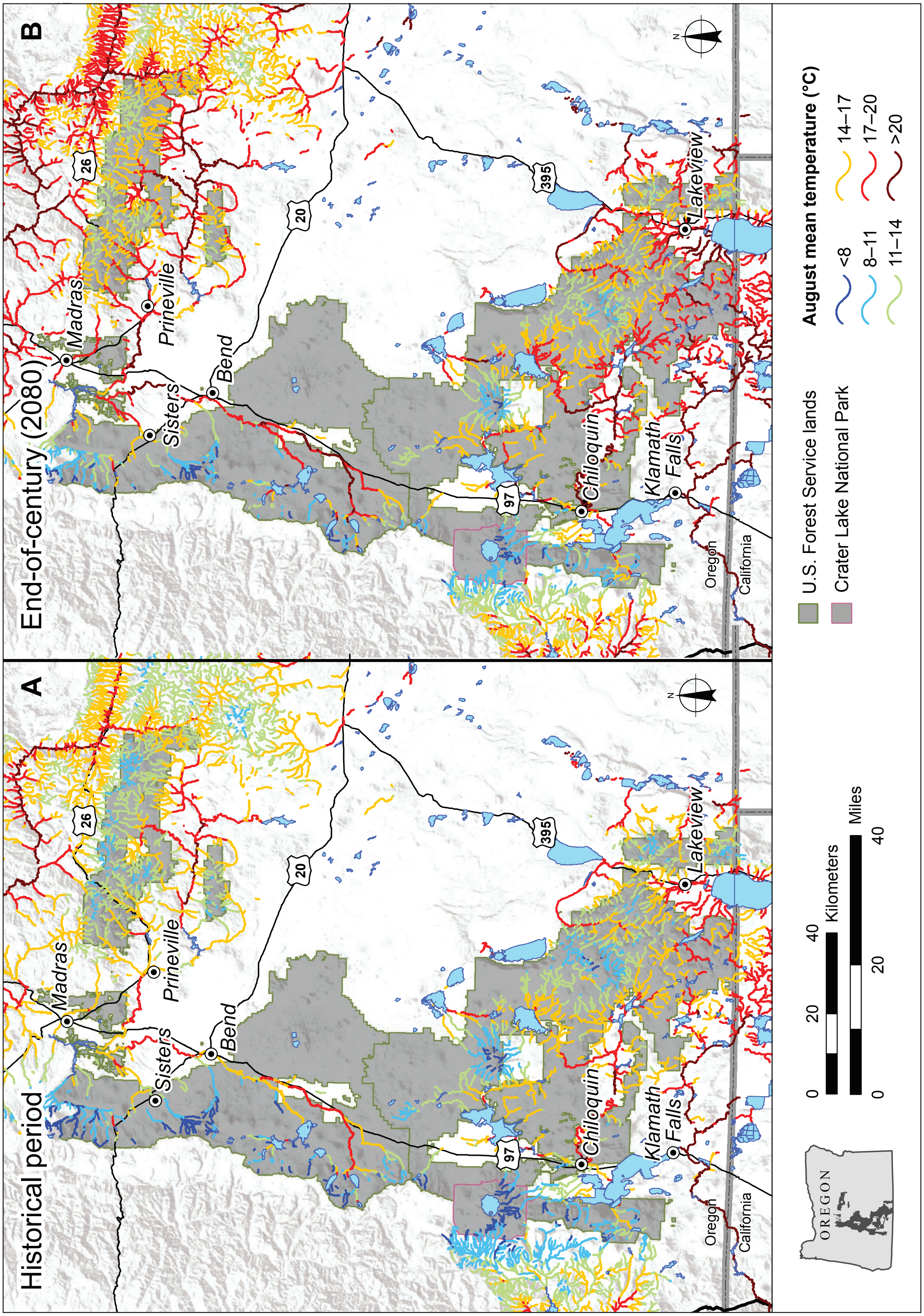

Figure 5.13—August stream temperature map for (A) the 1980s and (B) the 2080s based on NorWeST scenarios and the A1B emission trajectory.

contractions and habitat losses near warm downstream boundaries are often the focus of climate change vulnerability assessments, but upstream boundaries controlled by cold temperatures may be equally relevant for some species. Colonization of new habitats further upstream as warming progresses could offset a portion of downstream habitat losses for some species and populations (Isaak et al. 2017). Populations may also adapt phenologically by using habitats at different times of the year to avoid stressful conditions. For example, evidence exists that migration dates of some salmon species have been advancing in recent decades (Crozier et al. 2008, Keefer et al. 2008, Petersen and Kitchell 2001) and that these trends are related to warmer temperatures (Crozier et al. 2011). Documentation of phenological shifts for fish species other than salmon are limited, but the strong temperature dependencies of physiological and metabolic processes usually translate to earlier timing of life history events in most species (Parmesan and Yohe 2003, Root et al. 2003).

Potential Effects on Specific Populations

Populations in areas with poor baseline habitat conditions, or occurring in habitats near important thresholds, are considered to be more susceptible to climate change because fish populations in complex habitats are more stable and have greater capacity to buffer the effects of environmental change (Schlosser 1982, 1991; Sedell et al. 1990). Those general expectations are tempered by several factors. First, some populations may persist in streams that exceed species' perceived thermal limits (Zoellick 1999) because of increased availability of food or lack of competition with other species. Second, species and populations may cope with changing environments by adapting their life histories and phenology to better exploit thermal refugia or other important habitats (Crozier et al. 2008, Jonsson and Jonsson 2009). Third, rapid evolution may alter the environmental tolerances of species, although such changes in fishes usually involve timing of life history events rather than increased thermal tolerance, which is relatively fixed (Kovach et al. 2012, McCullough et al. 2009). Furthermore, interactions among these factors will be complex, making predictions about species responses to climate change at a specific location challenging.

Redband trout—

Many redband trout populations in the SCOAP assessment area, with the exception of the Upper Klamath Basin, have limited distribution and abundance. All of the redband trout SMU populations were rated as either at risk or potentially at risk (ODFW 2005). Projected streamflow and water temperature changes could further increase risk to these populations. By 2080, the majority (>98 percent) of redband-occupied streams will experience greater than 10 days with the highest 5 percent of winter peak flows. Higher winter peak flows may affect rearing fish, especially in streams that lack low-velocity habitat and are prone to bedload scour. However, because redband are spring (March to May) spawners, higher winter (December 1 through February 28) peak flows will not affect eggs or alevins.

Summer baseflows are also anticipated to decline, particularly in headwater streams that do not have high groundwater contribution or floodplain connectivity. By 2080, 23 percent of the 4900 km of redband trout habitat within the SMUs may not have enough flow to sustain fish habitat during the driest times of the year (August to October) (fig. 5.14). Headwater habitat loss during summer will be most pronounced in the Goose Lake (14.5 percent decline), Chewaucan (7.7 percent decline), and Upper Klamath basin (7 percent decline) SMUs.

Future stream temperature increases will likely stress redband trout populations. Optimal stream temperatures for redband vary by life history. For summer rearing, optimal mean August temperatures are 11 to 16 °C, and the suboptimal range is 16 to 22.3 °C for MWMT. Based on these criteria, redband streams within the optimal range are projected to decrease from 67 percent (current) to 40 percent (2080) within the SMUs (fig. 5.15). Redband streams within the suboptimal range are projected to increase from 25 percent (current) to 44 percent (2080). Stream temperatures will likely increase most into the suboptimal range within the Warner Lakes (27 percent), Goose Lake (26 percent), and Malheur lakes (25 percent) SMUs.

Potential changes to individual redband areas are summarized below:

Chewaucan—The number of stream kilometers outside redband optimal temperature range are anticipated to increase by 13 percent within this SMU by 2080. This will likely further stress a "potentially at risk" population. Currently, 65 percent of the stream habitat in the Chewaucan Basin experiences winter peak flows more than 10 days a year. By 2080, it is estimated that as much as 99 percent of streams will experience peak flows greater than 10 days annually. As summer baseflow decreases, less water will flow into Chewaucan River, affecting connectivity between the Chewaucan, Crooked, and Willow populations. Foster Creek is a small, spring-fed stream that flows into Summer Lake from Winter Rim. The distribution of redband trout is less than 2 km, and the population is isolated from other streams and populations. Based on this extremely limited distribution and isolation, the Foster Creek population is already at risk of extinction and will likely be further stressed if spring flows decrease.

Fort Rock—There are only three tributaries that provide fish habitat in the Fort Rock SMU. Opportunities for migratory expression within Paulina Marsh and opportunities for population mingling between tributaries are currently limited to

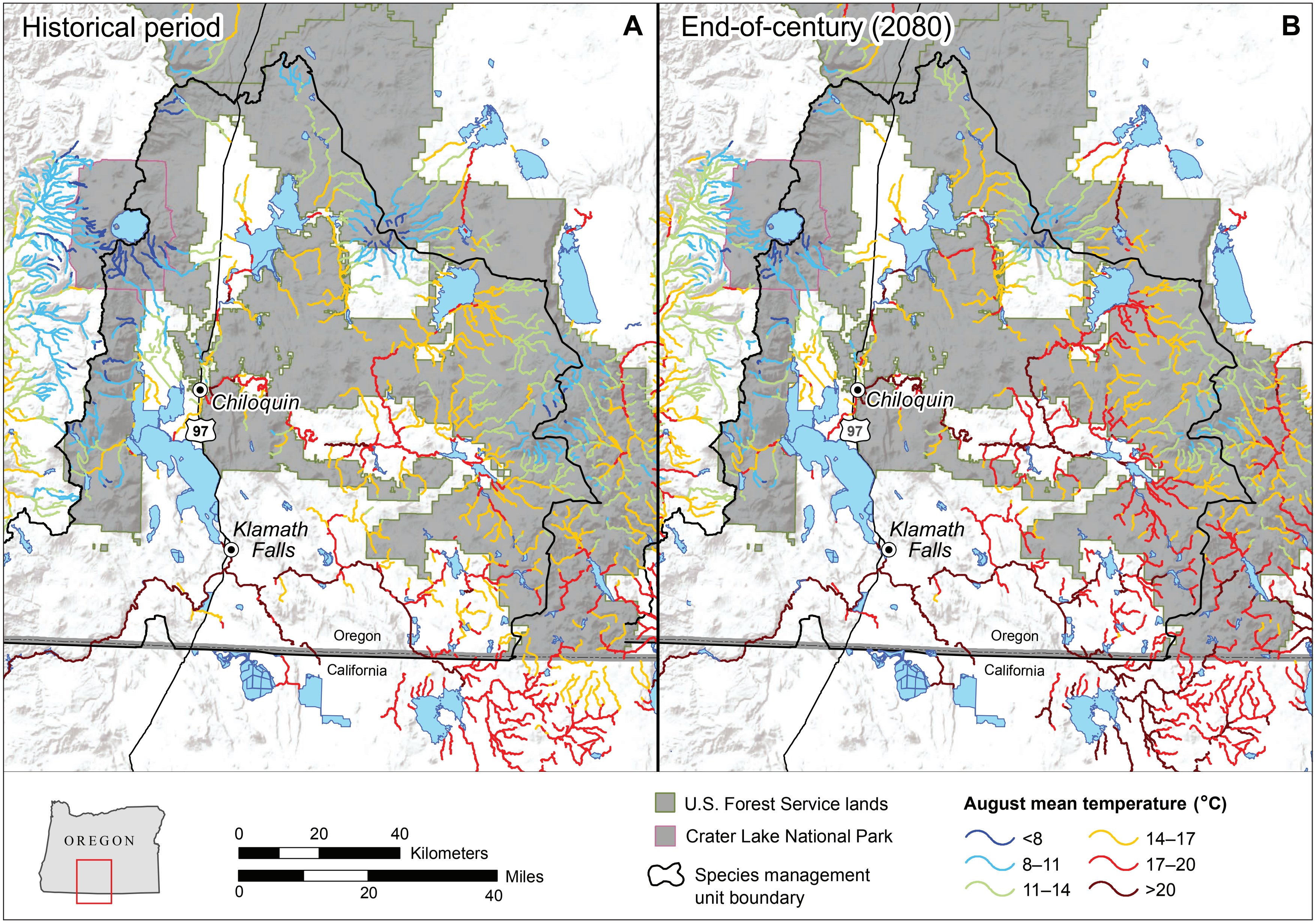

Figure 5.14—Summer stream temperatures for the Upper Klamath Basin redband species management unit in (A) the 1980s and (B) the 2080s based on NorWeST scenarios and the A1B emission trajectory.

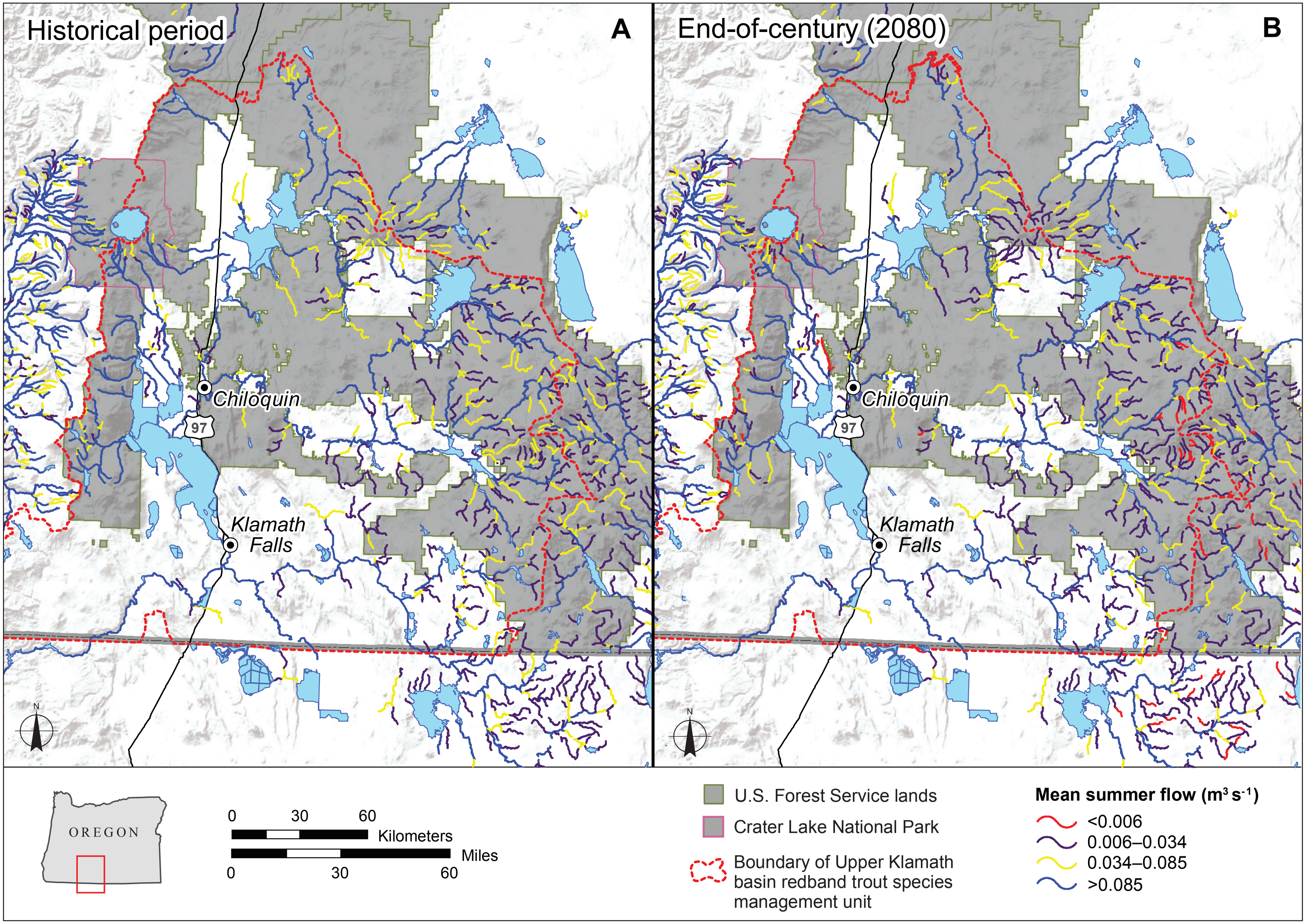

Figure 5.15—Mean summer flows for the Upper Klamath Basin redband species management unit in (A) the 1980s and (B) the 2080s based on the A1B emission trajectory. Red stream reaches depict locations where summer flows are < 0.006 $m^3 s^{-1}$ and are likely to become intermittent.

high water years. Prolonged winter peak flows may provide access between Paulina Marsh and the tributaries, benefitting redband productivity, but projections for the future do not show much change from current winter flow conditions. Although redband trout can tolerate warm water, the continued loss of cold and cool water habitats, combined with a slight reduction in summer baseflows, and loss of access to lake type habitats will likely negatively affect this SMU.

Goose Lake—The number of stream kilometers outside redband optimal temperature range are anticipated to increase by 26 percent within the Goose Lake SMU by 2080. This will further stress “at risk” populations, since 39 percent of redband streams are already temperature limited. As summer baseflows decrease, less water will flow into Goose Lake. If winter peak flows recede before Goose Lake fills, redband trout may have reduced access into spawning tributaries. If peak winter flows occur in mid-winter, and are followed by freezing temperatures, redband trout reproduction could be adversely affected.

Malheur Lake—The number of stream kilometers outside redband optimal temperature range are anticipated to increase by 25 percent within the Malheur Lake SMU by 2080. However, redband stream kilometers below the summer baseflow threshold are anticipated to increase by only 2 percent. Summer access to Harney and Malheur lakes is already limited by warm water temperatures, low flow conditions, and barriers. Redband that occupy isolated headwater tributaries may face greater risks as smaller, low-elevation streams warm.

Upper Klamath Basin—The Upper Klamath Basin SMU supports a great diversity of redband habitats (e.g., mountain headwater streams, large rivers, and large lakes) that may offer some protection against climate change impacts. However, the lack of current cold water refugia (currently 51 percent of kilometers are occupied by redband), combined with increasing water temperatures may have negative impacts on this SMU. Headwater coldwater summer habitat may continue to decrease to less than 5 percent of available habitat by 2080. Habitat with summer water temperatures exceeding 20 °C are projected to more than double from current conditions to 30 percent by 2080. Summer baseflows are projected to decrease slightly (to <10 percent) below the minimum needed to support fish in headwater streams by 2080.

Warner Lakes—Habitats for redband trout in the Warner Lakes SMU are currently available in the headwater reaches, although some populations are isolated by waterfalls. Access between Warner Lakes and headwater tributaries are limited by irrigation diversions and low water years, limiting productivity, which will likely continue to be limited with decreasing summer flows. Although redband trout can tolerate warm water, the continued loss of cold and cool water habitats, combined with slightly reduced summer baseflows, and loss of access to lake type habitats, may have negative impacts on this SMU.

Deschutes and South Fork John Day—Habitat conditions in the Deschutes and South Fork John Day have been degraded by grazing, past harvest activities, road building, recreation use, and stream manipulation. Habitats are also not well connected, making it difficult for redband to move into cold-water refugial areas. Increases in summer stream temperatures and winter peak flows are the largest risk to redband trout in this area. Summer stream temperatures are expected to increase outside the optimal range by 27 percent by 2080, reducing the amount of suitable habitat and cold-water refugia for redband trout. Summer streamflows are not expected to substantially decline from current conditions to 2080. However, because of the degraded condition of habitat outside of the SMU, likelihood of direct mortality during rain-on-snow events is higher.

Steelhead trout—

According to the most recent 5-year status review, the John Day MPG is at moderate risk, whereas the Cascade Eastern Slope MPG has mostly viable populations (NMFS 2011). By 2080, 100 percent (9 percent increase from current) of the Cascade Eastern Slope MPG streams and 85 to 89 percent (17 percent increase from current) of the John Day MPG will experience greater than 10 days with the highest 5 percent winter peak flows. Increased peak flows may affect rearing fish, especially in streams that lack low-velocity habitat and are prone to bedload scour. However, spawning will not likely be affected, because it occurs in spring.

Summer baseflows are anticipated to decline very little (by 1 percent) within both MPGs. Optimal stream temperatures for steelhead vary by life history but are expected to be similar to redband trout. For summer rearing, optimal mean August temperatures are 11 to 16 °C, and suboptimal temperatures range from 16 to 22.3 °C (MWMT). Based on these criteria, steelhead streams within the optimal range will decrease from 58 percent (current) to 31 percent (2080) within the two MPGs. Steelhead streams within the suboptimal range will increase from 36 percent (current) to 69 percent (2080).

Potential changes to individual steelhead MPGs are summarized below:

Cascades eastern slope tributaries—Increases in summer stream temperatures are the largest risk for steelhead in tributaries along the eastern slopes of the Cascades. Models project stream temperatures outside the optimal range will increase by 37 percent in occupied streams, reducing the habitat available for steelhead, much of which is already in a degraded condition from channel simplification and agriculture. However, this species has high adaptive capacity, with a range of life histories and wide environmental tolerances, which will reduce sensitivity to the potential effects of climate change. Habitat improvements will help improve the resilience of this MPG to climate change.

John Day River—Increases in summer stream temperatures are the largest risk to steelhead in the John Day River MPG. Models project stream temperatures outside the optimal range will increase by 33 percent in occupied streams. However, habitat in headwater areas within this MPG is well connected and may provide coldwater steelhead refugia during warm summer months. Winter peak flows are expected to increase by 17 percent by 2080. Shifts in timing of winter peak flows may result in changes in outmigration timing, survival, and availability of rearing habitats. High-quality headwater habitat may help reduce fish mortality from winter floods.

Bull trout—

In the SCOAP assessment area, most core bull trout populations survive in fragmented habitats, have low abundance (except the Lower Deschutes River core population), and are subject to competition and hybridization with brook trout. Climate change is likely to further increase risks to bull trout. Projections suggest that, by 2040, 90 percent of streams in all core populations will experience more than 10 days with high winter flows (64 percent increase from current), and by 2080, all area populations will experience 10 or more days with high winter flows (74 percent increase from current). Higher winter peak flows may affect bull trout redds and incubating eggs. Rearing fish, especially in streams that lack low-velocity habitat and are prone to bedload scour, may also be at risk.

Summer baseflows in core bull trout streams within the assessment area are anticipated to decline by 15 percent by 2040 and 18 percent by 2080, with the Upper Sprague, Sycan, and Upper Klamath projected to experience the largest declines. As summer flows decrease, the smallest headwater streams may become intermittent more frequently and not have enough flow to sustain fish populations during especially dry summers. Optimal temperatures for juvenile bull trout rearing are less than 17 °C MWMT (Dunham et al. 2003), which equates to less than 11 °C August mean temperatures based on extensive field datasets (Isaak et al. 2015, 2017). These criteria and projections of stream temperature increases suggest that bull trout streams within the optimal temperature range may decrease 31 percent by the 2040s and 52 percent by the 2080s within core areas.

Potential changes to individual bull trout core population are summarized below:

Lower Deschutes River—Summer stream temperatures are expected to increase outside the optimal range by 14 percent by 2080, reducing bull trout habitat. The highest 5 percent winter peak flows are expected to increase by 64 percent by 2080. Bull trout eggs will be at higher risk of dislodgment and burying by sediment. There will also be increased scour, which will have a negative impact on suitable spawning habitat for bull trout. However, because of the high-quality habitat available in the Lower Deschutes River core area, there should be lower fish mortality from winter floods. Summer streamflows are not expected to substantially decline from current conditions to 2080. Based on available information, bull trout in the Lower Deschutes River core area may decline from current conditions to 2080 owing to increased stream temperatures and more days with winter peak flows. This will leave bull trout in the Lower Deschutes River with less available spawning and rearing habitat and an increased risk to bull trout eggs and alevins. Lower elevation locations within and outside national forest boundaries, which generally have higher stream temperatures naturally and are closest to thresholds for fish species, will have the most significant near-term effects. Historical and future occurrence probability of bull trout in this core area are shown in figure 5.16.

Odell Lake—Winter peak flows are expected to increase substantially (100 percent) by 2080, with greater than 10 days having the highest 5 percent peak flows. Already reduced habitats will be subject to increased environmental fluctuation associated with wildfires, debris flows, and increased winter flooding. Summer stream temperatures are not expected to increase significantly by 2080. However, projections suggest that there will be a 10 percent reduction in headwater summer bull trout habitat. Currently, this core area already has a small population, fragmented habitat, and limited spawning habitat. The projected changes will put bull trout at high risk of extirpation because of the reduction in available habitat from increased winter peak flows that may dislodge and bury redds. Historical and future occurrence probability of bull trout in this core area are shown in figure 5.17.

Sycan River—Long Creek supports the only bull trout population in the Sycan core area. Bull trout will be at an increased risk of extirpation because of reduced summer headwater habitat from lower baseflows and winter peak flow increases. Winter peak flows are expected to increase substantially (100 percent) by 2080, with greater than 10 days having the highest 5 percent peak flows. Longer duration winter peak flows may lead to earlier runoff, increasing erosion and scour, sedimentation and redd disruption. Nearly 90 percent of the summer baseflows will be below a level that can support fish habitat by 2040, and it will remain low through

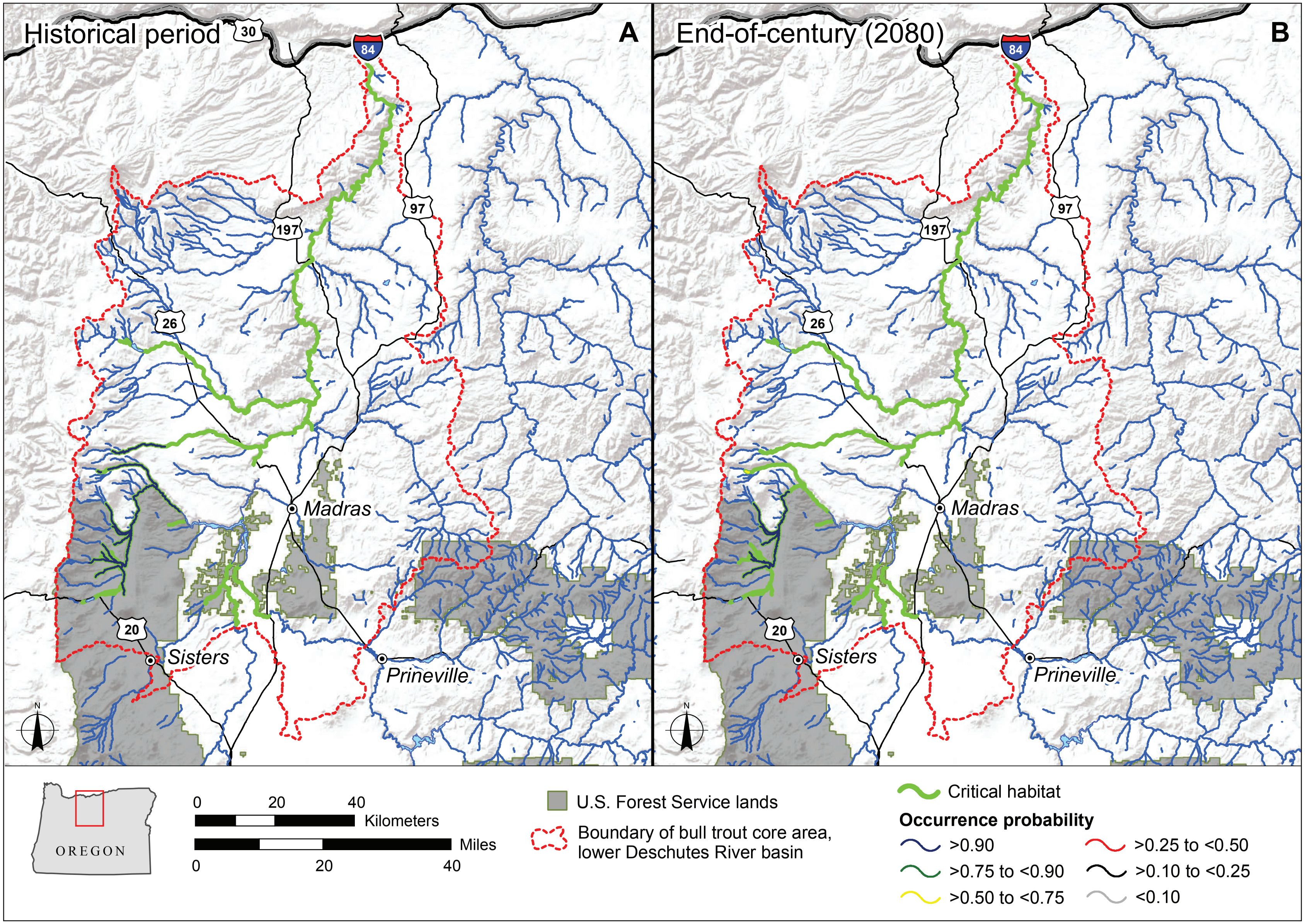

Figure 5.16—Occurrence probabilities of bull trout within the Lower Deschutes River core area for the 1980s and 2080s based on the A1B emission trajectory (probabilities are also based on the absence of brook trout). Heavy green lines show U.S. Fish and Wildlife Service critical habitat, whereas probability colored subsets of those lines are reaches with August mean temperatures <11 °C where juvenile fish are predicted to be most prevalent based on empirical relationships developed in the Climate Shield bull trout model (Isaak et al. 2015). In this core area, bull trout have a high probability of continued persistence in some streams by the 2080s, assuming that widespread brook trout invasions do not occur.

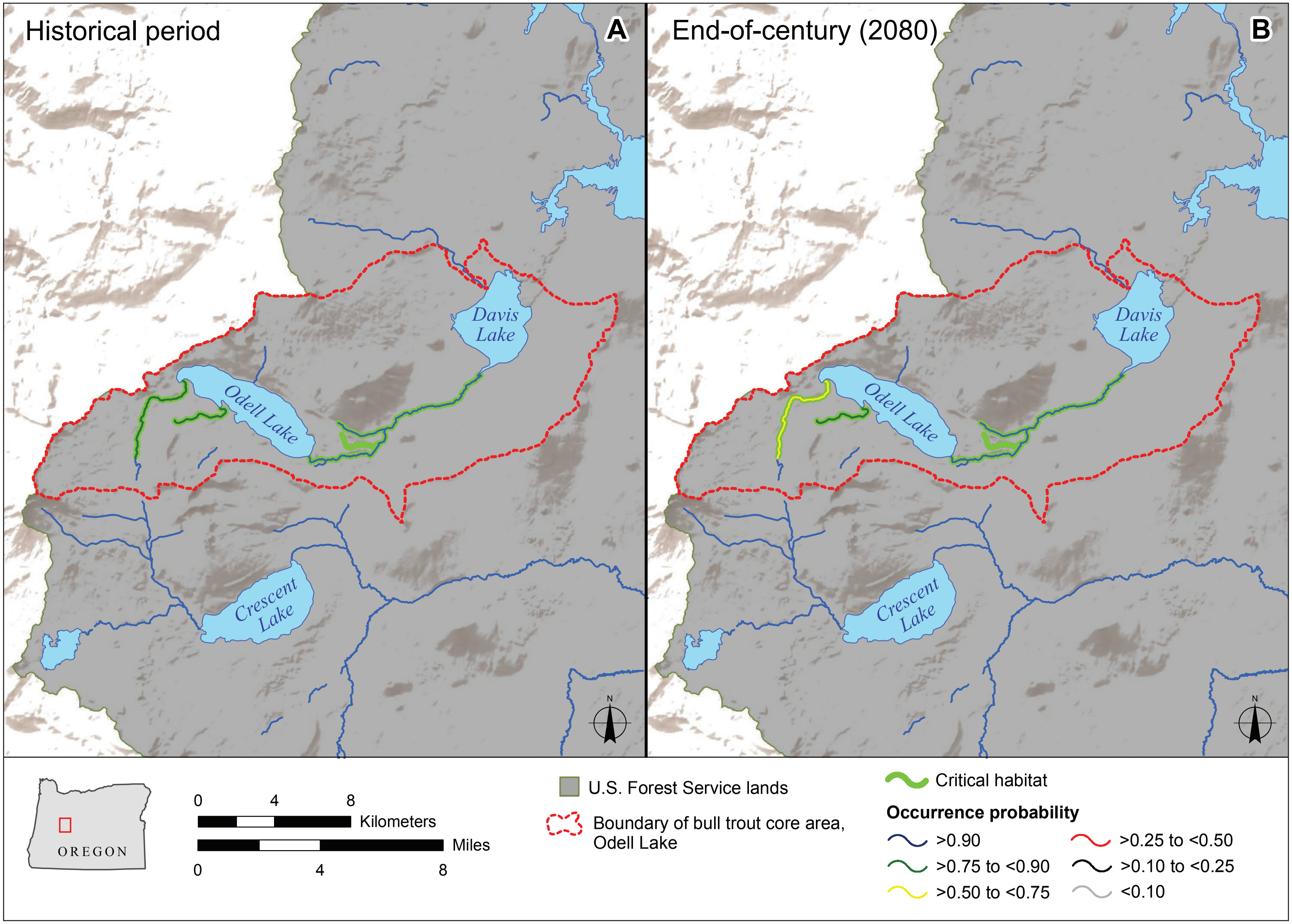

Figure 5.17—Occurrence probabilities of bull trout within the Odell Lake core area for the 1980s and 2080s based on the A1B emission trajectory (probabilities are also based on the absence of brook trout). Heavy green lines show U.S. Fish and Wildlife Service critical habitat, whereas probability colored subsets of those lines are reaches with August mean temperatures <11 °C where juvenile fish are predicted to be most prevalent based on empirical relationships developed in the Climate Shield bull trout model (Isaak et al. 2015). Stream habitats for bull trout in this core area are extremely limited and could be highly sensitive to brook trout invasion. Because the lake environment strongly affects the persistence of bull trout in this core area, Climate Shield model predictions are of limited utility.

2080. Summer water temperatures outside the bull trout's optimal range are anticipated to increase slightly (from 6 to 12 percent of the occupied habitat). The bull trout in Long Creek are isolated from other populations, without a strong migratory population to recolonize if habitat conditions become too stressful and the resident fish no longer can find adequate refugia. Historical and future occurrence probability of bull trout in this core area are shown in figure 5.18.

Upper Klamath Lake—Some lower elevation streams are projected to have temperatures above the optimal range by 2080. Even with these increases, the majority of streams will remain below 14 °C and are not projected to exceed 17 °C. Summer baseflows are projected to be similar to current baseflows. Habitat conditions for resident bull trout should remain similar to what is available currently, other than what will be experienced during winter peak flows. Winter peak flows are projected to last for greater than 10 days by 2040. Increased peak flows in the steep streams with already limited spawning habitats will have a negative effect on viability of bull trout in this core area. There is no indication of migratory life history in this core area. Historical and future occurrence probability of bull trout in this core area are shown in figure 5.19.

Upper Sprague River—Although the Upper Sprague River core area currently has the greatest number of bull trout populations in the Klamath Basin, populations are isolated, with no indication of migratory life history. Based on model projections, bull trout in the Upper Sprague River core area face a high risk of extirpation because of the combined effects of increased water temperatures, decreased summer baseflows, and increased duration of peak flows. Summer stream temperatures are projected to increase in lower elevation streams by 2080, negatively affecting rearing. However, the majority of habitat will still have temperatures within the range tolerated by bull trout. Winter peak flows will be greater than 10 days throughout the core area by 2040. By 2080, nearly 90 percent of summer baseflows are projected to be below the threshold that can support fish. Historical and future occurrence probability of bull trout in this core area are shown in figure 5.18.

Lost River suckers and shortnose suckers—

Stream temperatures will increase so that by 2080 nearly 80 percent of current stream habitats used by suckers will have summer temperatures greater than 20 °C. More problematic, however, may be future declines in summer flows and hydrologic alterations that degrade water quality in the limited stream and lake habitats used by suckers. Shortnose sucker populations in the Lost River Basin Recovery Unit (i.e., tributaries to Gerber Reservoir and Clear Lake Reservoir) may be especially vulnerable if declining flows in important spawning tributaries results in summer intermittency and fragmentation. Human water use and irrigation practices may also evolve in response to future hydrologic changes and could potentially compound deleterious effects on sucker populations.

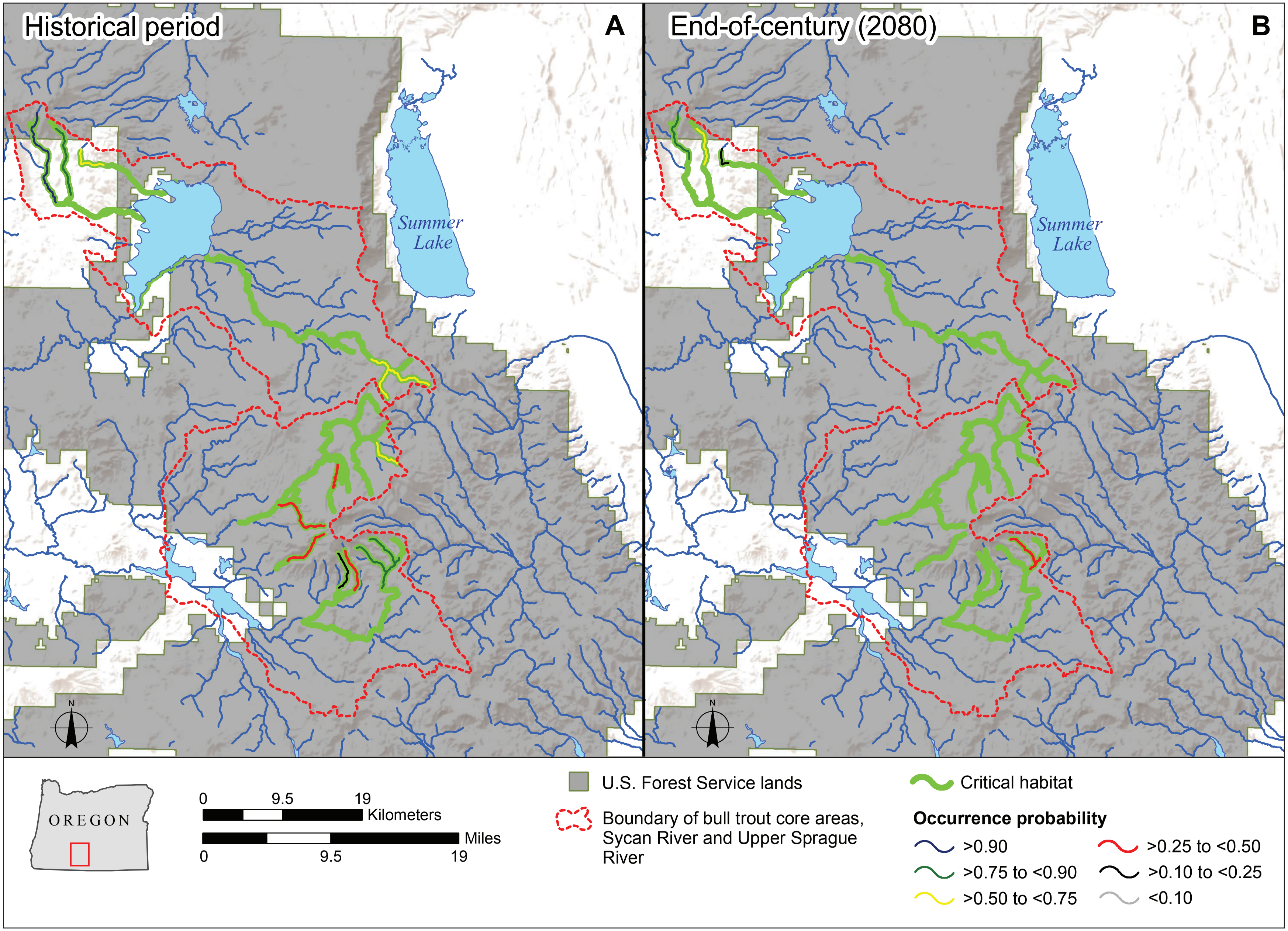

Figure 5.18—Occurrence probabilities of bull trout within the Sycan River and Upper Sprague River core areas for the 1980s and 2080s based on the A1B emission trajectory (probabilities are also based on the absence of brook trout). Heavy green lines show U.S. Fish and Wildlife Service critical habitat, whereas probability colored subsets of those lines are reaches with August mean temperatures <11 °C where juvenile fish are predicted to be most prevalent based on empirical relationships developed in the Climate Shield bull trout model (Isaak et al. 2015). In the Sycan River core area, bull trout have a high probability of continued persistence in some streams by the 2080s, assuming widespread brook trout invasions do not occur. However, projected probabilities of persistence are very low for the Upper Sprague River core area.

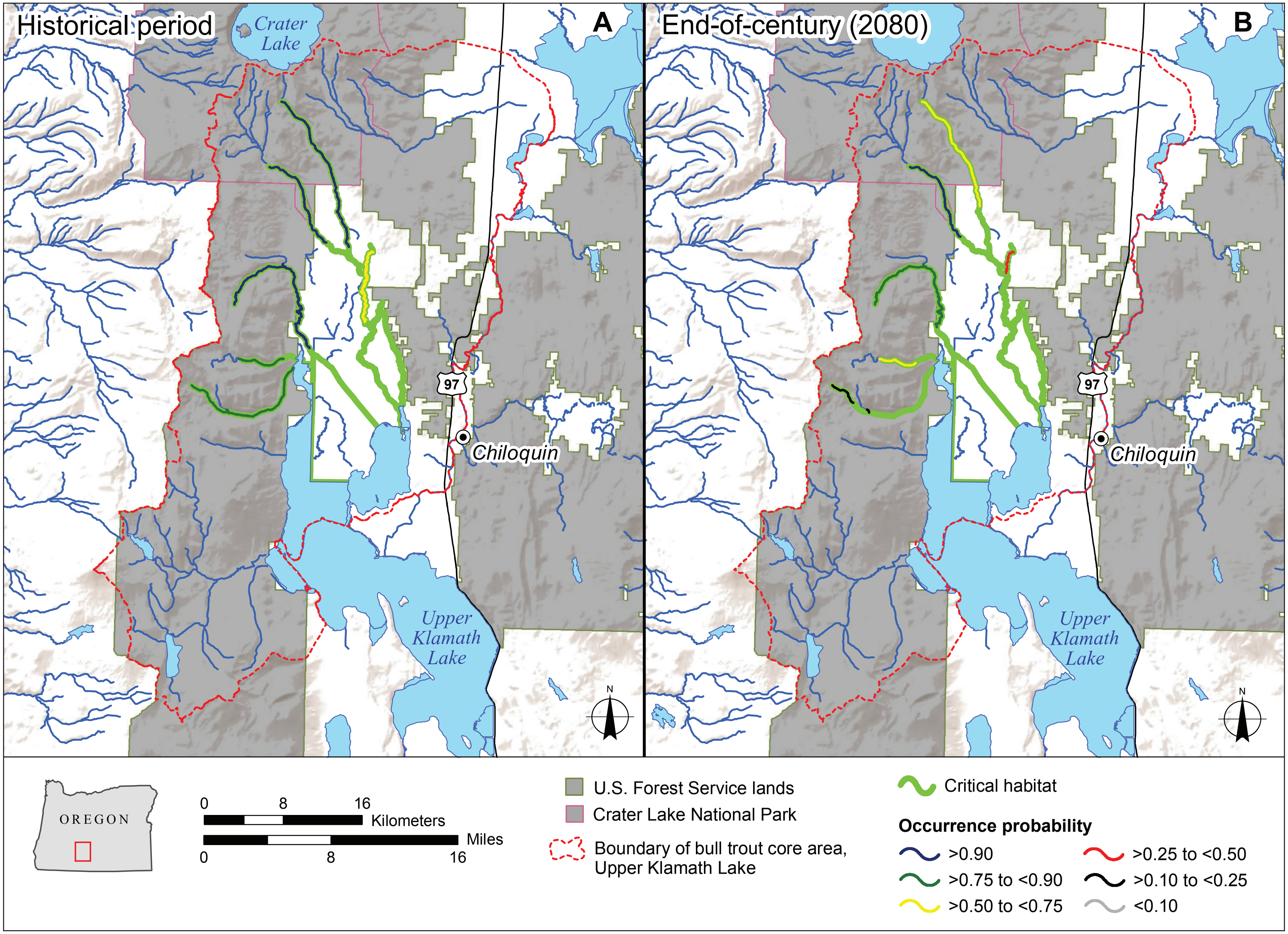

Figure 5.19—Occurrence probabilities of bull trout within the Upper Klamath Lake core area for the 1980s and 2080s based on the A1B emission trajectory (probabilities are also based on the absence of brook trout). Heavy green lines show U.S. Fish and Wildlife Service critical habitat, whereas probability colored subsets of those lines are reaches with August mean temperatures <11 °C where juvenile fish are predicted to be most prevalent based on empirical relationships developed in the Climate Shield bull trout model (Isaak et al. 2015). In this core area, bull trout have a high probability of continued persistence in some streams by the 2080s, assuming widespread brook trout invasions do not occur.

Climate Change Effects on Macroinvertebrates and Mollusks

Climate change effects on river and fish habitats will similarly affect aquatic invertebrate habitats. The most significant changes affecting aquatic invertebrates are anticipated to be:

- Increased summer water temperatures.
- Decreased summer flow, resulting in habitat loss and fragmentation (primarily in higher elevation watersheds with declining snowpack) (see chapter 3).
- Decreased hydro-period of wetlands (e.g., conversion of perennial to seasonal and seasonal to ephemeral).
- Increased frequency and magnitude of floods in streams (see chapter 3).
- Increased fine-sediment inputs (from floods and wildfires) (Huff et al. 2006, Relyea et al. 2012).
- Decreased quantity and quality of allochthonous inputs (from changes to riparian vegetation) (chapter 6).
- Increased algal blooms or changes to periphyton communities (from loss of riparian shading, increased temperatures, and altered flow regimes).
- Increased predation by fish as habitat shrinks.

Expected shifts in freshwater lotic invertebrate fauna—
Alpine cold stenothermic invertebrates, species requiring a narrow temperature range for survival, are the most vulnerable to climate change because of habitat drying and warming temperatures. Extirpation of these species in the coming decades is a distinct possibility. However, documenting these losses will be difficult given how little is known about these communities at present.

Invertebrate species associated with cold forested streams will shift to higher elevations. These headwater streams are expected to become increasingly fragmented and are especially vulnerable to the effects of climate change and disturbances (e.g., wildfires, floods, and sediment pulses). However, many of the streams in the Deschutes, John Day, and Klamath watersheds originate from forested springs at moderate elevations along the east slope of the Cascades, precluding a shift of coldwater-adapted invertebrates to higher elevations.

Invertebrate species, especially mollusks, that are restricted to groundwater-fed forested springs could experience extinction or local extirpation from a combination of climate change effects and human impacts (e.g., groundwater pumping). Few baseline data are available on the aquatic invertebrates associated with these springs for tracking changes brought on by climate change. To complicate matters, springs tend to have a high degree of individuality in their physiochemical characteristics and biota.

Coolwater invertebrate species associated with larger streams will likely experience altitudinal and longitudinal population compression into headwater reaches as rivers warm from below. Cool to cold water refugia may become seasonally limited or spatially intermittent. Dynamically shifting biotic interactions among species are anticipated, but unpredictable, as the area of suitable habitat shrinks and changes.

Habitat generalists associated with cool to warm water bodies will likely expand their populations along altitudinal gradients. Rivers and wetlands at low elevations may become too warm or otherwise altered in habitat characteristics (e.g., shift of riparian vegetation from dry conifer forest to grasslands) to support certain species.

Warmwater generalist species not currently found in the region are expected to shift north from the Great Basin and American Southwest. Documenting these gains will be difficult given the current lack of consistent freshwater biomonitoring programs and poor taxonomic resolution.

Effects on fish populations—

Aquatic invertebrates play an important role in nutrient cycling, primary productivity, organic matter decomposition, and translocation of materials. As consumers at intermediate trophic levels, they serve as the conduits of these processes, and are an important food source for fish, especially insectivorous salmonids. Invertebrate assemblages are good indicators of environmental change because they respond predictably and rapidly to environmental stresses, whether human induced or climatic.

Information gaps—

Little is known about the aquatic invertebrate fauna of alpine and forested headwater streams, springs, and wetlands in the assessment area. To understand what we currently have, and might eventually lose, will require an increased biomonitoring effort. Of greatest value would be periodic surveys from multiple fixed points along the profile of the major rivers and selected tributaries, from headwaters or springs to large rivers, at a fine level of taxonomic resolution (e.g., species level).

Potential Effects on Fish From Increased Water-Based Recreation

Overall demand for warm-weather activities (e.g., hiking, camping) is expected to increase with a longer recreation season (more snow-free access) and warmer air temperatures (chapter 8). Increases are expected to be moderate, because not all recreation sites (trails, campgrounds, day use areas) may be open early in the year. Extreme heat will likely encourage some people to seek water-based activities as a way to escape the heat but may discourage others to participate in outdoor recreation (Bowker et al. 2012).

Increased use of streams and lakes has the potential to disturb rearing and fall spawning fish, particularly in those areas that are more accessible to people (e.g., closer to main roads, campgrounds, and boat launches). Many of these sites likely already receive recreation use during peak times for floating, boating, and swimming, but longer periods of use brought on by warmer days and an extended recreation season may disproportionately increase fish disturbance in streams and smaller rivers that still provide the best remaining summer and fall baseflows and water temperatures.

For juvenile salmonids, disturbance can lead to behavioral changes that may result in alteration in feeding success, increased exposure to predators, and displacement into less suitable habitat. Although these effects can result in injury, most fish would be expected to access nearby cover and avoid injury or morality. Juvenile salmonids in streams are sensitive to overhead movements and usually hide under cover when approached (Chapman and Bjornn 1969, Hoar 1958). This is presumably an anti-predator response, as several species of birds are effective predators of juvenile salmonids (Elson 1962, Hoar 1958).

Concentrated water activities in fall-spawning bull trout habitat could disrupt site selection behavior by introducing a perceived threat that would drive the pair to other less suitable habitats, delay spawning, or perhaps cause spawning to be abandoned altogether. With increased water recreation activities, bull trout energy reserves could be consumed from frequent disturbance or displacement from redds, or perhaps the abandonment of a partially completed redd.

Where pools are lacking, the public may create small rock dams to create deeper water to cool off in more accessible streams. Summer rock structures can temporarily block habitat upstream if they span the stream channel in summer. Fish encountering a barrier will likely spend energy trying to find a way around the barrier. If unsuccessful, fish may move into available deeper habitat below the structure. Fish that are too tired to move or that remain in shallower habitat with less cover may be more prone to predation. Structures could delay upstream movement of juveniles until higher flows move rocks that created the dam.

Potential Effects on Fish From Vegetation Change and Disturbance

Another area of uncertainty for aquatic resources relates to potential changes in terrestrial vegetation across the SCOAP assessment area (chapter 6). Distributions of plant species and community dominance are projected to change in many watersheds, but changes will be strongly dependent on whether future climates become wetter or drier in conjunction with ongoing warming trends. Vegetative changes will have important secondary effects on stream and lake hydrology (timing and magnitude of runoff), nutrient cycling, sedimentation, and disturbance regimes (Goode et al. 2012, Luce et al. 2012). In addition, the frequency and extent of wildfires are expected to increase in many vegetation communities (see chapter 6, figs.

6.18 and 6.19). Wildfire may benefit aquatic ecosystems and native species in many instances by recruiting large wood and sediment into channels to create structural and habitat diversity. However, wildfires may also cause short-term declines in the local abundance of aquatic species (Dunham et al. 2007) and may pose larger future threats to populations that are already reduced in size or fragmented and isolated in headwater tributaries (Isaak et al. 2010).

Chapter Summary

Climate change will lead to warming air temperatures and potential changes in the amount, timing, and type (snow versus rain) of precipitation. Depending on scale and location, these will generally combine to cause warmer water temperatures, earlier snowmelt runoff, and lower summer baseflows. Relative to the 1980s baseline period, runoff timing (center of flow mass) of all streams in the SCOAP assessment area is projected to advance 8 to 18 days earlier in the year. The number of winter high-flow days is projected to increase slightly, as are winter peak flows, which could increase by 4 to 12 percent, as higher elevation terrain becomes more susceptible to rain-on-snow events. Summer flow reductions of 20 to 47 percent are projected, but the linear extent of the perennial network is projected to change very little. Summer flow reductions are predicted to be most prominent in the highest elevation watersheds, where flows are most dependent on winter snow accumulation. Summer stream temperatures are projected to increase across the SCOAP assessment area by an average of 1.3 °C in the 2040s and 2.2 °C in the 2080s. Larger than average increases are projected to occur in the warmest streams at low elevations, and smaller than average increases are projected for the coldest streams. Extreme events may also occur more frequently and persist over longer periods, including higher temperatures, severe droughts, and large wildfires.

Adapting fisheries to the environmental trends associated with climate change will require a diverse portfolio composed of many strategies and tactics (see chapter 10). Equally important is understanding a new concept of dynamic disequilibrium in which stream habitats will become more variable, undergo gradual shifts through time, and sometimes decline in quality. Most fish species and populations will retain enough flexibility to adapt and track their habitats (Eliason et al. 2011), but others may be overwhelmed by future changes without significant assistance. It may not be possible to preserve all populations of all fish species across the SCOAP assessment area. However, as better information continues to be developed, resource managers will be able to identify where resource commitments are best made to enhance the resilience of fish and fish habitat. As many species and populations adjust their phenologies and distributions to track climate change, Forest Service lands will play an increasingly important role in providing future aquatic habitats.

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Chapter 6: Climate Change, Vegetation, and Disturbance in South-Central Oregon

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Introduction

This chapter assesses the potential effects of climate change on vegetation in the South-Central Oregon Adaptation Partnership (SCOAP) assessment area, using information from the literature and output from models and other assessments. The chapter consists of four sections:

1. Understanding climate change effects
2. Disturbances
3. Vegetation group assessment
4. Riparian areas, wetlands, and groundwater-dependent ecosystems

The composition and productivity of vegetation differ greatly across south-central Oregon as a result of climate, elevation, substrate, and the land use history of the region (see chapter 2). From west to east, vegetation ranges from wet, temperate forests dominated by western redcedar (*Thuja plicata* Donn ex D. Don) and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) to dry grasslands and shrublands in the interior dominated by bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] Á. Löve) and big sagebrush (*Artemisia tridentata* Nutt.). At high elevations, vegetation is generally dominated by treeless alpine meadows and subalpine forests dominated by whitebark pine (*Pinus albicaulis* Engelm.), mountain hemlock (*Tsuga mertensiana* [Bong.] Carriére), and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.). Mid to high elevations can be dominated by mixed conifers, with Pacific silver fir (*Abies amabilis* Douglas ex J. Forbes) in high-precipitation areas and ponderosa pine (*Pinus ponderosa* Douglas ex P. Lawson & C. Lawson) in low-precipitation areas.

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Low to mid elevations in high-precipitation areas generally contain a combination of western hemlock, western redcedar, Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), grand fir (*Abies grandis* [Douglas ex D. Don] Lindl.), and white fir (*A. concolor* [Gordon & Glend.] Lindl. ex Hildebr.). At low to mid elevations in drier forested areas, Oregon white oak (*Quercus garryana* Douglas ex Hook.), lodgepole pine (*Pinus contorta* var. *latifolia* Engelm. ex S. Watson), ponderosa pine, and Douglas-fir are present. However, many of these species are greatly affected by the presence and depth of ash and pumice deposits. For instance, many species are severely limited in areas of deep ash and pumice deposits (e.g., Heyerdahl et al. 2014). In drier shrubland areas, western juniper (*Juniperus occidentalis* Hook.) and shrub-steppe species such as sagebrush and bitterbrush (*Purshia tridentata* [Pursh] DC.) generally dominate. Grasses dominate in areas where low precipitation excludes the growth of trees and shrubs.

This assessment uses a map of potential vegetation developed by the U.S. Forest Service (USFS) that incorporates local plant association classifications (Hopkins and Kovalchik 1983, Johnson and Clausnitzer 1992, Simpson 2007) that cover the SCOAP assessment area. The map has two hierarchical levels: vegetation zone (vegzone) and subzone. Both the vegzone and subzone levels are broader in scope than an individual plant association as described in the classification documents. The vegetation zones and subzones are listed in table 6.1, and their area within each of the administrative units is described in figure 6.1. Each vegetation subzone was associated with a plant functional type used in the MC2 ecosystem simulation model (see later sections for details).

Potential vegetation is mapped by vegetation subzone for Crooked River National Grassland (fig. 6.2), all three national forests—Ochoco National Forest (fig. 6.3), Deschutes National Forest (fig. 6.4), Fremont-Winema National Forest (fig. 6.5)—and Crater Lake National Park (fig. 6.6). However, the park uses a separate vegetation classification for planning purposes (box 6.1). Crooked River National Grassland, the lowest elevation unit, is dominated by juniper woodlands (50 percent) and upland shrub (29 percent) vegetation subzones.

Table 6.1—Eight broad vegetation groups used for discussion purposes in this chapter and the Simpson[a] plant classification system subzones and vegetation zones (vegzone)

Vegetation group (MC2 plant functional type)	Subzone name	Subzone	Vegzone name	Vegzone
Subalpine (subalpine forest, subalpine woodland, alpine tundra)	Dry mountain hemlock	91	Mountain hemlock	23
	Moist mountain hemlock	92	Mountain hemlock	23
	Wet mountain hemlock	93	Mountain hemlock	23
	Mountain hemlock wetlands	94	Mountain hemlock	23
	Dry subalpine fir	61	Subalpine fir-spruce	25
	Moist subalpine fir	62	Subalpine fir–spruce	25
	Wet subalpine fir	63	Subalpine fir–spruce	25
	Subalpine shrub	13	Subalpine parklands	30
	Subalpine grassland-forbland	14	Subalpine parklands	30
	Subalpine fir parklands	64	Subalpine parklands	30
	Mountain hemlock parklands	95	Subalpine parklands	30
	Dry whitebark pine	97	Subalpine parklands	30
	Moist whitebark pine	98	Subalpine parklands	30
	Whitebark pine parklands	99	Subalpine parklands	30
Moist forest (moist coniferous forest)	Moist western redcedar	75	Cedar–hemlock	18
	Wet western redcedar	76	Cedar–hemlock	18
	Western redcedar wetlands	77	Cedar–hemlock	18
	Moist western hemlock	82	Cedar–hemlock	19
	Wet western hemlock	83	Cedar–hemlock	19
	Western hemlock wetlands	84	Cedar–hemlock	19
	Lodgepole pine wetlands	28	Lodgepole pine	8
	Moist silver fir	87	Silver fir	22
	Wet silver fir	88	Silver fir	22
	Silver fir wetlands	89	Silver fir	22
	Wet white fir–grand fir	58	White fir-grand fir	20
	Engelmann spruce wetlands	68	White fir-grand fir	20
Mesic forest (coniferous forest, deciduous forest)	Wet Douglas-fir	43	Douglas-fir	14
	Riparian shrub	15	Hardwood forest	11
	Hardwood forest	17	Hardwood forest	11
	Wet lodgepole pine	27	Lodgepole pine	8
	Dry Shasta red fir	71	Shasta red fir	21
	Moist Shasta red fir	72	Shasta red fir	21
	Moist white fir–grand fir	57	White fir–grand fir	20
	Cold dry white fir–grand fir	59	White fir–grand fir	20

Table 6.1—Eight broad vegetation groups used for discussion purposes in this chapter and the Simpson[a] plant classification system subzones and vegetation zones (vegzone) (continued)

Vegetation group (MC2 plant functional type)	Subzone name	Subzone	Vegzone name	Vegzone
Dry forest (dry coniferous forests)	Dry Douglas-fir	41	Douglas-fir	14
	Moist Douglas-fir	42	Douglas-fir	14
	Jeffrey pine	37	Jeffrey pine	12
	Knobcone pine	38	Jeffrey pine	12
	Dry lodgepole pine	25	Lodgepole pine	8
	Moist lodgepole pine	26	Lodgepole pine	8
	Ponderosa pine–lodgepole pine	30	Ponderosa pine	10
	Dry ponderosa pine	31	Ponderosa pine	10
	Moist ponderosa pine	32	Ponderosa pine	10
	Dry white fir–grand fir	56	White fir–grand fir	20
Woodland (coniferous woodland, deciduous woodland, cool mixed woodland, warm mixed woodland)	Digger pine-oak	36	Digger pine-oak	7
	Oak woodlands	18	Hardwood forest	11
	Juniper steppe	21	Juniper	6
	Juniper woodlands	22	Juniper	6
	Ponderosa pine–white oak	34	Ponderosa pine	10
	Xeric pine	35	Ponderosa pine	10
Shrubland (shrubland, semidesert shrubland)	Salt Desert shrub	10	Shrub-steppe	5
	Scabland shrub	11	Shrub-steppe	5
	Upland shrub	12	Shrub-steppe	5
Grassland (grassland)	Upland grass	6	Meadows and grasslands	4
	Dry meadow	7	Meadows and grasslands	4
	Moist meadow	8	Meadows and grasslands	4
	Wet meadow	9	Meadows and grasslands	4

[a] Simpson, M.L. Vegetation zones and subzones across the Pacific Northwest. Unpublished data and map. On file with: U.S. Department of Agriculture, Forest Service, Central Oregon Area Ecology and Forest Health Protection Service Centers, 63095 Deschutes Market Road, Bend, OR 97701.

Note: A vegzone can be included in more than one vegetation group based on the subzone definition. Note that MC2 plant functional types are listed parenthetically and roughly correspond to the vegetation groups, although MC2 does not model species or their dynamics.

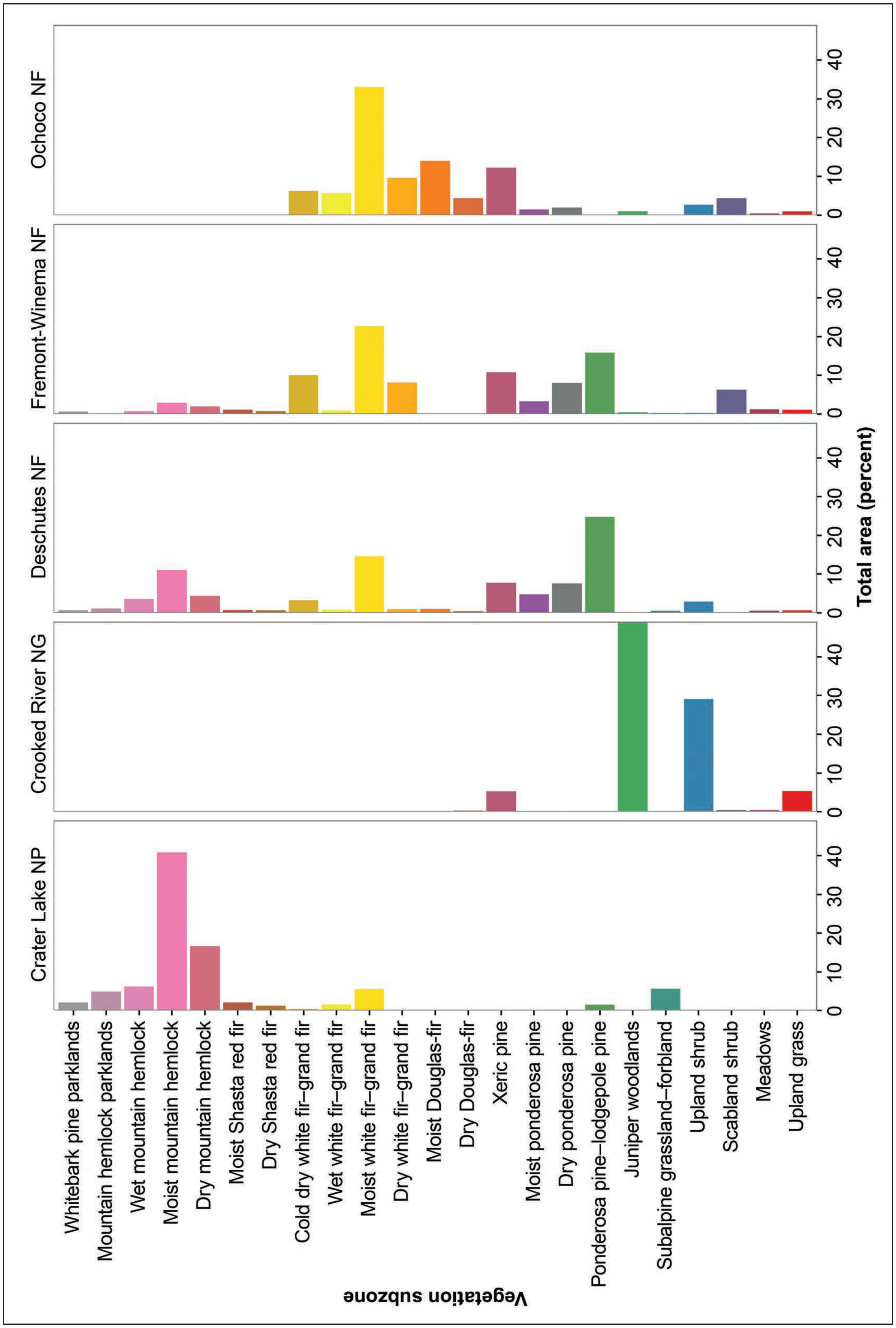

Figure 6.1—Area of vegetation subzones for each of the administrative units described in this chapter. NP = national park. NF = national forest. NG = national grassland.

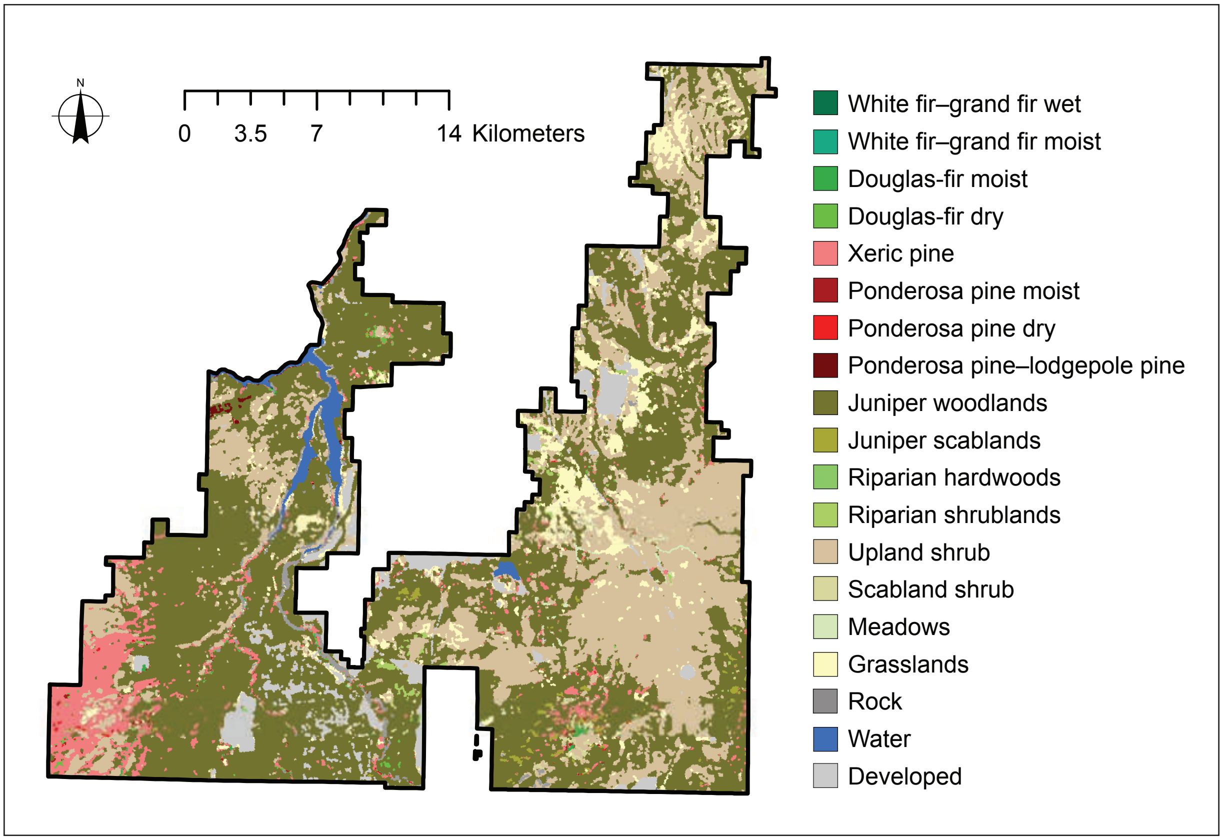

Figure 6.2—Vegetation subzones in Crooked River National Grassland.

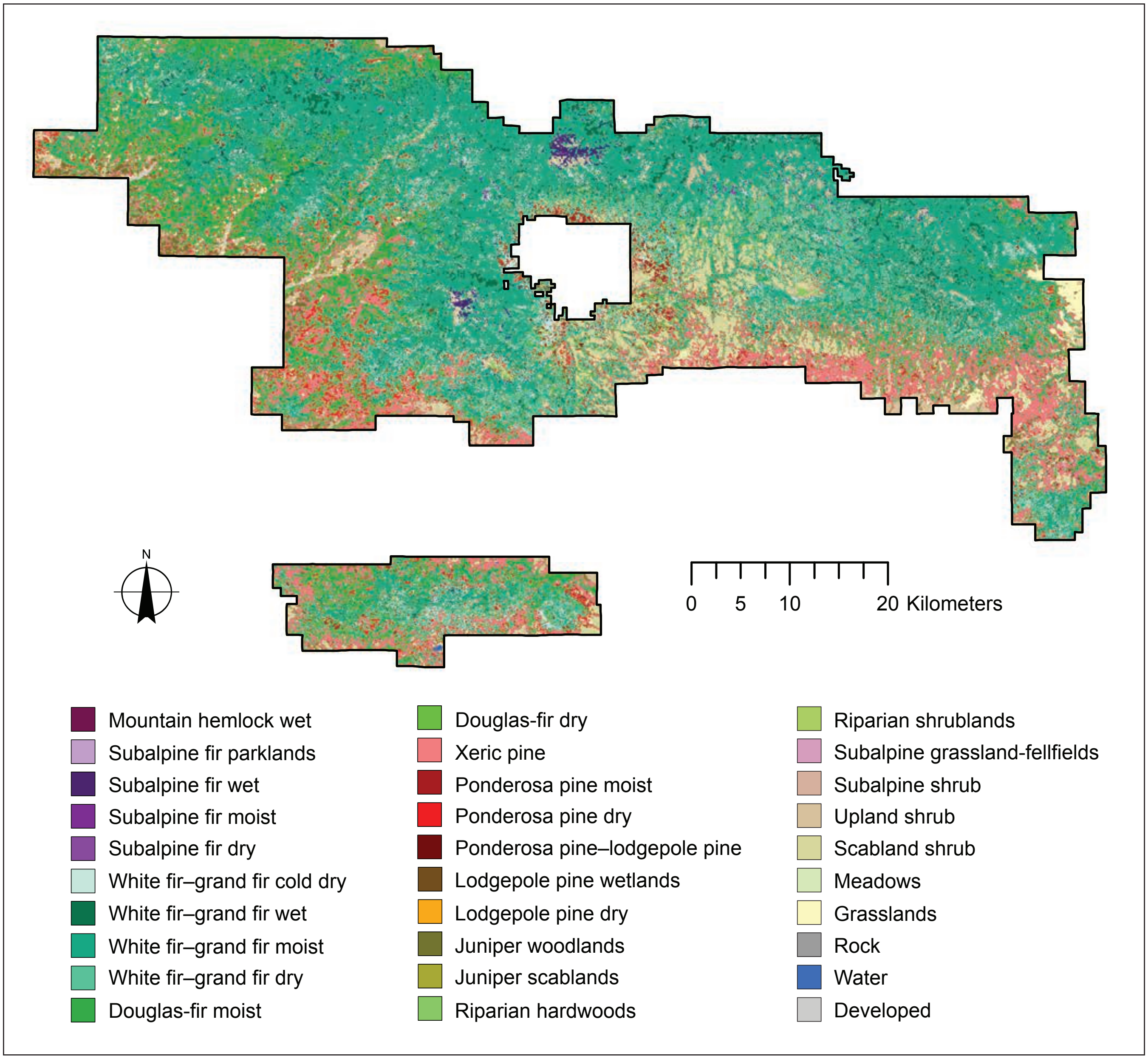

Figure 6.3—Vegetation subzones in Ochoco National Forest.

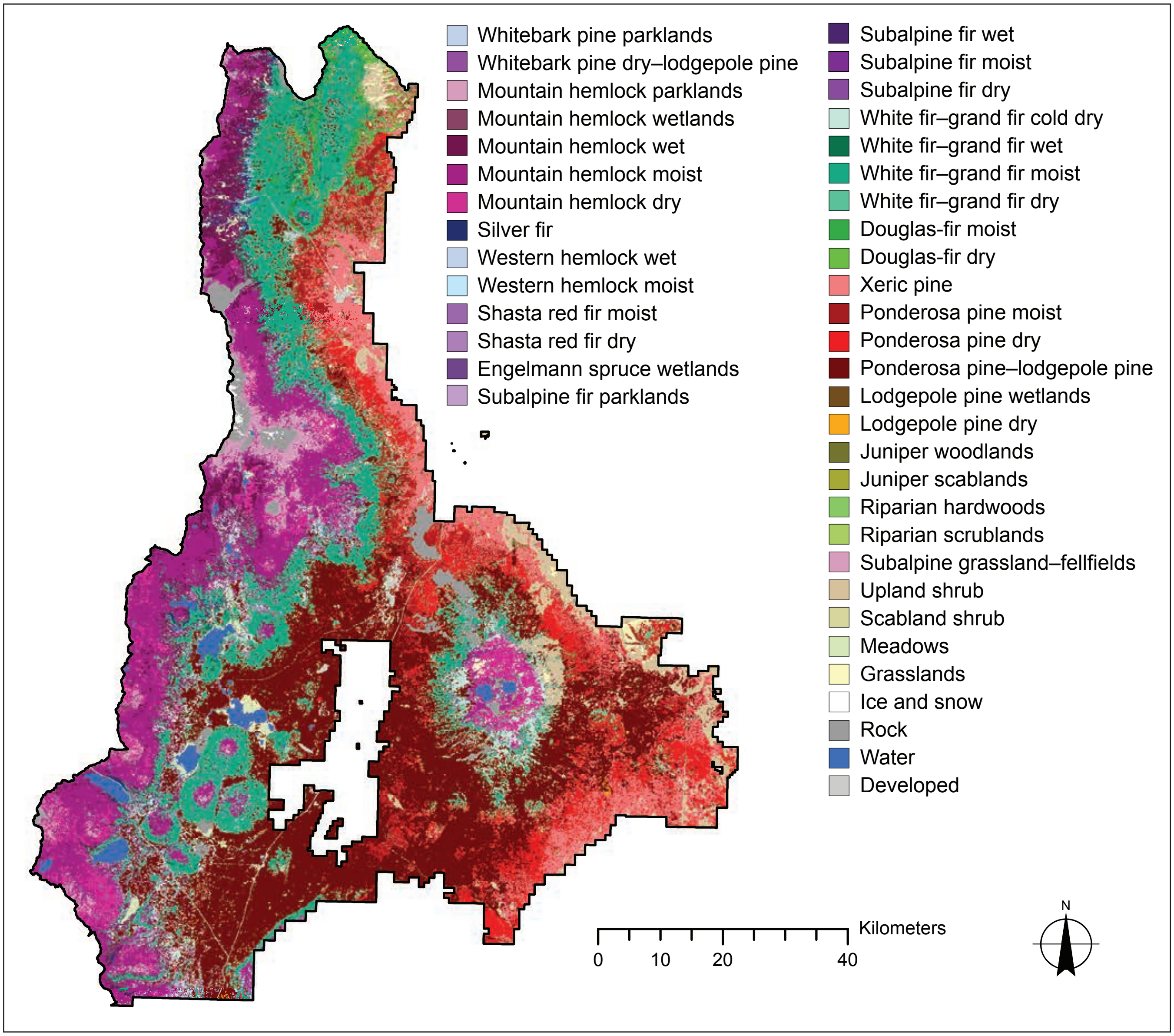

Figure 6.4—Vegetation subzones in Deschutes National Forest.

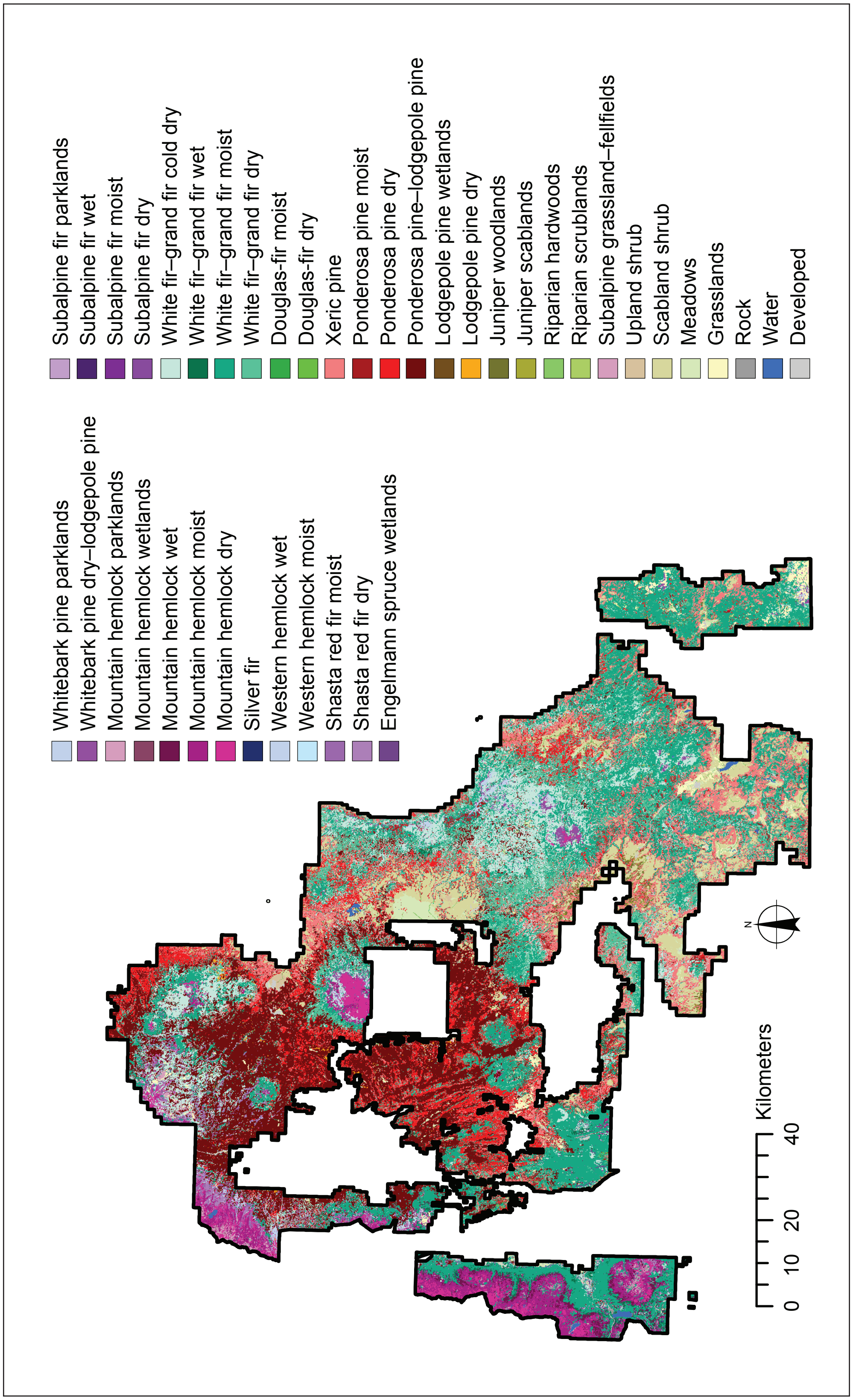

Figure 6.5—Vegetation subzones in Fremont-Winema National Forest.

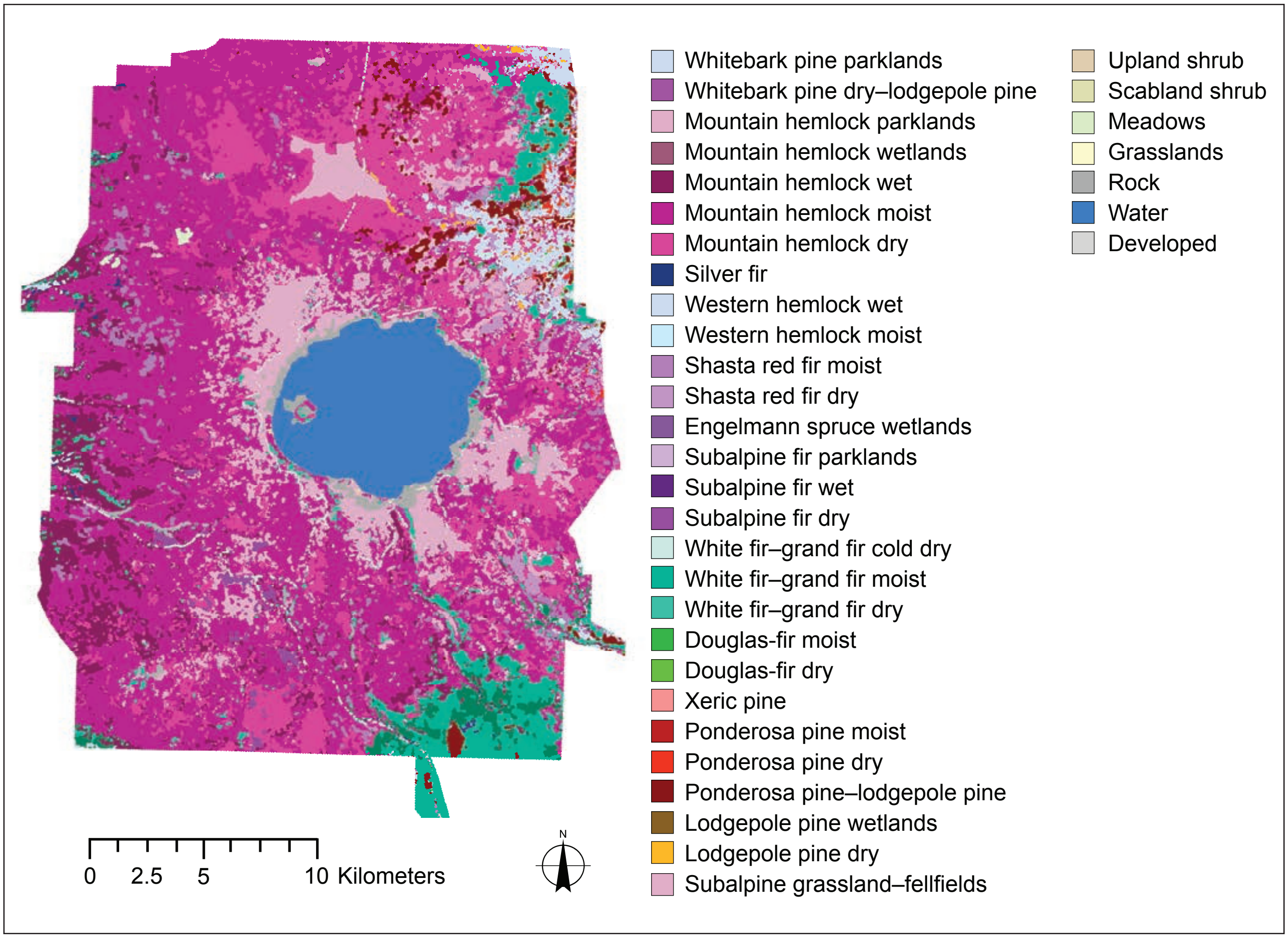

Figure 6.6—Vegetation subzones in Crater Lake National Park.

Box 6.1

Vegetation in Crater Lake National Park

Crater Lake National Park spans more than 74 000 ha across the crest of the Cascade Range. The iconic feature of the park is Crater Lake, which formed after the eruption and subsequent collapse of Mount Mazama 7,700 years BP (Bacon 2008). The caldera created by the eruption filled with rain and snowmelt to form the deepest lake (594 m) in the United States. The park is mostly forested but also contains montane and subalpine meadows, pumice deserts, rocky peaks, talus slopes, sharply dissected riparian canyons, and unique features such as shallow ponds and the rocky shore of Crater Lake. Elevations range from 1219 m in the southwest corner of the park to 2713 m at the summit of Mount Scott.

Vegetation in the park includes lower elevation mixed-conifer forests of ponderosa pine, white fir, Douglas-fir, sugar pine, and incense cedar. At middle elevations, forests are composed of pure Shasta red fir, pure lodgepole pine, or a montane mixed-conifer forest of Shasta red fir, western white pine, lodgepole pine, and mountain hemlock. At higher elevations, mountain hemlock is the dominant species, with whitebark pine occupying the highest peaks. These subalpine forests are either pure mountain hemlock, pure whitebark pine, or a mixture of mountain hemlock, whitebark pine, lodgepole pine, Shasta red fir, and subalpine fir. In riparian areas, Engelmann spruce is commonly found near creek margins and wetlands at lower elevations, with subalpine fir also occupying these habitats at low to high elevations. Small groves of quaking aspen (*Populus tremuloides* Michx.) occur in wetlands, along riparian zones, and in montane meadows. Western hemlock, Pacific madrone (*Arbutus menziesii* Pursh.), and bigleaf maple are confined to the lowest elevations on the west and more mesic side of the park.

Several large montane meadow systems (e.g., Sphagnum Bog, Thousand Springs, Poison Meadows, National Creek headwaters) are found on slopes that drain into the Rogue River. Subalpine meadows often consist of well-drained ashy or pumice substrates dominated by forbs, sedges, and grasses with trees and islands interspersed. Shrublands occur infrequently and are dominated by Fremont's silktassel (*Garrya fremontii* Torr.) in the southwest corner of the park, greenleaf manzanita (*Arctostaphylos patula* Greene), and snowbrush ceanothus (*Ceanothus velutinus* Douglas ex. Hook.) in montane forests, and Greene's goldenweed (*Ericameria greenei* [A. Gray] G. L. Nesom) in the subalpine zone.

Primary disturbance agents in Crater Lake National Park are wildfire and insects. Decades of fire exclusion have significantly influenced forest composition and structure, especially at lower and middle elevations, although recent efforts to manage lightning-ignited fires have attempted to restore fire as an ecosystem process. From 1931 to 2004, 13 354 ha burned in the park, compared to 9295 ha from 2005 to 2015. The 2015 fire season included the largest fire in the park's recorded history, the Crescent Fire of the National Creek Complex (5924 ha). An early onset to the 2015 fire season and dry fuels contributed to the large size of this fire. Mountain pine beetle (*Dendroctonus ponderosae* Hopkins) is the most conspicuous mortality agent in the park. The most recent outbreak (2005–2015) has

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been particularly damaging to whitebark pine (Murray 2010, Smith et al. 2011). White pine blister rust (*Cronartium ribicola* J.C. Fisch.) has caused significant declines of whitebark pine, western white pine, and sugar pine throughout the park.

The park actively manages for conservation of whitebark pine. Rust-resistant whitebark pines are identified through a regional screening process, and progeny of rust-resistant individuals are planted throughout the park in restoration plantings. Rust-resistant and old, large-diameter whitebark pines are protected against mountain pine beetle attack through application of anti-aggregating pheromones.

Longer growing seasons may facilitate an increase in nonnative, invasive plants in the park. Altered disturbance regimes, especially an increase in wildfire, may also provide opportunities for establishment of nonnative plant species. Longer snow-free periods may increase the number of park visitors, which could in turn increase nonnative plant introductions (Parks et al. 2005). Upgrades of park infrastructure can also introduce nonnative plants. New plant species are frequently found in the park, including annual grasses such as cheatgrass.

Rare plant species at Crater Lake National Park are often found at their upper elevation limits, including pumice moonwort (*Botrychium pumicola* Coville ex Underw.) and the endemic horizontal woody rockcress (*Boechera horizontalis* [Greene] Windham & Al-Shehbaz). Both species are affected by trampling by recreationists. The park maintains an ecological restoration program that attempts to counter deleterious effects of road construction and visitor use by using plant materials from native genotypes. National Park Service resource specialists monitor vegetation in collaboration with the Klamath Inventory and Monitoring Program.

Understanding Climate Change Effects

Warming temperatures, changing precipitation patterns, and altered disturbance regimes are affecting vegetation across North America (Chen et al. 2011, Root et al. 2003). Some species are flowering earlier (e.g., Abu-Asab et al. 2001, Cayan et al. 2001, Parmesan and Yohe 2003), tree growth rates are changing (McKenzie et al. 2001, Williams et al. 2010), and net primary productivity is being altered (Boisvenue and Running 2006, Reeves et al. 2014). In addition, the distributions of some plants are shifting in response to both warming temperatures and changes in available moisture (Beckage et al. 2008, Kelly and Goulden 2008). It has been suggested, but not proven, that a warmer climate has caused tree mortality in some systems (Allen et al. 2010, Anderegg et al. 2013, Breshears et al. 2005, Choat et al. 2012, van Mantgem et al. 2009). In addition, altered disturbances, such as fire and some insects and diseases, will substantially affect where plant species will be able to grow and how they interact (Brubaker and McLachlan 1996, Hicke et al. 2006, Littell et al. 2010, McKenzie et al. 2004).

Key features of change in the future climate are an increase in growing season temperatures, particularly in the spring and autumn, and possibly an overall increase in precipitation, mostly in winter, spring, and autumn (chapter 3). To better understand the effects that climate has on vegetation in the SCOAP assessment area, we highlight data from (1) paleoecological records, (2) observational and experimental studies, and (3) approaches such as vulnerability assessments and vegetation model output for the future. Assessments and model output are aggregated because vegetation models are often used as inputs into vegetation assessments.

Paleoecological Records

Pollen, macrofossils, and phytoliths can be used to reconstruct vegetation composition from earlier records (e.g., throughout the Holocene—our current geological era—which began 11,700 years BP). For example, pollen grains and macrofossils that are washed or blown into lakes and wetlands can collect in sediments that accumulate over time and can create layer upon layer of vegetation history. Different types of pollen and macrofossils from different species in lake sediments reflect the vegetation that was present around the lake or wetland. This information can also be used to infer climate conditions that were favorable for that vegetation. Phytoliths are morphologically distinct silica bodies from plants that exist in soil, sedimentary deposits, or archaeological material. In addition, historical vegetation information can be obtained from biological remains in nests and waste heaps (middens) created by several species of birds and small mammals, respectively, and they may be preserved for thousands of years, providing a detailed fossil record of past environmental conditions (Betancourt et al. 1990, Rhode 2001).

Early paleoecological records show that vegetation responds to changes in climate (Whitlock 1992) but that species respond individually (Delcourt and Delcourt 1991). For example, during warm, dry periods in the southern Puget Trough, tree species such as Douglas-fir, alder (*Alnus* spp.), oak (*Quercus* spp.), and giant chinquapin (*Chrysolepis chrysophylla* [Douglas ex Hook.] Hjelmq.) dominated at some sites (Whitlock 1992). In areas that have not been heavily manipulated by humans, the vegetation we see today developed under the cooler, wetter conditions of the past 100 years or so. However, vegetation often shifts in abundance rather than being extirpated in areas where species were formerly dominant. The southern extent of Pleistocene glaciation (2,588,000 to 11,700 years BP) limits our ability to reconstruct past vegetation. Therefore, we used environmental reconstructions for the Pacific Northwest based on pollen or other records obtained from lakes and wetlands in the wider region and, when possible, locally (Blinnikov et al. 2002; Hansen 1943, 1947; Mehringer and Wigand 1987; Whitlock 1992; Whitlock and Bartlein 1997; Worona and Whitlock 1995).

As the last glaciation waned, a warmer and drier climate than today occurred during the early to middle Holocene. This type of climate and associated vegetation change can provide insight into what might be expected with future climate change, although early-to-middle Holocene conditions were probably drier than projections from global climate models. In addition, the rate of future climate change will probably be faster than has occurred previously in the Holocene (Smith et al. 2015).

Whitlock and Bartlein (1997) studied vegetation history using pollen records from Carp Lake, located at 714 m elevation in south-central Washington. Carp Lake is in a volcanic crater that lies at the lower altitudinal limit of ponderosa pine forest and is near the sagebrush-steppe, making it a sensitive ecotone. The site is currently dominated by ponderosa pine, Douglas-fir, and some grand fir and alder species. The abundance of mesic species reflects the relatively wet climate and land-use history of the last century. However, about 4,000 to 9,000 years BP, the site was dominated by a pine-oak woodland, indicating that the climate was warmer and drier than currently. From 9,000 to 13,000 years BP, early Holocene steppe vegetation was dominant, also reflecting a warm, dry period. However, alder was still present in riparian settings, illustrating that these wet areas may provide a refuge for more mesic species. Between 13,000 and 31,000 years BP, the site was in its coldest, driest period, dominated by steppe vegetation, such as sagebrush, grasses, and nearby Engelmann spruce (*Picea engelmannii* Parry ex Engelm.). According to the pollen record, the site was probably cooler than present from 13,000 to 73,000 years BP; however, summers may have been warmer and wetter than currently. From 73,000 to 83,000 years BP, an open forest of Douglas-fir, larch (*Larix* spp.), western hemlock, fir (*Abies* spp.), and oak were present, suggesting warmer and wetter summers than currently.

Miller and Wigand (1994) summarized the paleoecological history for juniper and reported that about 4,000 years BP, juniper pollen increased in the Diamond Pond area of the northwestern Great Basin in response to increased winter precipitation and cooling temperatures. During this time, juniper (*Juniperus* spp.) expanded its range l150 m lower in elevation into more xeric communities. These more mesic conditions are supported by an increase in the grass-to-sagebrush ratio and higher regional water tables. Nevertheless, paleoecological data show that juniper has expanded its range under wetter conditions (Mehringer and Wigand 1987). Recently, wildfire exclusion and other factors may have been partially responsible for juniper expansion.

Blinnikov et al. (2002) presented a vegetation reconstruction from the interior Columbia River basin; although this region is not in south-central Oregon, it does provide insight into vegetation dynamics of western dry interior regional systems, showing large shifts in composition during the past 100,000 years. For example, sagebrush steppe dominated during cold, dry periods, transitioning to ponderosa pine during cool, wet periods, to present-day grasslands, dominated by fescue (*Festuca* spp.). Although future climates will probably differ from past climates, these changes in vegetation composition suggest potential pathways for dominant species.

Climate Change Studies

Observational studies show that climate directly affects vegetation growth, reproduction, and survival through temperature (notably winter temperature), snowpack duration, summer vapor pressure deficits, and soil water deficits. Climate can also influence vegetation indirectly by influencing disturbance regimes, such as fire and insect outbreaks. Furthermore, elevated carbon dioxide (CO_2) can affect vegetation by increasing growth rates and affecting biotic interactions such as competition. Changes in these interactions will influence the productivity and composition of plant communities and will ultimately influence ecosystem processes and functions.

In response to changes in climate, tree species will remain in their current locations, shift in distribution or abundance, or go locally extinct. The largest changes will likely occur in areas in which species are currently stressed or new colonizations are most likely, such as at treeline, forest-grassland ecotones, and more generally at the climatic limits of species distributions (Allen and Breshears 1998, Brubaker 1986, Thuiller et al. 2008, Williams et al. 2010). For example, there has been a drought-induced shift in species composition and forest structure over a 40-year period in northern New Mexico (Allen and Breshears 1998), where ponderosa pine forest decreased and pinyon pine (*Pinus edulis* Englem.) and one-seeded juniper (*Juniperus monosperma* [Engelm.] Sarg.) woodland increased. Pinyon pine and juniper outcompete ponderosa pine for available water and are better able to persist at lower elevations under drought conditions (Allen and Breshears 1998). In southern California, white fir moved upslope at a faster rate than Jeffrey pine (*Pinus jeffreyi* Balf.) in response to changes in regional climate over a 30-year period (Kelly and Goulden 2008). Although these results are not specific to the Pacific Northwest, they highlight climate sensitivities and responses of individual species.

Tree growth-climate relationships differ by species, location, and developmental stage (Ettinger et al. 2011, Fagre et al. 2003). For example, some tree species have higher growth at high-elevation sites during periods of warmer temperatures and longer growing seasons (Peterson and Peterson 1994, 2001; Peterson et al. 2002). However, there are limits to the effects of increased growth from warmer temperatures, and individual species have unique temperature thresholds (Way and Oren 2010). Above these thresholds, the rate of photorespiration can increase and photosynthesis and growth can decrease (Long et al. 1994).

Tree growth in low-elevation systems, such as juniper woodlands and ponderosa pine forests, are generally correlated with precipitation and soil water availability (Knutson 2006, Kusnierczyk and Ettl 2002), and reduced growth in common species such as Douglas-fir can be expected (Restaino et al. 2016). Growth of some plants in these systems could be significantly affected by summer soil-water deficits that occur annually for many species but could be lengthened under climate change.

Increased drought stress can also affect seedling establishment and survival (e.g., Harvey et al. 2016). Warmer temperatures can increase the frequency and severity of summer drought, which will in turn affect plant growth and species distribution and abundance.

For some species, elevated CO_2 may help offset the adverse effects of higher temperatures and reduced soil water availability. Increased atmospheric CO_2 allows some plants to reduce stomatal conductance and leaf-level transpiration while maintaining adequate CO_2 levels for photosynthesis within leaves, thereby increasing water-use efficiency (Ainsworth and Long 2005, Drake et al. 1997, Leakey et al. 2009, Long et al. 2004, Medlyn et al. 2001). Increasing atmospheric concentrations of CO_2 could lead to increased plant growth and higher ecosystem productivity when temperatures are not beyond the photosynthetic optimum and when soil water availability is adequate (Leakey et al. 2009, Long et al. 2004, Saxe et al. 2001). Furthermore, elevated CO_2 and higher water-use efficiency may in some cases improve shade tolerance (Drake et al. 1997), reduce drought stress, increase soil water availability (Holtum and Winter 2010), and reduce plant nutrient quality for insect and animal herbivores (Lincoln et al. 1993, Robinson et al. 2012, Zvereva and Kozlov 2006). The extent to which these studies are applicable to the vegetation in the SCOAP assessment area is unknown. For example, enhanced productivity may be constrained to wet years, and these gains may diminish over prolonged drought periods (Newingham et al. 2013).

Different vegetation types will respond differently to CO_2 enrichment and at different time scales, largely owing to variation in soil water availability. Climatic water deficit may increase significantly under the RCP 8.5 emission scenario (chapter 3) (fig. 3.10). Climate and CO_2 studies offer insights into potential vegetation responses, although they cannot represent the range of complexity in different ecosystems (Peterson et al. 2014). We address details in each section of this chapter, using information from these studies to provide context for projections of vegetation change in a warmer climate.

Vulnerability Assessments and Vegetation Modeling

Managing forests in the face of climate change will require an understanding of which species or systems will be most vulnerable to future climate change and which factors will increase vulnerability or resilience. **Vulnerability** to climate change has been defined as "the extent to which a species or population is threatened with decline, reduced fitness, genetic loss, or extinction owing to climate change" (Dawson et al. 2011), and is a function of sensitivity, exposure, and adaptive capacity. **Sensitivity** of an individual species is characterized by its ability to withstand changes in climate and is largely a product of species natural history, including life history traits, interspecific relationships, physiological factors, dependencies on sensitive habitats, and relationships with disturbance regimes. **Exposure** is the degree of climatic change or climate-induced change likely to be experienced by a species and is determined by the character, magnitude, rate, and variability of climate change (Dawson et al. 2011). Estimates of potential future exposure can be derived from projected changes in climate and climate-driven changes in fire regimes, hydrology, invasive species, and land use. Potential future exposure is also frequently estimated using predictive models (wholly or in part).

Adaptive capacity is the ability of a species to cope with climate change by persisting in situ or moving to more suitable locations (Dawson et al. 2011). This ability to respond physiologically or behaviorally to the effects of climate change is influenced by both intrinsic and extrinsic factors such as reproductive strategy, genetic variability, phenotypic plasticity, dispersal distance and barriers, and landscape permeability. Using sensitivity, exposure, and adaptive capacity, vulnerability assessments can identify (1) which species or systems are most vulnerable, (2) why those species or systems are vulnerable, and (3) which factors can be potentially leveraged to reduce vulnerability (Williams et al. 2008).

Predictive vegetation models are generally classified as empirical (correlative), mechanistic (process based), or landscape models (Guisan and Zimmermann 2000). **Empirical models** that identify correlative relationships between species distributions and biophysical and climatic factors are referred to as bioclimatic, climate envelope, species distribution, or niche models. These models use fitted statistical relationships between a species distribution and historical or present-day climate, often using these same relationships to project the species niche in the future under different climates. Although these models are correlative and do not necessarily represent causation, they can include limiting factors (temperature, water, nutrition), disturbance factors, and resource factors (energy, water) (Guisan and Thuiller 2005). Several modeling efforts have assessed potential future habitat for tree species in western North America (Bell et al. 2014, Crookston et al. 2010, Hargrove and Hoffman 2005, McKenney et al. 2011, Rehfeldt et al. 2006).

Summary output from species distribution models are problematic for vulnerability assessments because projections typically show large reductions in available climate habitat for many species, without consideration of physiological processes, competition (e.g., Peterson et al. 2014), and other vegetation that might occur in these habitats. The models are empirically driven, so future novel climates do not correspond well with modern conditions under which the species occurs. Climate change is expected to result in substantial areas that have novel climate with no modern analog (Williams and Jackson 2007, Williams et al. 2007). This may be especially true for the Western United States where almost half the land area may have novel climatic conditions by the end of the century (Rehfeldt et al. 2006). For example, the Pacific Northwest is expected to have a temperature regime outside the normal range of variability by the middle of the century (2040–2060) (Kerns et al. 2016a).

A novel climate could be favorable for some species (e.g., Kerns et al. 2009). As a result, novel climates often create a bias in empirical projections toward reduced area for most species under future climate, without identifying which species would replace them. Thus, the projected loss of habitat for a species may simply illustrate the widespread nature of novel future climate conditions. Some species have relatively broad ecological amplitudes (e.g., lodgepole pine, juniper) (Daubenmire 1975, Miller and Wigand 1994, Miller et al. 2005, Pfister and Daubenmire 1975) and may be competitive in a novel environment. Because we do not regard species distribution models as robust for projecting future vegetation, we do not summarize the numerous species distribution models available (but see Peterson et al. 2014).

In contrast, **mechanistic approaches** explicitly model processes and relationships. These models can be species-specific, such as forest gap models (Bugmann 2001), or they can simulate groups of species with similar form and function in ecosystems (i.e., plant functional types), including dynamic global vegetation models (DGVMs) (Prentice et al. 2007, Sitch et al. 2003). Mechanistic models employ a set of known or suspected physiological or ecological relationships, rules, or limits and do not rely on known occurrence records, although they may be calibrated to large-scale vegetation patterns. These models are based on current understanding of physiologically or ecologically limiting mechanisms for species. Mechanistic models generally require more detailed information on processes and a detailed understanding of the associated response of species to environmental factors and dynamics.

Mechanistic models better predict how a species will respond to a novel environmental state than do empirical models (Strasburg et al. 2007). These models make projections based on causal relationships for a given species or group of species (Guisan and Zimmermann 2000), thus helping to interpret why a species range has changed. Although mechanistic models have been used to simulate the distribution of individual tree species (e.g., Coops and Waring 2011), they require large amounts of specific information on growth, physiology, and competitive interactions, which is generally not available for most species. Therefore, many mechanistic models are parameterized for coarse classifications of vegetation such as biomes.

Most vegetation models do not deal with the persistence of existing vegetation (inertia), dispersal processes, or genetic adaptation. Although, some **landscape models** have the capacity to deal with inertia if they are parameterized to include climate change (Halofsky et al. 2013), they were not used for this study. The inclusion of disturbance and extreme events is still in the early stages of development for most models (Keane et al. 2004, Lenihan et al. 1998, Thonicke et al. 2001).

Most vegetation models do not incorporate disturbance processes, and although the process-based model used in this study (MC2) includes wildfire, it does not incorporate biotic interactions or phenotypic plasticity (Kerns et al. 2016a).

Other factors contributing to uncertainty in model output include scenarios about carbon emissions in the future (Representative Concentration Pathways) and downscaling of general circulation models (chapter 3), making validation of model output impossible because there are no future occurrence data for species. Models also do not identify potential refugia that may exist in areas with appropriate microtopography and other characteristics. Although the caveats regarding model accuracy are well known, models provide a template for discussing potential futures that are at least plausible under a set of known assumptions. These futures can be used simply as “what if” scenarios to frame discussions on management and climate change adaptation. Model output is not a “forecast” or “prediction” about the future. Paleoecological studies, observational and experimental studies, and local knowledge provide multiple lines of evidence in combination with model output to assess potential and plausible climate change effects.

Disturbances

Ecological disturbances play a large role in determining how vegetation is distributed across the landscape. Disturbance factors, such as fire, windstorms, harvesting, and insects and diseases, influence vegetation age and structure, species composition, and patterns across the landscape and over time. The relative importance of each disturbance factor changes from one ecosystem to another, but collectively they are profoundly important in each system and their effects are usually evident. For example, Merschel et al. (2014) stated that land management since the early 1900s has altered the structure and composition of mixed-conifer forests of central Oregon, suggesting that a lower density of large-diameter trees and a higher density of small-diameter trees have reduced resilience to other disturbances. In other systems, fire exclusion and soil characteristics such as coarse-textured pumice influence species density, composition, and fire occurrence (Heyerdahl et al. 2014).

Ecological disturbances are linked to climate and weather, and each climatic regime has its associated agents of change, often in a recognizable hierarchy of importance. As climate continues to warm during the 21st century, the most rapidly visible and significant short-term effects will be caused by altered disturbance, often occurring with increased frequency and severity. Increased disturbance will be facilitated by more frequent droughts, amplifying conditions that favor wildfire, insect outbreaks, and invasive species (Adams et al. 2009, Allen et al. 2010, Anderegg et al. 2013). The type and magnitude of disturbances will differ regionally, posing significant challenges for resource managers to alleviate damage to resource values.

Wildfire

A warmer climate will cause an increase in the frequency and extent of wildfire in most dry forest and shrubland ecosystems (e.g., Cansler and McKenzie 2014; Stavros et al. 2014; Westerling et al. 2006, 2011). Historical and presettlement relationships between drought and wildfire have been well documented in much of North America, with forest fire occurrence and area burned clearly increasing in response to drought (Vose et al. 2016). Drought interacts with other controls (forest productivity, topography, and fire weather) to affect fire intensity and severity. Fire histories from diverse climate regimes and forest ecosystems suggests that North American forest fire regimes were moderately to strongly controlled by climate prior to Euro-American settlement and subsequent fire exclusion and fire suppression (Heyerdahl et al. 2008, Westerling et al. 2006).

By around 2050, annual area burned in most of the Western United States is projected to be at least 2 to 3 times higher than it is today (Littell et al. 2010, McKenzie et al. 2004). However, McKenzie and Littell (2017) noted that increased area-burned projections may be suspect because (1) they do not account for the fact that the area available to burn is not unlimited, and (2) assumptions about stationary processes (e.g., hotter and drier weather causes more fire) do not hold in all ecosystems (e.g., because of fuel limitations). These authors conclude that changing fire climatology may invalidate annual area-burned projections at ecosection or regional scales, although these changes could cancel each other across the Western United States. Nevertheless, recent research continues to show that the occurrence of large fires has increased in the Western United States since the 1970s (Dennison et al. 2014). Fire seasons are also starting earlier and ending later (Jolly et al. 2015).

Although fire severity is not well studied, recent correlative modeling suggests that fire severity may decrease in many areas of the Western United States by mid-century as a result of increased water deficit, lower productivity, and less biomass (Parks et al. 2016). However, correlative models do not incorporate the potential growth response of vegetation to increased CO_2 and may underestimate potential productivity. Many dry forests that have not burned for several decades have high fuel accumulations, and initial fires may cause uncharacteristic tree mortality compared to low levels of mature tree mortality associated with a historical surface fire regime. If these areas recover as forested ecosystems, recurrent fires (if allowed to burn and not suppressed) may more closely resemble the frequency characteristic of presettlement, low-severity fire regimes.

Specific disturbance interactions for each of the major vegetation groups are discussed below for each vegetation group. LANDFIRE data (Rollins 2009) suggests that Deschutes National Forest has significant area in fire regime groups I, III, and IV (fire return intervals of <35 years to 200 years). Ochoco National Forest has similar area in groups I and III (fire return intervals of <35 years to 200 years). Fremont-Winema National Forest has 610 000 ha in group 1 (fire return intervals of <35 years), with significant area in groups III and IV (fire return intervals of 35 to 200 years).

Insects and Pathogens

Insects and pathogens are key disturbance agents and stressors in all ecosystems. Many of these agents are closely tied to host vigor, which can be influenced by changes in climatic conditions. For example, several pine species are generally more susceptible to bark beetle attack when trees are stressed, and may be susceptible to other insects and fungal pathogens.

Rising temperatures may make new habitats available for some well-known disturbance agents. For example, mountain pine beetle (*Dendroctonus ponderosae* Hopkins) has recently expanded into higher latitudes and higher elevations in some parts of North America (Bentz et al. 2010). The life cycle for this beetle has been shortened, and winter mortality has been reduced in areas where freezing temperatures were previously important population regulators, although not necessarily in south-central Oregon. Over time, the effect of warmer temperatures on mountain pine beetle hosts may lead to different dynamics than we see today (Bentz et al. 2010).

A diverse combination of insect and plant life histories produces a wide variety of potential responses to warming climates (Bale et al. 2002). In the short term (until adaptations occur), herbivory will be facilitated on some plants but not on others. Insects such as aphids (*Aphididae*) with no cold requirement in their life cycle and with rapid development rates may expand their range in a warmer climate, whereas insects requiring cold temperatures may contract their range. In other cases, the range of herbivores may simply shift along with shifts in the distributions of their host plants, as southern portions of ranges become too warm and northern portions become suitable for colonization. Many insects have an obligatory diapause (a period of reduced development and activity), which is a mechanism that synchronizes them with their hosts. Such insects may not be able to expand their ranges and may be detrimentally affected by climate change (Bale et al. 2002).

Phenological synchrony is required for certain herbivore species to perform well on a host plant (Feeny 1970). Climate change is likely to cause asynchrony between host plant and insect herbivores, with insects becoming active earlier when suitable hosts are unavailable (Dewer and Watt 1992). The effects of temperature on insect performance may also vary on different host plants. Phenological windows differ, even for the same species feeding on different hosts. The ability of insects to deal with a range of different host plants, including low-quality ones, may indicate their ability to cope with climate change. Insect species that can feed on multiple plant species (compensatory feeding) may adjust to climate change-induced phenological distribution (Bale et al. 2002).

In addition, "warmer and wetter" conditions may produce a different outcome than "warmer and drier" for some herbivore-plant combinations. For example, Williams and Liebhold (1995) modeled future spruce budworm (*Choristoneura fumiferana* Clemens) populations under different temperature and precipitation regimes and found that an increase of 2 °C without change in precipitation resulted in a decrease of the projected defoliated area to less than half that under ambient conditions; the projected defoliated area spread southwestward and increased significantly when both temperature and precipitation increased. However, a decrease in precipitation with increasing temperature reduced defoliated area.

Numerous studies (summarized by Stiling and Cornelissen 2007) have examined plant growth under elevated CO_2 along with the associated responses of herbivores. Typically, plants growing under higher concentrations of CO_2 are less nutritious, having lower nitrogen concentrations and higher amounts of defense compounds (Stiling and Cornelissen 2007). Therefore, herbivores are generally more successful on plants grown under ambient conditions.

The effects of disturbance agents in a warmer climate are difficult to project because of uncertainties about factors that regulate ecological systems, and the compensatory processes that tend to push altered systems back into balance. Many of the complex relationships among herbivores, their hosts, and their associates are poorly understood (Bale et al. 2002), making projections of climate change difficult (Bentz et al. 2010). In addition, many of the vegetation models do not agree on future distributions of tree species. Some of these disagreements may arise from inappropriate applications of the models (Littell et al. 2011), but if uncertainty exists in the distribution of tree species, that uncertainty will be transferred to their disturbance agents as well. For example, climate envelope models do not incorporate predator-prey interactions and dispersal, which markedly affect the distributions and abundances of species. As a result, using climate envelope models may lead to serious errors (Davis et al. 1998).

Given that environmental conditions will change over time, it is possible that insects and pathogens that are not currently significant disturbance agents may become important under altered climate scenarios. For example, warmer winters are expected to encourage the expansion of mountain pine beetle northward in

British Columbia and into eastern Alberta (Safranyik et al. 2010). Insects may also change reproductive strategies that can alter their impact and duration of disturbance (Bentz and Schen-Langenheim 2007). An increase in extreme events may outweigh small increases in mean temperature for some insects (Bale et al. 2002). In New Mexico, the pinyon ips beetle (*Ips confusus* Le Conte) responded to an extreme drought by killing millions of pinyon pines in 2003 (Raffa et al. 2008). Evidence suggests that increased variability may have larger effects than small increases in mean values (Bale et al. 2002).

Bark beetles and spruce budworm have been the most important forest insect disturbance agents in central Oregon in recent times. Some bark beetle outbreaks have been significant, affecting entire forested landscapes. Most notable of these is a mountain pine beetle outbreak that killed entire stands of mature lodgepole pine throughout the region during the 1970s and again in the 2000s, when additional host stands became vulnerable. Mountain pine beetle outbreaks were fueled primarily by an abundance of a mature host in a susceptible stand condition, whereas other bark beetles have responded to episodic climatic events. A severe drought in the early 1990s triggered a large-scale outbreak of fir engraver (*Scolytus ventralis* Le Conte) in white fir in mixed-conifer forest in Fremont-Winema National Forest. Shorter, less extreme dry periods plus wildfires led to elevated populations of western pine beetle (*D. brevicomis* Le Conte) in mature stands of ponderosa pine. Wind events producing significant blowdown have led to local increases in pine engraver (*Ips pini* Say), followed by tree mortality. Spruce budworm affected stands of true fir and Douglas-fir on more than 2.4 million ha in eastern Oregon and Washington in the late 1980s.

It is difficult to project which insects and diseases may become more or less important in a warmer climate. However, disturbance agents that depend on reduced host vigor or on extreme weather events (many bark beetles) can be expected to prosper and perhaps occupy a more important role than they do today. Similarly, if wildfires increase, then bark beetles are likely to be favored, especially in systems that include ponderosa pine and Douglas-fir.

Interacting disturbances and other stressors, termed stress complexes, are a normal component of forest ecosystems, affecting species composition, structure, and function (McKenzie et al. 2009). Altering one particular factor can potentially magnify the effects of other stressors, leading to a rapid and possibly long-lasting change in forest ecosystems. The effects of disturbance across large geographic areas are especially pronounced where forest regeneration is slow or delayed, leading to a potential change in dominant vegetation. A warmer climate is expected to alter and often exacerbate the effects of stress complexes, although few such complexes have been sufficiently documented (Tylianakis et al. 2008).

Heat Stress and Drought

Increased vulnerability to drought may occur in environments that have not been historically water limited (Adams et al. 2009, Allen et al. 2010). Some systems are more vulnerable than others, and some may become increasingly vulnerable to drought with increased rates of tree mortality. Vose et al. (2016) established a scientific foundation for managing drought resilience and adaptation. A number of local resources can help identify the geographic location and magnitude of soil drought in the Pacific Northwest, including potential soil drought stress maps (fig. 6.7). Although the existence of "droughty soils" does not automatically imply vulnerability, the map may be useful for identifying where seedling survival and establishment will not be deterred by future drought.

Vegetation Assessment

We assessed the effects of climate change on vegetation with information from several recent published assessments and studies, our own MC2 simulation modeling efforts (presented and summarized below), paleoecological studies, and relevant literature and studies for the different vegetation groups. First, table 6.2 summarizes species-specific scores from three studies (species list based on Devine et al. 2012), and these results are discussed under each vegetation group below. Note that the Case and Lawler (2016) assessment refers to the entire range for a species, whereas the Devine et al. (2012) and Coops and Waring (2011) assessments consider species ranges within the SCOAP assessment area.

The assessments listed in table 6.2 differ from one another in several ways. Devine et al. (2012) and Case and Lawler (2016) combined elements of sensitivity, exposure, and capacity to adapt to climate change to quantify vulnerability of tree species in the Pacific Northwest. Specifically, Devine et al. (2012) used the Forest Tree Genetic Risk Assessment System (Potter and Crane 2010), ranking the vulnerability of 16 forest tree species in central Oregon with respect to distribution, reproductive capacity, habitat affinity, adaptive genetic variation, and insect and disease threats. The Case and Lawler (2016) assessment is based on expert knowledge, published studies, and projected changes in climate for 11 tree species in western North America, using a multivariate approach to quantify elements of sensitivity, exposure, and capacity to adapt to climate change. Coops and Waring (2011) based their assessment on modeled changes in suitable habitat, assuming that the resilience of a species to climate change is inversely related to the modeled probability of presence (Nitschke and Innes 2008). To estimate potential changes in species range, they used existing predictions of forest stand growth and a decision tree model to map current and future distribution of tree species in northwestern North America.

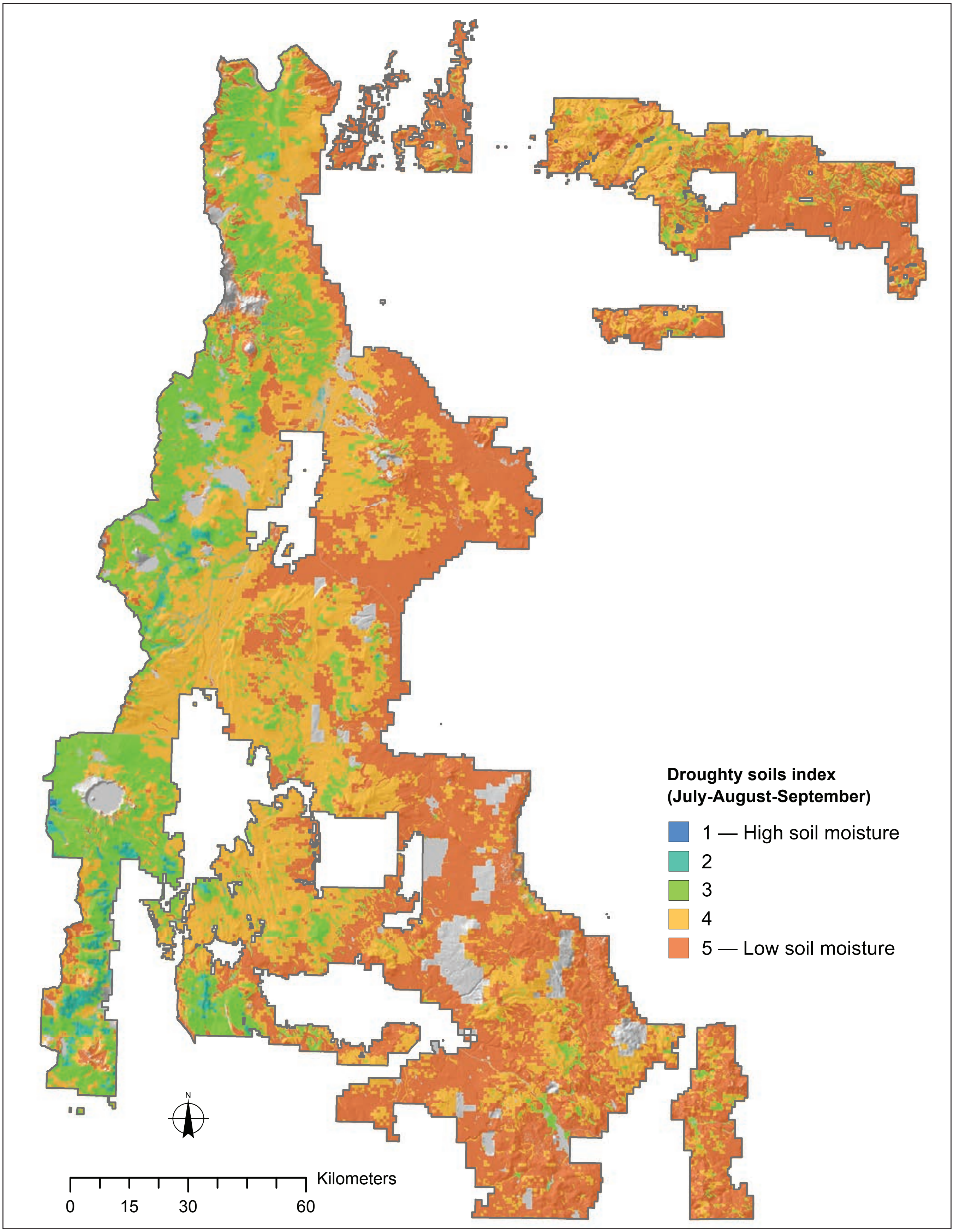

Figure 6.7—Potential soil drought stress in south-central Oregon during July–September. Data are based on Ringo et al. [n.d.] (Ringo, C.; Bennett, K.; Noller, J. [N.d.]. Climate change vulnerability assessment: resources for national forests and grasslands in the Pacific Northwest. Soil drought index. Unpublished report. On file with: Oregon State University, College of Agricultural Sciences, Department of Crop and Soil Science, Corvallis, OR 97331.)

Table 6.2—Summary of vulnerability assessment scores and model projections for some common tree species in the Pacific Northwest

Common name	Devine score	Case and Lawler score[a]	Coops and Waring score[b]
Whitebark pine	78	High	High
Subalpine fir	69	High	High
Pacific silver fir	59	Moderate	NA
Engelmann spruce	61	NA	Moderate/high
Douglas-fir	60	NA	Low
Sugar pine	51	NA	NA
Western hemlock	51	NA	Moderate
Noble fir, Shasta red fir	48	Moderate/high	Moderate
Grand fir-white fir	47	Moderate/high	Low
Western larch	43	Moderate	Low
Mountain hemlock	41	NA	Low/moderate/high
Incense cedar	38	NA	High
Lodgepole pine	36	NA	High
Western white pine	33	Moderate/high	NA
Ponderosa pine	32	NA	Low
Western juniper	27	NA	NA

NA = not available.
Note: Species are listed from highest to lowest vulnerability.
[a] Scores are for the entire range of species and are not specific to south-central Oregon.
[b] Vulnerability was estimated by visual examination of modeled stress in south-central Oregon using maps at http://www.pnwspecieschange.info/index.html.
Source: Case and Lawler (2016), Coops and Waring (2011), and Devine et al. 2012.

We also use a recent forest vulnerability assessment produced by Mildrexler et al. (2016) based on "forest group" and "area" rather than species. Mildrexler et al. (2016) calculated a forest vulnerability index (FVI) using drought and high temperatures across Washington and Oregon from 2003 to 2012. High temperatures and high drought stress were found to occur most often in August and September, but peak vulnerability occurred at different times for various forest type-groups, and different forest-type groups have different sensitivities to the driving variables. For the SCOAP assessment area, substantial portions of the area did not show positive FVI values until September when 21 percent of the area had high FVI scores, but only 7.5 percent of the area was statistically significant (fig. 6.7).

Mildrexler et al. (2016) compared mapped FVI values and mortality observed in Google Earth™ images, revealing that as p-value associated with FVI decreased, the proportion of stressed plots increased, confirming that positive FVI areas with very low p-values (high statistical significance) are associated with greater amounts of stress and mortality. The highest FVIs were for drier forest type groups (fig. 6.8). Of the areas with positive FVI values, about 32 percent occurred in the moist white

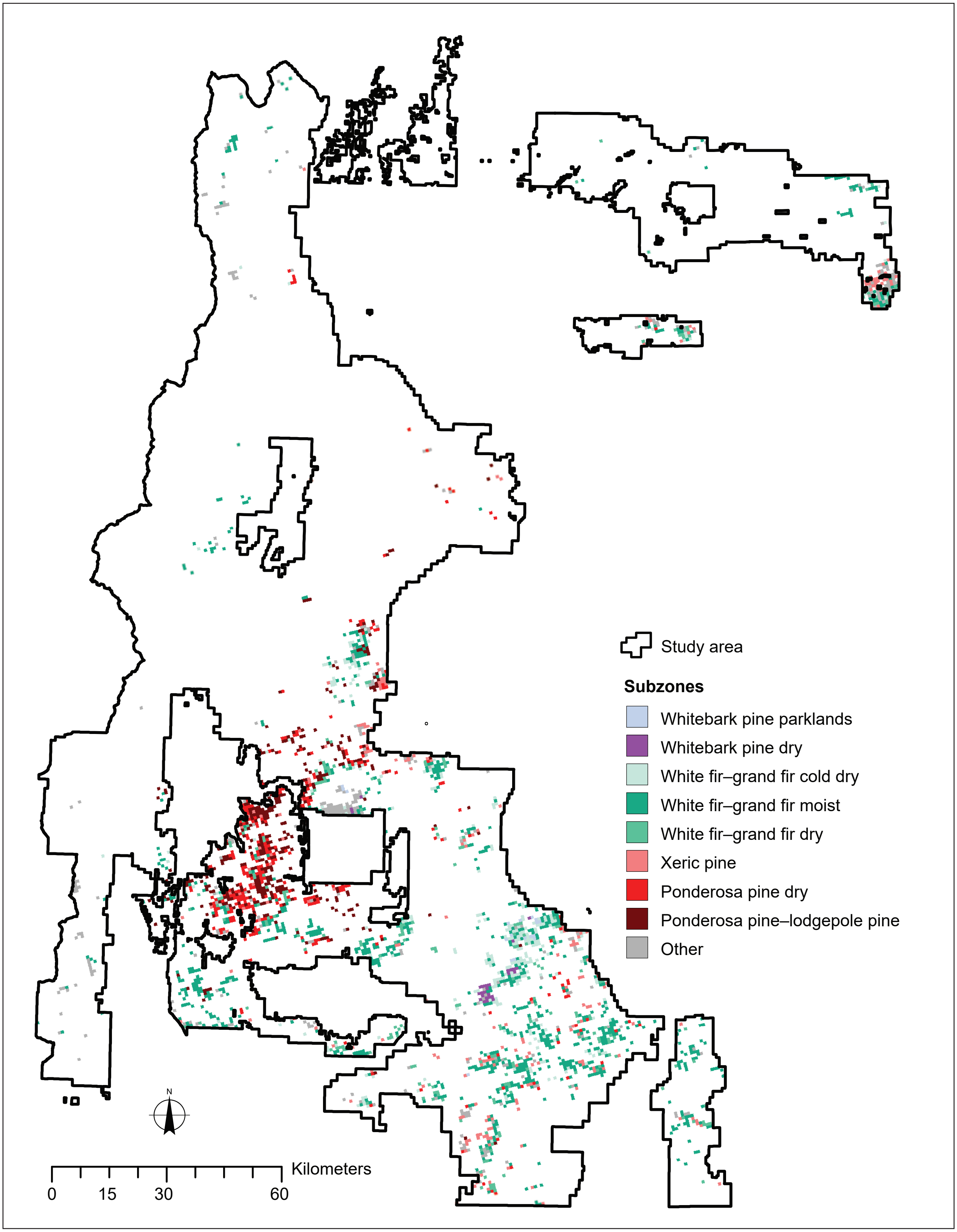

Figure 6.8—Positive forest vulnerability index values (FVI) (p-value <0.05) for September in the South-Central Oregon Adaptation Partnership assessment area by vegetation subzone (Simpson 2015). Positive FVI values denote increased vulnerability. Only vegetation subzones with more than 5 percent positive FVI values are shown. Data are based on Mildrexler et al. (2016).

fir–grand fir subzone, 13 percent in ponderosa pine–lodgepole pine, 11 percent in dry ponderosa pine, and 10 percent in the cold dry white fir–grand fir subzone. Much of the area with positive FVI values occured within Fremont-Winema National Forest.

Although the Mildrexler et al. (2016) results are informative about where historical and future high temperatures and drought may occur, there are some caveats. For example, some species are well adapted to a period of drought stress, and a single FVI may not have the same stress effects on all species. The index is based on land surface temperature and water balance, which are calculated as a function of precipitation and evapotranspiration. Therefore, the index may be skewed where soils are atypical because the differential release of water in various soils will modify the effective water balance. Much of the core of the SCOAP assessment area consists of coarse ash and pumice deposits with extreme infiltration rates and a delay in peak runoff and water release of 1 to 2 months, a situation in which soil moisture is not tied as directly to monthly precipitation.

MC2 Modeling

We modeled potential changes in broad vegetation groups in the SCOAP assessment area using the DGVM MAPSS-CENTURY 2 (MC2) for 28 future climate scenarios for the study area. Vegetation type, carbon fluxes and stocks, and fire occurrence and effects are emergent properties of this process model. Our goal is to summarize the general trends of potential vegetation change and fire, highlighting model agreement for future climate scenarios. MC2 runs on a monthly time-step and is able to capture the interactions between climate and broad vegetation types, disturbance, and ecosystem carbon balance. MC2 simulates the response of plant functional types to climate change, including plant physiology, biogeography, water relations, and interactions with fire.

MC2 requires climate and soil data as input. We used a 30 arc-second (approximately 800-m grid), monthly time step version of PRISM climate data.[2] Soils data were synthesized from the best available regional soil surveys and converted to a format required by MC2. We calibrated MC2 for the USFS Pacific Northwest Region (Oregon and Washington) for this assessment. We selected a spatial extent larger than the limits of the SCOAP spatial domain, so vegetation patterns that are not in the current study area but that may arise under future scenarios can also be calibrated.

MC2 was calibrated for the historical period (1895–2009) using a hierarchical approach. First, we created a calibration sample by sampling every fifth grid cell

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[2] **Daly, C.; Smith, J.; Doggett, M. 2009.** An assessment of temporal and spatial trends in historical climate data for the Klamath network parks. Unpublished report. On file with: Klamath Network—National Park Service, Southern Oregon University, 1250 Siskiyou Boulevard, Ashland, OR 97520.

along latitude and longitude in the 30-arc-second spatial grid. We then calibrated the MC2 productivity algorithm by comparing the simulation output for the calibration sample with moderate resolution imaging spectroradiometer (MODIS) net primary production (NPP) data (Zhao and Running 2010). We then adjusted thresholds in its biogeography algorithm by comparing the simulation output for the calibration sample with a map of potential vegetation zones.[3]

We adjusted and calibrated the MC2 fire algorithm by comparing the simulated fire patterns for the calibration sample with the fire return interval and severity data from LANDFIRE (Rollins 2009). Fire suppression was not simulated. Because LANDFIRE fire data are modeled, we also presented calibration results to local area managers and further adjusted parameters to more closely simulate historical vegetation conditions (1970–1999). Once calibration was complete, we ran the simulation at full resolution for 1895–2009.

Future vegetation conditions were simulated for 1950–2100 using the NASA NEX-DCP30 climate dataset (Thrasher et al. 2013). This is the same dataset used to examine future climate for the SCOAP assessment area (chapter 3). The NEX-DCP30 dataset includes outputs from 31 global climate models (GCMs) as a part of Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al. 2012), downscaled to 30- arc-second resolution for the conterminous United States. The 28 downscaled future climate projections that included vapor pressure data were used in MC2. We used the same soils data as in the historical simulation phase.

CMIP5 uses a set of representative concentration pathways (RCPs) to describe scenarios of emissions and land use, based on consistent scenarios representative of current literature (van Vuuren et al. 2011). For this study, we selected RCP 8.5, which represents a rapidly warming scenario without any effective climate change mitigation activities, leading to approximately 1,370 ppm CO_2 (Riahi et al. 2011) and a 3.7 °C increase in global mean surface temperature by the end of the 21st century (Stocker et al. 2013). We selected RCP 8.5 because it represents a “business as usual” or “worst case” scenario, an important benchmark for risk-averse decision-making. The likelihood of a particular RCP being realized is unknown. Examining detailed model output from 28 models is problematic, so we selected five GCMs to illustrate a range of potential futures among the largely better performing models for the Northwest as ranked by Rupp et al. (2013). We use the same five illustrative models as in chapter 3 to show a range of MC2 output for specific variables (table 3.2): “mean” CESM1(CAM5), “hot-wet” CanESM2, “hot” BNU-ESM, “hot-dry” MIROC-ESM-CHEM, and “warm” MRI-CGCM3.

[3] **Simpson, M.L.** Vegetation zones and subzones across the Pacific Northwest. Unpublished data and map. On file with: USDA Forest Service, Central Oregon Area Ecology and Forest Health Protection Service Centers, 63095 Deschutes Market Road, Bend, OR 97701.

MC2 Output

Vegetation—

The projected shift and agreement among the 28 simulation outputs of vegetation and biome types between the historical period (1970–1999) and end of century (2070–2099) in the SCOAP assessment area and the entire domain of Washington and Oregon are summarized in figure 6.9. Agreement among the 28 simulation outputs is high for the higher elevation Cascade Range and eastern and southeastern portions of the study area. Agreement among the 28 simulations is also high for the eastern part of the study area for shifts in biomes. These include shifts among forest, woodland, shrubland, and grassland.

Modeled forest gain (fig. 6.10) caused by forest expansion and conversion of woodlands to forests at lower elevations is largely responsible for these simulated shifts in biomes. This is most likely driven by increased precipitation and longer growing seasons simulated by the GCMs in high-elevation areas. Most GCMs show decreased precipitation in the summer months, increased precipitation in the spring and fall, and increased length of the growing season and wet growing degree days (chapter 3). The definition of "growing season" will need to be adjusted to interpret potential changes in vegetation resulting from projected climate changes.

Much of the SCOAP assessment area, especially higher elevations, is projected to have increased productivity by mid-21st century (fig. 6.11), most likely driven by warming temperatures, coupled with increased precipitation in a longer growing season. This trend is apparent for even the most "hot-dry" extreme model MIROC-ESM-CHEM, and most likely reflects the dominance of high-elevation landscapes that might respond positively to future warming. However, MC2 does not model the potential effects of summer drought very well. In the model, productivity shuts down when water is limited, and complex plant responses (e.g., branch death, biomass loss, mortality) are not modeled, so it is possible summer drought and climatic water deficits (chapter 3) might offset these gains.

Results for modal (most often occurring) vegetation type for the historical period, and middle and end of the century, are shown in figures 6.12 through 6.16. MC2 plant functional types are broad groups that approximate local vegetation groups (table 6.1), and because species-specific dynamics are not modeled in MC2, species-specific interpretations from MC2 are not recommended. Figure 6.17 summarizes changes in vegetation for the end of the century by MC2 vegetation type, allowing an assessment of the range of outcomes for each vegetation type simulated for the 28 GCMs. Four new vegetation types appear in the future: alpine tundra (treeless), deciduous woodland, cool mixed woodland, and warm mixed woodland.

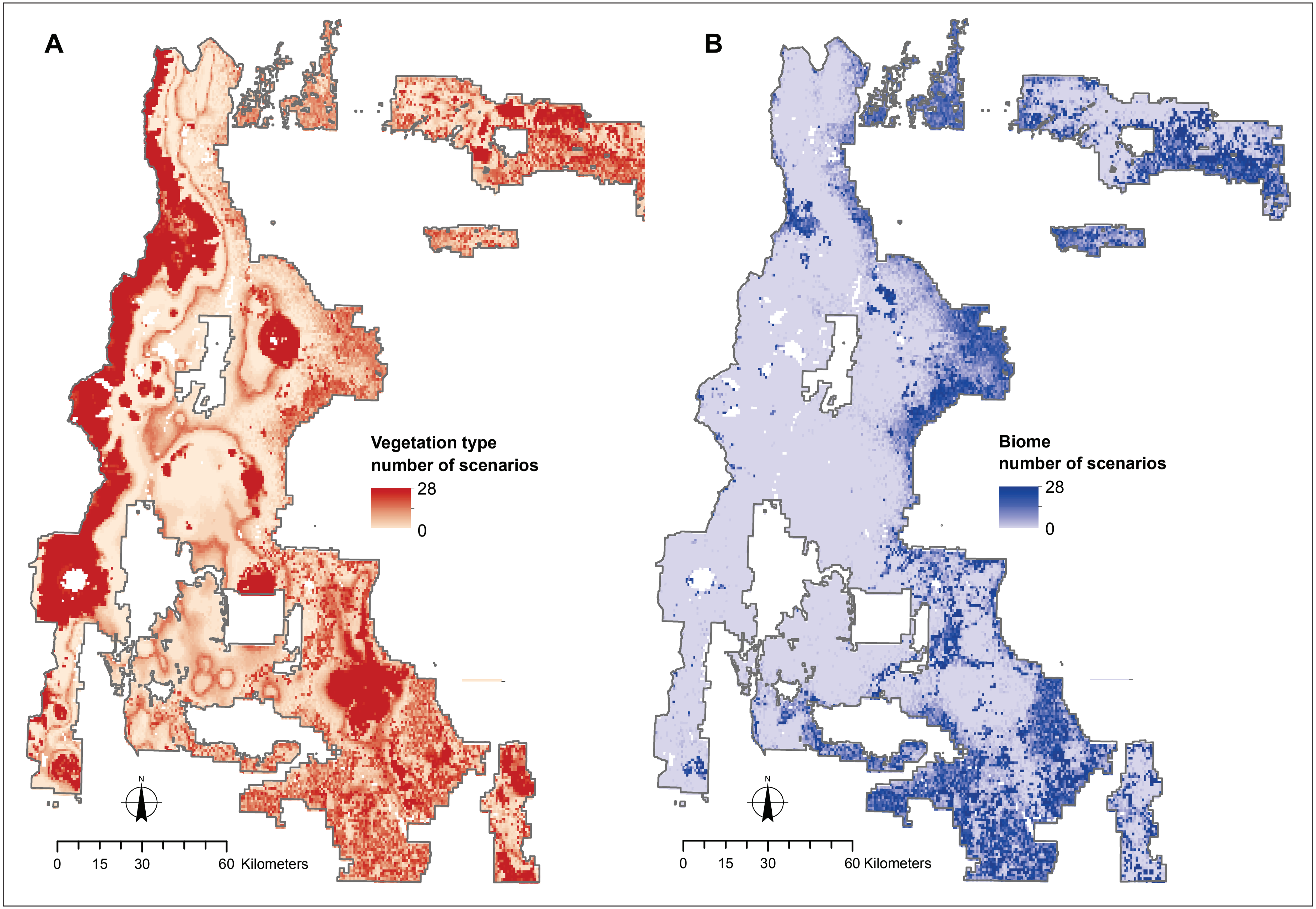

Figure 6.9—Model agreement maps from MC2 for the end of the century (2070–2099) for (A) simulated change in vegetation type and (B) simulated change in biome (e.g., forest to woodland or shrubland to grassland).

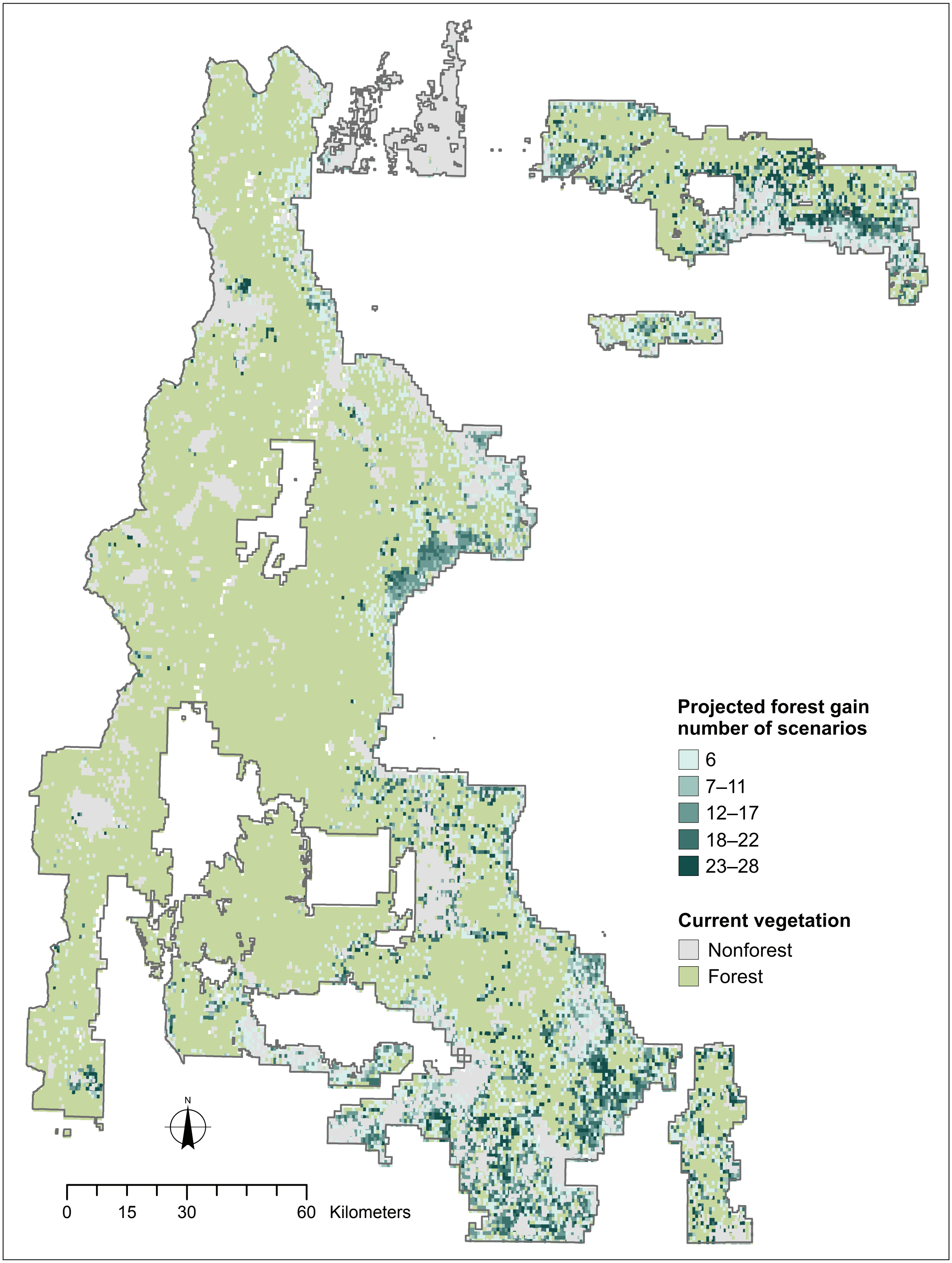

Figure 6.10—Number of global climate model scenarios for which MC2 simulated a gain in forested vegetation types across the South-Central Oregon Adaptation Partnership assessment area under RCP 8.5.

Although the spatial extent of these vegetation types is limited, they indicate the potential occurrence of novel vegetation types, and in the case of deciduous components, may be partly explained by temperature and precipitation increases.

Figure 6.17B also shows a similar summary of changes in vegetation for the end of the century by MC2 vegetation type for Oregon and Washington. Only vegetation types relevant to the SCOAP assessment area are shown, although more plant functional types occur across the region. These data provide a broader context for the range of projections in the Pacific Northwest compared to the SCOAP assessment area (fig. 6.17A).

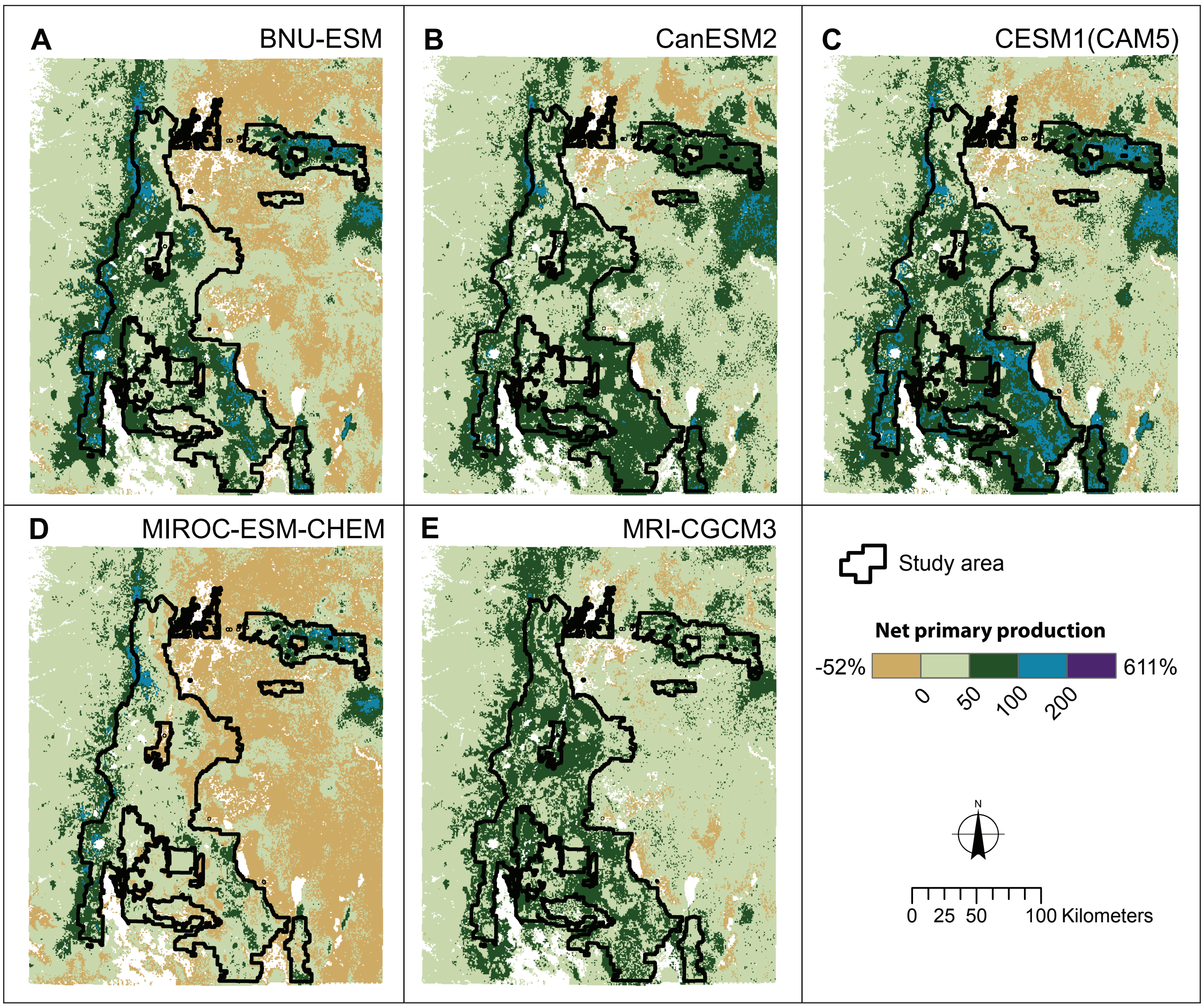

Figure 6.11—Output for percentage change in net primary production from MC2 for the end of the century for five global climate models representing a range in potential future conditions. CESM1(CAM5) is a top model performer for the Pacific Northwest with output similar to the model ensemble mean. CanESM2 represents the "hot-wet" extreme, BNU-ESM "hot," MIROC-EMS-CHEM "hot-dry," and MRI-CGCM3 "warm" (less warming than the hot extremes).

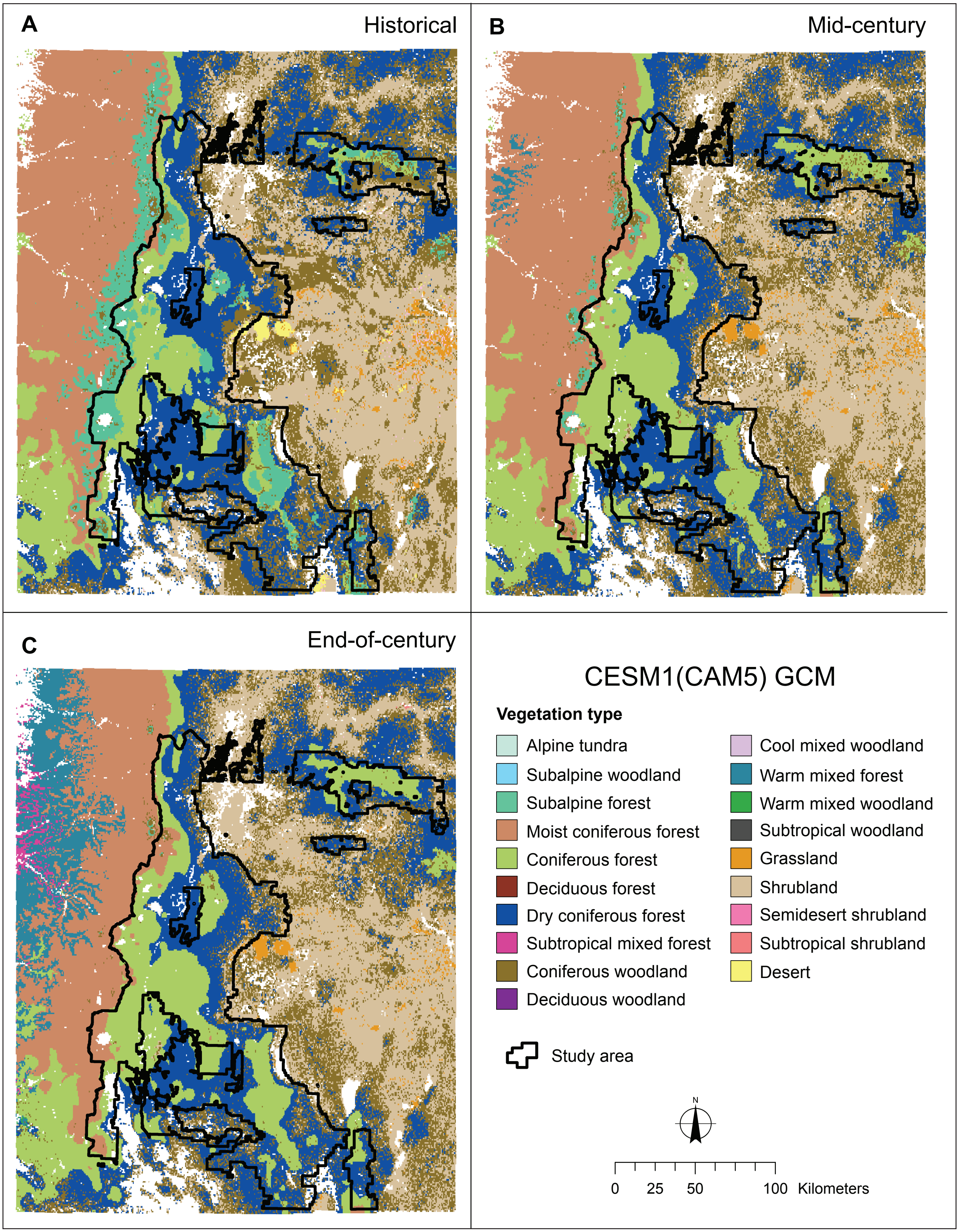

Figure 6.12—Mode vegetation results from MC2 for the South-Central Oregon Adaptation Partnership assessment area for (A) the historical period, (B) mid-century, and (C) end of century for the CESM1(CAM5) global climate model (GCM) under RCP 8.5. This model is a highly ranked model for the Pacific Northwest (Rupp et al. 2013), with projected changes in temperature and precipitation similar to the ensemble mean ("near mean").

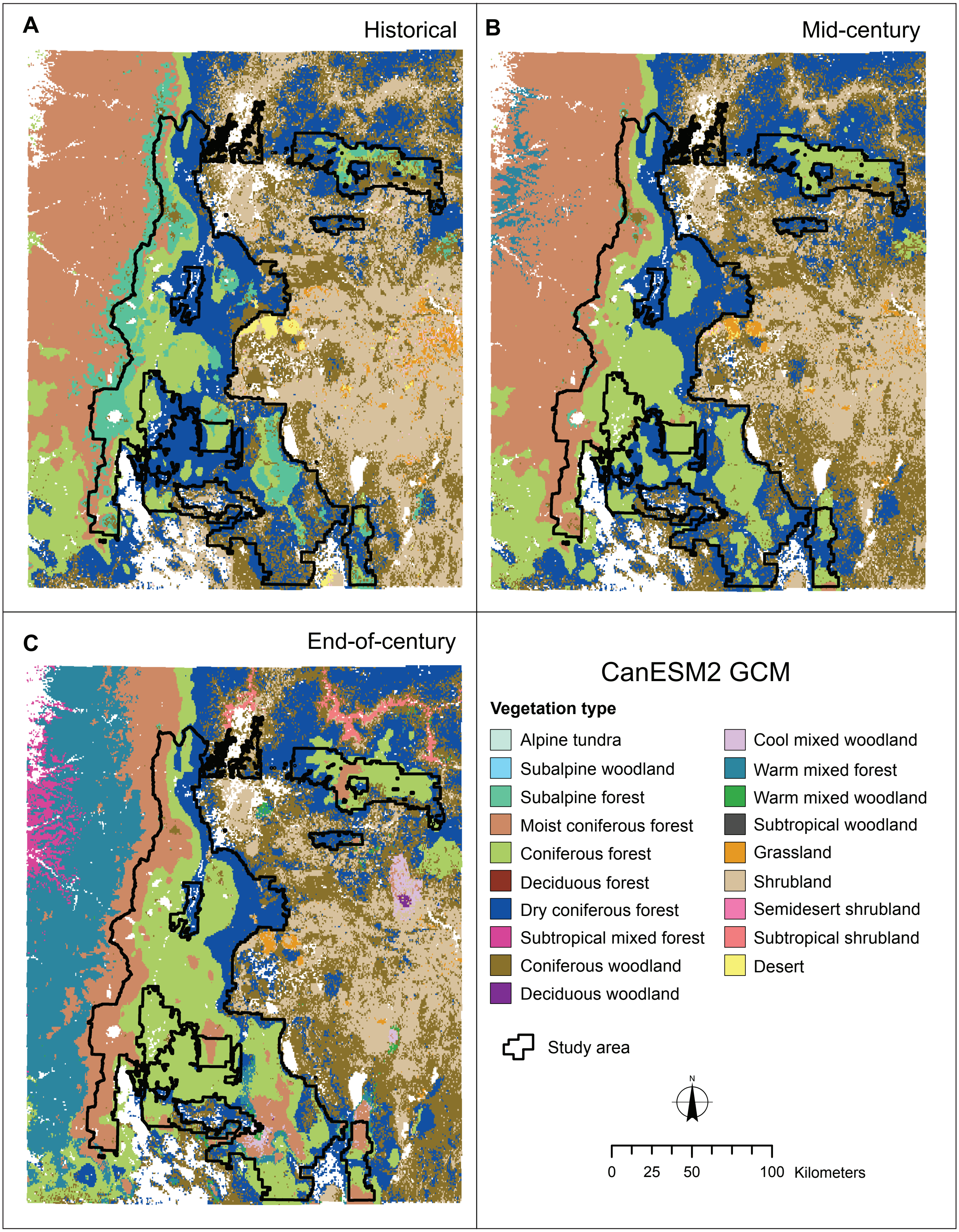

Figure 6.13—Mode vegetation results from MC2 for the South-Central Oregon Adaptation Partnership assessment area for (A) the historical period, (B) mid-century, and (C) end of century for the CanESM2 global climate model (GCM) under RCP 8.5. This model has projected changes in temperature and precipitation that represent the "hot-wet" extreme of higher performing models for the Pacific Northwest (Rupp et al. 2013).

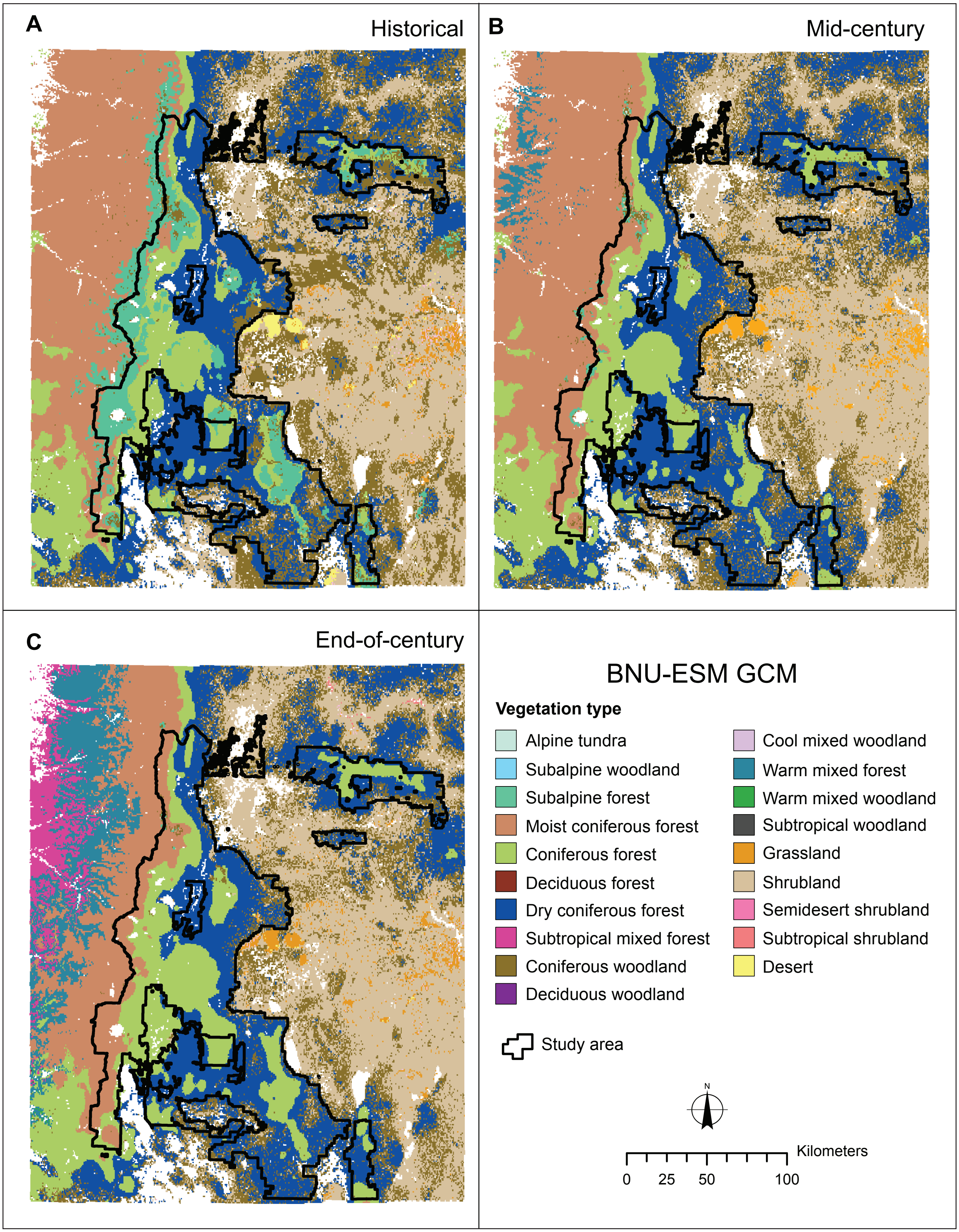

Figure 6.14—Mode vegetation results from MC2 for the South-Central Oregon Adaptation Partnership assessment area for (A) the historical period, (B) mid-century, and (C) end of century for the BNU-ESM global climate model (GCM) under RCP 8.5. This model has projected changes in temperature and precipitation that represent the "hot" extreme of higher performing models for the Pacific Northwest (Rupp et al. 2013).

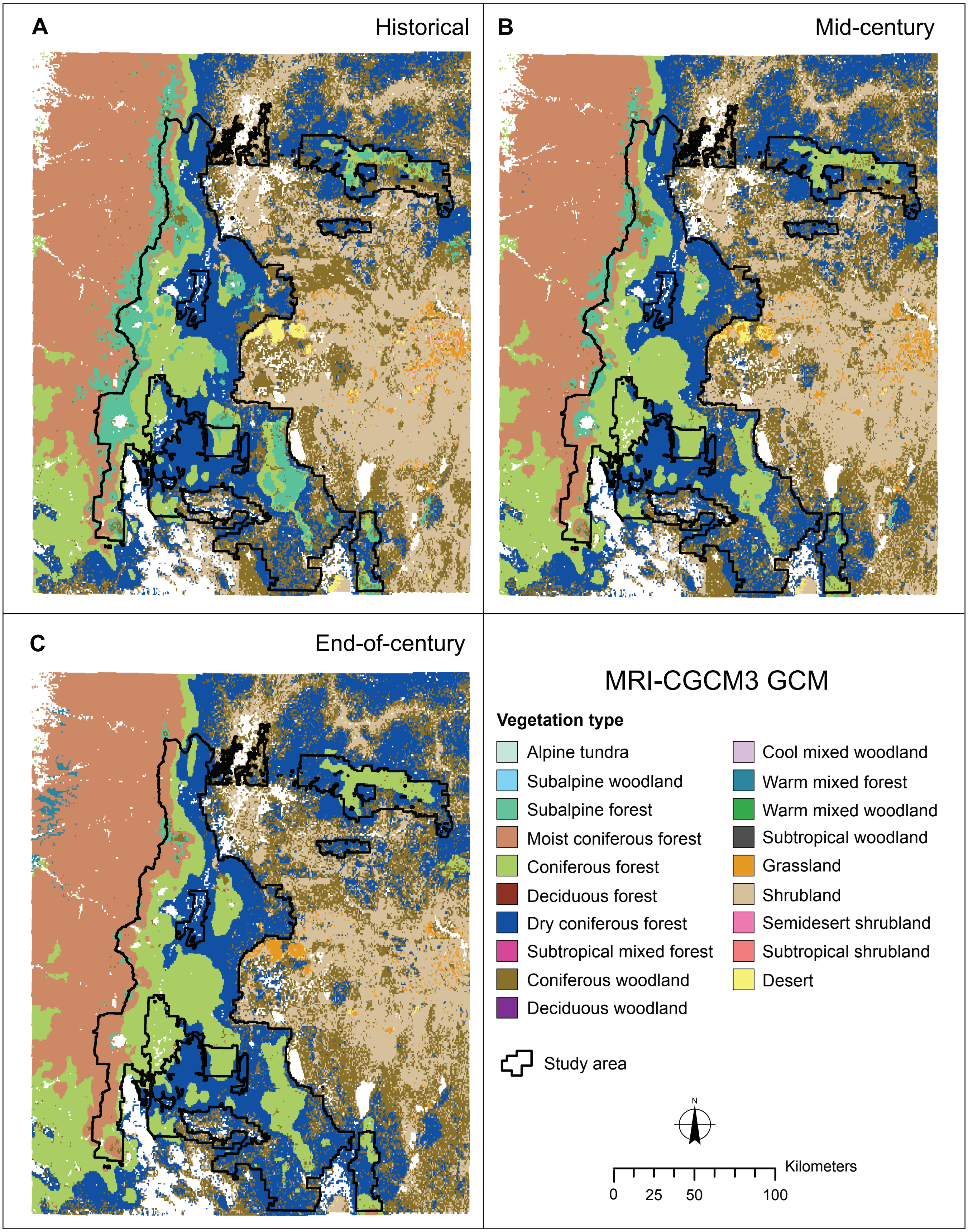

Figure 6.15—Mode vegetation results from MC2 for the South-Central Oregon Adaptation Partnership assessment area for the (A) historical period, (B) mid-century, and (C) end of century for the MRI-CGCM3 global climate model (GCM) under RCP 8.5. This model has projected changes in temperature and precipitation that represent the "warm" (less warming than hot) but not wet extreme of higher performing models for the Pacific Northwest (Rupp et al. 2013).

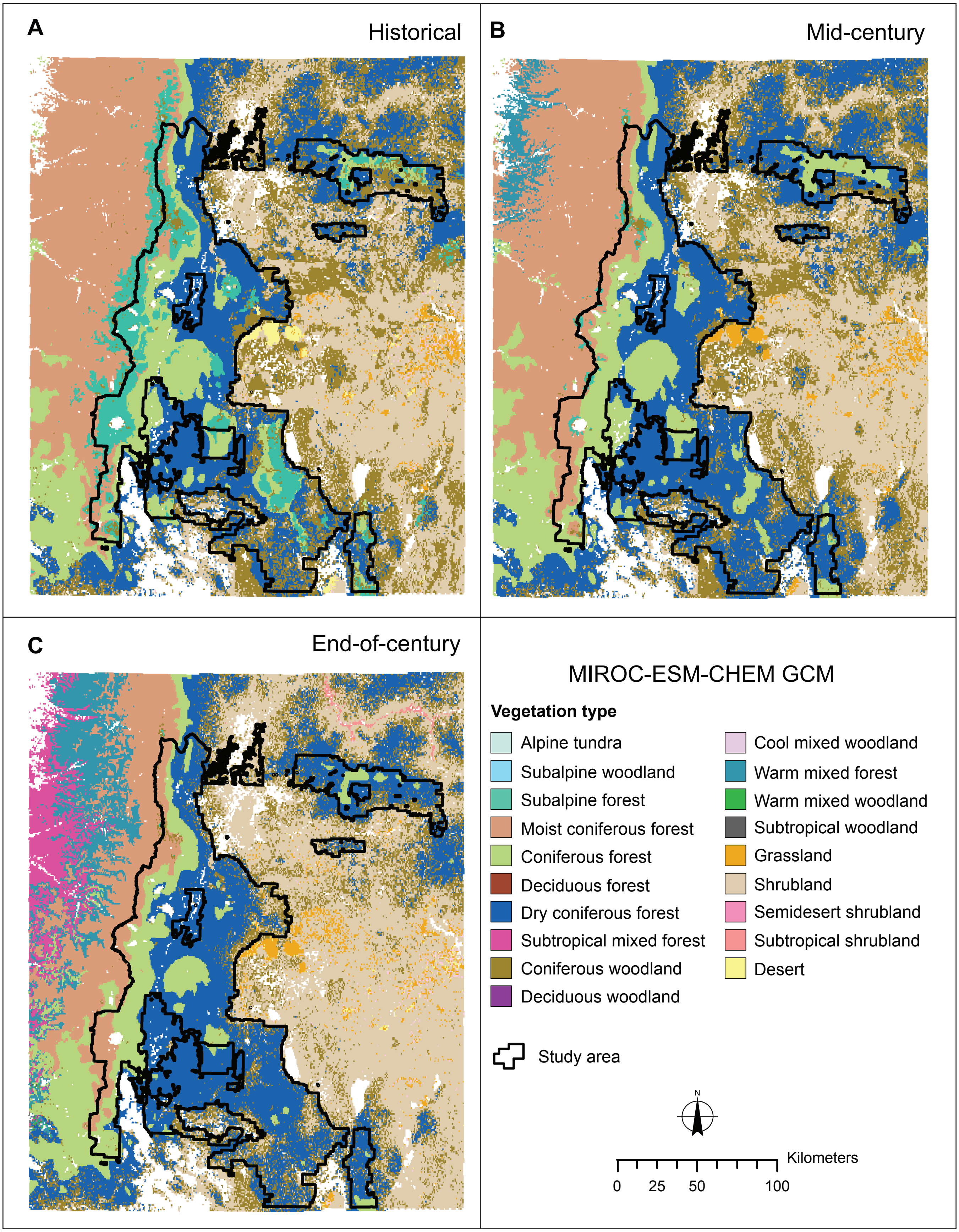

Figure 6.16—Mode vegetation results from MC2 for the South-Central Oregon Adaptation Partnership assessment area for (A) the historical period, (B) mid-century, and (C) end of century for the MIROC-EMS-CHEM global climate model (GCM) under RCP 8.5. This model has projected changes in temperature and precipitation that represent the “hot-dry” extreme of higher performing models for the Pacific Northwest (Rupp et al. 2013).

Forest types—

Under all 28 scenarios, MC2 simulates that climatic conditions that support subalpine forest will not exist in the future (fig. 6.17), with high agreement among GCMs. Compared to historical conditions, almost all scenarios show that conditions that support moist coniferous forest will increase more than 8 percent. Much of this gain is from conversion of subalpine forests to moist coniferous forests (figs. 6.12 through 6.16), although this may be less common on well-drained pumice soils that will remain colder than soils without pumice. Many GCMs also simulated that coniferous forest types will increase by 13 percent, although the "hot-dry" model MIROC-ESM-CHEM projected a small decrease. As with moist forests, simulation based on the "hot-wet" CanESM2 GCM projects the largest increase in this forest type.

Although the 28 scenarios largely agree about the direction of change regarding coniferous forest, the magnitude of change varies greatly. Increased coniferous forest under warmer, wetter conditions is supported somewhat by the paleoecological evidence from Carp Lake discussed earlier, where areas currently dominated by ponderosa pine forests were composed of a mix of Douglas-fir, western larch (*Larix occidentalis* Nutt.), western hemlock, true fir, and Oregon white oak in warmer, wetter conditions in the past. Simulations for dry coniferous forests disagree about the direction and magnitude of future change. Warmer models project increases in this forest type at the expense of coniferous forest (figs. 6.15 and 6.17). Increases in ponderosa pine under hotter, drier conditions than in the past are corroborated by paleoecological studies in the Pacific Northwest (Whitlock 1992, Whitlock and Bartlein 1997).

Woodlands—

The extent of coniferous woodlands decreases about 6 percent across many of the GCMs (fig. 6.17). Much of this woodland decrease is caused by conversion to the dry forest type. The biggest decrease was simulated for the "hot-wet" GCM CanESM2. Because MC2 is not species-specific, the change from woodland to dry forest in the model is related to increased productivity and carbon and the conversion of woodland to forest. The shift from woodland to dry forest could be interpreted as a shift from juniper woodlands to juniper forests. Other woodland types show few changes for the future, although these types are not well represented in the SCOAP assessment area. Projections for the entire simulation domain (Oregon and Washington) generally show decreased suitability for woodland vegetation types (fig. 6.17).

Shrubland, grassland, and desert—

Climatic conditions for shrublands (represented by shrubland vegetation subzones in table 6.1) show a small increase or decrease, with the multiple-model mean for the future close to historical conditions. Precipitation differences among the models

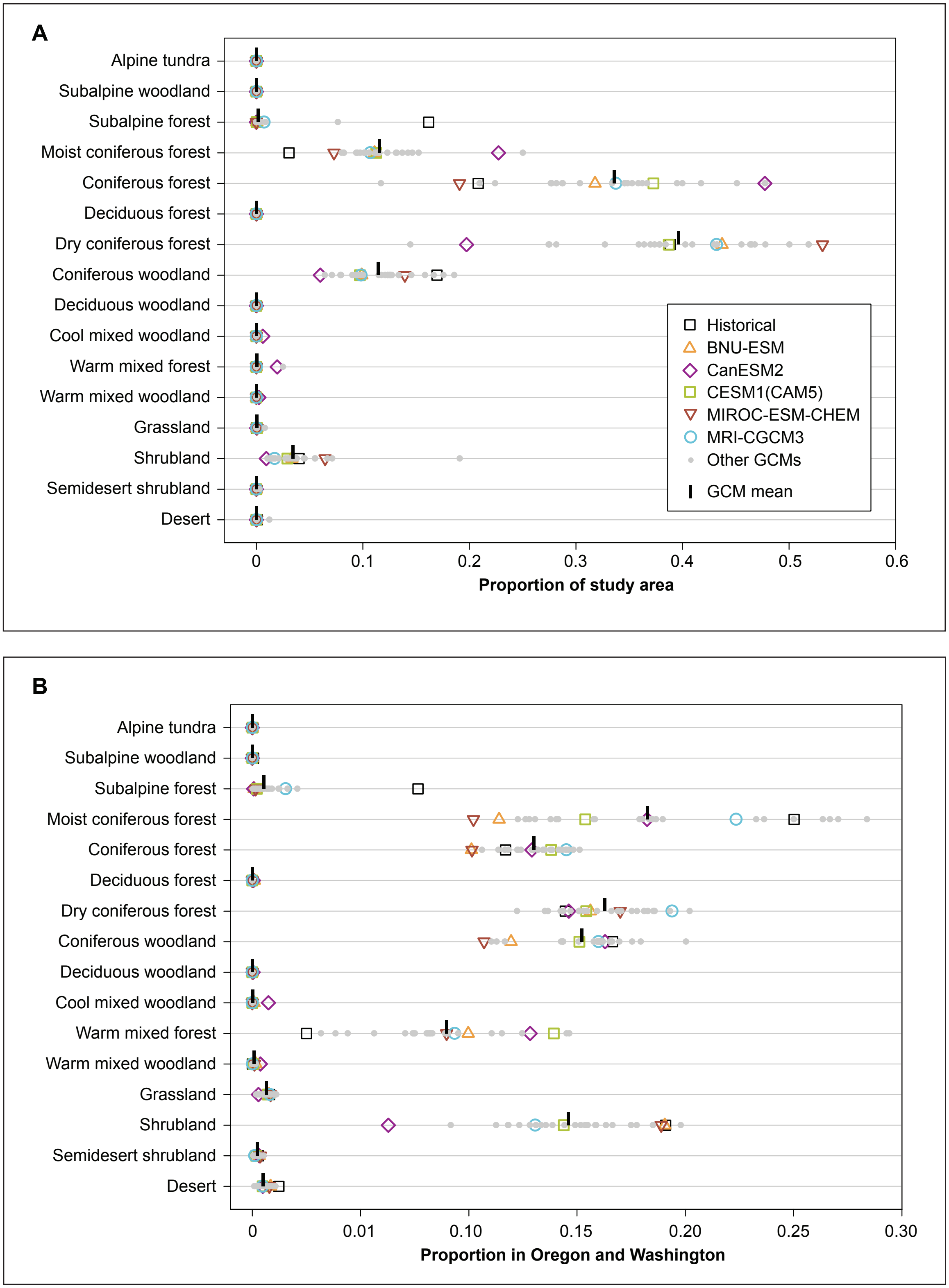

Figure 6.17—Results for changes in future vegetation from MC2 for (A) the South-Central Oregon Adaptation Partnership assessment area and (B) Oregon and Washington between the historical period (black squares) and end of century for 28 global climate models (GCMs) used in this assessment (under RCP 8.5) (other symbols). The five illustrative models represent a range in potential future conditions. CESM1(CAM5) is a top model performer for the Pacific Northwest, with output similar to the model ensemble mean. CanESM2 represents the "hot-wet" extreme, BNU-ESM the "hot" extreme, MIROC-EMS-CHEM the "hot-dry" extreme, and MRI-CGCM3 the "warm" extreme (less warming than the hot extremes). The other 23 GCMs are labeled as "other." The mean of all GCMs is shown with a vertical black line. Four MC2 plant functional types emerge in the future that have no current analog in the study area—alpine tundra (treeless), deciduous woodland, cool mixed woodland, warm mixed woodland—although their spatial extent is very small.

seem to drive whether or not shrublands are projected to increase or decrease; hotter models show increases in shrublands, whereas wetter models show decreases in shrublands but increases in woodland and dry forest types. Other vegetation types show little change, although nonforest types are not well represented (e.g., grasslands were represented by only three grid cells in the historical simulation). Trends for grasslands (cool-season grasslands) across Oregon and Washington show little change (fig. 6.17). Small amounts of desert vegetation types are simulated to appear in the future, and although not spatially extensive, may be important. Novel dryland habitats may be present in the future in the SCOAP assessment area. However, given that only a few pixels emerged in this category, we suspect that these habitats may not be spatially extensive or a dominant trend.

Wildfire—

Results for fire severity (measured as aboveground carbon killed by fire) and mean fire return interval (MFRI) are shown for four of the five illustrative models (MIROC-ESM-CHEM GCM, which did not rank well in the Pacific Northwest, is not included). Overall, MC2 generally simulated a decreasing trend in MFRI for most of the vegetation types, indicating more frequent fires in the future (fig. 6.18). Although this trend generally agrees with other studies, exceptions are noted for some vegetation types and for some GCMs within each type. MC2 results for fire severity (measured as mass of live carbon killed by fire) were more variable across vegetation type and GCMs (fig. 6.19). Note that all data presented in these figures are simulated data, and because historical MFRIs may not closely match historical observations, graphs should be examined in terms of relative changes.

For **subalpine forests**, MC2 projects substantial increases in MFRI and fire severity, indicating that wildfires will become less frequent but more severe. MC2 projects that subalpine forests will shrink substantially or disappear by the end of the century, and thus fire projections for the end of the century may be spurious. For **moist forests**, MC2 projects a small to moderate decrease in MFRI for three of the four GCMs ("mean," "hot," and "warm"), although MFRI increased for the "hot-wet" GCM by the end of the century. Although three of the four GCMs project that fires will become more frequent, changes in MFRI from historical to future time periods are relatively small. MC2 projects that fire severity may increase a small to moderate amount, depending on the GCM; increases in severity are higher for the "hot-wet" and "warm" GCMs.

For **mesic forests** and **dry forests**, MC2 projects a substantial decrease in MFRI by the end of the century. This pattern is evident across all GCMs except for the "hot-wet" GCM. MC2 projects a relatively small change or a small increase in fire severity, although GCMs differ in terms of temporal patterns and magnitude of change. For **woodlands**, MC2 projects a decrease in MFRI and increase in fire sever-

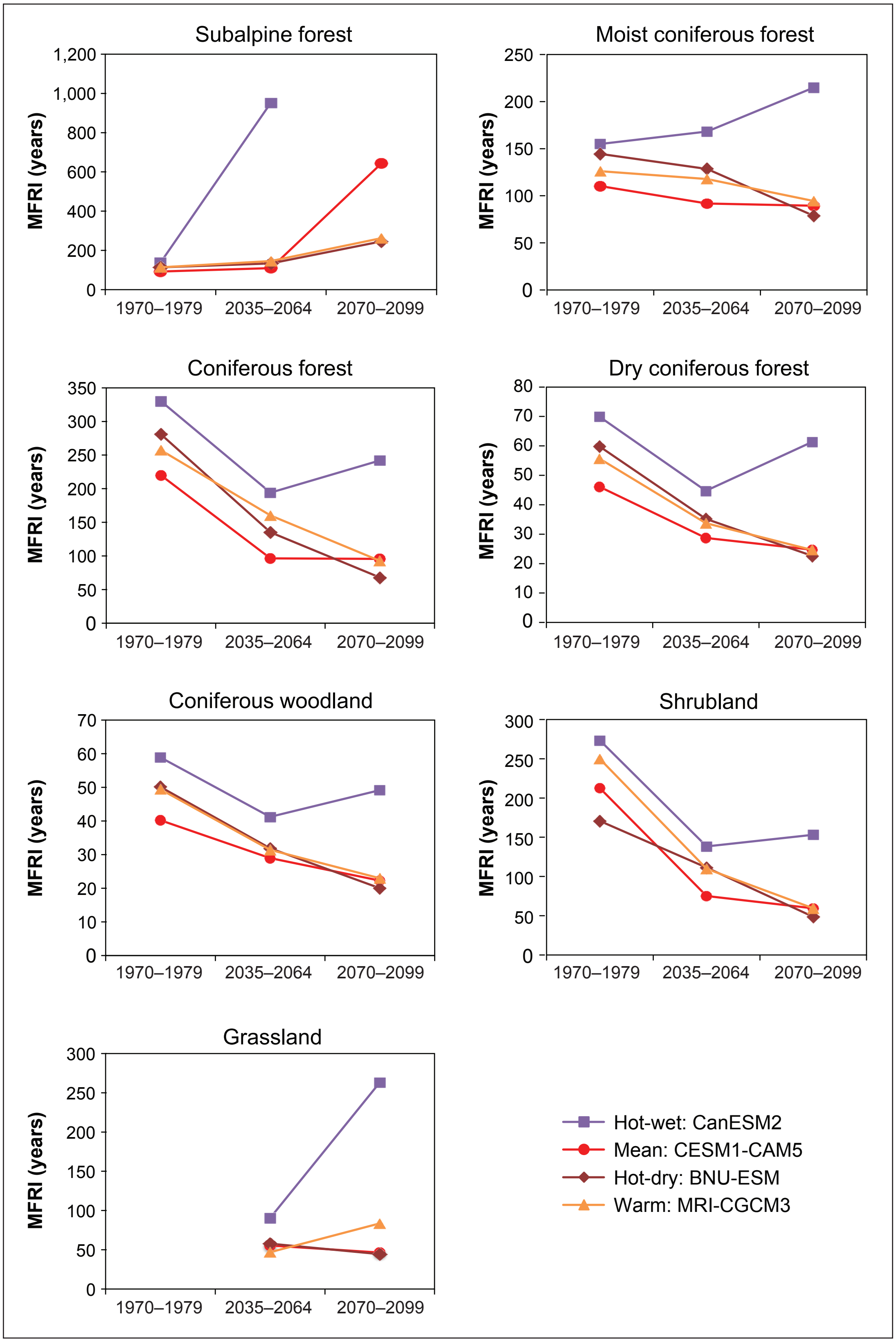

Figure 6.18—Projected mean fire return interval (MFRI) in years for historical (1970–1999), mid-century (2035–2064), and end of century (2070–2099) for relevant MC2 vegetation types and global climate models. Historical data are unavailable for grasslands.

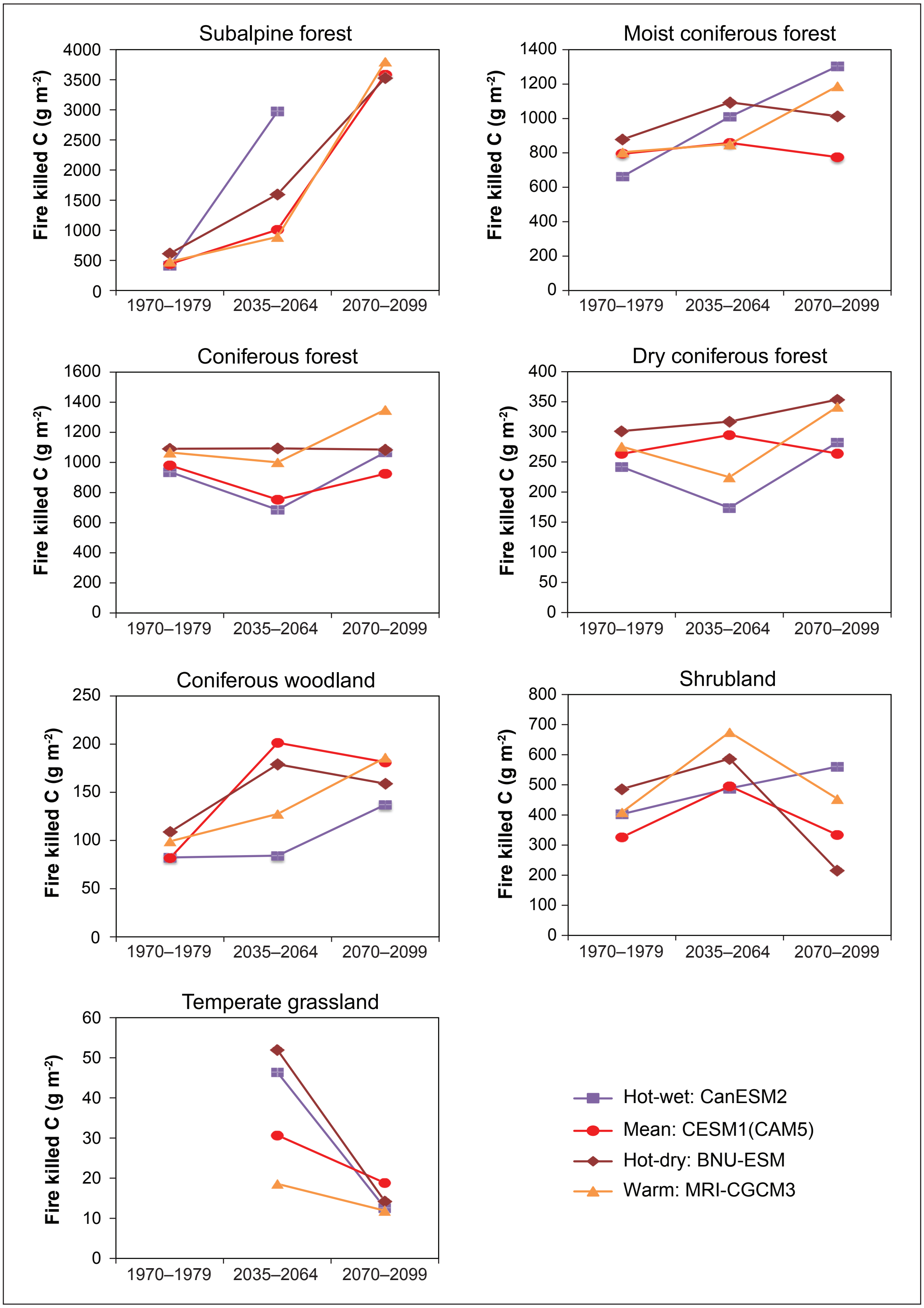

Figure 6.19—Projected fire severity for historical (1970–1999), mid-century (2035–2064), and end of century (2070–2099) for relevant MC2 vegetation types and global climate models. C = carbon. Historical data are unavailable for grasslands.

ity by the end of the century. For **shrublands**, MC2 projects a decrease in MFRI and decrease in fire severity, but changes in fire severity vary by GCM. All GCMs except the "hot-wet" example show a small increase in fire severity at mid-century, and then a decrease by the end of the century. The "hot-wet" GCM projects a linear increase in fire severity for shrublands. For **grasslands**, MC2 projects variable MFRI depending on the GCM. All GCMs project a decrease in fire severity in the future. There are few grassland vegetation pixels, so these results should be interpreted cautiously.

Projected changes in MFRI and fire severity can be explained by seasonal changes in temperature and precipitation projected for each of the GCMs that drive fuel moisture content, plant productivity, and aboveground biomass. Fire occurrence in the MC2 model is based on fuel moisture (fuels must be dry enough to burn) and a stochastic algorithm. Fire severity is coupled with standing biomass or productivity. In general, as FRIs become longer, fuel accumulates and then fire severity increases (as observed for subalpine forest), and vice versa. The amount of fuel or biomass may change for some vegetation types in the future, which influences fire severity.

Figure 6.20 depicts a conceptual model for understanding changes in fire severity based on potential changes in MFRI and plant productivity or biomass. Some forest types and GCM combinations showed decreases in MFRI and minimal change in fire severity. We might expect that if fire frequency increases, aboveground carbon (fuel) would be reduced, resulting in a trend of decreasing fire severity in future fire. However, if forest biomass is increasing through time, fire severity may actually increase or remain unchanged even if fires are more frequent. The "hot-wet" CanESM2 GCM projects increased precipitation, with a substantial increase in summer season precipitation (chapter 3), which could contribute to higher fuel moisture, possibly reducing the occurrence of fire, but also higher plant productivity and therefore higher fire severity.

Change in productivity	Change in MFRI (fuel moisture): -	0	+
+	No change	Severity increases	Severity increases
0	Severity decreases	No change	Severity increases
-	Severity decreases	Severity decreases	No change

Figure 6.20—Conceptual matrix showing potential changes in future fire severity based on the interplay between changes in mean fire return interval (MFRI) (driven by fuel moisture) and plant productivity in the MC2 model. MFRI = mean fire return interval.

Interpreting MC2 Results by Unit

Implications for the different federal administrative units in the SCOAP assessment area can be inferred by considering the scenarios in figures 6.12 through 6.16 and evaluating figure 6.17 in relation to dominant vegetation in each unit. Fine-scale, pixel-by-pixel examination is not recommended, and even national forests and national parks are relatively small compared to the resolution of MC2 output. For example, Crooked River National Grassland is composed of mostly juniper and upland shrub vegetation. Figure 6.12 (the "mean" GCM) shows some possible gain of shrublands and loss of woodlands, whereas fig. 6.13 ("hot-wet" GCM) shows a modest increase in woodland and dry forest. The results in figures 6.12 through 6.16 can be used for each unit as "what-if" scenarios across the range of illustrative GCMs (mean, hot-wet, hot, hot-dry, warm).

MC2 simulations for the future suggest possible increases in forest vegetation types in the SCOAP assessment area, particularly for GCMs that project increased precipitation. Subalpine forest types are projected to convert to moist forest types, and coniferous forests are projected to expand into areas once dominated by both subalpine and moist forest types. Lower elevation woodlands and shrublands may convert to forests (with or without significant changes in species composition). Productivity in the SCOAP assessment area is limited by cold temperatures and growing season precipitation, so higher temperature, coupled with higher precipitation in the new future growing season, are driving the potential increase in productivity and forest types. The projected decrease in winter temperatures essentially creates a less "continental" environment and extends the growing season in the early spring and late autumn (chapter 3).

MC2 Model Caveats

Like most vegetation models, MC2 does not include dispersal processes, genetic adaptation, biotic interactions, or phenotypic plasticity. Although it does incorporate fire, other disturbance processes, such as insect and disease interactions, are not parametrized. MC2 also does not model the complexities of summer drought and climatic water deficit as noted above, so projected productivity increases may not be realized. As noted above, the historical MFRIs may not align well with observations because they are emergent properties of the model. Although we used broadly defined literature values for MFRI for different vegetation types, as well as LANDFIRE MFRI as calibration guidelines, these are model simulation outputs. This modeling exercise did not intend to accurately reproduce observed MFRI, which depends on a particular sequence of vegetation-fire interaction history. MC2 is not designed to reproduce individual observed fires.

Vegetation Group Assessment

In this section, we synthesize multiple sources of information for seven broad vegetation groups in the SCOAP assessment area: subalpine, moist forests, mesic forests, dry forests, woodlands, shrublands, and grasslands (table 6.1). For each vegetation group, we provide an overall description of current vegetation, summarize potential changes from multiple lines of evidence, and discuss current and potential future disturbance processes. When possible and appropriate, we draw on multiple sources of information and literature (some described earlier in this chapter), as well as local knowledge.

Subalpine Forest Group

The subalpine forest group consists mostly of subalpine forests and parklands that occupy high-elevation sites (see table 6.1). Dominant tree species include mountain hemlock, lodgepole pine, subalpine fir, Engelmann spruce, and whitebark pine (box 6.2). The growing season is short because of persistent winter snowpack, cool air and soil temperatures, and slow nutrient cycling rates. Winters are typically cold and wet, and summers are cool and dry. The majority of precipitation is in the form of snow that generally melts by June. However, the depth and persistence of winter snowpack have been declining in response to warming temperatures (Furniss et al. 2010, Karl et al. 2009, Lute et al. 2015, Stewart et al. 2004).

Late-seral subalpine forest stands are typically dominated by mountain hemlock, Shasta red fir (*Abies magnifica* A. Murray), lodgepole pine, subalpine fir, Engelmann spruce, and whitebark pine. Some species, such as whitebark pine and lodgepole pine, can also function as persistent, early-seral species on some sites. Whitebark pine can establish and eventually dominate late-seral stands at treeline sites with well-drained soils or southern exposures. At high elevation, where soils are thin and the growing season is short, subalpine forests transition to a treeless alpine zone. These two zones are often separated by a narrow band of dwarf (krummholz) trees. Subalpine forests typically transition to moist, dry, or mesic forests at their lower edge.

Disturbances—

Disturbances such as wildfires can be infrequent to moderately frequent in subalpine areas because of the lack and discontinuity of fuels. Most historical fires in this zone are characterized as infrequent, small, and of relatively low intensity. However, this may change with earlier snowmelt, smaller snowpacks, longer growing seasons, and an increase in biomass production. Some vegetation types (lodgepole pine, mountain hemlock) can have infrequent, higher severity fire regimes.

Historical fire regimes differ by site, dominant species, and land management. LANDFIRE identifies an MFRI of about 200 years for many subalpine and alpine areas. However, MFRI can range from 50 years in some whitebark pine and subalpine fir stands to more than 1,500 years in some mountain hemlock stands (Agee 1993, Arno 1980). Nonetheless, subalpine composition and structure can be altered by large wildfires because recovery from stand-replacing wildfires can be very slow (Little et al. 1994). With the exception of lodgepole pine and whitebark pine, most tree species in the subalpine zone persist best in environments without frequent or intense fires (Agee 1993). Therefore, if large fires do occur in forest types without species like lodgepole pine, it can take decades to centuries for tree reestablishment (Agee and Smith 1984, Little et al. 1994). The recovery of these relatively sensitive subalpine forests following large wildfires will require nearby seed sources, favorable climate, and favorable biotic and abiotic microsite conditions (Bansal et al. 2011, Harvey et al. 2016, Stueve et al. 2009, Zald et al. 2012). In contrast, an increase in fire occurrence, but not intensity, may benefit older stands of whitebark pine by reducing competition and exposing mineral soil for seedling establishment (Agee 1993).

Insects and diseases also pose significant risks to subalpine species. Mountain pine beetle initially attacks lodgepole pine and whitebark pine under stress from injury, poor site conditions, fire damage, overcrowding, root disease, or drought. However, as mountain pine beetle populations increase, the infestation may involve more and larger trees in the outbreak area. Warmer temperatures in recent years have allowed mountain pine beetles to shift upward and persist in higher elevation forests (Logan et al. 2010). Mountain pine beetle is now the primary cause of recent whitebark pine mortality at Crater Lake (Murray 2010). Daly et al. (2009) (see footnote 2) noted an increasing tendency for the summer dry season to extend into early autumn at Crater Lake and elsewhere in the Oregon Cascade Range over the last few decades. Longer growing seasons at higher elevations could favor pines, contributing to increased growth in some locations (Bunn et al. 2005). Increased growth of other conifers could put whitebark pine at a competitive disadvantage. Although whitebark pine seeds can be dispersed relatively long distances by birds, some populations may not be able to migrate quickly enough to suitable habitats in the future (box 6.2).

Other insects found in the subalpine zone include the silver fir beetle (*Pseudohylesinus sericeus* Mannerheim), which generally attacks Pacific silver fir and can result in outbreaks in mature stands. Western spruce budworm can be a major defoliator of subalpine fir, but outbreaks are most likely to start at lower elevations and in forests dominated by true fir. Although large outbreaks of balsam woolly

Box 6.2

Whitebark Pine

Whitebark pine plays an important role in maintaining biodiversity and ecosystem functions at high elevations (Keane et al. 2012, Tomback et al. 2011). White pine blister rust, mountain pine beetles, and fire exclusion have contributed to a rangewide decline; the species was proposed for listing under the Endangered Species Act and is listed as endangered by the Canadian government.

Some characteristics of whitebark pine may facilitate its survival in a warming climate. A pioneer species, it can germinate and persist on exposed bedrock, facilitating the establishment of other species (Tomback et al. 2001). Whitebark pine dispersal by Clark's nutcracker (*Nucifraga columbiana*) may provide an advantage over other conifers by being planted far inside burned areas (Keane et al. 2013). Whitebark pine is more drought tolerant than other subalpine trees in the Pacific Northwest (Arno and Weaver 1990) and may be favored by warmer, drier summers that reduce competition from late-seral conifers (Weaver 2001).

Although whitebark pine has mechanisms to help it adapt to climate change, its range may also decline in the future (Peterson et al. 2014). Reduced soil moisture during an extended summer drought may push whitebark pine past a threshold conducive to regeneration (Larson and Kipfmueller 2010). Increased temperatures have been shown to boost growth rates of high-elevation trees (Salzer et al. 2009), including whitebark pine (Daneshgar 2003), by extending growing season length. However, increased temperature without corresponding increased moisture may reduce growth and regeneration of subalpine tree species (Peterson and Peterson 2001). Warmer temperatures and drier summers have been shown to reduce growth of

continued on next page

adelgid (*Adelges piceae* Ratzeburg) are not common on subalpine fir, insects could become more abundant as temperatures warm.

Whitebark pine is also threatened by the nonnative pathogen white pine blister rust (*Cronartium ribicola* A. Dietr.) (Smith et al. 2013, Tomback and Achuff 2010), a fungus that forms lesions of necrotic tissue that girdle tree boles or stems and can lead to tree mortality (box 6.2). To complete its life cycle, the fungus must disperse from the pines to an alternate host, a shrub in the genus *Ribes* (currant, gooseberry) or the herbs *Castilleja* (Indian paintbrush) and *Pedicularis* (lousewort) (Geils et al. 2010). These spores move from pines to alternate hosts in spring (April–May) and from the alternate hosts to pines in fall (September–October). Lower humidity during the fall produces spores that might be more vulnerable than spring spores. Altered phenology of alternate hosts for blister rust could affect the effectiveness of spore transfer. Drier summers may also inhibit the formation and spread of rust spores and fruiting body development.

whitebark pine and shift the period of growth earlier in the season (Daneshgar 2003). Some projections for climate change effects on whitebark pine suggest it will move upward in elevation (Campbell et al. 2011, Romme and Turner (1991), Tomback and Resler 2007, Turner 1991, Weaver 2001)

Warmer, wetter conditions may favor blister rust propagation (Kendall and Keane 2001, Larson 2010, Tomback and Resler 2007), but warmer, drier conditions could reduce blister rust occurrence (Kliejunas 2011, Kliejunas et al. 2009, Larson 2010, Sturrock et al. 2011). Mountain pine beetle outbreaks are projected to increase in severity and extent at higher elevations with climate change (Hicke et al. 2006, Littell et al. 2010, Williams and Liebhold 2002). Whitebark pine has not evolved with recurring beetle outbreaks and has little resistance to attack, so beetles can kill whitebark pine with genetic resistance to blister rust, hastening the decline of whitebark pine communities (Hicke et al. 2006).

Because wildfires in whitebark pine habitat are often easy to control, fires may continue to be suppressed rather than managed for resource benefit. This could facilitate continued establishment by late-seral conifers and increase stand densities that could predispose whitebark pine stands to increased water stress, insect outbreaks, and pathogens. More frequent fires in whitebark pine habitat may kill rust-resistant trees, and eliminate whitebark pines that are old enough (>60 years) to produce cones (Loehman et al. 2011).

Whitebark pine restoration is a high priority for all federal agencies. This includes (1) developing rust resistance in whitebark pine populations through rust-screening efforts and planting progeny from rust-resistant trees, (2) managing for landscape heterogeneity to help mitigate against extended mountain pine beetle outbreaks, (3) carefully reintroducing fire within whitebark pine habitat, and (4) promoting resilience in whitebark pine populations through identification of refugia and other durable habitats (Keane et al. 2013).

Potential future changes—
Subalpine forests have short growing seasons and slow nutrient cycling, and tree growth is generally limited by cool temperatures. Therefore, a small increase in temperature (and possibly elevated atmospheric CO_2) may increase tree growth and productivity of some species at high elevations (Latta et al. 2010). There is a negative correlation between tree growth and winter precipitation or snowpack depth for many subalpine species (Ettl and Peterson 1995; Graumlich and Brubaker 1986; Heikkinen 1985; Peterson and Peterson 1994, 2001; Peterson et al. 2002). Therefore, warmer temperatures could lengthen the growing season by reducing snowpack depth and increasing soil temperatures. Most precipitation (about 66 percent) is in the form of snow at high-elevation sites in the SCOAP assessment area, and snowmelt is critical for tree growth and seedling establishment (Burns and Honkala 1990). Snow also provides protection from damaging ice particles in high winds (Tranquillini 1979) and is a limiting factor for some encroaching lower elevation

tree species (Franklin et al. 1971, Harsch et al. 2009). Disturbances such as fire also have a substantial impact on treeline migration by reducing shrub and plant density and exposing mineral soil for seedling establishment.

A longer growing season could also result in the upward movement of treeline in some locations (Fonda and Bliss 1969, Franklin et al. 1971, Heikinnen 1984, Taylor 1995, Zald et al. 2012). However, a recent study suggested that treeline advanced over the past century at only about half of the sites measured (Harsch et al. 2009). Successful regeneration at treeline depends on multiple factors, including microsite facilitation, and may be limited by unsuitable topographic and edaphic conditions of upslope areas, wind exposure, and patterns of snow distribution (Holtmeier and Broll 2012, Macias-Fauria and Johnson 2013, Smith et al. 2003). The effects of landforms, microtopography, and overstory tree canopies on snow distribution can also influence treeline advance.

Although few paleoecological studies exist for high-elevation forests in south-central Oregon, Hakala and Adam (2004) provided a history of vegetation and climate from Grass Lake, California (1500 m elevation). When mean annual temperatures were within 10 to 20 °C, vegetation responded to changes in precipitation, with shrub-steppe transitioning to open pine forest (woodland) and eventually to dense pine forest as precipitation increased. Hakala and Adam (2004) showed that *Pinus* pollen exceeded 40 percent only in areas receiving more than 300 mm annual precipitation, and that *Pinus* levels greater than 65 percent were found only in areas with more than 500 mm annual precipitation. The opposite trend was found during drier climatic periods—dense forest transitioned eventually into sagebrush steppe. The area around Grass Lake was dominated by alpine tundra grasses during cold periods, illustrating that low temperatures rather than arid conditions restricted vegetation.

Whitlock and Bartlein (1997) examined vegetation composition over the past 125,000 years from Carp Lake, located at 710 m elevation in south-central Washington. This study shows that, during warmer climates, lodgepole pine, Douglas-fir, and ponderosa pine replaced more cold-tolerant species such as Engelmann spruce (although lodgepole pine can also be as cold- or wet-tolerant as Engelmann spruce in some areas). Other studies indicate that forested subalpine areas could transition to more open woodland or parklands in a warmer, drier climate (Hansen 1943). Species that could be present under such a scenario include ponderosa pine, lodgepole pine, and Douglas-fir. If conditions warmed and were excessively dry, sagebrush and some grass species could dominate (Blinnikov et al. 2002). Studies from northwestern Washington show that subalpine species such as subalpine fir expanded their range into alpine tundra during historical warm periods (Brubaker and McLachlan 1996, Gavin et al. 2001, McLachlan and Brubaker 1995). However, a broad review of paleoecological studies shows that treeline has rarely been more than 100 m higher than its current level throughout the Holocene (Rochefort et al. 1994).

MC2 projects that subalpine forest vegetation could shrink considerably, with strong agreement among GCMs for both mid-century and end of century. All scenarios showed that Crater Lake National Park is projected to experience a substantial decrease in subalpine forest by the end of the century. Deschutes National Forest may support refugia for this vegetation type, according to MC2 results. Vulnerability scores agree that most subalpine species have moderate to high vulnerability in the Pacific Northwest (table 6.2). Devine et al. (2012) and Case and Lawler (2016) suggest that climate change and a combination of white pine blister rust, mountain pine beetle, and large, high-severity fires (without adequate regeneration) threaten whitebark pine. Fir-spruce-mountain hemlock forests (Ruefenacht et al. 2008) have increased FVI during September, indicating higher temperatures and water deficits (Mildrexler et al. 2016). Reduced snowpack (Mote et al. 2005), changes in the rain-snow transition zone (Klos et al. 2014), and changes in spring precipitation (Mote and Salathé 2010) could reduce water availability and increase forest stress.

Moist Forest Group

Moist forests in south-central Oregon occur in locations with the highest amounts of precipitation, ranging from low to high elevations. This vegetation type generally transitions to either subalpine or mesic forest at its upper edge, and to mesic or dry forest at its lower edge. Moist forests are characterized by longer growing seasons than in subalpine forests and by a warmer, wetter climate than mesic and dry forests. Moist forests are generally dominated by long-lived coniferous trees and have high productivity, carbon, and biomass. Vegetation subzones within the moist forests group are listed in table 6.1.

Common tree species include Douglas-fir, western hemlock, western redcedar, grand fir, and Pacific silver fir. Although this forest type includes white fir and grand fir, these species tend to occupy drier sites, whereas Pacific silver fir occupies cooler, more maritime environments (Simpson 2007). Western redcedar and western hemlock are typically codominant on the wettest sites, and western redcedar can tolerate warmer temperatures. Elevation varies considerably, and most stands tend to have relatively deep soils, often with volcanic ash in the surface horizons. This forest type also has relatively high species diversity, closed forest canopy, and complex structure.

Disturbances—

Moist forests are generally characterized by high-severity fire regimes but can support mixed-severity fire regimes because both low-severity and high-severity regimes also occur (Stine et al. 2014). In general, the majority of this forest type is characterized by a relatively long MFRI (200 years or more). High amounts of coarse woody debris, litter, and live biomass can produce occasional large, high-severity wildfires when fire weather and dry fuel conditions coincide. Some species, such as white fir and grand fir, are sensitive to high-intensity fires because they have thin bark, low branches, and shallow roots (Agee 1993, Miller 2000).

Many moist forests (e.g., those not burned in recent decades) have relatively high stand densities, smaller trees (compared to historical structure), and few large fire-tolerant trees, and are dominated by shade-tolerant and fire-intolerant tree species (Stine et al. 2014). Longer growing seasons and an increase in drought severity could result in higher surface and canopy fuel loads and lower fuel moisture in the future. This pattern would allow wildfires to burn sites that were previously too wet and cool to burn. Although severe fires could ultimately reduce the total standing biomass in moist forests, it is unlikely that they would necessarily lead to changes in forest composition. Increased stand densities also increase competition for water and nutrients, which leads to higher susceptibility to insect and disease outbreaks.

Warming temperatures could increase the potential for insect and disease outbreaks. These forests are affected by Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins), Douglas-fir tussock moth (*Orgyia pseudotsugata* McDonnough), western spruce budworm, flatheaded fir borer (*Melanophila drummondi* Kirby), laminated root rot (*Phellinus weirii* [Murr.] Gilb.), Armillaria root disease (*Armillaria* spp.), Swiss needle cast (*Phaeocryptopus gaeumannii* [T. Rohde] Petrak), and Douglas-fir dwarf mistletoe (*Arceuthobium douglasii* Engelm.). Furthermore, Douglas-fir tussock moth and western spruce budworm currently have much more available habitat than they did in the past, and their damage has become more severe than it was historically. The tussock moth is on a 9- to 10-year outbreak cycle with each outbreak lasting around 3 years, whereas spruce budworm cycles are unpredictable. Douglas-fir tussock moth tends to be most common in low- to mid-elevation, late-seral stands (Hessburg et al. 1994). Spruce budworm outbreaks can persist for many years, with host trees being defoliated year after year. Complex forests with several ages of trees and a high percentage of host component are most heavily damaged by budworm, including tree mortality in smaller host trees and top-kill in larger trees. Douglas-fir beetle populations typically emerge only after a disturbance such as defoliation, wildfire, or extensive windthrow.

Potential future changes—

Moderate warming, increased atmospheric CO_2, and increased growing season precipitation may lead to increased growth and productivity in moist forests. However, because these systems are limited by low soil water availability, if growing season precipitation or summer precipitation does not increase but temperature does, then growth could decrease. Some moist forests are also energy limited where competition and closed canopies reduce light and nutrients for many individuals. For example, tree growth in some temperate moist forests in western Washington is energy limited, responding positively to warmer temperatures over the past 100 years (McKenzie et al. 2001). Some energy-limited forests could transition to more water-limited systems, particularly in soils without a deep ash or loess component. The presence of ash- or loess-influenced soils in these forests greatly increases water-holding capacity and forest productivity.

Decreased precipitation and increased drought stress during the growing season will probably cause decreased tree growth and productivity for some moist forests, particularly at the edge of species ranges (Kim et al. 2017). Susceptibility will vary, with Douglas-fir being more drought tolerant and western hemlock and western redcedar less tolerant. However, Douglas-fir is in fact sensitive to summer water balance deficit (i.e., potential evapotranspiration minus actual evapotranspiration) in most parts of the Western United States (Littell et al. 2008, Restaino et al. 2016) and will probably decrease in growth by later in the century, except perhaps at some high-elevation sites (Case and Peterson 2005; Littell et al. 2008, 2010).

Western hemlock has been shown to move up in elevation to areas occupied by Pacific silver fir and mountain hemlock during historically warmer (and drier) periods (Dunwiddie 1986). Paleoecological evidence also shows that during warm and dry periods, species such as Douglas-fir and lodgepole pine can become more abundant in areas that moist forests currently occupy (Whitlock 1992). Disturbance regimes can also change in response to climate change and during warm and dry periods when fire frequency is higher (Cwynar 1987, Prichard et al. 2009), thus favoring Douglas-fir and lodgepole pine.

MC2 projects modest increases in the area of moist coniferous forests in the SCOAP assessment area, as this forest type moves into areas once occupied by subalpine forests (figs. 6.13 through 6.18). There was strong agreement among GCMs for this potential increase, although the "hot-wet" GCM-CanESM2 projected the most potential expansion. Most of the expansion is projected to occur along the western edge of Deschutes and Fremont-Winema National Forests and Crater Lake National Park by the end of the century.

Vulnerability of tree species in the moist forest group ranges from low to moderate (table 6.2). Case and Lawler (2016) ranked vulnerability of western redcedar and bigleaf maple (*Acer macrophyllum* Pursh) as relatively low and grand fir as moderate. Devine et al. (2012) ranked vulnerability of Pacific silver fir as relatively high, but Case and Lawler (2016) identified it as low, with relatively high adaptive capacity. Mildrexler et al. (2016) show that western hemlock-Sitka spruce (*Picea sitchensis* [Bong.] Carr.) forests have relatively low FVI during August–September compared to other forests (Ruefenacht et al. 2008). This indicates that higher temperatures and water deficits have a significant influence on growth. In addition, Pacific silver fir cannot tolerate extended periods of summer drought.

Mesic Forest Group

Mesic forests occur in areas that receive considerable amounts of precipitation and occur from low to high elevations. This vegetation type generally transitions to moist or subalpine forests at its upper edge and into dry forest types at its lower edge. Mesic forests are characterized by relatively long-lived conifers, high diversity of species, and high forest productivity and biomass. Dominant species include Douglas-fir, white fir, grand fir, lodgepole pine, and Shasta red fir. Some species, such as Douglas-fir, incense cedar (*Calocedrus decurrens* [Torr.] Florin), and western larch are largely absent from deep (over 0.7 m) coarse ash deposits in south-central Oregon. These deposits are less than 7,000 years old and include Mazama ash, Newberry ash, and some minor ash deposits near the Three Sisters. The vegetation subzones found within the mesic forest group (table 6.1) consist of a mix of both shade-tolerant and shade-intolerant conifers.

Disturbances—

Mesic forests are characterized by mixed-severity fire regimes, with MFRIs of 35 to 200 years (based on LANDFIRE data) (Rollins 2009). However, recent data suggest that MFRIs in mesic forests may be lower, similar to MFRIs for dry forests. Merschel and Spies (2016) characterized historical fire regimes, stand dynamics, and current conditions across 10 000 ha, spanning an annual precipitation gradient of 63 to 1140 mm southwest of Bend, Oregon (mesic and dry forest groups, table 6.2). Historically, large spreading fires frequently burned across the dry to mesic ecotone. The interval between fires that burned at least 25 percent of a study area (CF125) was 12.5 years. The natural fire rotation (NFR), or the time it takes to burn an area equal to the study area, was 19 years, and fire intervals varied slightly with stand precipitation and composition (15 to 20 years in dry versus mesic stands). Mixed-conifer stands on buttes isolated by flats dominated by lodgepole pine often did not record large spreading fires, and burned in small isolated fire events. Mixed-conifer stands in this isolated landscape context had longer maximum fire-free intervals (<70 years) than nonisolated stands (<30 years).

Merschel and Spies (2016) suggest that dry and mesic mixed-conifer stands with different species composition had similar fire regimes, except where landscape context limited the spread of frequent fires. Similar results are reported for the southern Blue Mountains (Johnston 2016). Tree-ring reconstructions of fire regimes in forests in the interior Western United States have shown that mixed-conifer forest at lower elevations historically had a low-severity fire regime similar to ponderosa pine forest, but that fire frequency decreased and severity increased with elevation (Brown et al. 1999, 2008; Fulé et al. 2003; Heyerdahl et al. 2012). Forest development following fire exclusion (high densities of mature shade-tolerant trees) demonstrates that moist mixed-conifer forest in a frequent-fire landscape context is significantly departed from historical conditions (Merschel et al. 2014).

Although frequent-fire, low-severity regimes are generally more common and high-severity regimes are less common, exceptions exist. For example, moderate to high levels of coarse woody debris, litter, and live biomass can produce occasional large, high-severity wildfires when fire weather and dry fuel conditions coincide. However, these forests generally burn more often, and severity is lower compared to moist forests. Fuel accumulation rates, not ignitions, are probably a limiting factor to fire, especially at higher elevations. At these sites, a somewhat dry climate coupled with cold winters contributes to slow fuel accumulation. This fuel limitation is less prominent in lower elevation mesic forests. Nevertheless, increased fuel loads because of increased biomass production would likely increase fire frequency and severity across this forest type, especially if summer drought duration or severity increases.

Warmer temperatures in mesic forests may cause insect and disease outbreaks to be more common. As noted above, species such as Douglas-fir and grand fir are susceptible to Douglas-fir beetle, Douglas-fir tussock moth, western spruce budworm, flatheaded fir borer, laminated root rot, *Armillaria* root disease, Swiss needle cast, and Douglas-fir dwarf mistletoe. Fir engraver beetle is normally associated with trees infected by root pathogens, but during drought periods, can be found wherever the true fir host occurs. Tree mortality caused by fir engraver beetle is greatest where annual rainfall is 500 to 650 mm; damage decreases with increasing moisture. Defoliator outbreaks are often followed by elevated fir engraver beetle populations.

Potential future changes—

Warming temperatures and increased drought stress could facilitate a transition of mesic forest species to dry forest species, such as ponderosa pine and lodgepole pine. However, warming temperatures and increased precipitation could also increase the growth of Douglas-fir, grand fir, and white fir, particularly at high elevation. Grand fir and white fir may be favored on sites with coarse ash and pumice deposits. Mesic forests could also expand into areas currently occupied by subalpine forests but may also lose suitable habitat on lower and drier sites because of expanding dry forests. During past warm and dry periods, Douglas-fir and lodgepole pine were more abundant in areas currently occupied by moist and mesic forests (Whitlock 1992). This transition could be further facilitated by increased wildfire frequency.

Mesic forests in the southern Cascades (Lassen National Forest) are interspersed with montane chaparral as a result of recent high-severity or stand-replacing wildfires (Lauvaux et al. 2016). The development of similar shrub stands in central Oregon in a hotter climate is possible. Many shrub species in central Oregon are fire adapted and establish rapidly following fire by resprouting or establishing from a long-lived seed bank in the soil. Once established, they can impede tree seedling establishment and growth, slowing forest development. Fire return intervals in chaparral were longer than in adjacent forest (25 years versus 11 years), and chaparral fires occurred during drier, potentially more extreme conditions (Lauvaux et al. 2016). Shrub stands were apparently maintained by less frequent, more severe fires.

MC2 projects modest increases in the area of coniferous forests (roughly analogous to mesic forests) in the SCOAP assessment area. There was strong agreement of this potential increase among nearly all GCMs. Potential expansion is projected for both mid-century and end of century. Most of this potential expansion is projected to occur along boundaries of the current distribution of this forest type, although it is unclear if the presence of pumice soils would limit this expansion, particularly for Douglas-fir. For example, substantial organic matter accumulation appears to be needed on coarse pumice soils for Douglas-fir to establish. In addition, Douglas-fir requires nearby seed sources. However, pumice soils may not limit the expansion of mesic forest species (e.g., white fir, some pine species) into areas currently occupied by dry forests.

Vulnerability was identified as low to moderate for Douglas-fir and moderate to high for white-fir, Shasta red fir, and lodgepole pine (table 6.2). Assessing historical changes in drought and high temperatures, Mildrexler et al. (2016) showed that lodgepole pine forest (Ruefenacht et al. 2008) has higher FVI during September, indicating higher temperatures and greater water deficits. Douglas-fir and western white pine (*Pinus monticola* Douglas ex D. Don) forest did not have nearly as high FVI during this same period, indicating that these forest types are less vulnerable to drought and high temperatures.

Dry Forest Group

This vegetation group occupies low to mid elevations, receiving more precipitation than woodlands but less precipitation than mesic forests. Distribution of tree species is closely tied to available soil moisture. Climate in dry forests is characterized by relatively dry summers, with warm to hot daytime and cool nighttime temperatures, and cold, somewhat moist winters. Most of the annual precipitation falls as snow in winter or as rain during the spring.

Late-seral stands are generally dominated by ponderosa pine, grand fir, or Douglas-fir, although a short fire-return interval may have prevented late-seral stands from establishing in some locations in the past. Under these conditions, lodgepole pine, ponderosa pine, and Douglas-fir typically function as early- or mid-seral species. Frequency and intensity of past disturbance events, depth to rock or bedrock, and slope also determine dominant species and stand age structure. For example, lodgepole pine is usually dominant as an early-seral species in areas with deep pumice-ash deposits and gentle slope, whereas ponderosa pine is usually dominant in areas with moderate slope and deep pumice-ash deposits (Dyrness and Youngberg 1966). However, ponderosa pine may be intolerant of sites with poor soil drainage or excessively well-drained soils that trap cold air (Simpson 2007). Other species found in dry forests include incense cedar, western juniper, sugar pine (*Pinus lambertiana* Douglas), and Oregon white oak. Ponderosa pine is generally the dominant and sometimes only species present in areas with deep pumice-ash deposits.

Disturbances—

Dry forests are often referred to as frequent-fire forests. MFRI in ponderosa pine forests of central Oregon and northeastern California ranges from 7 to 56 years. Ponderosa pine develops thick bark with age, which allows for survival in frequent, low-intensity fire. In forest dominated by ponderosa pine on Pringle Butte (Deschutes National Forest), MFRI was 7 to 20 years for the period 1362–1900, where mean annual precipitation was 610 mm (Bork 1984). In a nearby but drier location (annual precipitation 240 mm), MFRI was 16 to 38 years for the period 1460–1970. In scattered ponderosa pine in sagebrush in the upper Chewaucan River basin near Paisley, Oregon (annual precipitation 400 mm), MFRI was 3 to 38 years for the period 1601–1897. In the Buck Creek watershed on the west side of the North Warner Mountains, for the period 1650–1879, MFRI was 2 to 56 years at a lower elevation site (1600 m) dominated by juniper and ponderosa pine, and was 1 to 11 years at a higher elevation site (1700 to 1900 m) dominated by ponderosa pine (Goheen 1998). Vegetation spatial pattern is more heterogeneous at lower elevation sites where limited soil moisture regulates plant density and biomass production.

Limited fuel quantities and lack of continuity result in longer intervals between fires, and more gentle slopes at lower elevation are less conducive to fire spread.

Heyerdahl et al. (2014) examined fire history in central Oregon, where coarse-textured pumice soils limit forest composition to lodgepole pine with scattered ponderosa pine and shrub understories dominated by antelope bitterbrush (*Purshia tridentata* [Pursh] DC.). They reconstructed historical fire regime from tree rings and simulated fire behavior. Between 1650 and 1900, mixed-severity fires occurred every 26 to 82 years, creating a multi-aged forest and shrub mosaic. Simulation modeling indicated that a mix of surface and passive crown fire was driven by shrub biomass and windspeed. Several decades of fire exclusion have reduced the potential for high-severity patches of fire that were common historically, likely by reducing bitterbrush, the primary ladder fuel. Crown fire potential may increase, even with current fuel loadings, in a warmer climate but only if extreme winds occur.

In ponderosa pine forests, present-day stand structure, species composition, fuel accumulation, and associated risk of severe fires and insect outbreaks are regarded as historically uncharacteristic. These conditions are commonly attributed to decades of fire exclusion, timber harvest, and overgrazing (Hessburg et al. 2005, Tiedemann et al. 2000, Wright and Agee 2004). The importance of fire as a disturbance process (Agee 1993, Fulé et al. 1997, Hessburg and Agee 2003) and disruption of fire regimes coinciding with Euro-American settlement and associated fire exclusion have been extensively documented for dry forests dominated by ponderosa pine (Covington and Moore 1994, Hessburg et al. 2005, Merschel et al. 2014, Swetnam et al. 1999).

Management goals for dry forests, such as reducing the risk of severe wildfires and sustaining biodiversity, have prompted the use of stand density management (thinning) and surface fuel reduction (prescribed fire, mechanical removal). Prescribed fire simulates the frequent, low-intensity surface fires considered characteristic of the historical environment of fire-prone forests prior to Euro-American settlement (Agee 1993, Cooper 1960, Covington and Moore 1994, Weaver 1943). However, prescribed fires are typically conducted in the spring and mid autumn, whereas historical wildfires occurred mostly during summer and early autumn. The ecological implications of the current seasonal timing of prescribed burns are uncertain (but see Kerns et al. 2006). Busse and Riegel (2009) found that frequent fire (11 years) impeded the recovery of antelope bitterbrush and that bitterbrush recovered only where local tree mortality resulted in an open stand. Therefore, it may be possible to use repeated burning to reduce long-term fire risk imposed by bitterbrush as an understory ladder fuel.

Lodgepole pine is susceptible to mountain pine beetle, *Ips* bark beetle, *Armillaria* root disease, Elytroderma needle blight (*Elytroderma deformans* [Weir]

Darker), and western gall rust (*Endocronartium harknessii* [J.P. Moore] Hirats.). When lodgepole pine stands reach about 100 years of age, they become particularly vulnerable to infestation by mountain pine beetle. Outbreaks can last for several years, and most larger trees in the stand are typically killed. Pandora moth (*Coloradia pandora* Blake) feeds on lodgepole pine as readily as on ponderosa pine, and large-scale outbreaks occur at irregular intervals.

Ponderosa pine is susceptible to western pine beetle, mountain pine beetle, and pine engraver beetle. Western pine beetle is generally associated with larger, older trees with reduced vigor, whereas mountain pine beetle occurs in second-growth stands, and pine engravers tend to affect small pines (100 cm diameter). Western pine beetle is a key mortality agent in older low-vigor ponderosa pines, especially in dense stands, although second-growth stands can also be affected. Turpentine beetles (*Dendroctonus valens* Le Conte) are also common, especially if ponderosa pine has been wounded to the point of exuding pitch. Trees are often killed in groups, creating openings in stands. In second-growth stands, mountain pine beetle "thins from above" (killing larger trees) in low-productivity sites and "thins from below" (killing smaller trees) in high-productivity sites (Sartwell 1971).

Potential future changes—

Tree establishment and growth in dry forests are limited by water availability during the growing season, length and timing of summer drought, and changes in disturbance frequency and severity (Boisvenue and Running 2010). For example, regeneration pulses are often associated with one or more consecutive high-precipitation years (Barrett 1979, Brown 2006). It has been suggested that tree seedlings have shifted toward cooler environments relative to the distribution of mature trees in some locations in the Western United States (Monleon and Lintz 2015). Tree growth is typically negatively correlated with summer temperature and positively correlated with precipitation for dry forest species such as ponderosa pine (Carnwath et al. 2012, Knutson and Pyke 2008, Kusnierczyk and Ettl 2002), Douglas-fir (Carnwath et al. 2012, Case and Peterson 2005, Chen et al. 2010, Griesbauer and Green 2010, Littell et al. 2008, Restaino et al. 2016), and lodgepole pine (Case and Peterson 2007). Tree mortality is often indirectly related to summer drought through changes in disturbance regimes, insects, species competition, and forest vigor (Peterson et al. 2014). Dry forests in many areas have increased potential for stand-replacing crown fires when fuel loadings are high (Heyerdahl et al. 2014).

Higher temperature and lower precipitation will almost certainly reduce growth of dry forests in some locations, especially at lower elevations. Modeling studies generally support this projection for a warmer climate, showing reduced tree productivity across low-elevation dry forests (Latta et al. 2010). Furthermore, negative water balances during the growing season can constrain photosynthesis and growth (Hicke et al. 2002, Restaino et al. 2016). Some of the potential decrease in productivity may be offset by increasing concentrations of CO_2, which can increase the water-use efficiency of plants (Neilson et al. 2005). However, in arid ecosystems the enhanced productivity gains from CO_2 may be realized only in wet years and potentially outweighed by drought and soil water deficits in dry years (Newingham et al. 2013).

Summer droughts that are more frequent and of longer duration will also potentially lengthen the fire season in dry forests and may increase the extent of wildfires. Because of the current accumulation of live and dead fuels, large and severe wildfires may become the norm in these forests at least for the next few decades. At lower elevations, these fires may cause conversion to shrublands or grasslands, a trend that is supported by MC2 output for hotter and drier scenarios. However, the type and depth of soil substrates greatly influence species composition, density, and fire occurrence. For example, fire histories on pumice soils indicate that extensive mixed-severity fires occurred every 26 to 82 years, resulting in a multi-aged forest and shrub mosaic (Heyerdahl et al. 2014).

Paleoecological evidence shows that under warmer and wetter climates, open forests of Douglas-fir and western larch moved into areas previously dominated by dry forest species such as ponderosa pine (Whitlock and Bartlein 1997). During warmer and drier periods, ponderosa pine replaced species now restricted to higher elevations (Blinnikov et al. 2002). A warmer and drier climate facilitates transition to pines and even shrub-steppe in forested areas that were previously cooler and wetter (Whitlock and Bartlein 1997). Although disturbance regimes will have a major effect in determining which species persist in a given location, dry forests may be more resilient than other forest types. Simulation of dry forest dynamics under various climate and management scenarios in central Oregon found that dry mixed-conifer forests increased in area (21 to 26 percent by 2100) in a warmer climate, whereas moist mixed-conifer forests decreased (36 to 60 percent by 2100) (Halofsky et al. 2014). Even if the lower edge of some dry forest species distribution is vulnerable to a warmer climate, new habitat will almost certainly emerge in areas at higher elevation.

MC2 projects both small increases and decreases in the area of dry coniferous forest in the SCOAP assessment area in a warmer climate. As noted previously, the uncertainty associated with projections for dry forests seems to revolve around projections for precipitation associated with different GCMs. A 1-percent increase in this forest type is projected when all GCMs are averaged, with the mean GCM (CESM1(CAM5)) projecting -0.2 percent. The “hot-dry”

GCM (MIROC-ESM-CHEM) projected the most expansion, and the "hot-wet" GCM (CanESM2) projected the most contraction. These patterns were consistent for projections for both mid-century and end of century. Much of the potential increase in dry coniferous forests is projected to occur along the eastern and southern edges of its current mapped distribution, a trend that has been anecdotally observed. Again, increased precipitation, increased growing season, warming in energy-limited ecosystems, and possibly increased water-use efficiency are driving these modeled changes.

Vulnerability of ponderosa pine was identified as low (table 6.2), although Mildrexler et al. (2016) suggest that ponderosa pine, lodgepole pine, and Douglas-fir have higher FVI during September and are the most vulnerable of all forest types analyzed. Projected future reductions in snowpack (Mote et al. 2005), changes in the rain-snow transition zone (Klos et al. 2014), and altered spring precipitation (Mote and Salathé 2010) could all affect water availability and forest stress (Mildrexler et al. 2016). This may be especially important in shallow soils, because moisture availability is more common in the deeper rooting zones on high pumice-ash soils during the late growing season. Therefore, established trees may have better access to this late-season soil moisture compared to seedlings and herbaceous vegetation.

Woodlands

Woodlands are partially forested habitats (sometimes referred to as parklands) that generally occupy the transition between shrublands and dry forests. Woodlands found at higher elevations (e.g., subalpine woodlands) are not considered here. In south-central Oregon, woodlands exist in the driest of the tree-dominated sites between shrub-steppe and dry forests. Western juniper is the dominant tree species, with some ponderosa pine, lodgepole pine, and Oregon white oak. Common shrubs include big sagebrush and bitterbrush (Miller et al. 2005). Summers are hot and very dry, and winters are cold and somewhat wet. Annual precipitation in western juniper woodlands ranges from 130 to 750 mm, but most sites fall within 250 to 500 mm (Gedney et al. 1999). Dry forests typically replace woodlands on ash-pumice soils deeper than 30 cm. On shallow, stony soils with annual precipitation of 50 to 60 cm, woodlands may extend up to 1500 to 1800 m elevation.

Prior to Euro-American settlement, juniper was confined primarily to rocky substrates, ridges, shallow soils, and pumice sands with sparse vegetation (Miller and Rose 1999, Waichler et al. 2001, West 1984). In northeastern California, the most extensive stands of old juniper are found on shallow heavy clay soils supporting low sagebrush (*Artemisia arbuscula* Nutt.) and Sandberg bluegrass (*Poa* *secunda* J. Presl) where stands are typically open with less than 10 percent canopy cover. On fuel-limited sites such as rocky outcrops, western juniper can attain ages exceeding 1,000 years (Waichler et al. 2001). In Devils Garden (north of Alturas, California), most old trees growing in with low sagebrush and Sandberg bluegrass were 200 to 500 years old (Riegel et al. 2006). Widely scattered old trees (canopy cover less than 5 percent) and limited surface fuels suggest that stand-replacement fires were infrequent (MFRI greater than 100 years).

Most western juniper woodlands in Oregon and California are still in transition from shrub-steppe to juniper woodland (Miller et al. 2008). Although western juniper abundance has increased greatly in the past 130 years, it can potentially occupy a much larger area under current climatic conditions (Gedney et al. 1999; Miller et al. 2000, 2008). A wet period between 1905 and 1917 (Woodhouse et al. 2005) coincided with peak establishment and infill of western juniper and other juniper and pinyon pine species in the intermountain West region (Barger et al. 2009, Floyd et al. 2004, Johnson and Miller 2008). However, wet periods also would have resulted in increased fine surface fuels in the absence of livestock grazing, resulting in increased fire in subsequent dry seasons (Miller and Rose 1999, Swetnam and Betancourt 1998).

During early stages of encroachment, juniper initially adds structural diversity to shrub-steppe communities, which often increases wildlife abundance and diversity (Miller 2001, Reinkensmeyer 2000). However, structural diversity declines as woodlands become fully developed and the understory becomes depleted because of shading (Miller et al. 2000). In Modoc County, California, western juniper overstory increased and live shrubs decreased in permanent transects measured between 1957 and 1998 (Schaefer et al. 2003). Sagebrush, which is an important ladder fuel during the early stages of woodland development, decreases as juniper dominance on the site increases. Production of fine fuels can also decrease with the decline of sagebrush, reducing fire hazard.

Disturbances—

Wildfire is an important disturbance agent in woodlands. However, historical fire regimes are not well described for juniper savannas and woodlands in Oregon (Agee 1993, Young and Evans 1981). Young junipers have thin bark and are readily killed by fire, whereas older individuals develop thicker bark and some resistance to fire; these individuals can then suppress understory herbaceous plants by outcompeting them for water, thereby reducing fine fuels (Agee 1993). Consequently, fire-scarred junipers are limited to microsites with fine-fuel production. Fire scars in adjacent ponderosa pine forests suggest a mixed-severity fire regime, with an MFRI of 15 years to more than 100 years (Agee 1993, Miller and Rose 1999, Miller et al. 2005).

Juniper trees less than 50 years old are generally easily killed by fire (Bunting 1984b; Burkhardt and Tisdale 1969, 1976; Miller and Rose 1999). Therefore, as MFRIs increase (>50 years), the potential for postfire tree survival increases. Places where MFRI is very long (>100 years) are generally fuel limited (Romme et al. 2009).

Land use change, livestock grazing, and invasive species are other key disturbances in woodlands. Juniper has expanded its range throughout the interior Pacific Northwest, invading and creating savannas and woodlands in semiarid ecosystems that were formerly shrub-steppe and grassland communities (Miller et al. 2000). Much of this expansion has been attributed to heavy livestock grazing and less frequent fires. In addition, some evidence exists that woodland expansion during the mid to late 1800s may have been a response to warmer, wetter conditions (Miller et al. 2005).

Woodlands are also sensitive to invasive species, such as nonnative annual grasses, particularly after tree harvest and natural disturbances (box 6.3). In general, sites supporting moist and cooler upland woodlands and sites dominated by mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana* [Rydb.] Beetle) are more resistant to invasion by juniper than sites dominated by other species or subspecies of sagebrush (e.g., Wyoming big sagebrush [*A. tridentata* ssp. *wyomingensis* Beetle & Young]) in warmer, drier conditions (Miller et al. 2013).

Potential future changes—

Although many woodlands in south-central Oregon are only partly forested, denser western juniper woodlands can also develop. The area of juniper forest and woodland is estimated to have increased fivefold between 1936 and 1988 (Gedney et al. 1999), and greater than 90 percent of the 3.2 million ha of current juniper savannas and woodlands developed in the past 100 years (Miller et al. 2000). Reduced fire occurrence and optimal climatic conditions for establishment at the turn of the century were probably the causes of postsettlement expansion of western juniper (Miller et al. 2005). Because junipers can live for up to 1,000 years, woodlands can persist for a very long time in the absence of disturbance. Climate change effects on fire frequency and severity will probably depend on changes in soil water availability and its effect on the understory.

Similar to dry forests, tree establishment and growth in woodlands are limited by precipitation and soil moisture. Because most precipitation falls during the winter and is stored in a shallow snowpack or shallow soil, little recharge occurs during the growing season, forcing plants to concentrate growth and reproduction during spring and early summer. Therefore, lower precipitation could decrease tree establishment and possibly increase tree mortality. However, higher precipitation could facilitate further juniper expansion, and higher intensity rainfall events could move moisture

Box 6.3

Nonnative Annual Grasses

Nonnative plant invasions (hereafter "invasives") are a growing challenge to the management of native biodiversity, ecosystem function, and fuels and fire management. The effects of invasives are particularly significant when they alter disturbance regimes beyond the range of variation to which native species are adapted, resulting in community shifts and ecosystem transformations (D'Antonio and Vitousek 1992, Mack and D'Antonio 1998). Nonnative annual grasses that alter fire regimes are recognized as some of the most important ecosystem-altering species on Earth (Brooks et al. 2004). Cheatgrass, medusahead, and North Africa grass are affecting millions of hectares of grassland and shrub-steppe ecosystems in the Great Basin (DiTomaso 2000).

Cheatgrass is widely distributed in western North America and is abundant and dominant in woodland, shrubland, and grassland communities (Chambers et al. 2014, Mack 1981). Following disturbance, this species can invade low-elevation forests (Keeley and McGinnis 2007, Keeley et al. 2003, Kerns et al. 2006), creating surface fuel continuity between arid lowlands and forested uplands. Highly competitive traits enhance its ability to exploit soil resources after fire and to increase its dominance in the community (Melgoza and Nowak 1991, Melgoza et al. 1990). Kerns and Day (2017) demonstrated that cheatgrass establishment after fires in ponderosa pine stands with cheatgrass present is highly correlated with burn extent. Following establishment, cheatgrass tends to increase the probability of further disturbance, and it alters the fire regime because the fine, continuous, and highly combustible fuels dry early in the season, increasing the length of the fire season in some ecosystems (Chambers et al. 2014). Conversion of forests and woodlands to grasslands has important implications for carbon cycling and feedbacks between climate and the biosphere (Bonan 2008).

Bradley (2009) used a species distribution model to examine the potential changes in climate habitat for cheatgrass. Results varied greatly depending on model input data for future changes in precipitation. Climate models that project lower precipitation in the future, especially in summer, project expansion of cheatgrass, whereas models that project higher precipitation project reduced habitat for cheatgrass by as much as 70 percent.

Lovtang and Riegel (2012) modeled the presence of cheatgrass in central Oregon. In the landscape on the east side of the Cascade Range northwest of the Great Basin, the best predictors of cheatgrass presence were low March precipitation, warm minimum May temperature, low tree density, high western juniper density, and a short distance to the nearest road. Future changes in climate, some of which are consistent with the predictor variables cited above, could facilitate expansion of cheatgrass in south-central Oregon.

Elevated CO_2 can increase cheatgrass productivity and may have already contributed to higher fuel loads, with subsequent effects on wildfire intensity (Ziska et al. 2005). More area burned, more frequent large wildfires, greater extent of stand-replacing high-severity fire, longer wildfire durations, and longer wildfire seasons are expected in the future (Lutz et al. 2009, Miller et al. 2008, Nydick and Sydoriak 2014, Westerling et al. 2006), increasing invasion

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risk for nonnative grasses. Balch et al. (2013) demonstrated that cheatgrass invasion in the Great Basin has substantially altered the regional fire regime.

North Africa grass is a recently arrived nonnative species that is becoming a problem, mostly in Ochoco National Forest, Crooked River National Grassland, and the Blue Mountain Ecoregion (Kerns et al. 2016b). North Africa grass is an aggressive invader and can dominate large areas of a landscape. The plant dries earlier in the summer than native species, but later than other nonnative grasses, remaining highly flammable throughout the fire season. It has spread in mountain meadows and scablands over the past decade, although little is known about its basic ecology (Wallace et al. 2015) or potential response to climate change. Even less is known about its response to wildfire and how its abundance can be influenced by management activities (Johnson et al. 2013, Northam and Callihan 1994, Scheinost et al. 2008). Work focused on understanding North Africa grass, and ecosystem change is currently underway (Kerns et al. 2016b).

Climate change is expected to increase opportunities of invasion of forest lands, woodlands, and shrublands by nonnative annual grasses. As warming proceeds, conditions in lower elevations may become unsuitable for some grasses, while new habitat emerges at higher elevations in areas that were previously too cold. In addition, invasions may increase through increased disturbance, competitiveness of nonnative plants whose growth is enhanced by elevated CO_2, and increased stress to native species and ecosystems (Breshears et al. 2005, Dukes and Mooney 1999, Pauchard et al. 2009, Ziska and Dukes 2011). Temperate and mountainous regions have greater risk of invasion with warming, because many invasive species have range limits set by cold temperatures, which have tended to limit their establishment in forests. Some studies have shown reduced herbicide efficacy in elevated CO_2 environments (Archambault et al. 2001, Ziska and Teasdale 2000), and some biocontrol methods may be less effective in a warmer climate (Hellmann et al. 2008), potentially reducing tools for controlling nonnative species.

deeper in the soil profile, allowing juniper and other woody plants to access moisture more effectively than grasses and herbs (Kulmatiski and Beard 2013). Western juniper growth is positively correlated with winter and spring precipitation and negatively correlated with spring and summer temperatures (Knutson and Pyke 2008).

Although tree abundance within woodlands could increase, and woodlands may expand their range with increased precipitation, higher spring and summer temperatures may negatively affect woodlands, particularly at lower elevations. For example, areas with increased juniper density caused by recent land use may be particularly vulnerable, especially where soils are shallow. However, suitable habitat currently occupied by dry forests at higher elevations may offset some of these potential losses.

Cold winter temperatures limit photosynthesis in juniper woodlands (Runyon et al. 1994), so warmer winter temperatures could increase growth. However, extreme cold temperatures can also function as a disturbance agent, and severe dieback could occur if trees are actively photosynthesizing when extreme cold occurs (Knapp and Soulé 2005). Knapp et al. (2001) documented increased juniper growth consistent with CO_2 fertilization, but little experimental work has been conducted on response of junipers to elevated CO_2 or warming temperatures. Junipers could potentially benefit from increasing atmospheric CO_2 if it reduces stomatal conductance and delays depletion of deep soil water, although it is unclear if improved water-use efficiency would significantly increase growth or simply reduce drought stress. In arid systems, enhanced productivity from elevated CO_2 may be realized only in wet years, but could be outweighed by drought and soil water deficits in dry years (Newingham et al. 2013).

As temperatures warmed during the early Holocene, western juniper migrated north into its present range in the Pacific Northwest, establishing in semiarid ecosystems that were formerly shrub-steppe and grassland communities (Miller et al. 2000). In central and eastern Oregon, western juniper abundance and distribution have fluctuated considerably (ca. 4,800 to 6,600 years BP) (Miller et al. 2005). Dry climatic periods tend to result in regional declines of juniper, whereas wet (particularly in summer) and mild (particularly in winter) periods result in expansion.

MC2 projects a modest decrease in the area of coniferous woodlands (fig. 6.17). Three GCMs project small increases and the "hot-dry" GCM MIROC-ESM-CHEM projects a small decline. The "hot-wet" GCM CanESM2 projects the most decline. This pattern was consistent for both mid-century and end-of-the-century projections. Much of the projected decrease results from dry forest and coniferous forest expansion associated with increased precipitation. Temperate woodland contraction is projected for Ochoco and Fremont-Winema National Forests and in southeastern Deschutes National Forest. As noted previously, MC2 does not model species-specific dynamics, meaning that the change from woodland to dry forest is related to increased productivity and CO_2, so the shift from woodland to dry forest could be interpreted as increased productivity and density of juniper woodlands.

Devine et al. (2012) suggested that western juniper has low vulnerability, because it has a large range and is found at low elevations. However, western juniper has low reproductive capacity because it depends on animals for seed dispersal and has a relatively high seed-bearing age. Oregon white oak was identified as relatively sensitive to climate change (Case and Lawler 2016), because it depends on periodic low-intensity fire to suppress competition and intrusion by conifers such as Douglas-fir (Voeks 1981). Warming temperatures may also create new opportunities for Oregon white oak establishment in some areas that were historically too cold.

Shrublands and Grasslands

Shrublands occupy some of the driest locations in south-central Oregon, comprising the ecotone between woodlands and grasslands. These sites occur in arid to semi-arid areas with low precipitation, warm-hot dry summers, and cold winters. In most of central and southeast Washington and much of eastern Oregon, shrub-steppe communities occur in areas with low precipitation (<200 mm adjacent to juniper woodlands, <350 mm adjacent to ponderosa pine) or where soil texture or depth limits forest development. In eastern Oregon, shrublands are generally dominated by sagebrush, curl-leaf mountain mahogany (*Cercocarpus ledifolius* Nutt.), and bitterbrush with an understory of grass species. For the purpose of this assessment, shrublands consists of scabland shrub (box 6.4), upland shrub, and salt desert shrub subzone types (table 6.1). Shrublands cover a significant portion of south and central Oregon and comprise 29 percent of vegetation types in Crooked River National Grassland. Shrublands are a minor component of vegetation in Crater Lake National Park and SCOAP assessment area national forests.

True grasslands in the SCOAP assessment area are limited in extent, consisting of the subzone types upland grassland, dry meadow, moist meadow, and wet meadow (table 6.1). Grasslands comprise a small portion (about 6 percent) of vegetation in Crooked River National Grassland, and even smaller portions of the national forests and Crater Lake National Park. Upland grassland communities are often found mixed in a mosaic with shrub-steppe and forest, and much of our focus in this section is on this mosaic. The grassland zone also includes mountain meadows that are essentially permanent herbaceous habitats found on gentle topography along and near the heads of streams (Franklin and Dyrness 1973).

Disturbances—

Shrublands and grasslands are substantially affected by wildfire, land use change (grazing, agricultural production), and invasive species (box 6.3). Cattle and sheep grazing became major factors in Pacific Northwest grasslands in the early to mid 1800s. Settlers introduced numerous nonnative grasses, including cheatgrass (*Bromus tectorum* L.), which was well adapted to the climate within parts of the region (Mack 1981). The spread and dominance of nonnative grasses was facilitated by intense grazing in some locations. Modeling of the potential expansion of invasive grasses projects that changes in precipitation, and to a lesser extent winter temperature, will increase the area with climatically suitable conditions for cheatgrass (Bradley 2009) (box 6.3). Large portions of past grasslands have also been cultivated for agricultural crops like winter wheat or irrigated to produce summer fruits, vegetables, and grains.

Box 6.4

Scablands

Scabland habitats are typical of the Ochoco Mountains and are characterized by shallow, gravelly, and rocky soils in a xeric moisture regime and frigid temperature regime (David 2013). Soil moisture varies from saturated in the late autumn, winter, and early spring to dry in late spring, summer, and early autumn. Soil temperature ranges from frozen in late autumn, winter, and early spring to warm in the late spring, summer, and early autumn. These conditions subject these habitats to severe water saturation and frost heaving in winter and hot, dry conditions in summer (Dewey 2013).

Plant associations occurring in scablands include low sagebrush/Sandberg's bluegrass, stiff sagebrush (*Artemisia rigida* [Nutt.] Gray)/Sandberg's bluegrass, and Sandberg's bluegrass/onespike oatgrass (*Danthonia unispicata* [Thurb.] Munro ex Macoun) (Johnson and Clausnitzer 1992, Johnson and Swanson 2005). The low sagebrush/Sandberg's bluegrass association occurs in scablands with soil depth less than 250 mm. This community occurs at mid to upper montane on gentle slopes at ridgetop locations, on shallow soil with fractured basalt bedrock (Johnson and Clausnitzer 1992). Stiff sagebrush/Sandberg's bluegrass is the lowest elevation sagebrush-dominated plant association in the Blue Mountains and Ochoco Mountains and occurs on gentle slopes and shallow soils over fractured bedrock (Johnson and Clausnitzer 1992). The Sandberg's bluegrass/onespike oatgrass association occurs throughout the Blue and Ochoco Mountains over a broad elevation range (1200 to 2100 m). Slopes are gentle, soil depths are shallow, and substrates include basalt, andesite, and rhyolite. This association occurs on soils often saturated in spring owing to perched water over bedrock and clay, but their capacity to store water is low (Johnson and Swanson 2005).

Plants adapted to scablands can endure drought by going dormant for long periods, or can avoid severe drought stress by developing root systems that allow them to store water throughout the summer (Simpson 2015). Forbs occurring in these plant associations can tolerate the dry warm scabland environment, and include biscuitroots (*Lomatium* spp.), pussytoes (*Antennaria* spp.), yarrow (*Achillea millefolium* L.), wild onions (*Allium* spp.), and buckwheats (*Eriogonum* spp.). Soil biocrusts, formed by mosses and lichens, are important to the integrity of these habitats, providing moisture longer in the season and contributing nitrogen (Farris 2013).

Henderson's needlegrass (*Achnatherum hendersonii* [Vasey] Barkworth) and Wallowa needlegrass (*A. wallowaensis* Maze & K.A. Robson) are two rare regional endemic grasses that are federal species of concern (in review for listing under the Endangered Species Act). These two grasses are on the Oregon biodiversity information center list 1, which includes taxa threatened with extinction (Oregon Biodiversity Information Center 2013), and are listed as Oregon sensitive species by the U.S. Forest Service Pacific Northwest Region.

Henderson's needlegrass occurs in Oregon and Washington. Wallowa needlegrass occurs only in north-central (Crook County) and northeastern (Wallowa County) Oregon. Both species are found exclusively in scablands. Competition from nonnative, invasive plant species may be the greatest

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threat to the persistence of these species in northeastern and north-central Oregon (Dewey 2013). Invasive winter annual grasses have colonized scablands, potentially competing for limited resources of soil moisture and nutrients (Farris 2013). The annual invasive North Africa grass (*Ventenata dubia* [Leers] Coss.) germinates in the fall, grows through the winter, and reproduces early in the spring, taking advantage of higher soil moisture content and nutrient availability before needlegrass begins its growth and reproductive cycle (Farris 2013).

Climate change may play a role in the decline of Henderson's needlegrass (Farris 2013). As winter temperatures increase, there could be less snowpack and frost heaving to which needlegrass is well adapted (Maze and Robson 1996), favoring establishment and growth of winter annuals. If there is less snowpack but still freezing temperatures, frost heaving might increase with less insulation from snow (Simpson 2015). If a warmer climate causes additional stress in native ecosystems, they will be more susceptible to establishment of nonnative plant species.[3]

Newly described Ochoco lomatium (*Lomatium ochocense* Helliwell & Constance) is a rare forb endemic to scablands in the Ochoco Mountains that was first discovered in 1994 (Helliwell 2010). Like the needlegrasses, it is a federal species of concern, on Oregon biodiversity list 1, and listed as sensitive by the U.S. Forest Service Pacific Northwest Region. Populations are restricted to areas with exposed bedrock, occurring in plant communities dominated by rigid sagebrush and Sandberg bluegrass (Helliwell 2010).

[3] **Bautista, S. 2008.** Climate change and invasive plants: information for PNW invasive plant NEPA. Unpublished report. On file with: S. Bautista, USDA Forest Service, Pacific Northwest Region, 1220 SW 3rd Avenue, Portland, OR 97204.

Historical fire frequencies vary across shrublands, and proxy information must be used to infer fire regimes for sagebrush-steppe because little direct information is available (Riegel et al. 2006). Wildfires are limited by a lack of ignitions during the fire season and by a lack of continuous fuels in some locations. Increased biomass buildup of nonnative grasses such as cheatgrass could promote the spread of fires in the future. Cold-season bunchgrass communities also tend to have more continuous fuels to carry fire. Presettlement MFRIs for some of the wetter mountain big sagebrush communities adjacent to forested communities have been described (Houston 1973, Miller and Heyerdahl 2008, Miller and Rose 1999), but descriptions of fire regimes for the majority of plant communities in sagebrush-steppe are lacking. In productive mountain big sagebrush plant associations, MFRI was 10 to 25 years, with large fires every 38 years (Miller et al. 2005). MFRI was 50 to 70 years in more arid plant associations, such as Wyoming big sagebrush–Thurber's needlegrass (*Achnatherum thurberianum* [Piper] Barkworth). Fire-free periods of 90 years (Young and Evans 1981) and 138 years (Miller and Rose 1999) were also reported in northern California and south-central Oregon, and fire-free periods probably exceeded 150 years for some sites in low sagebrush–Sandberg bluegrass systems (Miller and Rose 1999, Young and Evans 1981). Baker (2006) suggested that historical fire rotations were 70 to 200 years in mountain big sagebrush and longer in other sagebrush types.

Long-term charcoal records suggest that fire regimes in shrublands are affected by both climate and fuels, with higher fire frequencies and sagebrush densities during wet periods (decades to centuries) and lower during dry periods (Mensing et al. 2006). Recovery of shrub canopy cover to predisturbance levels can require 10 to 50 years, with recruitment of new shrubs from soil seed banks being an important factor controlling recovery time (Ziegenhagen and Miller 2009). Short FRIs can cause significant changes in species and productivity if shrub communities have not fully recovered between disturbances (Davies et al. 2012).

Wildfire causes an immediate reduction of the shrub layer. Shrubs associated with sagebrush-steppe plant communities across south-central Oregon are composed of both fire-tolerant and fire-intolerant species, and some species of sagebrush are easily killed by fire. The rate of big sagebrush recovery following fire varies but tends to be slower in more arid sites (Bunting 1984a, Miller and Heyerdahl 2008). Within about 20 years following fire, mountain big sagebrush canopy cover can be 15 to 25 percent (Bunting et al. 1987, Ziegenhagen 2003). Because big sagebrush subspecies and forms of low sagebrush do not resprout (Pausas et al. 2016), they depend on unburned seed for reestablishment. The potential for large inputs of sagebrush seed following a fire is limited, depending on the amount of unburned edge and amount and distribution of unburned sagebrush shrubs. Sagebrush seed is mainly distributed by wind, with no evidence of seed caching by animals. Seed movement from adjacent unburned areas is slow, requiring many years to move into the interior of the burn (Johnson and Payne 1968, Mueggler 1956, Riegel et al. 2006).

Response of antelope bitterbrush to fire varies because this species can resprout in many sites, especially younger plants (<15 years old) following a low-intensity burn (Blaisdell and Mueggler 1956). In central Oregon, survival of bitterbrush resprouts appears to be related more to soil surface texture than fire intensity (Driscoll 1963). When bitterbrush successfully resprouts following fire, the species can recover to high densities within 10 years (Wright et al. 1979). In sites where bitterbrush is mixed with sagebrush (northern California, southeastern Oregon, northwestern Nevada), reestablishment was primarily from seed and occurred at the same rate as sagebrush. In heavily browsed winter range for deer in south-central Oregon, bitterbrush did not recover to preburn levels 40 years after fire (Riegel et al. 2006). Seed caches of small mammals are an important vector of bitterbrush seed dispersal, although seedlings compete poorly with cheatgrass, thus limiting reestablishment in some locations (Holmgren 1956).

Rubber rabbitbrush (*Ericameria nauseosa* [Pall. ex Pursh] G.L. Nesom & Baird), green rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt.) and horsebrush (*Tetradymia* spp.) are capable of sprouting and more rapidly recovering following fire than big sagebrush, although rubber rabbitbrush is more sensitive to fire than green rabbitbrush (Wright et al. 1979). In some areas, establishment is from both seeds and shoots (Young and Evans 1978). The abundance of these sprouting species usually declines over time as sagebrush abundance and intervals between disturbances increase (Whisenant 1990, Young and Evans 1978). However, density and cover of these species can exceed preburn levels, especially on degraded sites (Chadwick and Dalke 1965). Heavy grazing following fire can also increase abundance of rabbitbrush and horsebrush. Curl-leaf mountain mahogany is a weak sprouter and highly susceptible to fire (Wright et al. 1979). Plants that established prior to Euro-American settlement are found on rocky ridges protected from fire (Davis and Brotherson 1991, Dealy 1975, Gruell et al. 1984). Reestablishment following fire depends mostly on seedling establishment (Wright et al. 1979), so a nearby seed source is important.

Many dominant bunchgrasses recover well from fires by resprouting from belowground organs and can achieve prefire abundance within 5 years. Rate of recovery and composition following a fire are largely determined by moisture regime, plant composition prior to the burn, soil seed reserves, fire tolerance of species in the site, fire intensity, weather conditions, and management following fire. In mesic communities, Lemmon's needlegrass (*Achnatherum lemmonii* [Vasey] Barkworth), Idaho fescue, and bluebunch wheatgrass recover rapidly and often exceed preburn levels within 2 to 3 years (Miller et al. 2013). In arid plant communities that contain fire-sensitive grasses and forbs, recovery of cover is slower and may not exceed preburn levels for many years.

Broadleaf grasses such as squirreltail (*Elymus elymoides* [Raf.] Swezey), bluebunch wheatgrass, and Lemmon's needlegrass are relatively resistant to fire, recovering quickly and often producing greater amounts of biomass following fire (Blaisdell 1953, Bunting et al. 1987, Riegel et al. 2006, Wright 1971). Fine-leaved grasses such as Idaho fescue and Thurber's needlegrass are more sensitive to fire, with high crown mortality and slow recovery rates (Blaisdell 1953, Wright 1971). Fine-leaved grasses accumulate more dead material in the crown, causing the plant to burn more slowly and transferring more heat to the growing points (Wright 1971). Although most of the literature reports that Idaho fescue is fire sensitive and declines in the first year following fire (Blaisdell 1953, Conrad and Poulton 1966, Countryman and Cornelius 1957), this species usually recovers in time, and biomass and cover can exceed preburn levels within 3 to 5 years (Riegel et al. 2006).

Contradictory results in the literature regarding this species may partially result from differing intensities of postfire herbivory (Miller et al. 2013).

Forb species that resprout belowground from a caudex, corm, bulb, rhizome, or rootstock usually recover rapidly following fire. The majority of these forbs are dormant at the time of the fire, and their growing points are protected from burning. However, forbs that are suffrutescent (mat forming) such as sandwort (*Arenaria* spp.) and wild buckwheat (*Eriogonum* spp.) have their growing points aboveground and can be severely damaged by fire, resulting in crown area reduction and mortality. Perennial forb production usually increases two- to threefold following fire in mesic sagebrush communities (Blaisdell 1953, Riegel et al. 2006), although perennial forb response is usually less robust in drier plant communities (Blaisdell 1953, Bunting et al. 1987, Fischer et al. 1996, Riegel et al. 2006).

In relatively productive sites, the largest increases in vegetation during the first several years following fire occur among native annuals, if sufficient moisture is available. Most species have completed their life cycle by early summer, prior to fire events. During the first growing season following fire, annuals are able to take advantage of increased nutrient availability and decreased competition from perennials. In several fires in northeastern California and northwestern Nevada, annuals increased 300 to 500 percent in the first and second year following fire (Riegel et al. 2006). Annual response typically lasts 2 to 5 growing seasons following fire, and response can be greatly limited by dry conditions in spring. In heavily disturbed or warmer sites (often dominated by Wyoming big sagebrush), native annual response is generally overwhelmed by nonnative annuals and biennials.

Other disturbances and stressors, such as juniper expansion, livestock grazing, and land conversion by agriculture and urban development will also affect shrublands and mixed shrublands and grasslands. In dry areas, shrublands are especially prone to invasion by nonnative annual grasses (box 6.3). In some areas, introductions of invasive plant species such as cheatgrass and medusahead (*Taeniatherum caput-medusae* [L.] Nevski) have significantly altered fire regimes by producing sufficient fine fuels to carry wildfires (D'Antonio and Vitousek 1992) (box 6.3). If density of native species is less than three plants per square meter (Bates et al. 2000) and cheatgrass is abundant in the understory, burning will likely convert the site to nonnative annual grassland.

Potential future changes—

Shrublands and grasslands have a large continental range, and their distribution has fluctuated in response to previous climatic variation. For example, at Waits Lake (northeastern Washington), steppe and sage-steppe vegetation alternated with dry coniferous (pine) forest for thousands of years following the last glacial period before being replaced by the current Douglas-fir forest around 2,300 years BP

(Mack et al. 1978). At Carp Lake in south-central Washington, a 125,000-year pollen record shows that the site has alternated between periods of montane coniferous forest, pine forest, and steppe vegetation, and it currently supports dry coniferous forest (Whitlock et al. 2000). In southeastern Washington, a 100,000-year record from grass phytoliths indicated large shifts in vegetation over time, with a low-elevation site alternating between different grassland communities, and two higher elevation sites transitioning from cold sagebrush-steppe and subalpine parkland vegetation to dry forest and grassland vegetation, before transitioning to modern dry mixed-conifer and subalpine forests (Blinnikov et al. 2002). Shrublands may be one of the more sensitive vegetation types to changes in climate because many shrub species have shorter life cycles than tree species.

Grasslands are generally well adapted to cold winter temperatures and low soil moisture, although these factors do influence species composition and abundance. Grasses and forbs can avoid summer drought stress by concentrating growth in the spring and early summer when soil water is still available and cooler temperatures promote high water-use efficiency (Comstock and Ehleringer 1992). Decreased winter or spring precipitation may shift the composition and abundance of grasslands to more drought-tolerant or invasive species. This is corroborated by paleoecological studies that show grasslands at lower elevations shift in dominance toward more drought-tolerant species (Blinnikov et al. 2002). In contrast, increased winter or spring precipitation may increase woody vegetation in areas currently dominated by grasslands. This is also supported by paleoecological studies that show grasslands transition to sagebrush-steppe and eventually ponderosa pine woodlands during cooler, wetter periods (Blinnikov et al. 2002).

Establishment and growth in shrublands is strongly controlled by soil moisture and winter temperatures, with the former dependent on precipitation, temperature, soil texture, and soil depth (Bates et al. 2006, Comstock and Ehleringer 1992, Schlaepfer et al. 2012a). Because summers are hot and dry, winter precipitation in the form of snow and rain is particularly important for recharging water storage in deeper soil layers (Schlaepfer et al. 2012b, Schwinning et al. 2003). Extended periods of high temperatures and low precipitation during the summer lead to soil moisture deficits and seasonal drought. Warmer winter temperatures could also reduce the amount of snowpack and water storage in deep soil layers. Warmer spring temperatures could also lead to earlier winter snowmelt and increased evapotranspiration, causing an earlier start of seasonal drought. Drier conditions could also have negative effects on sagebrush germination and seedling survival and could lead to lighter seeds, thus reducing germination success (Schlaepfer et al. 2014).

Many shrubs, including sagebrush, are well adapted to summer drought. For example, sagebrush cover and density were relatively unaffected by shifts in the seasonality of precipitation (Bates et al. 2006). Some species of shrubs can also tolerate extended droughts and remain photosynthetically active during periods of water and heat stress (Depuit and Caldwell 1975). Some shrubs can also avoid severe drought stress by developing deep root systems that allow them to access deep soil water reserves throughout the summer (Franklin and Dyrness 1973). However, shrubs that exist at the edge of their distribution may decrease in productivity in response to prolonged summer drought, or abundance may shift to more drought-tolerant species. As disturbances increase, abundance of rubber rabbitbrush may increase in areas once dominated by sagebrush, partly because disturbed sites could be warmer and drier than undisturbed sites.

Although increased winter precipitation may allow soil moisture to recharge in some areas, it is unclear how shrub species may respond. Paleoecological evidence suggests that sagebrush has historically expanded its distribution during drier climatic periods (Blinnikov et al. 2002, Whitlock and Bartlein 1997). Species distribution models built with current shrub species project major losses of suitable climate space for mountain mahogany and bitterbrush by the end of the 21st century (McKenney et al. 2011), but projections for big sagebrush range from major losses (McKenney et al. 2011, Schlaepfer et al. 2012b) to expansion into newly suitable areas (Withey et al. 2014). Nevertheless, species distribution models do not provide insight into whether sagebrush will be able to disperse to and establish in areas that become climatically suitable, or whether sagebrush will be able to adapt to changing climatic conditions and persist in areas of projected range contraction.

Several studies show that grasslands may be resistant to climate change effects (Dukes et al. 2005, Grime et al. 2008) and that short-term changes in interannual precipitation may not result in significant changes in semiarid vegetation communities (Jankju 2008). Modeling results also suggest widespread changes in the length of the frost-free season that may favor cold intolerant annual grasses, changes in the frequency of wet winters that may alter the potential for establishment of invasive annual grasses, an earlier onset of fire season, and a longer period during which conditions are conducive to wildfire (Abatzoglou and Kolden 2011).

MC2 projects less than a 1 percent decrease in shrubland extent when all GCMs are averaged, although GCM output differs. Seven GCMs project potential increases in temperate shrubland, whereas 21 GCMs project a decrease. The "hot-dry" GCM (MIROC-CHEM) projects modest increases in shrublands, and the "hot-wet" CanESM2 GCM projects modest decreases. A potential increase in temperate shrubland is projected for Crooked River National Grassland. Our personal observations suggest that when mean annual precipitation is less than 150 mm, juniper woodlands decrease and are replaced by shrub-steppe. MC2 mapped only three cells (800 m^2) as temperate grasslands in the historical vegetation simulation. Projections for cool-season grasslands show relatively little change (figs. 6.12 through 6.16). In addition, small amounts of desert vegetation types are simulated to appear in the future.

Increased CO_2 concentrations could theoretically benefit some shrubland species that utilize the C3 photosynthetic pathway. Higher CO_2 concentrations have been shown to increase the water-use efficiency of some plants and allow them to survive in drier conditions (Morgan et al. 2011). However, CO_2 enrichment will probably have the greatest benefits for plants in sites where water is limiting but nitrogen is not (McMurtrie et al. 2008). In addition, in arid ecosystems, the enhanced productivity gains from CO_2 may be realized only in wet years, and gains may be outweighed by drought and frequent low-precipitation years (Newingham et al. 2013). Elevated CO_2 concentrations have been shown to increase biomass production of cheatgrass and other nonnative annual grasses (Lucash et al. 2005, Smith et al. 2000). These species may be more capable of extracting water and growing quickly compared to native species. Increased annual grass biomass in these ecosystems also tends to increase fire frequency by increasing fine fuel loads.

Riparian Areas, Wetlands, and Groundwater-Dependent Ecosystems in South-Central Oregon

Definitions

Numerous definitions exist for riparian areas, wetlands, and groundwater-dependent ecosystems (Mitsch and Gosselink 2015, Naiman et al. 2005). Here, we provide working definitions that are currently used by the USFS Pacific Northwest Region, recognizing that there is overlap among the definitions, and that they may be refined as more is learned about these systems.

Riparian areas—

Riparian areas are diverse, ranging from broad floodplain forests along low-elevation rivers and streams to narrow zones along intermittent or ephemeral streams in incised, headwater channels. In south-central Oregon, riparian ecosystems occur along steep-gradient, low-order headwater streams; montane channels flowing through segments of varying valley width; and low-gradient, alluvial rivers in wider reaches of the Deschutes and Crooked Rivers and their tributaries (Crowe et al. 2004, Kovalchik 1987, Riegel et al. 2017). A combination of stream sizes, landforms, valley widths and gradients, and hydrologic regimes determine the biotic communities associated with riparian areas (Gregory et al. 1991).

The dimensions of riparian areas include the (1) longitudinal continuum from headwaters to the mouths of streams and rivers (Vannote et al. 1980); (2) vertical dimension that extends upward into the vegetation canopy and downward into the subsurface, including hyporheic and belowground interactions (Gannett et al. 2003; Stanford and Ward 1988, 1993); and (3) lateral dimension that extends to the limits of flooding on either side of the stream (Stanford and Ward 1993). The dynamic influence and extent of each of these spatial dimensions depends on watershed hydrologic regime, location within the stream network of the watershed (elevation, connectivity), and watershed physical characteristics and geomorphic processes. These physical characteristics and processes largely regulate the structure and function of riparian ecosystems (Gregory et al. 1991, Naiman and Décamps 1997, Naiman et al. 2005). The fourth dimension is temporal, incorporating successional changes in response to disturbance and climate over time. Ecological definitions of riparian areas can also include the aquatic-terrestrial transition zones surrounding lakes, ponds, and wetlands.

Wetlands—

For all federal regulatory activities, wetlands are ecosystems that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil (Federal Interagency Committee for Wetland Delineation 1989). Wetlands can be diverse, exhibiting a wide range of vegetation, soil, and hydrologic characteristics (Cowardin et al. 1979, National Research Council 1995). However, all definitions emphasize hydrologic variables, particularly duration, seasonality, and depth of inundation and soil saturation, that result in distinctive hydric soils and wetland vegetation.

Three broad categories of wetlands occur in south-central Oregon: palustrine, lacustrine, and riverine (Cowardin et al. 1979). Palustrine wetlands are freshwater wetlands that include marshes, wet meadows, and forested wetlands, and may be dominated by trees, shrubs, or emergent vegetation. Some palustrine wetlands may be associated with streams, particularly in headwaters, whereas many are isolated, occurring in basins, depressions, or wet meadows. Lacustrine wetlands border lake shores.

Riverine wetlands are associated with streams and rivers, occurring along stream channels. In the Oregon Wetlands Geodatabase, most riparian areas are treated as riverine wetlands, demonstrating overlap in definitions of riparian areas and wetlands. This designation may result in an overestimate of wetland area, because some riparian areas may not qualify as jurisdictional wetlands, but it does provide a basis for management, because all wetland and riparian areas in national forests in south-central Oregon are managed as Riparian Habitat Conservation Areas (USDA FS 2012c).

Groundwater-dependent ecosystems—

Groundwater-dependent ecosystems (GDEs) are communities of plants, animals, and other organisms whose life processes depend on access to or discharge of groundwater (USDA FS 2012a, 2012b). GDEs occur at aquifer discharge locations (springs, rheic, lentic, or alluvial systems) (Aldous et al. 2015), which are also referred to as surface or terrestrial GDEs (Bertrand et al. 2012). Many wetlands, lakes, streams, and rivers receive inflow from groundwater, which can contribute substantially to maintenance of water levels, as well as water temperature and chemistry required by native biota (Lawrence et al. 2014, Winter 2007). Most GDEs contribute significantly to local and regional biodiversity (Murray et al. 2006).

In south-central Oregon, GDEs include springs (including seeps and springbrooks), streams and rivers, fens, and riparian wetlands along gaining river reaches (Brown et al. 2009, 2010). The extent of groundwater dependence of wetlands, rivers, and lakes depends on their hydrological, geological, and climatic setting. The Nature Conservancy has developed an approach to assist in determining groundwater dependence for wetlands (Brown et al. 2007), which includes a decision tree that was modified for the USFS GDE inventory field guide (USDA FS 2012a).

The high number of springs (953) in Ochoco National Forest and Crooked River National Grassland reflects the dormant landslide terrain, faults, inner-flow zones of basalts, and contacts between different lithologies. Springs and seeps associated with faults, contacts, and dormant landslide terrain are especially common on the John Day and Clarno Formations on the western side of the Emigrant Ranger District. In the past 6 years, Level 1 GDE surveys have been completed on 66 springs (7 percent of the total). The sample includes springbrooks, fens, and other wetlands located on all major lithologies. Fens are rare in Ochoco National Forest, and none have been mapped to date in Crooked River National Grassland.

Groundwater input is important to many stream and river ecosystems in south-central Oregon (Brown et al. 2009). Groundwater can contribute substantially to late-summer streamflow (Gannett et al. 2003, Tague and Grant 2009) and is the source for cool-water upwellings that serve as refugia for cold-water aquatic species (Lawrence et al. 2014; Torgersen et al. 1999, 2012). Springbrooks, defined as runout channels from springs that may become a stream at some distance from the spring source (USDA FS 2012a), may also contribute to the mediation of stream temperature.

Fens are commonly defined as peat-forming, groundwater-fed wetlands, developing where a relatively constant supply of groundwater is available in the plant rooting zone most of the year (Bedford and Godwin 2003), typically supporting sedges and bryophytes (Hájek et al. 2009). The USFS classifies a wetland as a fen if it is primarily supported by groundwater, and has organic soils meeting the definition of a histosol or histic epipedon in at least some part of the contiguous wetland (USDA FS 2012a). Many rare plant species occur in these ecosystems, particularly relative to the small fraction of the overall landscape that they represent in south-central Oregon (Bedford and Godwin 2003).

Current Resource Conditions

Fens in the SCOAP assessment area are distributed unevenly, with most fens occurring between Chemult and the Three Sisters Wilderness Area (Dewey 2016), where the hydrogeological setting is favorable for their development. Most of this landscape contains a surficial layer of pumice and ash, much of which was deposited 7,700 years BP during eruptions of Mount Mazama. These tephras overtop a former landscape surface of low relief and low permeability (Aldous et al. 2015, Cummings 2014). Elevation in this area is mostly between 1400 and 1800 m, with a large percentage of annual precipitation falling as winter and early spring snow. Spring snowmelt percolates downward through the highly permeable tephra layer to the less permeable former landscape surface, forming an aquifer with slow lateral movement. Where slope breaks or post-depositional erosion results in groundwater appearance at or near the tephra surface, the opportunity for fen development and peat formation occurs (Aldous et al. 2015, Cummings 2014).

Plant species composition supported by fen habitats is distinct among plant communities found across the rest of the SCOAP assessment area, most likely because the water source is primarily nutrient-poor groundwater near the source of its initial, diffuse surface discharge. Fen ecosystems may or may not contribute surface water output to riparian systems, but they do not receive significant amounts of water and nutrients from these systems (Bedford and Godwin 2003).

Fens in south-central Oregon are dominated by herbaceous vegetation, although shrub-dominated fens (20 to 25 percent cover) are also common. Forested fens are less common. In general, the vegetation of fens is distinguished by high cover of sedges (and other Cyperaceae) and mosses. Plant species commonly found in fens in south-central Oregon (Dewey 2011) are summarized in table 6.3. The primary range of many of these taxa is boreal, and the presence of these taxa in south-central Oregon and elsewhere in the Pacific Northwest represents a disjunct distribution (Dewey 2016). Fens near the crest and east flank of the Cascades Range support the most species-rich plant communities. A few Cascadian fen species appear to be absent from fens of the Chemult fen cluster and elsewhere in Fremont-Winema National Forest. Many Cascadian fen species are lacking in fens in Ochoco National Forest. However, the only Oregon record of the fen-associated moss *Calliergon richardsonii* is in Ochoco National Forest.

Table 6.3—Common plant species in fens in south-central Oregon

Life form	Scientific name
Graminoids	*Carex aquatilis* Wahlenb.
	Carex echinata Murray
	Carex jonesii L.H. Bailey
	Carex limosa L.
	Carex simulata Mack.
	Eleocharis quinqueflora (Hartmann) O. Schwarz
	Eriophorum spp. (especially *E. gracile* W.G.J. Koch, *Eriophorum angustifolium* Honck. ssp. *angustifolium*)
	Juncus ensifolius Wikstr.
	Juncus nevadensis S. Watson
Forbs	*Dodecatheon* spp. (especially *D. jeffreyi* Van Houtte)
	Drosera spp. (*D. anglica* Huds., *D. rotundifolia* L.)
	Hypericum anagalloides Cham. & Schltdl.
	Menyanthes trifoliata L.
	Mimulus primuloides Benth.
	Pedicularis groenlandica Retz.
	Platanthera spp. (especially *P. dilitata* (Pursh.) Lindl.ex Beck)
	Saxifraga oregana Howell
	Scheuchzeria palustris ssp. *americana* (Fernald) Hultén
	Spiranthes romanzoffiana Cham.
	Triantha glutinosa (Mishx.) Baker
	Utricularia spp. (especially *U. minor* L., *U. intermedia* Hayne)
Shrubs	*Betula glandulosa* Michx.
	Kalmia microphylla (Hook.) A. Heller
	Vaccinium oxycoccos L.
	Vaccinium uliginosum L.
Mosses	*Calliergonella cuspidata* (Hedw.) Loeske
	Calliergon richardsonii (Mitt.) Kindb.
	Calliergon stramineum (Brid.) Kindb.
	Drepanocladus aduncus (Hedw.) Warnst.
	Elodium blandowii (F. Weber & D. Mohr) Warnst.
	Hamatocaulis vernicosus (Mitt.) Hedenäs
	Hypnum pratense (Rabenh.) Koch ex Spruce
	Meesia triquetra (L. ex Jolycl.) Ångstr.
	Meesia uliginosa (Hedw.)
	Plagiomnium ellipticum (Brid.) T. Kop.
	Splachnum ampullaceum Hedw.
	Sphagnum L. spp.
	Tomentypnum nitens (Hedw.) Loeske
	Warnstorfia exannulata (Schimp.) Loeske

Although nonnative plant species are widespread in south-central Oregon, nonnative species in riparian areas, wetlands, and GDEs (special habitats hereafter) are relatively uncommon, probably because prolonged wetness provides poor habitat for most common invasive species. Some weedy wetland species, particularly reed canarygrass (*Phalaris arundinacea* L.) have a significant presence, such as in Trout Creek Swamp in northern Deschutes National Forest.

Groundwater pumping has the potential to lower water tables and alter plant communities in special habitats, but in most cases, these habitats are distant from pumping sites and separated from the regional groundwater system by stratigraphic barriers (Aldous 2015). Gravity-driven movement of piped water to livestock troughs from shallow wells in aquifers supporting special habitats are located in public lands in the southern part of the SCOAP assessment area. With appropriate engineering, these systems can utilize relatively low volumes of diverted groundwater, but such engineering can be difficult to maintain. Passive groundwater diversion systems with unregulated flow to troughs are occasionally encountered. High-volume diversion of groundwater from aquifers supporting special habitats may create water stress in fen plant communities in years of below-average recharge.

Livestock grazing in special habitats can damage fen vegetation, and in some cases, alter hydrologic processes. Common visible alterations include hoof pits and soil pedestals. Compaction of peat under hoof pits can impede subsurface water movement of water through low-permeability soils. Repeated creation of bare peat, which at a subsoil level is likely destructive to fibrous root networks, can decrease stability of the peat surface. Livestock trails can become routes of directed surface flow during periods of maximum groundwater discharge in the spring. This directed flow can in turn lead to development of erosional channels in the peat, which can reduce groundwater retention. Finally, nutrient additions by livestock urine and feces may alter competitive balances between plant species (Hájek et al. 2009).

Potential Climate Change Effects

Our ability to anticipate climate change effects in special habitats depends on the reliability of climate change projections and our understanding of the hydrogeological settings of special habitats in south-central Oregon. Temperature is projected to increase for this region, but annual precipitation is projected to change relatively little or increase (chapter 3). However, the fraction of precipitation falling as snow below about 2000 m elevation will decrease, and the fraction as rain will increase, with the “seasonal snow zone” transitioning to a “transient snow zone” (Sproles et al. 2013) (chapter 4). Based on this projection, it is reasonable to anticipate negative consequences to special habitats that depend on hydrologic recharge by snowmelt-fed water in summer.

Aldous et al. (2015) cite projections by Waibel et al. (2013) of average increases in Cascadian aquifer recharge volumes of 56 percent during December–February, followed by average decreases in recharge volumes of 28 percent during March through summer. For special habitats that depend on shallow, local aquifers, water tables may be significantly reduced during much of the growing season, with potential for water stress in some plant species. Based on hydrologic projections for the SCOAP assessment area (chapter 4), reduced summer streamflow associated with the trend toward transient snow will be prominent in uplands of Fremont-Winema National Forest. The effects of reduced snowpack on summer streamflow will be less prominent in the lower elevation landscapes of Ochoco National Forest.

If water table levels are chronically lower in the future, then some plant species that are competitive in high-water conditions may be less competitive with species typically found in drier conditions adjacent to special habitats. For example, fen moss species, most of which are tolerant of persistently wet soil conditions, are very intolerant of drought. Water table monitoring in the north Chemult area between 2010 and 2015 demonstrated that water table levels are strongly tied to total precipitation in the current water year, and it appears that as few as two successive below-average water years can cause stress to GDE plant communities, particularly to the moss component. This was especially obvious during the drought years of 2012 through 2014, although it is likely that water-stressed plant communities can rebound quickly in response to one or more average water years.

An inverse relationship exists between species richness of special habitats, and their distance between neighboring special habitats (Bedford and Godwin 2003, Nekola 1999). Loss of species or possibly whole communities in special habitats would increase the geographic isolation of these communities, reducing opportunities for between-habitat immigration and genetic exchange. In addition, if plants used by livestock for forage become more common in special habitats, they would attract more grazing, thus exacerbating degradation of the plant community.

In Ochoco National Forest and Crooked River National Grassland, where a high concentration of GDEs exist, potential effects of climate change will differ based on underlying geology, presence or absence of faults or interflow zones between basalt flows, and depth of landslide springs. The groundwater source for some GDEs is deep, suggesting limited potential for modification from altered snowpack and hydrologic routing. The John Day and Clarno Formations have high clay content, which will facilitate water retention. Springs may not see significant change in flow for 30 to 50 years, although shallow groundwater-sourced seeps and springs in landslide terrain could be more susceptible. Groundwater drawdown by wells on public and private lands is too small to be a concern.

Conclusions

Climate change is expected to alter disturbance regimes, vegetation structure and composition, and terrestrial ecosystem processes in south-central Oregon. Climate influences the spatial distribution of major vegetation biomes, abundance of species and communities within biomes, biotic interactions, and geographic ranges of individual species. Considerable uncertainty exists about how climate change will affect species distribution, forest productivity, and ecological disturbance. Paleoecological data demonstrate that new climatic conditions will create no-analog plant communities, because individual species, not intact communities, will respond to change. Climate also influences disturbance processes that catalyze changes in vegetation structure and composition. Potential climate change effects are summarized by vegetation groups in box 6.5. Although uncertainty exists about the exact consequences and timing of climate change effects on vegetation, we infer that the effects in box 6.5 are likely, based on multiple lines of evidence, although they are not predictions.

In general, a warmer climate combined with increased precipitation and a longer novel growing season in the largely cold and high-elevation environment of south-central Oregon may increase forest production and the extent of forest communities in some locations (although summer growing season precipitation is projected to increase only for a small set of scenarios). Increased growing degree-days and wet growing degree-days (chapter 3) will effectively increase the growing season and decrease continentality in the study area. Most of the better performing GCMs in the Pacific Northwest project warming and higher precipitation, and a no-analog climate. In a warmer, wetter climate, tree growth in energy-limited portions of the landscape (high elevations, north aspects) may increase as the climate warms and snowpack decreases.

Projections for seasonal precipitation patterns drive much of the uncertainty in understanding vegetation change. For example, although overall precipitation may increase, summer drought will intensify according to most scenarios, which may offset potential gains in productivity. Some species may respond positively to higher concentrations of ambient CO_2 as a result of increased water-use efficiency, although this fertilization effect may diminish as other factors become limiting, especially soil moisture.

Box 6.5

Summary of Potential Effects of Climate Change on Vegetation in South-Central Oregon

This summary is based on multiple sources of information covered in chapter 6. For most vegetation groups, a shift in species composition and abundance will be a likely outcome of future climate change, especially at the trailing and leading edges of the distribution of a species. Novel species combinations are expected for all vegetation groups.

Subalpine forest—

- Cold temperatures and snowpack limit the upper extent of subalpine forest.
- Minor warming and decreased snowpack may lead to increased growth and productivity, but projections are for more pronounced warming, which puts these forests at risk.
- Lower elevation competitors are expected to move into some subalpine habitats.
- Future projections indicate an increase in wildfires and insects.
- Tree seedling establishment may be a challenge for some species in a warmer climate.

Moist forest—

- Warmer temperatures may increase growth and productivity in some locations, especially if precipitation increases; however, drought stress could limit expansion of moist forest and favor species adapted to drier conditions.
- High amounts of biomass could result in severe wildfires.
- Species are long lived, so changes may not be realized for many decades or even centuries.
- Insect outbreaks will probably increase with warmer temperatures and could catalyze rapid change.

Mesic forest—

- Warmer temperatures may increase growth and productivity in some locations, especially if precipitation increases; however, drought stress could limit expansion of mesic forest and favor species adapted to drier conditions.
- Pumice soils could limit expansion in some areas.
- Severe wildfires are possible in areas with high fuel loading.

Dry forest—

- Dry forests are less sensitive to warming than other forest types, and species in this type can expand into more suitable habitat (e.g., higher elevation).
- Dry forests are sensitive to duration and severity of summer drought stress at lower elevations.
- Increased precipitation could lead to expansion of dry forest.
- Establishment and growth will be affected by water availability.

continued on next page

- Compounding stresses could lead to widespread mortality in the current range.
- Wildfire will continue to be an important factor.

Woodland—

- Woodlands are limited by precipitation and soil moisture, but facilitated by grazing and wildfire suppression.
- Temperature increases during spring and summer may negatively affect woodlands; however, expansion of juniper woodlands may continue, including conversion of juniper woodlands to juniper forests.
- Frequent wildfire and nonnative annual grasses are important stressors, and may combine to reduce the distribution and abundance of woodlands.

Shrubland and grasslands—

- Shrublands are limited by snowpack, soil moisture, and winter temperatures.
- Continued loss of snowpack may lead to continued decline, especially of big sagebrush; drought-tolerant species may replace big sagebrush in some locations.
- Increased precipitation could lead to an increase in woody species.
- Land use conversion, grazing, and nonnative invasive species will compound the effects of climate change on shrublands.
- Shrublands will be sensitive to altered wildfire frequency and severity.
- Soil moisture and winter temperatures strongly control grassland composition and extent.

Increases in ecological disturbance (fire, insect outbreaks) will be extremely important in affecting species distribution, tree age, and forest structure (successional stage), facilitating transitions to new combinations of species and vegetation patterns. Mountain pine beetle may be particularly important in lodgepole pine and ponderosa pine forests, and western spruce budworm, and Douglas-fir tussock moth may also increase periodically. Annual area burned by wildfire is expected to increase substantially, and fire seasons will probably lengthen. In dry forest types where fire has not occurred for several decades, crown fires may result in high tree mortality. In addition, interaction of multiple disturbances and stressors will create or exacerbate stress complexes. For example, an extended warm and dry period may increase bark beetle activity that would increase fine fuels in the short term. Positive feedback processes of multiple stressors may also be expressed in more mesic forest types if they become increasingly water limited.

Assessment of the vulnerability of vegetation to climate change is a function of sensitivity, exposure, and adaptive capacity. Much focus has been placed on species sensitivity and exposure to climate change, with little discussion of species adaptive capacity, including the ability of a species to move to a more suitable location. Simulation models provide science-based projections of how a warmer climate could modify the growth environment of species and broad patterns of ecological disturbance, supplemented by other studies for the region. However, because the future climate may differ considerably from what has been observed in the past, it is difficult to project vegetative response accurately at fine spatial and temporal scales. Based on scientific information and the appropriate caveats, inferences in this chapter have been used to develop appropriate adaptation options aimed at building resilience for systems, species, and management organizations in south-central Oregon (chapter 10).

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Chapter 7: Climate Change, Wildlife, and Wildlife Habitats in South-Central Oregon

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Introduction

Wildlife may respond to climate change in a variety of ways, including changes in distribution (Chen et al. 2011, Hitch and Leberg 2007, Parmesan and Yohe 2003, Prince and Zucherberg 2015); reproduction (Blaustein et al. 2001, Corn 2005); behavior (Boutin and Lane 2014, Hoffmann and Agro 2011, Wong and Candolin 2015); and evolutionary adaptation (Davis et al. 2005, Parmesan et al. 2006). Ecosystem responses to climate change are expected to affect wildlife through changes in food availability, competition, predator-prey dynamics, and availability of key habitat features, including nesting or resting structures and ephemeral water sources (Foden et al. 2013, Ockendon et al. 2014). Despite the flexibility and adaptive capacity of many species, widespread shifts in animal ranges, local extirpation of some species, and extinctions have been observed or are projected to result from climate change and related pressures (Cahill et al. 2013, Lawler et al. 2009, Moritz and Agudo 2013, Urban 2015). Evolutionary processes may not be rapid enough to provide for species persistence in many cases (Parmesan et al. 2006). Understanding the ways in which wildlife is vulnerable to climate change, understanding how climate effects interact with other stressors, identifying strategies that promote sustainability of habitats and populations, and providing opportunities for species to adapt or be more resilient to a rapidly changing environment are core challenges for federal land managers (Peterson et al. 2011).

Climate projections indicate that future conditions are likely to be warmer, with changes in seasonal precipitation and more extreme weather events, including heat waves, droughts, and floods (IPCC 2014, Melillo et al. 2014). Downscaled climate projections for the South-Central Oregon Adaptation Partnership

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(SCOAP) assessment area (based on current trends in carbon emissions) suggest an increase in mean annual temperature of about 6 °C by the end of the 21st century, with uncertain changes in total annual precipitation (chapter 3). Two important patterns projected for the region are (1) a shift to rain as the predominant precipitation form in much of the area, which historically has received most precipitation as snow (Melillo et al. 2014) (chapter 3); and (2) a longer growing season facilitated by warmer and wetter spring and fall conditions. Both increased warming and increased climatic variability—including extreme storms, droughts, and heat waves—are likely to influence biotic communities (Vazquez et al. 2015).

Changes in climate and weather extremes are expected to have direct and indirect effects on wildlife. Physiological effects in animals, including heat stress and desiccation, may directly cause injury or mortality. Changes in the timing of ecological processes (phenological changes) may contribute to mismatched ecological relationships. For example, food resources may not be available when they are needed by a given species, or changes in reproductive timing may expose young to inhospitable conditions such as spring storms. Extended droughts and altered disturbance regimes have the potential to change the availability and configuration of critical habitat elements, including food and shelter (Vose et al. 2016). For example, wildfires are generally projected to become larger and more intense with anticipated climate changes, producing changes in the availability of forest structure characteristics required by some species (Barbero et al. 2014, Dennison et al. 2014). Changing species interactions, particularly those influencing food availability, have been observed to be an important proximate cause of recent climate-related species extinctions and declines (Cahill et al. 2013, Ockendon et al. 2014). Changes in small mammal, bird, and insect prey availability in particular have the potential to produce cascading effects on higher order predators.

Expected climate change effects will interact with non-climate stressors to determine outcomes for wildlife. Habitat loss and fragmentation caused by human land uses (primarily urban and agricultural development) have been a leading cause of wildlife species declines (Wilcove et al. 1998). Those pressures will continue, and associated threats to wildlife are likely to be amplified by changes in habitat suitability associated with climate change (e.g., Jongsomijit et al. 2013). A primary long-term consequence of climate change is likely to be a change in human population distribution and associated changes in the distribution and intensity of agriculture (IPCC 2014, Melillo et al. 2014). These pressures are likely to contribute to ongoing habitat loss, fragmentation of remaining habitats, and fewer opportunities for animals to move between habitat patches (i.e., reduced habitat connectivity).

Likely consequences of these combined climate change effects include changes in species distributions (i.e., range shifts) and wildlife community composition as animals move or change their behavior in response to new environmental conditions. At global and continental scales, north-temperate species are moving northward, moving upward in elevation, and shifting behaviors to times earlier in the year (Chen et al. 2011, Hitch and Leberg 2007, Lawler et al. 2009, Prince and Zucherberg 2015), but there is also substantial variability at local and regional scales (Rapacciuolo et al. 2014, Rowe et al. 2015, Stralberg et al. 2015, Tingley et al. 2012). Animals are projected to respond to climate change at broad spatial scales through changes in distribution, but also at fine scales through changes in foraging and thermoregulatory behaviors (Carroll et al. 2015, Rapacciuolo et al. 2014, Rowe et al. 2015). Availability of topographic and habitat characteristics that provide thermal refugia and other key habitat components (particularly food and water) will be important in providing for species persistence in a warming environment (e.g., Carroll et al. 2015).

This assessment addresses climate exposure, sensitivity, and adaptive capacity for wildlife species and the composite effects for communities associated with eight focal habitat types (see below) in south-central Oregon. Because habitat is described by dominant vegetation, we address exposure, sensitivity, and adaptive capacity for both plant species and associated habitat types. Where possible, those concepts are extended to the resilience of abiotic habitat attributes that may also respond to climatic variation. Finally, we aggregate the population-level effects of these projected responses to address the futures of wildlife communities in each of the eight habitat types.

Federal land managers will be best positioned to retain the greatest degree of current biodiversity, and to enhance future biodiversity patterns, by retaining and recruiting diverse habitat conditions across large landscapes. This habitat-oriented focus should not be interpreted as suggesting that managers strive to retain static habitat conditions; rather, we use this approach to highlight the variety of conditions that contribute to diverse wildlife communities and identify management strategies that could facilitate a shifting mosaic of those conditions in a changing environment.

Historical Context

The SCOAP assessment area includes Deschutes, Fremont-Winema, and Ochoco National Forests; Crooked River National Grassland; and Crater Lake National Park. The historical and cultural context of this landscape is described in chapter 2. Current and projected vegetation conditions are presented in chapter 6.

Humans and climate have been important drivers of wildlife distribution and abundance in south-central Oregon for millennia (Aikens et al. 2011). Peccaries (*Tayassuidae*), giant ground sloth (*Megatherium*), giant bison (*Bison latifrons* Harlan), camel (*Camelops* Leidy), horse (*Equus* spp. L.), mastodon (*Mammut* Blumenbach), and mammoth (*Mammuthus* Blumenbach) all occupied parts of south-central Oregon and surrounding regions during the Pleistocene Epoch (11,700 years BP), but are no longer here (Aikens et al. 2011). Other species, including mule deer (*Odocoileus hemionus* Rafinesque), elk (*Cervus canadensis* Erxleben), black bear (*Ursus americanus* Pallas), cougar (*Puma concolor* L.), bobcat (*Lynx rufus* Schreber), coyote (*Canis latrans* Say), and many others, were also present and have persisted to modern times.

Changes in species composition in the upper Great Basin and Columbia Plateau at the end of the Pleistocene included a large reduction in hooved animals (artiodactyls, especially horses) and increased diversity of mice (*Mus*), rats (*Rattus*), and squirrels (cricetids and sciurids) (Marcot et al. 1998). Individual species responded in unique ways to altered conditions, producing a rearrangement of biotic communities. These changes took place over longer periods (millennia) compared to current rates of climate change (Barnosky et al. 2004, Bliss-Ketchum et al. 2013, Marcot et al. 1998).

Wildlife distribution and abundance in south-central Oregon has also been influenced by human pressures (Hessburg and Agee 2003, Marcot et al. 1998). Historically, American Indian populations were dependent on wildlife resources for food, clothing, and shelter, influencing wildlife populations through hunting and habitat manipulation (Aikens et al. 2011, Hunn 1990). Subsequent human population growth associated with Euro-American settlement and commerce in the Pacific Northwest resulted in substantial changes (Hessburg and Agee 2003). The commercial trapping era of the early to mid-19th century resulted in the near extirpation of American beavers (*Castor canadensis* Kuhl) and fur-bearing carnivores such as fishers (*Martes pennanti* Erxleben) and wolverines (*Gulo gulo* L.). The industrial grazing era of the late-19th to early-20th century (particularly after transcontinental railroads provided access to eastern livestock markets) further contributed to extirpation of large carnivores such as gray wolves (*Canis lupus* L.) and grizzly bear (*Ursus arctos* L.), resulting in widespread grazing impacts on native vegetation.

Substantial changes in forest structure as a result of timber harvest and fire exclusion throughout the 20th century also affected wildlife populations in south-central Oregon by reducing the extent of large-tree forest conditions, particularly in low- and mid-elevation settings. The combination of widespread removal of large trees and fire exclusion resulted in a substantial rearrangement of forest age class and structure distributions, with a reduction in the number of large trees and a large increase in the extent of small-tree, closed-canopy forest (Hessburg and Agee 2003). These events have played out against a backdrop of increasing human population and associated urban, agricultural, and transportation development, all contributing to changes in the nature, amount, and accessibility of wildlife habitats.

Assessment Approach

Climate change vulnerability assessments are being used to inform wildlife conservation and management at global to local scales (e.g., Case et al. 2015, Chapman et al. 2014, Halofsky et al. 2011, Hixon et al. 2010, IUCN 2008, Marcot et al. 2015, Pacifici et al. 2015, Raymond et al. 2014). Vulnerability to climate change effects has been characterized as having three components: exposure, sensitivity, and adaptive capacity (Turner et al. 2003, Williams et al. 2008). Although these assessment components have typically been applied to individual species, we use this conceptual framework to consider broader groups of species associated with general habitat categories. We define these terms by asking the following questions:

- **Exposure**—To what extent will climate conditions or climate-driven processes change in areas occupied by a given species?
- **Sensitivity**—How much will those changes affect wildlife responses via key fitness elements tied to persistence (including survival, reproduction, and dispersal)?
- **Adaptive capacity**—Are there opportunities for wildlife to change in ways that compensate for climate effects (e.g., behavioral changes, evolutionary adaptation, range shifts)?

We assess eight focal habitats selected to represent the range of landscape conditions associated with wildlife habitat management in south-central Oregon (tables 7.1 and 7.2; fig. 7.1). This is not an exhaustive list of all habitat types and conditions; the habitat types are intentionally characterized as broad in order to capture a variety of local wildlife communities. Our objective is to synthesize and interpret modeling products presented in other chapters (particularly vegetation [chapter 6] and hydrology [chapter 4]) in the context of wildlife populations and habitats. The approach described for these habitats provides a point of departure for addressing other habitat conditions not specifically presented here.

Table 7.1—Focal habitats addressed in chapter 7 and corresponding classes from MC2 vegetation modeling

Focal wildlife habitat	MC2 model[a]	Johnson and O'Neil (2001)	Altman (2000), Altman and Holmes (2000)	Simpson (2007)	Wisdom et al. (2000)[b]
Low-elevation grassland/ shrubland/woodland	Grassland Shrubland Woodland	Eastside grasslands Shrub-steppe Western juniper Woodlands	Steppe (grasslands) Shrub-steppe Juniper-sage/steppe	Ponderosa pine Western juniper	Rangeland and early-seral forest Woodland Range mosaic Sagebrush Grassland and open-canopy sagebrush
Open ponderosa pine	Dry forest	Ponderosa pine	Ponderosa pine	Ponderosa pine Douglas-fir	Low-elevation old forest
Wetland/riparian/open water	Occurs in all types	East-side riparian–wetlands	Aspen riparian	Wet types, several series[c]	
Mid-elevation old forest	Mesic coniferous forest Moist coniferous forest	East-side mixed-conifer forest	Mixed conifer	White fir–grand fir Western hemlock Shasta red fir	Broad-elevation old forest Forest mosaic
Mid-elevation early seral	Mesic coniferous forest Moist coniferous forest	East-side mixed-conifer forest	Mixed conifer	White fir–grand fir Western hemlock Lodgepole pine	Early-seral montane Forest, woodland, and montane shrub
High elevation cold forest/ contrasts	Subalpine	Montane mixed-conifer forest	Subalpine fir	Mountain hemlock Silver fir	Broad-elevation old forest Forest mosaic
High-elevation woodlands/ whitebark pine	Subalpine	Subalpine parklands	Whitebark pine	Mountain hemlock Parkland	Forest, woodland, and sagebrush
High-elevation meadow/ grassland/barren	Subalpine	Alpine grasslands and shrublands	Montane meadows	Mountain hemlock (upper extreme)	

[a] See table 6.1 in chapter 6.
[b] From Wisdom et al. (2000: 69–112).
[c] Wet riparian types might include wet western hemlock associations (TSHE-LYAM, THPL-CLUN) (although these types are mostly restricted to north of the South-Central Oregon Adaptation Partnership assessment area) and wet grand fir/white fir associations (ABCO-ABGR/ASCA3, CLUN, ACTR, LIBO2).

Table 7.2—Summary of focal wildlife habitats, characteristic species, key habitat features, exposure, sensitivity, adaptive capacity, and nonclimate stressors for the South-Central Oregon Adaptation Partnership assessment area

Focal habitat	Characteristic species	Habitat features	Exposure	Sensitivity	Adaptive capacity	Other stressors
Low-elevation grass/shrub/woodland	Greater sage-grouse, western scrub-jay, grasshopper sparrow, kangaroo rat, leopard lizard, desert horned lizard	Shrub/bunchgrass structure; ungulate forage and winter range; water sources; rocks, cliffs, and talus; deep soils (for denning and burrows)	Hottest and driest type; likely to expand; conditions likely to become more extreme; no-analog conditions may occur at lower elevations	Species adapted to dry conditions, but extreme temperature may exceed physiological thresholds; water may be more limiting; increased wildfire may decrease shrub structure	Depends on micro-refugia and water availability; good upslope range shift opportunity	Nonnative species; land use change; grazing; roads; recreation; high-intensity fire
Open large ponderosa pine	White-headed woodpecker, flammulated owl, pygmy nuthatch	Big trees with open, irregular spacing; large snags; cavities; diverse, productive understory	Currently distributed across a wide elevation range; lower elevations likely to have increased heat and drought stress	Big trees resilient to disturbance and some drought stress; high-severity fire and long-term drought may convert some areas to grassland or shrubland	Good capacity for range shift if pine is retained in mixed-species stands and transition to open structure is facilitated by thinning and fire	Nonnative species; land use change; grazing; roads; recreation; high-intensity fire; wood harvest
Wetlands/riparian/open water	Cascades frog, yellow-legged frog, spotted frog, clouded salamander, northern waterthrush, American beaver	Moving and still water; high water table; deciduous trees and shrubs; abundant snags and logs; provide connectivity and microclimates	Found in all vegetation types; degree of exposure depends on topography and hydrology	Sensitive to changes in hydrology; extreme flooding events can damage habitat structure	Adaptive capacity is limited by hydrology and topographic context	Nonnative species; land use change; grazing; roads; recreation; high-intensity fire; water use
Cold moving water	Cascade torrent salamander, American dipper, water shrew, Pacific giant salamander	Cold water temperature; moderate stream gradient (moving water); cobble and rock stream substrate	Found in mid- to high-elevation settings	Distribution will decrease as water temperatures increase and summer flows decrease; loss of riparian vegetation will increase stream temperatures	Adaptive capacity is limited by hydrology and topographic context	Roads; recreation; water use; high-intensity fire

Table 7.2—Summary of focal wildlife habitats, characteristic species, key habitat features, exposure, sensitivity, adaptive capacity, and nonclimate stressors for the South-Central Oregon Adaptation Partnership assessment area (continued)

Focal habitat	Characteristic species	Habitat features	Exposure	Sensitivity	Adaptive capacity	Other stressors
Mid-elevation old forest	Fisher, northern goshawk, spotted owl, northern flying squirrel, olive-sided flycatcher	Moderate to closed, multilayer canopy; multi-aged with big-tree component; snags and down logs; multiscale spatial and structural heterogeneity	Lower elevations likely to have increased heat and drought stress; may transition to drier types with higher frequency fire regimes	Fire regime changes could produce high-intensity fire and loss of forest structure and spatial heterogeneity; current landscape patterns are conducive to high-intensity fire	Potential exists for upward elevation shifts as species composition changes in colder forest types	High-intensity fire; roads; wood harvest; recreation
Mid-elevation early seral	Gray flycatcher, three-toed woodpecker, western bluebird, pocket gopher, Cassin's finch, kestrel	Biological legacies; snags; logs; remnant large trees; shrubs; diverse, productive understory	Distributed across a broad elevation range; lower elevations may become too hot and dry for tree regeneration	Lower elevations likely to have increased heat and drought stress; may transition to grassland or shrubland with high-intensity disturbance	Opportunities for upward elevation shift with disturbance	High-intensity fire; roads; nonnative species; recreation
High-elevation cold forest	Great gray owl, American marten, varied thrush, Vaux's swift	Moderate to closed canopy; big-tree component; snags and down logs; multiscale spatial and structural heterogeneity; deep snow and subnivean habitat	Lower elevations likely to have increased drought stress; potential for high-intensity fire in summer; extent, depth, and duration of snow will be reduced	Lower elevations may transition to mid-elevation mixed conifer; high-intensity fire could reduce structural diversity; drought stress could reduce resistance to insect and disease outbreaks	Limited opportunities for upward range shifts	High-intensity fire; recreation; insect and disease outbreaks
High-elevation woodlands	Clark's nutcracker, Townsend's solitaire, ermine	Meadow-woodland interface; whitebark pine; deep snow and subnivean habitats	Cold, high type; will be subject to increased summer drought stress; reduced winter snowpack	Summer heat, drought stress, and disease could reduce whitebark pine survival; tree encroachment may reduce woodland extent	Limited opportunities for upward range shifts	High-intensity fire; recreation; insect and disease outbreaks
Alpine meadow/ barren	American pika, yellow-bellied marmot, gray-crowned rosy finch	Diverse herbaceous vegetation; rock and talus features; deep snow and subnivean habitats	Coldest, highest type; will be subject to increased summer temperatures and drought stress; reduced winter snowpack	Increased summer temperature and drought stress may alter herbaceous vegetation; tree encroachment will reduce meadow area	Limited opportunities for upward or northward range shifts	Nonnative species; recreation

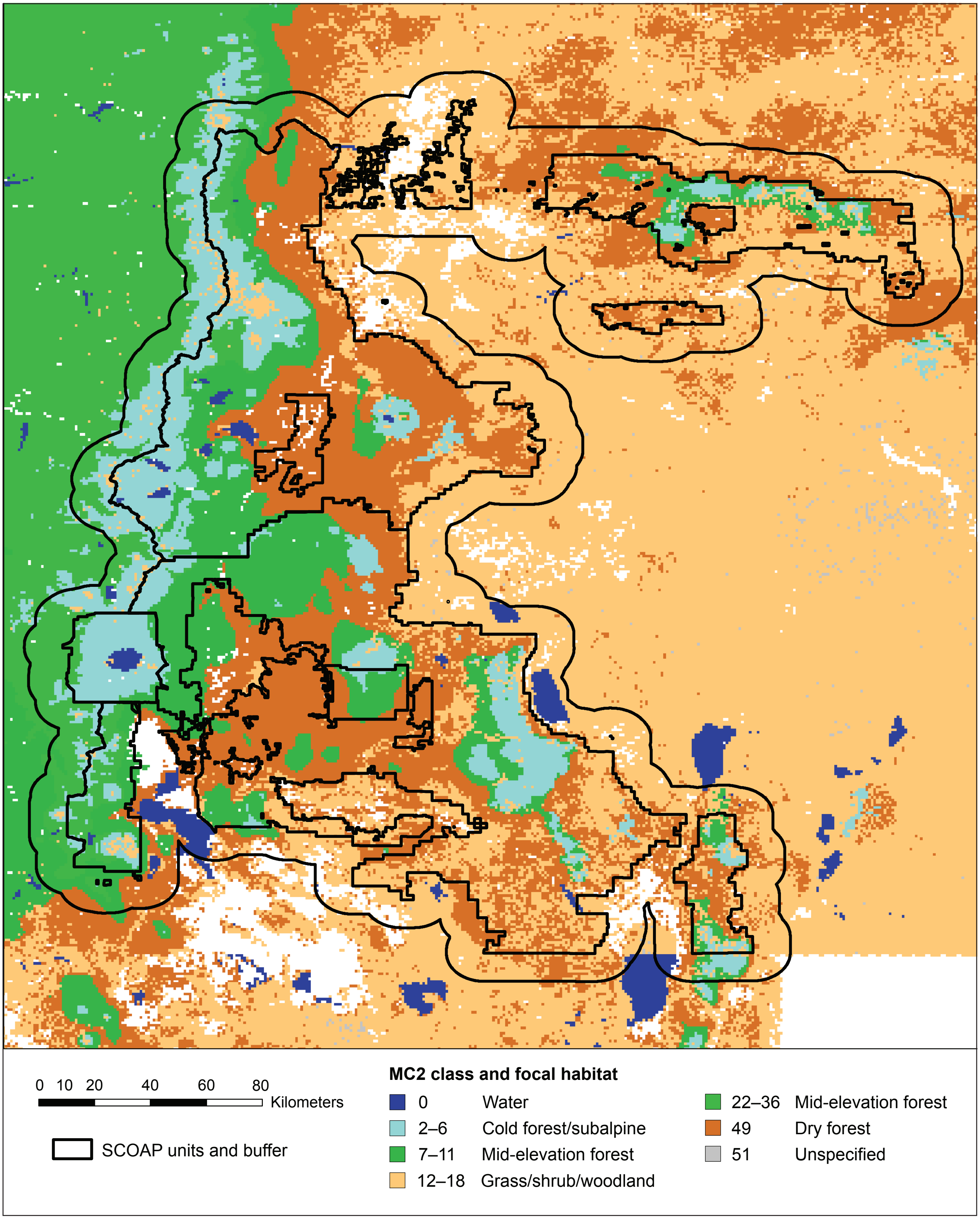

Figure 7.1—Elk and mule deer winter range in the South-Central Oregon Adaptation Partnership assessment area (spatial data are from the Oregon Department of Fish and Wildlife Oregon Conservation Strategy: https://nrimp.dfw.state.or.us/DataClearinghouse/default.aspx?).

In the following sections, we describe each focal habitat and characteristic wildlife species associated with the habitat, identify common non-climate threats, and summarize current land and natural resource management priorities (including species listed by the Interagency Special Status/Sensitive Species Program (ISSSSP) (https://www.fs.fed.us/r6/sfpnw/issssp). This assessment relied heavily on landmark literature sources on species-habitat relationships and assessment (e.g., Altman 2000, Altman and Holmes 2000, Johnson and O'Neil 2001, USDA FS 2011, Wisdom et al. 2000).

We assessed the area of current and projected vegetation types that may support the focal habitats, including a 10-km buffer around SCOAP administrative units. This assessment used two different mapping products to assess these changes: (1) U.S. Forest Service Pacific Northwest Region potential vegetation maps showing existing conditions based on Simpson (2007) vegetation series; and (2) MC2 dynamic global vegetation model products produced specifically for this assessment (chapter 6). These spatial data products are generally coarse scale. Because animal populations are influenced by habitat conditions on both SCOAP administrative units and adjacent areas, including the 10-km buffer provides a suitable scale of interpretation and appropriate context for projected landscape changes in south-central Oregon.

Focal Habitat Types

Low-Elevation Shrub-Steppe: Grassland/Shrubland/Woodland

Description—

The grassland/shrubland/woodland focal habitat group captures a range of conditions characterized by a mix of grass and herbaceous ground cover, several species of sagebrush (*Artemisia* spp.), antelope bitterbrush (*Purshia tridentata* Pursh [DC.]), other shrubs, and juniper (*Juniperus* spp.) woodlands. Specific structural characteristics of these habitats are determined by local growing conditions and disturbance history. Grass and herb vegetation may be characteristic of early-seral conditions in some areas, and juniper woodlands may be characteristic of late-seral conditions (Vander Haegen et al. 2001). This type is defined by its relative aridity and exposure to environmental extremes. It occupies the lowest elevation and warmest climatic setting in south-central Oregon, but can also occur at higher elevations depending on local disturbance history and site productivity characteristics.

These habitat conditions are commonly found in western juniper (*Juniperus occidentalis* Hook.) and ponderosa pine (*Pinus ponderosa* Douglas ex P. Lawson & C. Lawson) potential vegetation series (Simpson 2007), but can also be found in the Douglas-fir (*Pseudotsuga menziesii* Mirb. [Franco]), and dry grand fir (*Abies grandis* Douglas ex D. Don) vegetation series. Approximately 32 percent of the buffered SCOAP assessment area is capable of supporting this type under current climate conditions (table 7.3). It is the predominant focal habitat type in Crooked River National Grassland and low-elevation areas in the SCOAP assessment area. Wildlife communities and habitat characteristics associated with east-side shrubland and grassland were described by Vander Haegen et al. (2001). This focal habitat corresponds to the woodland, range mosaic, sagebrush, and grassland-open canopy sagebrush families described by Wisdom et al. (2000).

Characteristic wildlife species associated with these habitat conditions include greater sage-grouse (*Centrocercus urophasianus* Bonaparte), western scrub-jays (*Aphelocoma californica* Vigors), western meadowlarks (*Sturnella neglecta* Audubon), Ord's kangaroo rats (*Dipodomys ordii* Woodhouse), sagebrush lizards (*Sceloporus graciosus* Baird and Girard), and short-horned lizards (*Phrynosoma douglassi* Bell). Several additional species of passerine birds are associated with these habitat conditions, including horned larks (*Eremophila alpestris* L.), vesper sparrows (*Pooecetes gramineus* J.F. Gmelin), sage thrashers (*Oreoscoptes montanus* J.K. Townsend), loggerhead shrikes (*Lanius ludovicianus* L.), Brewer's sparrows (*Spizella breweri* Cassin), green-tailed towhees (*Pipilo chlorurus* Audubon), and gray flycatchers (*Empidonax wrightii* S.F. Baird) (ABC 2015). These species have a variety of physiological and behavioral traits for survival in

Table 7.3—Area of potential vegetation types capable of supporting focal habitats, by administrative unit for the South-Central Oregon Adaptation Partnership (SCOAP) region (from Simpson [2007])

Administrative unit	Low-elevation grass/shrub	Open ponderosa pine	Mid-elevation forest	High-elevation cold forest	High-elevation woodland	High-elevation meadow
				Hectares		
Crater Lake National Park	7 013	791	13 309	42 128	50 297	52 692
Crooked River National Grassland	44 504	826	0	0	0	0
Deschutes National Forest	79 314	367 851	191 881	103 010	99 416	107 255
Fremont-Winema National Forest	136 164	440 248	504 493	45 167	59 187	60 538
Ochoco National Forest	37 280	85 003	122 355	2 805	3 779	3 784
10-km buffer (other ownership)	1 268 941	270 561	311 221	188 721	136 190	136 631
SCOAP total	304 276	894 719	832 038	193 111	212 679	224 268
Grand total	1 573 216	1 165 281	1 143 259	381 832	348 869	360 899
General MC2 Projection	Little change	Little change	Increasing	Decreasing	Decreasing	Decreasing

Note: Some areas are capable of supporting multiple focal habitat types, so row sums may be greater than the total area of the administrative unit.

this environment, including adaptations for tolerating aridity and extreme heat (Vander Haegen et al. 2001). Several species of elevational migrants, including American pipits (*Anthus rubescens* Tunstall), mountain bluebirds (*Sialia currucoides* Bechstein), mule deer, and elk, use low-elevation shrub-steppe habitats for winter range (box 7.1).

Key ecological features for this habitat include native bunchgrasses, shrubs, woodland tree structures, water sources, deep soils, rocky features (cliffs, talus), and ungulate forage (ABC 2015, Altman and Holmes 2000, Vander Haegen et al. 2001, Wisdom et al. 2000). Woodland tree, shrub, and herbaceous vegetation structures provide shading, nest sites, and security cover for a variety of species. Different shrub species and growth forms provide different habitat structures (reviewed by Altman and Holmes [2000] and Vander Haegen et al. [2001]). For example, horned larks are associated with grassland conditions, sage sparrows (*Amphispiza belli* Cassin) with shrub-steppe, and Townsend's solitaire (*Myadestes townsendi* Audubon) with juniper woodlands (Reinkensmeyer et al. 2008).

Maintaining a diverse mix of woodland, shrub, and native grass structures is important for maintaining biodiversity at large spatial scales. Depending on the specific shrub-steppe community, different levels of interspersion of trees (mostly junipers), shrubs of different heights, and openings with native herbaceous vegetation provide a mix of habitat features (Altman and Holmes 2000). Although many animals are well adapted to arid conditions, some species are water limited and require access to open water sources. For example, all amphibians associated with low-elevation shrub-steppe require access to water for breeding or larval development. The riparian-arid interface provides a habitat mix for birds and amphibians, often occurring in shaded canyons that provide protection from extreme weather.

Deep soils suitable for denning and burrows provide habitat values for many species. Burrows provide security from predators, foraging sites, egg deposition sites, thermal refugia for regulating body temperature, and resting sites that minimize evaporative water loss (Vander Haegen et al. 2001). Rocky features can provide unique security and thermal values. Cliffs provide nesting and roosting sites for birds and mammals. Talus provides thermal micro-refugia and security cover for mammals and reptiles. Low-elevation shrub-steppe also provides winter range areas for seasonally migratory mule deer and elk (box 7.1).

Important nonclimate stressors affecting low-elevation shrub-steppe habitats include disruption of historical disturbance regimes, expansion of juniper woodlands, establishment of nonnative annual grasses, and human development (Altman and Holmes 2000, Davies et al. 2011). Grassland, shrubland, and woodland

Box 7.1

Migratory Ungulates: Mule Deer and Elk

Mule deer and elk are keystone species both ecologically and socially because of their herbivory effects on vegetation, their role as prey for large carnivores, and their importance for recreation and human subsistence (ODFW 2003a, 2003b). The combined effects of weather and habitat changes associated with a changing climate are likely to contribute to changes in seasonal movement patterns for these species, with potential cascading impacts on population sizes, ecological functions, and hunting opportunities.

Mule deer and elk in south-central Oregon both winter in several low-elevation areas in the eastern and southern portions of the SCOAP assessment area, then move to more dispersed higher elevation ranges in the summer (see map). Published information on elk migration movements in central Oregon is limited. Recent research conducted by the Oregon Department of Fish and Wildlife highlighted the importance of elevational movements for wildlife (Coe et al. 2015, Cupples and Jackson 2014, Mulligan 2015). The majority of deer tagged in the study were migratory (87 percent), although some were resident on year-round ranges (13 percent). Migratory deer had higher survival rates than resident deer, suggesting that benefits of moving to track seasonal changes in habitat quality outweighed the risks of movement (Mulligan 2015). Migration patterns appear to have changed since surveys were conducted in the 1960s and 1970s, possibly caused by changes in human population distribution and development (Coe et al. 2015). Some portions of U.S. Highway 97 have traffic volumes that preclude deer movement across the highway and appear to have contributed to limited accessibility of high-elevation habitat west of the highway (Coe et al. 2015). Forest management and residential development also appear to be reducing mule deer habitat, particularly on summer ranges near Bend (Duncan and Burcsu 2012, Kline et al. 2010).

Mule deer populations in central Oregon declined 24 percent from 2001 to 2015 (Mulligan 2015) because of limited forage availability, habitat loss to urban and agricultural development, migratory movement barriers, and illegal hunting (ODFW 2003b, 2011). Predation is a primary cause of mortality for mule deer, but predator removal studies suggest that predation is compensatory (i.e., predators take only animals that have substandard health), particularly at high deer densities, and that nutrition and weather are major determinants of population dynamics (Forrester and Wittmer 2013).

Climate-driven changes in weather and forage quantity and quality can be expected to influence mule deer populations, but specific effects are difficult to project. For example, mule deer in central Oregon had higher survival rates during winters with more precipitation, mostly falling as rain in winter range areas (Mulligan 2015). Increased winter precipitation may have contributed to increased forage quantity and quality during those years. However, ongoing nonnative annual grass colonization and associated changes in the abundance of native bunchgrasses and shrubs have the potential to substantially reduce forage availability across broad areas (Peterson et al. 2014).

Extended growing seasons and warmer, wetter, less snowy winter conditions may bring changes

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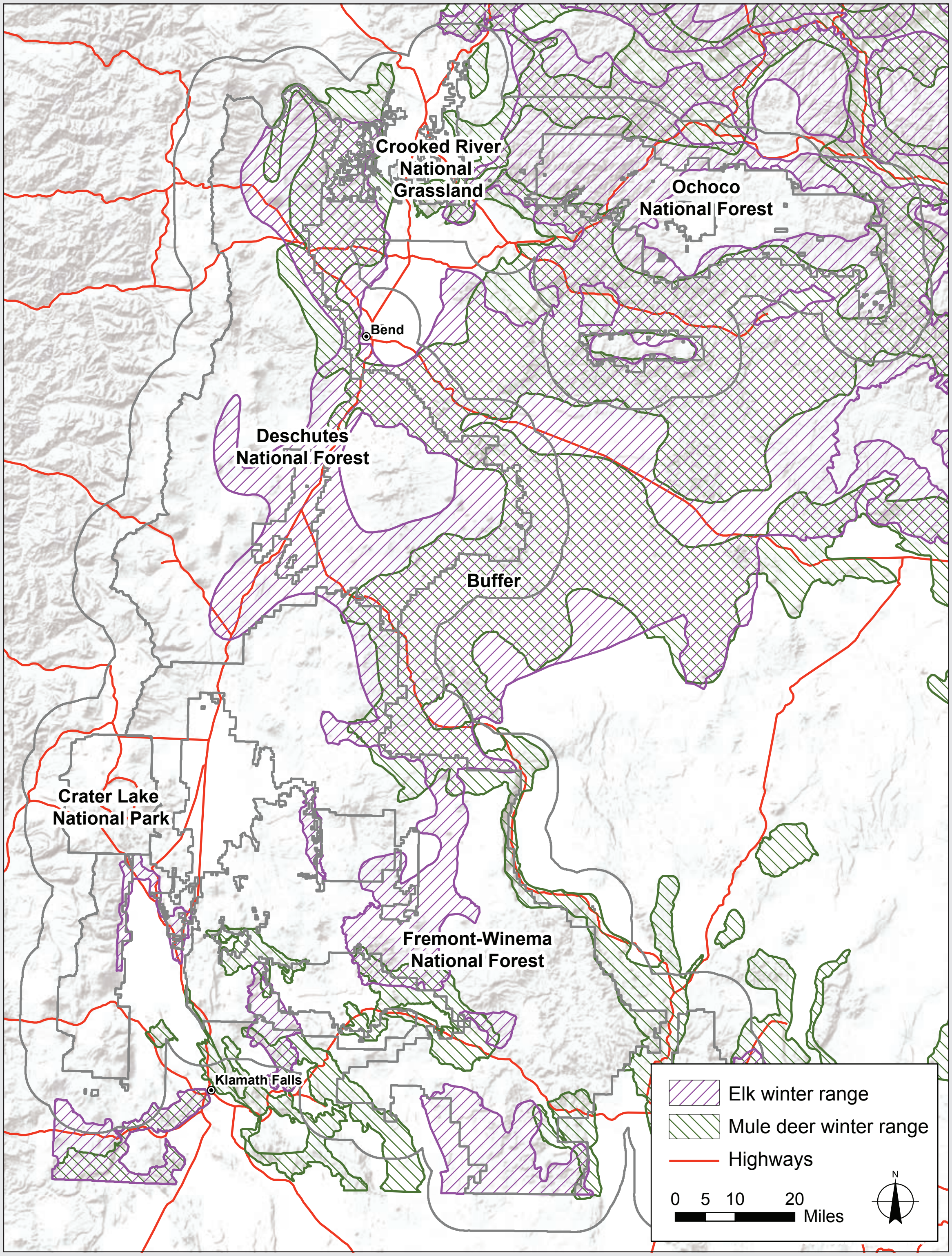

Elk and mule deer winter range in the South-Central Oregon Adaptation Partnership assessment area (spatial data are from the Oregon Department of Fish and Wildlife Oregon Conservation Strategy: https://nrimp.dfw.state.or.us/DataClearinghouse/default.aspx?).

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in migratory movement patterns. Some herds may stop migrating altogether. Such changes in seasonal movement patterns could result in substantial herbivory effects if animals stay in one place year-round. Both mule deer and elk exhibit diverse migration behaviors that are influenced by local weather, food availability, and age or condition of the individual (Middleton et al. 2013a, Monteith et al. 2011). This plasticity of migratory behavior suggests that these species are likely to adjust seasonal movement patterns to track changes in plant phenology and seasonal food availability associated with climate change, but broad-scale changes in landscape patterns and habitat quality may contribute to ongoing declines (Middleton et al. 2013b, Mysterud 2013). Wildlife crossings, such as the Lava Butte crossing on Highway 97, may help facilitate migration and buffer highway impacts (Bliss-Ketchum et al. 2013, Ochwat and Steward 2011).

habitats have been affected by both increases and decreases in fire frequency (Davies et al. 2011). In many areas, suppression of periodic fire has resulted in encroachment of conifers (particularly juniper) into areas that historically supported more open conditions. Juniper encroachment can have negative effects on habitat values for several species, including Brewer's sparrows, sage thrashers, green-tailed towhees, and greater sage-grouse (Baruch-Mordo et al. 2013, Noson et al. 2006). In contrast, substantial invasive grass colonization in some areas, particularly by cheatgrass (*Bromus tectorum* L.) or ventenata (*Ventenata dubia* [Leers] Coss.) in warmer and drier settings, has contributed to more frequent and higher intensity fire, resulting in loss of bunchgrass and shrub habitat structures (chapter 6).

Areas capable of supporting low-elevation shrub-steppe habitats have experienced more conversion to developed or agricultural land uses than any other habitat in south-central Oregon (Wisdom et al. 2000). Transportation, residential, and agricultural development have contributed to fragmentation and loss of low-elevation shrub-steppe habitats at a regional scale. Ninety-three percent of the developed and agricultural land cover within 10 km of SCOAP administrative unit boundaries falls in areas capable of supporting this habitat type (Multi-Resolution Land Characteristics Consortium 2011). Degradation of low-elevation shrub-steppe habitat is prevalent across the interior Columbia River Basin and northern Great Basin (Davies et al. 2011, Vander Haegen et al. 2001, Wisdom et al. 2000). Even areas that have not been converted to agriculture or developed land uses have frequently been altered by grazing, off-road vehicle activity, shrub clearing, and other human impacts (Wisdom et al. 2000), reducing wildlife habitat quality.

Management priorities—

- State or federal threatened or endangered species (table 7.4); greater sage-grouse.
- ISSSSP: greater sage-grouse, gray flycatcher, merlin (*Falco columbarius* L.); peregrine falcon (*F. peregrinus anatum* Bonaparte); bald eagle (*Haliaeetus leucocephalus* L.); purple martin (*Progne subis* L.); pallid bat (*Antrozous pallidus* LeConte); pygmy rabbit (*Brachylagus idahoensis* Merriam); Townsend's big-eared bat (*Corynorhinus townsendii* Cooper); spotted bat (*Euderma maculatum* J.A. Allen).
- Socially important species or habitat values: wild turkey (*Meleagris gallopavo* L.); mule deer (box 7.1); elk (particularly winter range); watchable wildlife (particularly in the arid-riparian interface).

Table 7.4—State and federal threatened and endangered species that may occur within the South-Central Oregon Adaptation Partnership assessment area

Common name	Scientific name	State status	Federal status
Amphibians:			
Columbia spotted frog	*Rana luteiventris*		Candidate
Oregon spotted frog	*Rana pretiosa*		Threatened
Birds:			
Northern spotted owl	*Strix occidentalis caurina*	Threatened	Threatened
Mammals:			
Fisher	*Martes pennanti*		Candidate
Gray wolf	*Canis lupus*	Endangered	Endangered
Wolverine	*Gulo gulo*	Threatened	

Exposure—

MC2 vegetation projections suggest that the area of vegetation types most associated with low-elevation shrub-steppe habitats may decrease by the mid- to late-21st century, transitioning to dry forest conditions (fig. 7.2). Approximately 35 percent of the SCOAP assessment area fell within low-elevation shrub-steppe types based on historical MC2 estimates. Approximately 27 percent remained in these vegetation types under most MC2 scenarios by the end of the century, with 9 percent of the assessment area changing from low-elevation shrub-steppe to other types (predominantly dry forest; fig. 7.2). Most of the MC2 scenarios showed contraction of low-elevation shrub-steppe conditions in the southeastern portions of Fremont-Winema and Ochoco National Forests. Some scenarios (fewer than half) showed expansion of low-elevation shrub-steppe along the eastern edge of Deschutes National Forest and areas adjacent to the western portion of Ochoco National Forest.

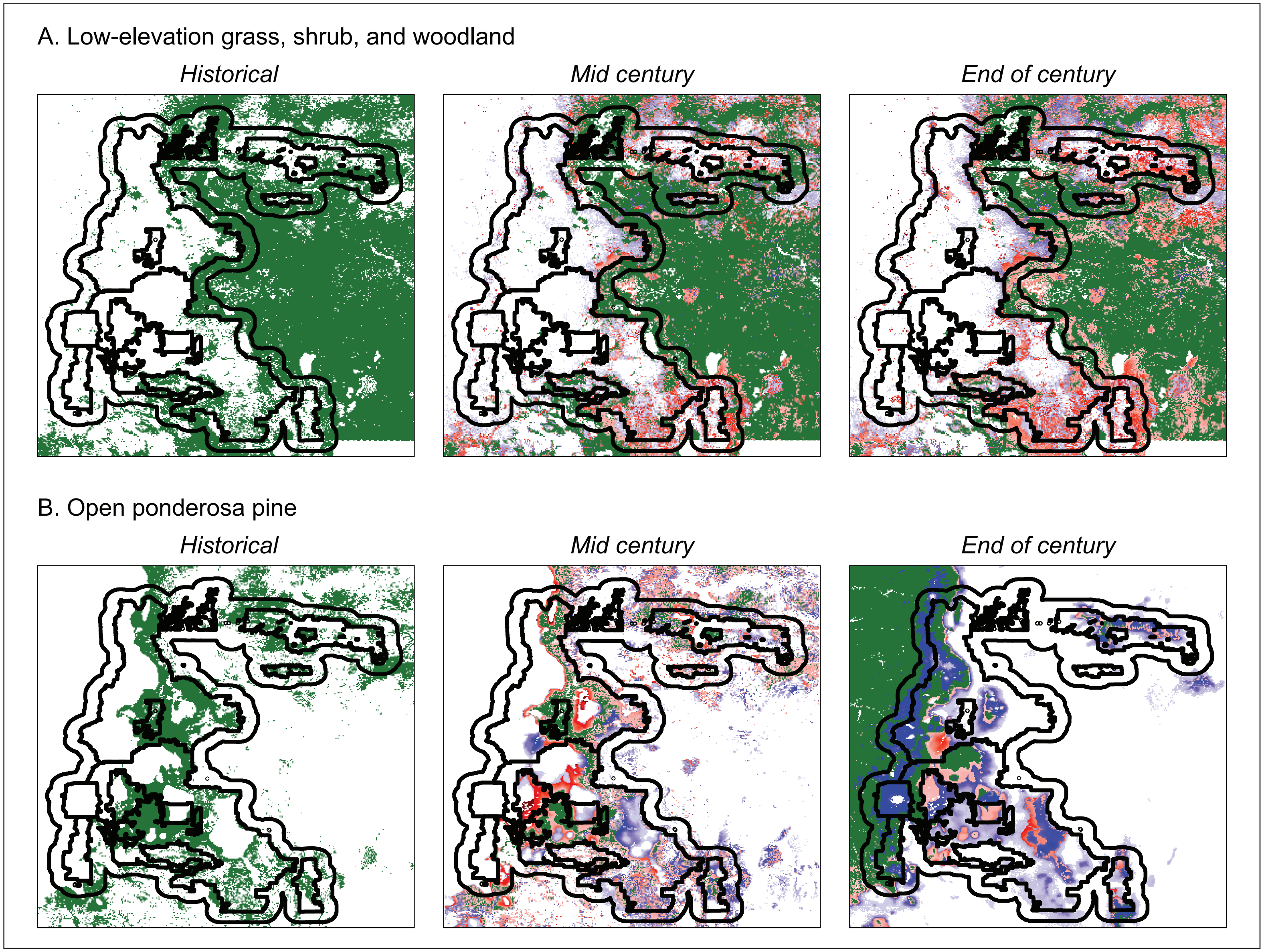

Figure 7.2—Projected distribution changes for primary vegetation types associated with focal wildlife habitats based on MC2 vegetation simulations using 28 climate change scenarios (see chapter 6). MC2 projections are displayed for historical (1970–1999), mid-century (2035–2064), and end-of-century (2077–2100) time periods. The focal wildlife habitats displayed are (A) low-elevation grass, shrub, and woodlands; (B) open ponderosa pine; (C) mid-elevation coniferous forest; and (D) high-elevation cold forest, woodlands, and subalpine meadows. Green areas remain capable of supporting the type across all scenarios, blue areas indicate expansion of area capable of supporting the type, red areas indicate contraction of area capable of supporting the type, and darker shades of red or blue indicate more agreement across scenarios.

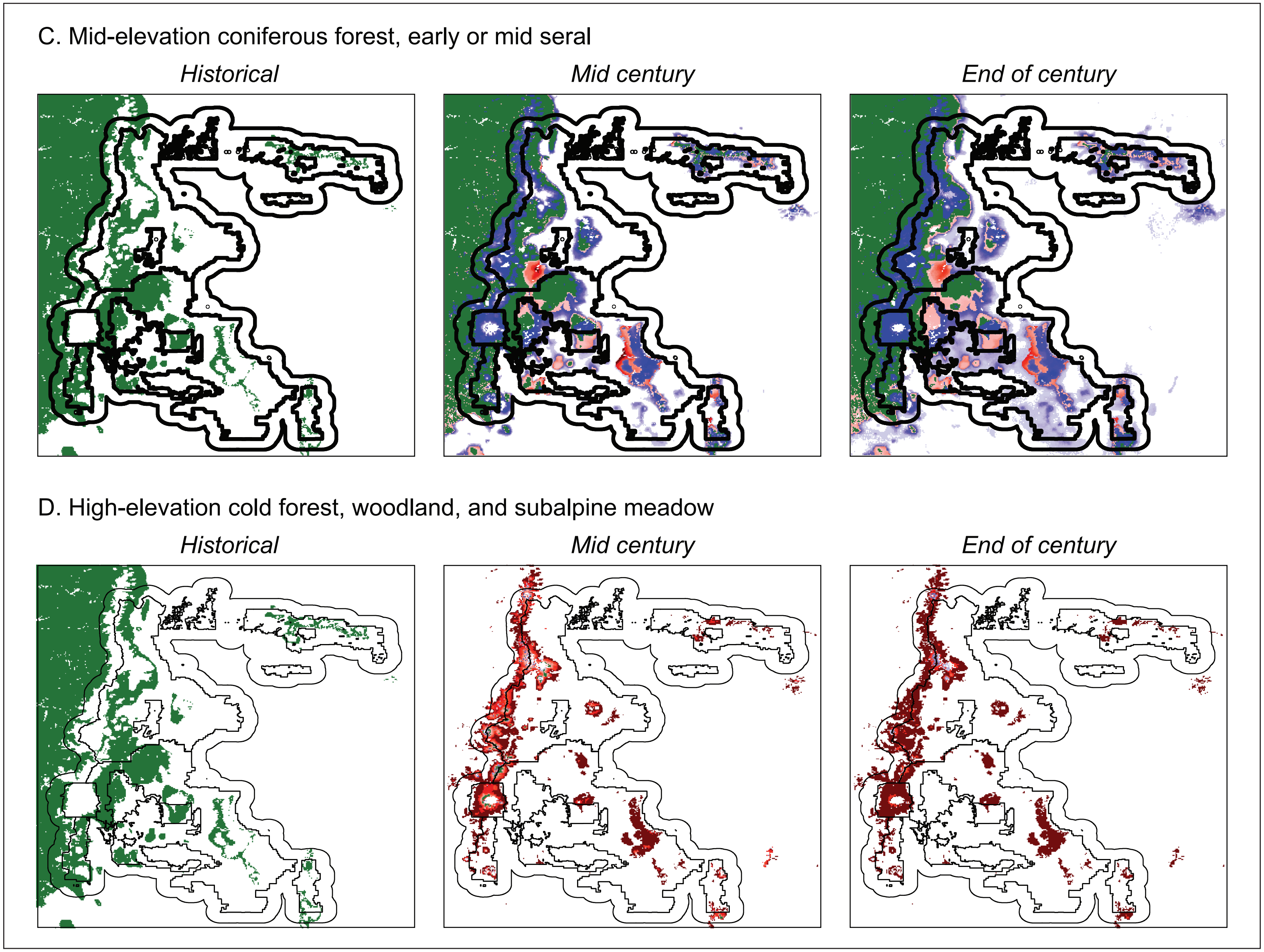

Figure 7.2 (continued)—Projected distribution changes for primary vegetation types associated with focal wildlife habitats based on MC2 vegetation simulations using 28 climate change scenarios (see chapter 6). MC2 projections are displayed for historical (1970–1999), mid-century (2035–2064), and end-of-century (2077–2100) time periods. The focal wildlife habitats displayed are (A) low-elevation grass, shrub, and woodlands; (B) open ponderosa pine; (C) mid-elevation coniferous forest; and (D) high-elevation cold forest, woodlands, and subalpine meadows. Green areas remain capable of supporting the type across all scenarios, blue areas indicate expansion of area capable of supporting the type, red areas indicate contraction of area capable of supporting the type, and darker shades of red or blue indicate more agreement across scenarios.

Because summers are hot and dry, winter precipitation in the form of snow and rain is particularly important for recharging water storage in the deeper soil layers (Schlaepfer et al. 2011, Schwinning et al. 2003). Therefore, extended periods of high temperatures and low precipitation during summer could lead to soil moisture deficits and seasonal drought. Although many shrubland plants and animals are adapted to drought, warmer spring temperatures could lead to earlier winter snowmelt and increased evapotranspiration, contributing to earlier and more severe seasonal drought (Schlaepfer et al. 2012). Hydrologic projections show that low-elevation shrub-steppe may not experience the same degree of change in water flows as higher elevation areas that are more dependent on snowpack (chapter 3). However, water sources in lower elevation, hotter settings may be more sensitive to changes in water availability because of higher temperatures, accelerated drying, and competition with human water uses.

Sensitivity—

Altered disturbance regimes will largely determine habitat structure and distribution in low-elevation shrub-steppe habitats. Overall, MC2 projects more frequent fires in shrubland and woodland vegetation types (see fig. 6.19). Elevated carbon dioxide (CO_2) concentrations have also been shown to increase biomass production of cheatgrass and other annual grasses, which could affect shrubland composition and disturbance regimes (Lucash et al. 2005, Smith et al. 2000). However, wildfires are generally limited in shrublands by a lack of ignition sources, particularly during the fire season. Altered fire frequency may have two countervailing influences on the distribution of shrub-steppe habitat characteristics. Increasing fire frequency will likely reduce structural diversity associated with shrubs and trees, contributing to a decline in habitat suitability for many species. However, increased fire frequency in low-elevation forest, as projected by MC2, may facilitate some expansion of shrub-steppe habitat. The spatial and structural simplification caused by increased fire frequency is likely to provide habitat conditions favored by species like horned larks, while reducing the extent of spatially and structurally diverse shrub habitat favored by species like sage-grouse and pygmy rabbit.

Projected warming of mean annual temperatures coupled with increased variability of summer maximum temperatures may exceed thermal tolerances for some animals. Species that are best adapted to hot and dry conditions may be preadapted to increasingly arid and hot conditions (e.g., horned lizards, kangaroo rats). Small-bodied animals that can exploit fine-scale thermal refugia (e.g., rock crevices or burrows) may be less sensitive to extreme temperatures than large-bodied animals that have more limited physiological capacity for heat dissipation and fewer opportunities to escape the heat (Speakman and Krol 2010). Variability of summer maximum temperatures will be particularly important if water availability becomes more limiting for some species. For example, species that depend on open water sources (e.g., amphibians, large mammals) are likely to be at risk if those water sources dry up. Seasonal food availability (grass and herbaceous forage, fruit from mast-producing plants) may be reduced if the frequency and magnitude of drought increase (Finch et al. 2016).

Adaptive capacity—

Adaptive capacity of wildlife associated with low-elevation shrub-steppe habitats is expected to be strongly influenced by tolerance to extreme temperatures, behavioral adaptation to those temperatures, and mobility in response to changes in habitat structure and food availability. Availability of fine-scale thermal micro-refugia (e.g., burrows, talus slopes, shading vegetation and topography) is likely to become more important as animals attempt to behaviorally adapt to warmer temperatures. Topographic features like canyons and north-exposure slopes that provide cooler environments compared to the surrounding landscape may become increasingly important thermal refugia. Species that are able to alter their behavior and habitat selection patterns to minimize heat stress may be most likely to persist. Because shrub-steppe habitats are present at the lowest elevations in south-central Oregon, there are ample opportunities for these habitat conditions and associated species to shift to higher elevations. Opportunities for seasonal movements and range shifts will be particularly important for wildlife responding to hotter and drier seasonal conditions. Human-created barriers (e.g., urban development, major highways) have the potential to negatively affect opportunities for these movements.

Open Large-Tree Ponderosa Pine

Description—

This focal habitat is characterized by large, unevenly spaced ponderosa pine or Douglas-fir trees (early-seral, fire-resilient tree species) with a diverse herbaceous and shrub understory. The large-tree, open understory structure is most often maintained by intermittent low-, moderate-, or mixed-severity fires that kill competing smaller trees, preventing encroachment by shade-tolerant tree species and maintaining relatively light fuel loads (Hessburg et al. 2015). These disturbance processes historically produced complex landscape patterns that included a mix of treeless openings, open forest, and patches of dense forest (Hessburg et al. 2016). Landscape patterns were strongly influenced by fine-scale topographic characteristics, with ridgetops and southern exposures more likely to be in more open conditions, and northern exposure, lower slope settings more likely to have closed forest characteristics. These habitat conditions can be found in the ponderosa pine, Douglas-fir, and dry or moist grand fir potential vegetation series described by Simpson (2007). Areas capable of supporting this habitat type include about 25 percent of the SCOAP assessment area (table 7.3), overlapping broadly with areas that support shrub-steppe and mixed-conifer types. Habitat conditions and wildlife communities associated with this type were described by Sallabanks et al. (2001). This focal habitat is consistent with the low-elevation, old-forest family described by Wisdom et al. (2000).

Characteristic wildlife species associated with open large-tree ponderosa pine forest include white-headed woodpeckers (*Picoides albolarvatus* Cassin), flammulated owls (*Otus flammeolus* Kaup), and pygmy nuthatches (*Sitta pygmaea* Vigors) (Sallabanks et al. 2001, USDA FS 2011). This is the most biodiverse habitat type based on number of associated vertebrate species. Many wildlife species associated with adjacent habitat types, including low-elevation shrubland and woodlands, and mid-elevation mixed-conifer forests, are also found in ponderosa pine-dominated dry forests.

Key ecological features and habitat components include large living and dead trees (including snags and logs), a productive and diverse herb and shrub understory, and abundant spatial and structural complexity (Altman 2000, Sallabanks et al. 2001, USDA FS 2011). Big trees with open, irregular spacing provide nesting structures for arboreal nesting birds and perches for insectivorous birds. Large snags and logs provide cool, moist micro-refugia for smaller animals, including mammals, reptiles, and amphibians. Cool, moist microsites near seeps or under logs and accumulated vegetation are important for sensitive slugs (Klamath tail-dropper [*Prophysaon* sp. nov.]) and terrestrial snails (shiny tightcoil [*Pristiloma wascoense* Hemphill], Dalles mountainsnail [*Oreohelix variabilis* J. Henderson]).

Cavities in large live trees and snags provide nesting and roosting structures for woodpeckers (Picidae) and bats (*Chiroptera* spp.) (box 7.2). Diverse and productive understory vegetation, including mast-producing shrubs, provide food for a variety of small mammals and herbivores. Stand-scale spatial clumping of trees produces canopy patterns that provide small patches of interconnected canopy without producing contiguous fuel patterns (Churchill et al. 2013). Broad-scale landscape heterogeneity, including treeless openings and some patches of closed-canopy forest, are an important characteristic of dry forest landscapes (Hessburg et al. 2015, 2016) (box 7.3).

The current distribution of open large-tree ponderosa pine forest is greatly reduced compared to historical conditions because of removal of large trees during past timber harvests, encroachment of small shade-tolerant trees (particularly true firs [*Abies* spp.]) with fire exclusion, and conversion to urban or residential land uses (Hagmann et al. 2013, Hessburg et al. 2015, Wisdom et al. 2000). Low-elevation forest areas adjacent to federal lands are attractive for residential and recreational

Box 7.2

Legacy Structures

Increased frequency and severity of disturbances—drought, wildfire, insects, diseases, severe storm damage—are expected to have significant effects on wildlife habitat in a warmer climate. The biotic components of the predisturbance vegetation and animal communities that persist after disturbance, sometimes called biological legacies, influence ecological outcomes and postdisturbance recovery (Franklin et al. 2000). The most visible biological legacies in disturbed landscapes are often large, old surviving trees, snags, and logs.

Growing and maintaining large old trees and other biological legacies for wildlife habitat will be a significant challenge in a warmer climate. Reduced abundance of large trees, particularly in low and mid elevations, has been one of the most notable changes from historical conditions in the forests of central Oregon (Hessburg et al. 2016). These large old trees, both living and dead, are an important component of disturbance resilience (e.g., Bunnell and Houde 2010, Seidl et al. 2014, Swanson et al. 2011).

Ecological processes and functions important for wildlife are associated with five types of structures: living trees with decayed parts, trees with hollow chambers, trees with brooms (particularly from mistletoe), snags, and logs (Bull et al. 1997). Early-seral trees (e.g., ponderosa pine, Douglas-fir) generally provide the most persistent biological legacies, and forest restoration treatments typically favor early-seral species for their fire resilience and historical abundance on the landscape. True firs, which also provide habitat structures because of their soft wood and susceptibility to decay, are particularly important in stands where they are the dominant late-seral species.

Altered disturbance regimes, tree mortality patterns, and other biotic interactions associated with a changing climate are likely to influence the abundance and distribution of biological legacies. Large trees are valuable habitat components that take a long time to replace, and increasing fire frequency and severity are likely to reduce the number of large logs and snags in some areas. However, drought stress and associated stressors (e.g., insects) could increase large-tree mortality, contributing to short-term, local increases in snag and log abundance (Allen et al. 2015). Tree mortality and decay processes that contribute to the development of wildlife habitat structures are complex, involving many organisms, including arthropods and fungi.

Monitoring the availability of legacy structures will help determine potential trends in key elements of wildlife habitat. Identifying management strategies that facilitate the growth and retention of these biological legacies will be a critical component of maintaining wildlife habitat values in a changing climate.

Box 7.3

Heterogeneity in Dry Forests

Multiscale spatial heterogeneity, historically maintained by mixed-severity and low-severity wildfire, is an important component of resilient dry and mesic mixed-conifer forests. Variability of patch sizes, patch configuration, and tree clumping create spatial heterogeneity (Churchill et al. 2013; Franklin and Johnson 2012; Hessburg et al. 2005, 2015, 2016; Larson and Churchill 2012; Perry et al. 2011), which in turn provides a diversity of habitats for plants and animals.

White-headed woodpeckers (*Picoides arbolarvatus* Cassin) have been identified as a representative species for dry forest habitats, with the assumption that their needs will reflect the needs of other species associated with these habitats (Altman 2000, Raphael et al. 2001, Suring et al. 2011, Wisdom et al. 2000). This woodpecker uses open canopies for nesting and closed canopies for foraging; thus it needs patchy, heterogeneous forests for breeding habitat. Measures of landscape heterogeneity between open (<40 percent canopy cover) and closed (>40 percent canopy cover) forests are important components in habitat suitability index (HSI) models for the bird (Hollenbeck et al. 2011, Latif et al. 2015). Landscape metrics included in HSI models for white-headed woodpeckers include edge density (ED), interspersion and juxtaposition index (IJI), aggregation index (AI), and contagion (CONTAG) (McGarigal et al. 2002).

Two HSI models have been developed using nest site locations in central Oregon. Heterogeneity in the models was assessed for landscapes (100 ha) surrounding nest sites. ED and IJI were relatively high (Hollenbeck et al. 2011, Latif et al. 2015). In burned habitat, nest sites occurred in areas with patches of different burn severities that were intermixed, rather than areas that had a few large burned patches (Wightman et al. 2010). The AI of the landscape as a whole (162 ha), of open stands at the landscape scale (100 ha), and of closed forest at the stand scale (12 ha) were included in the final HSI models for white-headed woodpecker in the Blue Mountains. CONTAG was also in the final nest-site model. White-headed woodpeckers selected landscapes with moderately high overall AI and open-habitat AI, and low levels of CONTAG. At the stand scale, they selected for moderate to high AI for closed-canopy forest. Figures illustrate landscape- and stand-scale heterogeneity in the Blue Mountains in areas that were identified as highly suitable habitat.

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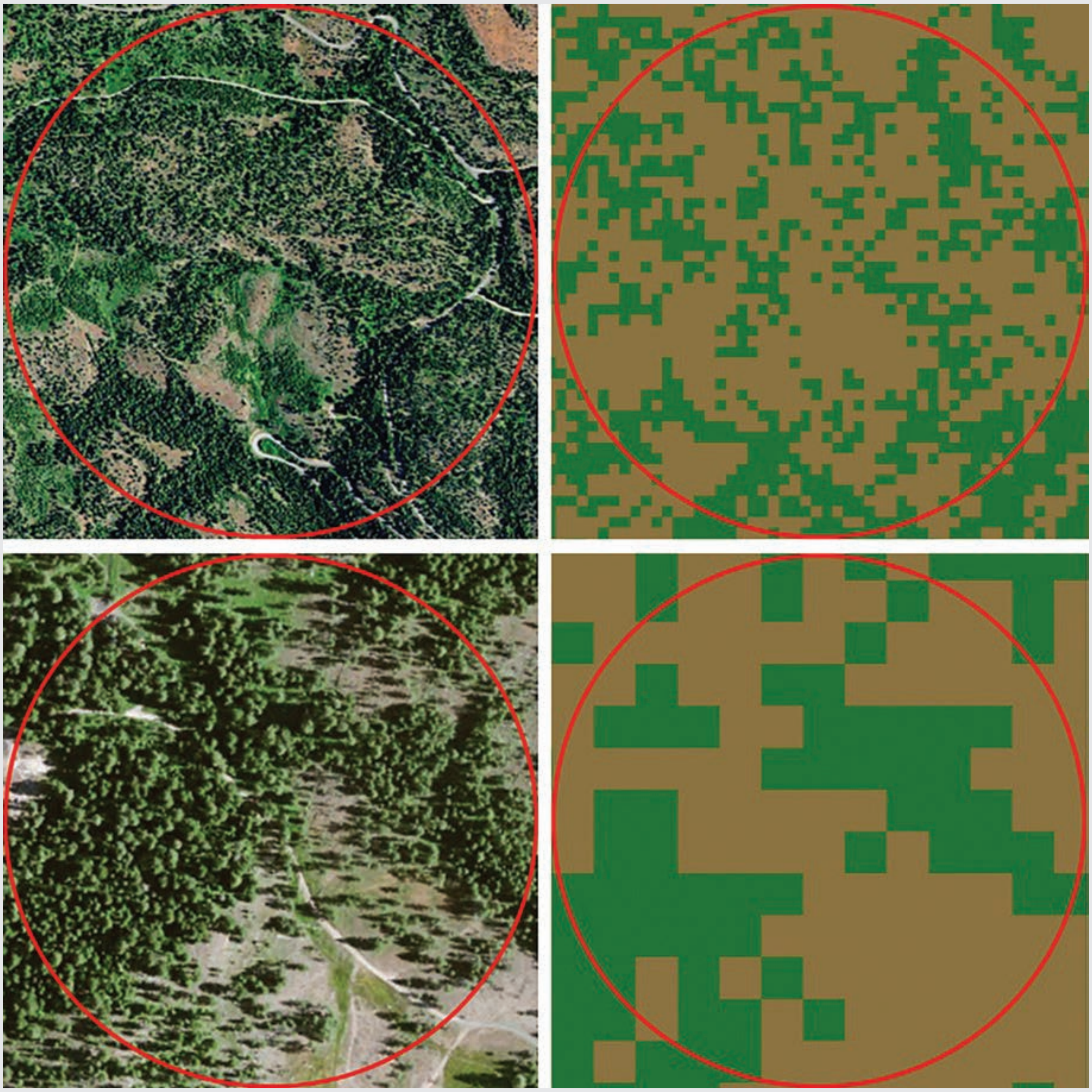

Heterogeneity at the 162-ha scale (area in red circle in top images) and at the 12-ha scale (area in red circle in bottom images) surrounding a 30-m pixel with a high habitat suitability index for white-headed woodpecker habitat. The images on the left are from National Agriculture Imagery Program imagery, and the images on the right are based on gradient nearest neighbor data. Brown represents open-forest pixels (<40 percent canopy cover), and green represents closed-forest pixels (>40 percent canopy cover). For the top images, the aggregation index for open habitat is 73 percent, the overall aggregation index is 66 percent, and contagion is 8 percent. For the bottom images, the aggregation index is 61 percent.

development, which have contributed to an emphasis on fire suppression in wildland-urban interface (WUI) areas, and subsequent encroachment by shade-tolerant tree species. Restoration of open ponderosa pine conditions has been a focus of much recent management activity in south-central Oregon (USDA FS 2015).

Non-climate stressors for this type include wildfire, invasive species, human land uses, grazing, roads, recreation, and wood harvest (Sallabanks et al. 2001, USDA FS 2011, Wisdom et al. 2000). Large ponderosa pine trees are generally resistant to fire under historical fire regimes. High fuel loads as a result of fire exclusion and encroachment by shade-tolerant trees have increased the risk of large-scale, high-intensity wildfire, and pine mortality when fire does occur. Colonization by invasive herbaceous species such as cheatgrass and knapweed (*Centaurea* spp.) reduces understory diversity and productivity, and degrades habitat suitability for ground-nesting birds, small mammals, herbivores, and invertebrates. Continued residential development on private lands could further reduce the extent of favorable habitat, increase fragmentation, and limit management options (e.g., prescribed fire in the WUI). Livestock grazing can facilitate colonization by invasive species and alter low-intensity fire dynamics. Roads contribute to fragmentation and invasive species colonization. Recreation can contribute to local soil compaction. Historical wood harvest has reduced the abundance of large trees, snags, and logs.

Management priorities—

- State or federal threatened or endangered species (table 7.4): gray wolf.
- ISSSSP: fringed myotis (*Myotis thysanodes* Miller); spotted bat (*Euderma maculatum* J.A. Allen); Townsend's big-eared bat; pallid bat (*Antrozous pallidus*); white-headed woodpecker; Klamath tail-dropper; shiny tightcoil; Dalles mountainsnail.
- Socially important species or habitat values: wild turkey; mule deer (box 7.1); elk (particularly winter-range values).

Exposure—

MC2 vegetation projections showed little change in the total area capable of supporting dry forest by the end of the century (average of 1 percent increase across all global climate models [GCMs]), but projections varied considerably by GCM, largely caused by differences in precipitation projections. For example, under the "hot-dry" GCM (MIROC-ESM-CHEM) scenario, MC2 projected the greatest amount of expansion of current habitat, whereas under the "hot-wet" GCM (CanESM2) scenario, MC2 projected the most contraction (chapter 6). Overall, projections suggested a redistribution of dry forests within the SCOAP assessment area (fig. 7.2). Much of the potential increase in dry forests was projected to occur along the eastern and southern edges of its current distribution (fig. 7.2). It is likely that precipitation increases, longer growing season, warming in cold-limited ecosystems, and possibly increased water use efficiency associated with increased CO_2 are driving these modeled changes. Approximately 33 percent of the buffered assessment area was within dry forest vegetation types, based on MC2 historical estimates. Approximately 28 percent of the assessment area was projected to remain in this type through the end of the century under most climate scenarios. Six percent of the SCOAP assessment area converted from dry forest to another type (predominantly moist conifer forest), and 7 percent converted from another type (mostly grass, shrub, and woodland) to dry forest under at least half of the climate scenarios.

Sensitivity—

Wildlife habitat conditions for this type will be influenced by broad-scale disturbance processes across several biomes. Big early-seral trees (ponderosa pine and Douglas-fir) are relatively resilient to disturbance and seasonal drought stress. Smaller trees and overstocked sites are less resilient. Large-tree open understory forests are likely to be more resilient to climate change stressors than other forest conditions. Ponderosa pine is distributed across a wide elevation range. Lower elevations may experience increased summer heat and drought stress. Some areas currently with low-elevation forest cover may not have historically retained that cover and have it now owing primarily to fire exclusion.

Transitions in fire regimes associated with changing climate conditions are expected to produce large-scale, high-intensity fire and consequent loss of forest structure and spatial heterogeneity (Barbero et al. 2014). Stand and landscape characteristics that are currently inconsistent with historical fire regimes are likely to become increasingly vulnerable with projected increases in fire frequency. MC2 projected a decrease of mean fire return interval, and there may also be an increase in fire severity (chapter 6). High-severity fire under extreme fire weather conditions can result in widespread tree mortality, even in stands that would be fire resilient under normal conditions. This is particularly true for stands surrounded by high fuel loading (Kane et al. 2015). However, the transition to more frequent fire could also serve to maintain lower fuel loads in open forest types, as long as those forests are able to survive the initial fire events that remove fuels accumulated as a consequence of recent fire suppression and forest management practices. Repeated fire may also reduce the abundance of snags, logs, and tree clumps, as well as reduce understory shrub structure.

Spatial homogenization resulting from increased disturbance frequency and tree mortality has the potential to cause detrimental changes in the availability and configuration of important habitat features for white-headed woodpeckers and other species that require a mix of open- and closed-canopy conditions (box 7.3). Consequences of the loss of structural diversity for animals associated with this habitat type may include loss of nesting and resting structures and thermal refugia associated with closed-canopy patches, large logs, and snags, and altered food availability from loss of mast-producing shrubs. Changes in overstory canopy cover, understory plant species composition, and growing season are expected to alter forage quality and quantity, and might produce an increase in herbaceous forage availability during spring and autumn.

Adaptive capacity—

The open large-tree ponderosa pine forest type is perhaps the best adapted forest type in south-central Oregon to warmer conditions and summer drought. It has good capacity for up-slope plant species movement if pine is retained in mixed-species stands, and the transition to open structure is facilitated by thinning or low- to moderate-intensity fire. Many associated animal species are relatively well adapted to hot, dry conditions and have opportunities for upward range shifts if this habitat structure is provided at higher elevations. However, development of large trees, snags, and logs may not keep pace with climate-induced shifts in areas capable of supporting these habitat conditions. Retention of these structures in areas where they currently exist may be important for providing transitional opportunities for wildlife. Forest restoration treatments that promote fire- and drought-resilient stand structures and landscape patterns are likely to become increasingly important.

Wetlands, Riparian Areas, and Open Water

Description—

This focal habitat captures a variety of wetland, riparian, and open-water conditions found near streams, springs, and lakes, and in areas with abundant groundwater. Complex and diverse, these habitats are the interface between aquatic and terrestrial systems (Gregory et al. 1991, Penaluna et al. 2017). The distribution of this focal habitat is primarily determined by precipitation, evaporation, and hydrology, particularly surface and groundwater flow patterns. These habitats comprise a relatively small portion of the landscape, but contribute biodiversity values disproportionate to their size (Penaluna et al. 2017). Wildlife communities associated with riparian habitats were described by Kauffman et al. (2001).

Characteristic species associated with wetland, riparian, and open-water habitats include Cascades frogs (*Rana cascadae* Slater), foothill yellow-legged frogs (*R. boylii* Baird), Oregon spotted frogs (*R. pretiosa* Baird and Girard), clouded salamanders (*Aneides ferreus* Cope), Pacific jumping mice (*Zapus trinotatus* Rhoads), and northern waterthrushes (*Seiurus noveboracensis* J.F. Gmelin). Rocky Mountain tailed frogs (*Ascaphus montanus* Mittleman and Myers), American dippers (*Cinclus mexicanus* Swainson), and water shrews (*Sorex palustris* Richardson) are characteristic of cold moving-water habitats. Beavers are a keystone species for this habitat because of their influence on streamflow and groundwater recharge patterns. A wide variety of birds, mammals, and reptiles also use resources associated with wetland and riparian habitats, even if they are not primarily associated with these conditions (Kauffman et al. 2001).

Many migratory birds, including yellow warblers (*Setophaga petechial* L.), common yellowthroats (*Geothlypis trichas* L.), and warbling vireos (*Vireo gilvus* Vieillot), reach their highest population densities in riparian deciduous vegetation. Other species, including great blue herons (*Ardea herodias* L.), common goldeneyes (*Bucephala clangula* L.), and hooded mergansers (*Lophodytes cucullatus* L.), are associated with open water or shorelines. Amphibians are associated with wetlands, riparian, and open-water habitats because they require at least transient aquatic habitat for parts of their life history. A variety of aquatic and semi-aquatic invertebrates are also important components of this community. The ISSSSP lists 34 species of sensitive aquatic snails, 4 species of freshwater mussels or clams, and 4 species of caddisflies for the national forests in the SCOAP assessment area.

Key ecological features and habitat components of riparian, wetland, and open-water habitats include moving and still water, seasonal flow or wetness (ephemeral or perennial waters), riparian vegetation, woody debris, including snags and logs, diverse and abundant invertebrate and plant food items, linear and connected spatial patterns (habitat connectivity), substantial topographic shading, and a cool, moist microclimate (Kauffman et al. 2001, Penaluna et al. 2017, USDA FS 2011). Riparian systems occupy the lowest topographic positions relative to surrounding areas, so they have substantial nutrient and energy inputs because organic matter simply flows into these systems (Gregory et al. 1991). Logs that fall into streams can create diverse systems of pools, providing habitat for aquatic vertebrate and invertebrate communities. Emergent adults of aquatic insects are prey for a variety of insectivorous wildlife, including birds, bats, reptiles, and amphibians (Baxter et al. 2005). Rapidly growing, deciduous trees, particularly cottonwoods (*Populus trichocarpa* Torr. & A. Gray ex. Hook.) and quaking aspen (*P. tremuloides* Michx.), contribute to the availability of cavities and snags.

The linear, connected pattern of riparian systems can provide opportunities for animal movement through productive and secure settings and across different elevations. Streamside vegetation, evaporative cooling from open water, cold air drainage, and topographic shading contribute to cool microhabitats. The appropriate stream gradient and forest shading to maintain cold water temperatures are typically found in moist grand fir, western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), mountain hemlock (*T. mertensiana* [Bong.] Carriere), and Pacific silver fir (*Abies amabilis* Douglas ex J. Forbes) forests. Coldwater flows in summer are often dependent on high-elevation snowmelt, but may also be found in spring-fed streams.

Non-climate stressors for wildlife include invasive species, land use change, grazing, roads, recreation, fire, and human water use (Penaluna et al. 2017, USDA FS 2011). Several diseases have been identified as threats to amphibian communities in recent decades (Van Rooij et al. 2015). Invasive species can alter community interactions, reduce food availability, and change habitat structure. Concentrated grazing by wild and domestic ungulates can contribute to loss of woody vegetation, streambed down-cutting, compromised hydrologic function, and reduced aquatic insect diversity (Brookshire et al. 2002, Sakai et al. 2012). Roads can alter flooding, sedimentation, and debris flow patterns in riparian systems (Jones et al. 2000). Riparian and open-water settings attract recreational and residential development, contributing to the loss of riparian vegetation, soil compaction, loss of dead-wood habitat structures, and high levels of human disturbance (Gaines et al. 2003). The historical role of fire in riparian areas is complex (Olson and Agee 2005). Relatively cool, moist riparian areas can make them fire refugia (Camp et al. 1997), but when fuels are dry, high-intensity fire can burn through riparian areas, with fire moving rapidly through the landscape via their linear shape and high fuel loads (Pettit and Naiman 2007).

Management priorities—

- State or federal threatened or endangered species (table 7.4): Oregon spotted frog.
- ISSSSP: fringed myotis, spotted bat, Townsend's big-eared bat, western pond turtle (*Actinemys marmorata* Baird and Girard), Columbia spotted frog (*Rana luteiventris* Thompson), northern leopard frog (*Lithobates pipiens* Schreber), Rocky Mountain tailed frog, purple martin, red-necked grebe (*Podiceps grisegena* Boddaert), American white pelican (*Pelecanus erythrorhynchos* Gmelin), northern waterthrush, Lewis's woodpecker (*Melanerpes lewis* G.R. Gray), least bittern (*Ixobrychus exilis* Gmelin), harlequin duck (*Histrionicus histrionicus* L.), bald eagle, yellow rail (*Coturnicops noveboracensis* Gmelin), bufflehead (*Bucephala albeola* L.), tule goose (*Anser albifron elgasi* Delacour & Ripley), tricolored blackbird (*Agelaius tricolor* Audubon), silver-boardered fritillary (*Boloria selene* Schiffermüller), Columbia clubtail (*Gomphus lynnae* Paulson). Also, 34 aquatic snails, 4 freshwater mussels or clams, and 4 caddisflies.
- Socially important species or habitat values: beaver, watchable wildlife.

Exposure—

This habitat type is found in all potential vegetation zones. Changes associated with climate change will be affected by changes in precipitation, evaporation, and hydrologic function. Degree of exposure will vary depending on the hydrologic setting and whether the local hydrologic regime is dominated by snowmelt or groundwater (chapter 3). All areas are likely to experience increased winter flows and decreased summer flows as more winter precipitation falls as rain, shifting peak flows earlier into late winter and exacerbating summer droughts. Snowmelt-dominated systems are projected to experience the most substantial changes in seasonal flow patterns.

Increased variability and potential for extreme precipitation events (chapter 4) will contribute to extreme floods. Increased fire frequency and severity may also affect riparian and wetland vegetation, particularly if high-intensity fire is carried into wetlands and riparian areas from adjacent portions of the landscape. Cold moving-water habitat will be highly exposed to climate change because of its association with snowmelt-dominated hydrologic systems. Lower summer flows and reduced high-elevation snowpack (cold water supply) are expected to contribute to increased summer stream temperatures and diminished cold moving-water habitat characteristics (chapter 5). Ephemeral habitats may dry much earlier in the year because of decreased summer streamflows and increased temperature and evaporation.

Sensitivity—

Seasonal drying caused by decreased summer streamflow and decreased groundwater availability may contribute to the decline of wetland, riparian, and open-water habitats. Sensitivity of individual areas will be determined by the hydrologic attributes of each area. Available open-water sources are particularly important in arid environments, where seasonal changes in water availability influence animal behavior and community composition. More frequent and intense flood events have the potential to damage or remove large trees and down wood, impacting the availability of nesting and resting structures for some species. Landslides and outburst floods can bury or scour riparian vegetation, add fine sediments to streams, and affect resident wildlife (Burnett and Miller 2007).

Changes in seasonal water availability and water temperature may affect aquatic insect populations that provide prey for insectivorous animals. Excluded from larger lakes that contain introduced predatory fish, amphibians in shallower fishless ponds may be vulnerable to seasonal drying (Ryan et al. 2014). Reduced streamflows, increased water temperatures, and sedimentation could reduce habitat suitability for aquatic molluscs. Distribution of cold streams is likely to decrease as water temperatures increase and summer flows decrease under future climate conditions. Groundwater-fed stream systems that currently support these conditions may be less sensitive to climate change than snowmelt-fed systems. Loss of riparian vegetation resulting from increased frequency and intensity of fire or winter flooding is likely to cause increased stream temperatures.

Adaptive capacity—
The adaptive capacity of wildlife will be limited by the hydrologic and topographic context in which they exist. Adaptation opportunities may be maximized by identifying and conserving or enhancing microclimate and microhabitat refuges and breeding sites, and manipulating water levels to provide for important aquatic life history stages, especially breeding (Shoo et al. 2011). Landscape management strategies that minimize the potential for landslides and debris flows with extreme flooding events will also be important (Burnett and Miller 2007). The linear, altitudinally connected pattern of riparian habitats may provide for upward range shifts for associated species to track cooler climatic conditions, although this connectivity could be reduced if seasonal drying and loss of riparian habitat are widespread.

Mid-Elevation, Old, Structurally Complex Forest

Description—
This type includes forest stands with diverse tree sizes and ages (including some large, old trees), multilayered canopies, and abundant snags and logs. In this and the following section, we discuss old, structurally diverse, and early-seral conditions for mid-elevation coniferous forest as separate focal habitats, recognizing that these seral stages exist within diverse conditions for mid-elevation forests, and therefore share many ecological features (Franklin et al. 2002).

Potential vegetation series capable of supporting this type include white fir (*Abies concolor* [Gordon & Glend.] Lindl. ex Hildebr.)–grand fir, Shasta red fir (*Abies magnifica* A. Murray), and western hemlock (Simpson 2007). These vegetation types are found on 28 percent of the SCOAP assessment area (Simpson 2007), with variable species composition, understory characteristics, and disturbance dynamics (Stine et al. 2014). Wildlife communities and habitat characteristics were described by Sallabanks et al. (2001). This focal habitat is consistent with the broad-elevation old forest and forest mosaic families described by Wisdom et al. (2000). The ecology of mid-elevation mixed-conifer forests was reviewed by Stine et al. (2014).

Characteristic wildlife species of mid-elevation old forests include fishers, northern goshawks (*Accipiter gentilis* L.), northern spotted owls (*Strix occidentalis caurina* Merriam) (box 7.4), northern flying squirrels (*Glaucomys sabrinus* Shaw), olive-sided flycatchers (*Contopus cooperi* Nuttall), Vaux's swifts (*Chaetura vauxi* J.K. Townsend), and brown creepers (*Certhia americana* Bonaparte). There is substantial overlap with species found in mid-elevation old forests and

Box 7.4

Northern Spotted Owl

Populations of the northern spotted owl, a rare but iconic species of old forests in the Pacific Northwest, are declining across their range because of habitat loss and competition with barred owls (*Strix varia* Barton) (Dugger et al. 2015). Northern spotted owls were listed as a threatened species largely due to concerns related to loss of old-forest habitat (Thomas et al. 2006, USFWS 2011). Implementation of the Northwest Forest Plan (NWFP) in 1994 called for limited loss of spotted owl habitat from forest management on federal lands (Davis et al. 2016).

Fire exclusion has altered the distribution of spotted owl habitat in forests that historically had more frequent disturbance (Hagmann et al. 2013, Hessburg et al. 2016). Much of the current spotted owl habitat in the eastern Cascade Range is in mixed-conifer forest that historically did not support as much of this structure type (Hagmann et al. 2013). As a result, wildfire is now the leading cause


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Northern spotted owl.

continued on next page

of habitat loss in this region (Davis et al. 2016). Balancing spotted owl habitat conservation with forest restoration and fuel reduction management objectives is a particular challenge in low- and mid-elevation portions of the SCOAP assessment area (Lehmkuhl et al. 2007, 2015).

Despite habitat conservation measures implemented through the NWFP, spotted owl populations have continued to decline, largely because of competitive interactions with recently established populations of barred owls (Dugger et al. 2015, Wiens et al. 2014). Barred owls were historically (prior to 1900) found in deciduous forests of eastern North America, then expanded their range north through the boreal forest of Canada and into the Cascade Range of Washington and Oregon by the 1970s (Livezey et al. 2009). They are now abundant throughout the range of the northern spotted owl. The two species are similar physically and ecologically, although barred owls use a broader variety of prey and habitats, have smaller home ranges, and are more aggressive than spotted owls (Singleton 2013, Wiens et al. 2014). Because of these differences, barred owls can occur in dense aggregations and displace spotted owls from otherwise suitable areas (Singleton et al. 2010).

Northern spotted owls face two threats that may affect a wider variety of species in the future: habitat loss and novel species interactions. Increasing fire frequency and severity with climate change will likely cause continued loss of spotted owl habitat in the eastern Cascades. Within the SCOAP assessment area, increasing wildfire frequency and severity could threaten critical closed-canopy, old-forest habitat. As habitat resources become more limited, competition with barred owls for those resources is likely to intensify (Dugger et al. 2015). It is important to recognize that the barred owl range expansion has been ongoing for more than a century and does not appear to be related to climate change. However, this pattern of an invasive, nonnative generalist species outcompeting a more specialized native species may become increasingly common in a warmer climate. The lessons from spotted owl conservation, and apparent disconnects between habitat protection and population function, can inform our preparation for similar conservation issues in the future.

those found in adjacent forest types (Altman 2000, Altman and Alexander 2012, Sallabanks et al. 2001). Passerine birds associated with mid-elevation old forests include red crossbills (*Loxia curvirostra* L.), pine siskins (*Carduelis pinus* A. Wilson), Swainson's thrushes (*Catharus ustulatus* Nuttall), and varied thrushes (*Ixoreus naevius* Gmelin). Northern spotted owls are closely associated with structurally diverse mid-elevation old-forest conditions in the eastern Cascade Range (USFWS 2011) (box 7.4).

Key ecological features and habitat components include the presence of moderate to closed forest canopy, multiple tree size and age classes (including large old trees), snags, abundant down wood (see box 7.2), and productive understory herbaceous and shrub patches (Sallabanks et al. 2001, USDA FS 2011).

Big, old trees with robust lateral branches and structural defects provide cavities, clumps of dense foliage, and platforms used for nesting and resting structures by a variety of species (e.g., fishers, northern goshawks) (Bull et al. 1997). Complex canopy structure produced by multiple tree age classes provide habitat for arboreal mammals, including northern flying squirrels, Douglas squirrels (*Tamiasciurus douglasii* Bachman), and Siskiyou chipmunks (*Neotamias siskiyou* A.H. Howell). Snags provide nesting and roosting sites for primary and secondary cavity users.

A key difference between old, structurally diverse forests and younger, mid-seral forests is that canopy gaps in the old forest allow light to penetrate to the forest floor and support diverse understory herbaceous and shrub vegetation that provide important food and security cover resources for wildlife. Down logs and abundant organic matter provide cool, moist microclimates on the forest floor and support diverse invertebrate communities. Hollow trees and logs (often grand and white fir) provide roosting and denning sites for many species, including Vaux's swift, black bear, American marten (*Martes americana* Turton), and several species of bats (Bull et al. 1997). Fungi provide truffles for small mammals (Lehmkuhl et al. 2004).

Non-climate stressors include timber harvest, wildfire, fire exclusion, roads, recreation, insect outbreaks, and fungal pathogens (USDA FS 2011). Ongoing wood harvest, both before and after disturbances, can influence habitat and stand successional trajectories. The combined effects of historical forest management practices and fire exclusion have produced contiguous forest landscape patterns, dominated by densely stocked small- and medium-sized trees that are vulnerable to wildfire, insects and disease (Stine et al. 2014, Wisdom et al. 2000). Roads can degrade habitat quality through vehicle traffic and other activities, resulting in displacement or avoidance by wildlife (Gaines et al. 2003).

Management priorities—

- State or federal threatened or endangered species: northern spotted owl (table 7.4; box 7.4).
- ISSSSP: Fisher, fringed myotis, spotted bat, Townsend's big-eared bat, harlequin duck, Johnson's hairstreak butterfly (*Callophrys johnsoni* Skinner), and seven terrestrial snails.
- Socially important species or habitat values: old-growth forest characteristics (box 7.2).

Exposure—

MC2 projects an increase in the area capable of supporting mid-elevation coniferous forest (fig. 7.2). There was strong agreement on this potential increase across most climate scenarios (with a few exceptions, e.g., the "hot-dry" model MIROC-ESM-CHEM). Approximately 20 percent of the buffered assessment area has been in vegetation types associated with mid-elevation forest, based on historical MC2 estimates. The area of these vegetation types is projected to increase to 36 percent by the end of the century under most scenarios. This increase is largely because of an upward expansion of mid-elevation forest into cold forest or subalpine areas along the Cascade crest, but also because of some expansion into lower elevation dry forests in Ochoco and Fremont-Winema National Forests.

Sensitivity—

Wildlife habitat conditions in mid-elevation forests will depend on future disturbance patterns, particularly wildfire and insects. The extent of closed-canopy, old-forest conditions may be reduced if summer droughts intensify and result in more frequent wildfire (Barbero et al. 2014, Dennison et al. 2014). MC2 projects a decrease in the mean fire-return interval and an increase in fire severity for mesic forests by the end of the century. However, there is some uncertainty as to how the projections for increased productivity and increased fire occurrence will affect habitat characteristics in mid-elevation forests. Although projected increases in productivity may contribute to more rapid development of forest habitat structures, these conditions may also contribute to higher fuel loading and increased fire risk (both trends are supported by MC2 projections).

Other assessments have also highlighted the effects of increased fire on mid-elevation coniferous forests in Oregon (e.g., Rogers et al. 2011). Their modeling suggests that suppression activities strongly influenced fire effects, although current suppression efforts may become less effective against more intense future fires. Halofsky et al. (2014) projected that there will be less moist mixed-conifer forest in the eastern Cascade Range under climate change, but decreases in area of moist mixed-conifer forest were lower with active management focused on restoring disturbance-resilient landscape patterns. More frequent droughts and associated disturbances may also increase tree mortality and vulnerability to insects (Allen et al. 2015, Clark et al. 2016). Increasing frequency of disturbances reduce spatial and structural heterogeneity of habitat.

Changes in disturbance regimes are likely to produce cascading effects on wildlife associated with old closed-canopy forests. Increased fire frequency may produce changes in forest structure and configuration that could limit available habitat for species such as northern spotted owls and fishers. Loss of large-tree and snag structures could reduce the availability of nesting and roosting structures for bats and other animals. Loss of large down logs from repeated fire could reduce availability of cool, moist microsites required by terrestrial snails.

Adaptive capacity—

Some mid-elevation forest species may be able to shift upward in elevation into adjacent areas. However, old-forest habitat characteristics take many decades to develop and may not keep up with rapidly changing climatic conditions. Retaining old-forest structural characteristics for as long as possible in areas where they currently exist will provide transitional opportunities for wildlife. Forest restoration treatments that promote stand structures and landscape patterns that are resilient to fire and drought effects are likely to become increasingly important (Stine et al. 2014). Stand and landscape characteristics that are currently inconsistent with historical fire regimes are likely to become more vulnerable under anticipated climate change conditions (Hessburg et al. 2015, 2016). Active management can improve forest resilience in areas managed for old-forest structure (Spies et al. 2010), although identifying where and when management can facilitate retention of old-forest habitat at large spatial scales will be an ongoing challenge.

Mid-Elevation Early Seral

Description—

Mid-elevation, early-seral focal habitat is characterized by various herbaceous and shrub communities found after major disturbance in the mid-elevation forests. This type can be found in relatively large patches after large high-intensity fires, and in smaller patches with more spatial and structural heterogeneity after mixed-severity fires (Hessburg et al. 2016). Early-seral habitats provide highly productive herbaceous and shrub vegetation, with legacy structures from the former forest stand (snags, logs, surviving trees) that support high levels of community diversity (Swanson et al. 2011) (box 7.2). As noted above, we have presented old, structurally diverse and early-seral conditions for the mid-elevation coniferous forest type as separate focal habitats, recognizing that these seral stages exist within a continuum of developmental conditions and share many ecological features.

Potential vegetation series capable of supporting this type include white fir-grand fir, Shasta red fir, and western hemlock (Simpson 2007). Areas capable of supporting mid-elevation forest are found on 28 percent of the buffered assessment area (based on Simpson 2007). This focal habitat corresponds to the early-seral montane family presented by Wisdom et al. (2000). Wildlife species and habitat characteristics associated with this habitat were reviewed by Sallabanks et al. (2001).

Characteristic animal species in mid-elevation, early-seral habitats include gray flycatchers, western bluebirds (*Sialia mexicana* Swainson), pocket gophers (*Thomomys talpoides* Richardson), Cassin's finches (*Carpodacus cassinii* S.F. Baird), kestrels (*Falco sparverius* L.), and chipping sparrows (*Spizella passerina* Bechstein). Species that depend on recently killed trees for food and nesting sites include black-backed (*Picoides arcticus* Swainson) and three-toed woodpeckers (*P. dorsalis* S.F. Baird). Ungulates (deer and elk) and their predators (wolves and cougars) are also associated with the abundant forage resources commonly found in early-seral habitats.

Key ecological features of mid-elevation early-seral habitats include woody structures, unique vegetation, and spatial patterns. Biological legacies from previous forest stands, including snags, logs, and surviving large trees, provide resting structures for woodpeckers and other species (Swanson et al. 2011) (box 7.2). Shrubs provide nesting and security cover and support diverse migratory bird communities. A diverse, productive herbaceous community can provide ungulate forage resources and plant foods for small mammals. Herbivory pressures from wild and domestic animals can be a substantial driver of vegetation development patterns in these habitats. Early-seral habitats eventually transition into mid-seral conditions that are less biologically diverse. A shifting mosaic of multiple seral stages helps to maintain biodiversity (Hessburg et al. 2015, 2016; Stine et al. 2014).

Non-climate stressors for early-seral, mid-elevation habitat include timber and wood harvest, wildfire, roads, invasive species, grazing, and recreation (Stine et al. 2014, USDA FS 2011). Loss of large snags, logs, and remnant trees following fire or harvest can have negative impacts on wildlife habitat values in early-seral landscapes. Large, simple-structure patch patterns resulting from high-intensity fire or postdisturbance harvest could set the stage for a long-term cycle of repeated disturbances if those patches develop into closed canopy, small-tree conditions with high fuel loading. Road access into recently disturbed areas may contribute to loss of dead wood from firewood collection and facilitate invasive species colonization. Invasive species can reduce understory diversity and productivity, thereby reducing forage quality and cover required by ground-nesting birds. Recreation activities can contribute to site degradation and reduce animal access to resources. Lack of hiding cover and long visual distances can contribute to negative effects of human disturbance in early-seral habitats.

Management priorities—

- State or federal threatened or endangered species: gray wolf (table 7.4).
- ISSSSP: spotted bat, Townsend's big-eared bat, purple martin, upland sandpiper (*Bartramia longicauda* Bechstein), mardon skipper (*Polites mardon* W.H. Edwards), Leona's little blue butterfly (*Philotiella Leona* Hammond and McCorkle), silver-bordered fritillary (*Boloria selene* Schiffermüller), western bumblebee (*Bombus occidentalis* Greene).
- Socially important species or habitat values: elk, mule deer, ruffed grouse (*Bonasa umbellus* L.), wild turkey.

Exposure—

MC2 simulations project mid-elevation coniferous forest area to expand, largely because of conversion of subalpine and cold forest types to moist mixed conifer (fig. 7.2). Growth responses to climate may result in changes to forest structure, with a potential increase in density of young cohorts. Although species composition may not change, an increase in stand density would shade out understory species that contribute to habitat and forage for animals such as elk, deer, grouse, and turkeys. Seral class distributions within this forest type will also depend on future fire patterns. The proportion of mid-elevation forest in early-seral habitats may increase with intensifying disturbance. Increased fire frequency could also slow forest succession if seed sources are reduced. However, the time required for tree regeneration may decrease because of warming temperatures, accelerating forest succession.

Sensitivity—

Lower elevations are likely to experience increased heat and summer drought stress. Some areas may transition to grasslands or shrublands (Clark et al. 2016). These transitions may be associated with high-intensity disturbance, because fire kills trees and eliminates seed sources, as climate conditions become less suitable for tree regeneration (Allen et al. 2015). Such transitions could favor grassland species including horned lark. Deciduous shrub productivity may increase with projected increases in productivity, favoring foliage-gleaning birds like orange-crowned warblers (*Oreothlypis celata* Say). However, seasonal availability of fruit foods (i.e., berries and nuts) and herbaceous forage could change with extended summer drought. Such changes could affect frugivores (e.g., black bear) and herbivores (e.g., deer, elk). If disturbances become larger and more frequent, spatial configuration of early-seral habitats could become more homogeneous, with larger patch sizes and fewer biological legacies.

Adaptive capacity—

Animal species associated with mid-elevation early-seral habitat may have high adaptive capacity compared to species associated with other focal habitats. Early-seral species tend to be good dispersers with high reproductive rates (important for tracking patchy and transient postdisturbance conditions). Many opportunities exist for mid-elevation early-seral associates to shift upward in elevation. Post-disturbance habitats are created quickly, and their abundance will probably increase in the future. However, critical habitat features, including large snags, large logs, and remnant large trees, may decrease.

High-Elevation Cold Forest

Description—

Like mid-elevation old forest, this group of habitats represents the old-forest seral stage of development for high-elevation forested vegetation types. Dominant tree species for this type include Pacific silver fir, mountain hemlock, Alaska cedar (*Callitropsis nootkatensis* [D. Don] D.P. Little), and western white pine (*Pinus monticola* Douglas ex D. Don). Potential vegetation series that support this type are mountain hemlock and Pacific silver fir (Simpson 2007). These types encompass 13 percent of the SCOAP assessment area (Simpson 2007).

High-elevation cold forest consists of colder and moister forest conditions than the mid-elevation forest focal types. Many habitat characteristics are similar to mid-elevation, late-seral forest, including the presence of large, old trees, substantial live-tree defects, large snags, and large logs. However, disturbance regimes and management opportunities differ substantially, at least partially because high-elevation forest develops a deep winter snowpack. Descriptions of species and habitat conditions associated with this type are provided by Sallabanks et al. (2001). Characteristics of this habitat occur in the upper portions of the broad-elevation old-forest family presented by Wisdom et al. (2000).

Characteristic animal species include great gray owls (S*trix nebulosi* J.R. Forster), American martens, dusky grouse (*Dendragapus obscurus* Say), and varied thrushes. Snowshoe hares (*Lepus americanus* Erxleben) are an important prey species for avian and mammalian predators in cold forests. Species composition of high-elevation cold forest overlaps with adjacent mid-elevation old forest and high-elevation woodlands.

High-elevation cold forests have moderate to closed forest canopy, multiple tree size and age classes, snags, abundant down wood, and productive understory herbaceous and shrub patches (Sallabanks et al. 2001, USDA FS 2011). Deep, persistent snowpack distinguishes high-elevation cold forest from mid-elevation old forests, providing under-snow (subnivean) habitat and security from common meso-carnivores (e.g., bobcats, coyotes). Heavy snow influences tree crown development, often producing more sharply conical forms that can result in less canopy connectivity compared to mid-elevation forests. In addition, high-elevation cold forests tend to be more patchy with more high-contrast edge than mid-elevation old forests. That spatial heterogeneity can provide for highly productive shrub or meadow patches as well as provide edge habitats for contrast species. The combination of late-seral habitat for old-forest species (e.g., marten, boreal owl [*Aegolius funereus* L.]) and the juxtaposition of early- and late-seral conditions for species such as silver-haired bats (*Lasionycteris noctivagans* Le Conte), hoary bats [*L. cinereus* Palisot de Beauvois), and great gray owls is a unique characteristic of this type (Wisdom et al. 2000).

Non-climate stressors in high-elevation cold forests include insects, disease, and recreation (USDA FS 2011). High-elevation cold forests are located predominantly in roadless or wilderness areas, so roads and wood harvest are not widespread. The historical fire regime of these forests was characterized by infrequent high-severity fires (>100 year return intervals; Agee 1993), so fire suppression has not altered structure as it has in mid-elevation forests.

Management priorities—

- State or federal threatened or endangered species: none.
- ISSSSP: Sierra Nevada red fox (*Vulpes vulpes necator* Merriam), fringed myotis, spotted bat, Townsend's big-eared bat, Crater Lake tightcoil (terrestrial snail: *Pristiloma crateris* Pilsbry).
- Socially important species or habitat values: dusky grouse, snowshoe hare (important prey species).

Exposure—

Wildlife associated with high-elevation cold forest habitats will have a high degree of exposure to climate change. Approximately 12 percent of the SCOAP assessment area was in this type based on historical MC2 estimates. These conditions are projected to be lost by the late 21st century under most scenarios, with most of the loss occurring by mid-century because of conversion to moist coniferous forest (fig 7.2). Higher temperatures will likely lengthen the growing season by reducing snowpack depth and warming soils. These changes may favor some species currently dominant at lower elevations. However, any change in the distribution and abundance of plant species is expected to occur gradually over many decades, with a high degree of uncertainty about the outcome (see chapter 6).

There may also be increased potential for large-scale, high-intensity fire with increased summer drought. Infrequent, high-intensity wildfires have historically dominated high-elevation cold forests. Late-seral tree species (e.g., subalpine fir [*Abies lasiocarpa* (Hook.) Nutt.]), Pacific silver fir) in this type are not resilient to fire. A particular risk may be the potential for high-intensity fire to move from adjacent mid-elevation forest during extreme events. Increased summer temperatures and drought stress may contribute to increased vulnerability to insects and diseases or to direct tree mortality.

Sensitivity—

Loss of winter snowpack will have important consequences for animals associated with cold forests. Some adaptations for cold, snowy environments may be disadvantageous in a warmer, snowless future. For example, snowshoe hair coloration that is inconsistent with changes in snow cover can increase vulnerability to predation (Mills et al. 2013). Altered snowpack depth and duration can also influence meso-carnivore abundance and species composition, with consequent effects on prey (Pozzanghera et al. 2016). Winter thermoregulatory behaviors may be affected by warmer winters. Large-scale forest structure loss could result from large, high-intensity fires, depending on summer drought patterns. Milder winters, longer frost-free seasons, and summer drought stress may contribute to increased severity of insect outbreaks (Weed et al. 2013). Longer summer droughts may also contribute to direct tree mortality, reducing availability of live-tree forest structures for nesting and resting (Allen et al. 2015, Clark et al. 2016). Recreation pressures in higher elevation areas could increase as people seek cooler settings during increasingly hot summers. Winter recreation pressures may become more concentrated as snowpack decreases, diminishing the spatial extent of recreational opportunities (see chapter 8).

Adaptive capacity—

Animals and plants associated with high-elevation cold forest may have limited adaptive capacity compared to other focal habitats. Most species are more tolerant of cold extremes than warm extremes, and opportunities for upward range shifts are limited. Availability of thermal micro-refugia (burrows cavities, large logs, shading vegetation) may be particularly important for short-term species persistence. Loss of winter snowpack may present adaptation challenges, particularly for species that rely on subnivean environments for refuge from predation.

High-Elevation Woodlands/Whitebark Pine

Description—

This habitat contains a patchy mix of trees and herbaceous or shrub vegetation typical of the upper edge of the distribution of trees in south-central Oregon (1800-2100 m elevation). Potential vegetation series that support this type are mountain hemlock and parkland, which encompass 3 percent of the buffered assessment area (Simpson 2007). Common tree species include subalpine fir, mountain hemlock, and whitebark pine (*Pinus albicaulis* Engelm). The historical disturbance regime was characterized by occasional lightning-ignited fires that produced complex spatial patterns and patches of snags. Trees found in high-elevation woodlands are generally not resilient to high-severity fire. The wildlife community and habitat conditions associated with high-elevation woodlands were described by Martin (2001). Wildlife species and habitat conditions were captured by forest mosaic and higher elevations in the broad-elevation old-forest families described by Wisdom et al. (2000).

Characteristic wildlife species associated with high-elevation woodlands include Clark's nutcracker (*Nucifraga columbiana* A. Wilson), mountain bluebird (*Sialia currucoides* Bechstein), Townsend's solitaire, Sierra Nevada red fox, and ermine (*Mustela ermine* L.). The wildlife community represents a mix of species associated with forested conditions described below (e.g., varied thrush, Cassin's finch, American marten) and those associated with subalpine grassland conditions above (e.g., chipping sparrow, American pipit). As with other cold mountain habitats, many species are seasonal migrants.

High-elevation woodlands contain a spatially complex meadow-woodland interface, mast-producing trees and shrubs, deep snowpack, and productive herbaceous vegetation. The high contrast between tree patches and adjacent open areas provides vertical structure for tree-dwelling mammals (e.g., Douglas squirrel) and cup-nesting birds (e.g., yellow-rumped warbler [*Setophaga coronate* L.]). Whitebark pine produces cones whose seeds are consumed by a variety of species, including Douglas squirrels and Clark's nutcracker (chapter 6). Nutcrackers are a primary seed disperser for whitebark pine, a function that may be compromised if extended drought or disease causes low cone production (Barringer et al. 2012). Deep, persistent snowpack provides thermal and security cover, particularly for species like meadow voles (*Microtus pennsylvanicus* Ord) that remain active beneath the snowpack during winter.

Non-climate stressors include insects, disease, and recreation (USFWS 2011). White pine blister rust (*Cronartium ribicola* A. Dietr.) is a fungal infection that has affected whitebark pine populations across western North America, with associated negative impacts to Clark's nutcrackers (McKinney et al. 2009). High-elevation woodlands are also highly valued recreation areas. High levels of recreational use can cause vegetation damage and soil compaction (Gaines et al. 2003).

Management priorities—

- State or federal threatened or endangered species: none.
- ISSSSP: Sierra Nevada red fox, spotted bat, Townsend's big-eared bat.
- Socially important species or habitat values: subalpine parkland aesthetics.

Exposure—

Wildlife associated with high-elevation woodlands will have a high degree of exposure to projected changes in climate. As described in the cold-forest section above, MC2 simulations suggest that high-elevation woodland is likely to transition to mid-elevation forest (fig. 7.2). These areas are projected to experience reduced winter snow depth and duration, as well as reduced soil moisture in summer. Warmer air and soil temperatures and a longer snow-free growing season will facilitate encroachment from subalpine tree species and possibly lower elevation species (chapter 6). However, a transition to different tree species assumes that they will be able to establish and persist in what will still likely be a cold, snowy environment. Successful establishment depends on microsite availability, which may be limited by unsuitable topographic and edaphic conditions upslope, wind exposure, and snow distribution patterns (Holtmeier and Broll 2012, Macias-Fauria and Johnson 2013, Smith et al. 2003).

Sensitivity—

Intensifying summer heat and drought stress, combined with insect and disease outbreaks, could reduce survival of high-elevation woodland tree species. Recent losses of whitebark pine caused by white pine blister rust and mountain pine beetle (*Dendroctonus ponderosae* Hopkins) have created stress in many whitebark pine communities in western North America (Keane et al. 2015). Tree encroachment from below may reduce woodland extent and contribute to altered species distribution and abundance. Loss of winter snowpack may particularly affect animals that use subnivean habitats or are sensitive to competition or predation from common meso-carnivores. For example, American martens use deep snow areas where bobcat winter movements are unlikely, and predation risk will be higher with diminished snowpack (Moriarty et al. 2015). Recreational pressures could increase as snow decreases, causing recreationists to seek a limited number of high-elevation settings in summer.

Adaptive capacity—

Wildlife associated with high-elevation woodlands will have limited opportunities for upward range shifts. Availability of thermal micro-refugia (burrows, cavities, or shading vegetation) may be particularly important for short-term species persistence. The patchy woodland spatial pattern may be possible to maintain through regular fire or manual removal of encroaching trees. Some fundamental changes may be unavoidable, including loss of snowpack and altered tree species composition. Animals that are seasonal migrants or whose breeding range overlaps high-elevation and low-elevation habitat (e.g., Townsend's solitaire, mountain bluebird) may be better adapted to warmer conditions than year-round residents. Even Clark's nutcrackers may be able to adapt to a future without whitebark pines if other food sources (e.g., ponderosa pine seeds) are available (Lorenz et al. 2011, Schamming 2016).

High-Elevation Meadow/Grassland/Barren

Description—

This focal habitat type captures the mix of herb, shrub, and nonvegetated conditions at and above treeline at the highest elevations in south-central Oregon, generally above 2000 m elevation. Approximately 4 percent of the SCOAP assessment area is above this elevation. Meadow patches can also be maintained at lower elevation by cold air drainage patterns or local soil and site moisture conditions (too wet or too dry) that create inhospitable local environments for tree growth in lower settings. Open conditions on ridgetops and upper slopes may be maintained by occasional lightning-caused fires. Avalanches can also maintain open or shrub communities at upper to mid elevations in these cold, heavy-snow landscapes. Because of the association of subalpine meadows with the highest topographic mountaintop settings, habitat has patchy, isolated landscape patterns. Animal and habitat characteristics associated with this type were described by Martin (2001). Areas capable of supporting this type are not well represented in potential vegetation type maps, because many of them do not support forest under current climate conditions (Simpson 2007).

Characteristic species include American pikas (*Ochotona princeps* Richardson), yellow-bellied marmots (*Marmota flaviventris* Audubon and Bachman), American pipits, and gray-crowned rosy finches. Seasonally abundant flowering plants support a variety of pollinating species, including Western bumblebees (box 7.5). Many species that use alpine habitats are seasonal migrants (e.g., gray-crowned rosy finch, elk). These communities also have overlap in species composition with low-elevation grassland and shrubland birds, including chipping sparrows, vesper sparrows, and savannah sparrows (*Passerculus sandwichensis* J. F. Gmelin), as well

Box 7.5

Pollinators

Pollinators are vital to maintaining healthy ecosystems. Bees, butterflies, hummingbirds, bats, and other animals help pollinate over 85 percent of the world's flowering plants, including more than two-thirds of the world's crop species. They are essential for plant reproduction and maintenance of natural plant communities and genetic diversity in the plants they pollinate. By contributing to the reproductive capacity of native plants, pollinators also influence other ecosystem services, including carbon sequestration, water filtration, erosion control, and the continuation of multiple trophic levels of the food web (Gilgert and Vaughan 2011, National Research Council 2007).

Global declines in pollinator populations, with highly visible decreases in honey bees (*Apis mellifera* L.), bumblebees (*Bombus* spp.), and monarch butterflies (*Danaus plexippus* L.), have brought into focus the importance of pollinator conservation (Cameron et al. 2011, National Research Council 2007, Pettis and Delaplane 2010, VanEngelsdorp et al. 2009). Pollinator populations and the many services they provide are threatened by habitat degradation and fragmentation, pests and pathogen effects, exposure to pesticides, and, in some cases, a warmer climate (National Research Council 2007).

The western bumblebee, a priority species in south-central Oregon, was recently added to the U.S. Forest Service Pacific Northwest Region sensitive list because of major declines in abundance and distribution. It was historically known throughout Oregon and Washington, but is now largely confined to high-elevation sites and areas on the east side of the Cascade Range (Cameron et al. 2011, Williams et al. 2014).

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Western bumblebee.

Western bumblebees require a diverse array of plants that bloom and provide adequate nectar and pollen throughout the colony's life cycle, including perennial forbs and legumes, shrubs, vines, and trees that initiate flowering in early spring and continue late into autumn. The amount of available pollen affects the number of new queens that a bumblebee colony can produce and future population size (Burns 2004). Increased summer temperatures and drought stress at high-elevation sites may alter the distribution of herbaceous vegetation and floral resource availability.

Altered plant phenology may put pollinators out of sync with their most important natural food sources (Forrest 2015). Some species of pollinators have co-evolved with one species of plant, and the two species time their cycles to coincide (e.g., insects mature from larva to adult precisely when nectar flows begin). If the snow melts earlier, flowers may emerge and bloom earlier, but bees may not be available to pollinate them. This phenology mismatch may be a problem for many pollinator and plant species, and the ecosystem services they provide.

as wide-ranging species such as prairie falcons (*Falco mexicanus* Schlegel), golden eagles (*Aquila chrysaetos* L.) red-tailed hawks (*Buteo jamaicensis* Gmelin), and common ravens (*Corvus corax* L.).

Key ecological features and habitat components include seasonally abundant insect and plant foods, rocky structures for denning, and deep snow in winter. Patches of diverse herbaceous and shrub vegetation provide plant food for mammals, including pikas and yellow-bellied marmots. Sedge and grass vegetation provide nesting sites for ground-nesting birds (e.g., American pipit, horned lark). Rock and talus provide burrows for pikas, marmots, and other species. Gray-crowned rosy finches often nest in crevices or ledges on cliffs or rock outcrops. Deep snowpack provides subnivean habitats that insulate small mammals from cold winter temperatures and provide security from predators. Deep snowpack also limits accessibility of these areas for meso-carnivores, particularly bobcats and coyotes.

Subalpine wetlands contribute insect prey for insectivores (bats, birds, small mammals), and provide habitat for amphibians (Ryan et al. 2014). Insect and plant foods are seasonally abundant, but the duration of availability is limited by the short frost-free season. Because of the degree of exposure to weather, fine-scale topographic features can influence microclimatic conditions and distribution of biotic communities. For example, south-facing slopes may be particularly exposed to extremes of heat, drying, and cold, whereas north-facing slopes and sheltered sites provide moderated conditions and often different dominant vegetation (Martin 2001).

Non-climate stressors include invasive species, fire exclusion, herbivory, and recreation (USDA FS 2011). Invasive plants can substantially change meadow community composition and ecological values. Montane meadows can provide forage for migratory ungulates, but may be affected by high levels of herbivory. These areas have high scenic value. Vegetation damage and soil compaction can be problems where motorized winter recreation contributes to snow compaction and degraded subnivean habitat (Gaines et al. 2003).

Management priorities—

- State or federal threatened or endangered species: none.
- ISSSSP: Sierra Nevada red fox, wolverine, spotted bat, Townsend's big-eared bat, peregrine falcon, merlin, gray-blue butterfly (*Plebejus podarce klamathensis* J. Emmel and T. Emmel in T. Emmel), western bumblebee.
- Socially important species or habitat values: high-elevation invertebrates (butterflies, moths, and other pollinators), subalpine meadow aesthetics.

Exposure—

Animals associated with high-elevation meadows, grasslands, and barren areas are projected to have a high degree of exposure to climate change. MC2 projections indicate that the subalpine vegetation type will transition to moist mixed-conifer forest because of increased temperatures and longer growing seasons under all climate scenarios (fig. 7.2). However, the advance of treeline must include the successful establishment of tree seedlings within and above the current treeline, a process dependent on multiple factors (Holtmeier and Broll 2012, Macias-Fauria and Johnson 2013, Smith et al. 2003). This habitat will experience increased summer temperatures and drought stress, as well as reduced winter snowpack depth and duration.

Sensitivity—

Increased summer temperatures and drought stress may alter herbaceous vegetation and subalpine wetlands. Seasonal availability of plant and insect foods may become more limited by water than by temperature as the frost-free season lengthens and potential for summer drought increases. The future distribution of these habitat conditions will be determined by tree establishment and disturbance processes. High-elevation meadow communities can be maintained by fire, particularly when encroaching trees are not fire resilient. Warmer winter temperatures and reduced depth and duration of snowpack can potentially affect resident mammal communities. Loss of subnivean habitats may reduce protection from predation and increase winter thermal stress for species like meadow voles. Changes in snowpack depth may increase access for bobcats and coyotes.

Longer summers may contribute to changes in migration timing and duration of residence for elevational migrants (box 7.1). Abundance and timing of food availability may be particularly important drivers of altered migratory behavior. Deer and elk populations may change the timing of migration or stop migration when forage is abundant, which may contribute to increased herbivory in high-elevation meadows. Higher summer maximum temperatures and potential for summer drought may increase vulnerability of summer residents to thermal stress and altered food availability. Emerging phenological mismatches between high-elevation vegetation and invertebrate pollinators may be a particular concern in herbaceous communities (box 7.5). Recreation pressures could increase as winter recreation opportunities become more limited and recreationists seek cooler settings in summer.

Adaptive capacity—

Species associated with high-elevation meadow, grassland, barren habitats have limited opportunities for upward range shifts. There is some overlap in wildlife species composition between high- and low-elevation grassland communities (e.g., vesper sparrows, chipping sparrows, horned larks). Some of these species have genetically unique alpine subpopulations (e.g., horned larks), but at the species level, they may have the phenotypic plasticity to adapt to warmer, low-snow conditions. Resident nonmigratory species reliant on long-season, deep snow conditions for denning (e.g., yellow-bellied marmot, American pika) or predator avoidance (e.g., snowshoe hare, meadow vole) may be quite sensitive. Habitat structure changes may be determined to a large degree by disturbance processes. If increased fire frequency offsets tree growth and encroachment, current habitat characteristics may be sustained. However, substantial changes in seasonal temperature and snowpack characteristics are unavoidable.

Conclusions

Of the wildlife habitats in the SCOAP assessment area, high-elevation cold habitats (cold forests, woodlands, and meadows) have high exposure and sensitivity to climate change, and more limited adaptive capacity compared to other habitat types. Climatic conditions associated with cold habitats are projected to effectively disappear from the SCOAP assessment area by the mid- to late-21st century. The total area capable of supporting mid-elevation forests is projected to either expand (for mid-elevation temperate conifer forest, including old forest and early-seral stages) or remain about the same (for dry forest, including large open ponderosa pine) based on most climate scenarios. However, the spatial arrangement and disturbance regimes for mid-elevation types are expected to change. The combined area capable of supporting low-elevation grass, shrub, and woodland habitats may not change substantially, but they may become hot and seasonally dry. Riparian, wetland, open-water, and cold moving-water habitats will be affected by changes in precipitation, evaporation, and hydrology, particularly the loss of high-elevation snowpack, altered seasonal water flow, and more frequent and intense winter floods.

Federal land managers in south-central Oregon will be challenged to provide the variety of habitat characteristics that supports diverse wildlife communities in a changing climate. Some focal wildlife habitats are more vulnerable than others, although many adaptation options can be implemented. Strategies that are common across all focal habitats include identifying and protecting refugia, using mechanical treatments and prescribed fire to maintain and increase spatial heterogeneity, removing invasive species, and maintaining and increasing landscape permeability for seasonal movements and range shifts (chapter 10). Engaging private landowners, and public outreach and education provide opportunities for timely implementation. Wildlife communities will change as the climate continues to warm, and federal land managers are well positioned to maintain a high degree of biodiversity by retaining and recruiting diverse habitat conditions at large spatial scales.

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Chapter 8: Climate Change and Recreation in South-Central Oregon

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Introduction

Public lands provide opportunities for outdoor recreation and connections to nature. Outdoor recreation is increasingly recognized as a source of wide-ranging benefits, from economic expenditures that support national industries and local gateway communities to personal and social benefits such as improved health and well-being, cultural and spiritual practices, and sustained family ties and traditions. Access to recreation opportunities is a key consideration that shapes where people live, work, and travel, particularly in south-central Oregon, where federal lands offer year-round opportunities for outdoor recreation. Deschutes, Ochoco, and Fremont-Winema National Forests and Crooked River National Grassland host an estimated 2.56 million visits per year; Crater Lake National Park accounts for an additional 476,000 visits per year.

National forests and national parks provide recreation opportunities at sites that offer a wide variety of characteristics across all seasons of the year (table 8.1, fig. 8.1). Recreation in public lands in south-central Oregon is inseparable from ecosystems and natural features. Whether skiing, hiking, hunting, or camping, visiting developed sites or the backcountry, or simply driving through the mountains, natural and ecological conditions in large part determine the overall recreation experience.

Climatic conditions and environmental characteristics that depend on climate are key factors that determine the availability of and demand for different recreation opportunities (Shaw and Loomis 2008). Changing climate conditions may alter the supply of and demand for recreation opportunities, resulting in changes

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Table 8.1—Categories of recreation activities by season in south-central Oregon[a]

Recreation activity	Winter	Spring	Summer	Autumn
Motorized recreation (snowmobiles)	✓			
Nonmotorized recreation (downhill skiing, cross-country skiing, fat-tire bicycling, dog sledding, sledding/tubing, general slow play, mountaineering, nature viewing)	✓			
Scenic driving (nature viewing)	✓	✓	✓	
Other forest uses (Christmas tree harvest, foraging, firewood cutting)	✓			
Recreation residences	✓	✓	✓	✓
Boating		✓	✓	✓
Fishing		✓	✓	✓
Horseback riding		✓	✓	✓
Cycling (mountain biking, road biking)		✓	✓	✓
Special forest products (e.g., mushrooms, cones)		✓	✓	✓
Hiking, backpacking (including long-distance hiking)		✓	✓	✓
Motorized recreation		✓	✓	✓
Picnicking, camping		✓	✓	✓
Swimming			✓	
River rafting			✓	

[a] Recreation activities identified in this table may differ somewhat from the categories in the National Visitor Use Monitoring data (see table 8.3 on p. 376).

in the pattern of and benefits derived from recreation in the future. Climate change is projected to increase warm-weather based recreation participation at mid- and northern-latitude recreation destinations (Bowker et al. 2013) and to decrease winter recreation where snow-based winter activities are currently prevalent (Loomis and Crespi 2004, Mendelsohn and Markowski 2004, Wobus et al. 2017).

Although broad trends in recreation participation under climate change scenarios (see chapter 3) may be borne out at the regional scale, little is known about how recreation in south-central Oregon will change. This chapter describes the broad categories of recreation activities that may be sensitive to climate-related changes in south-central Oregon, and assesses the likely effects of projected climate changes on recreation participation. Effects on the distribution of recreation opportunities (gains and losses) among different sectors of recreation users are also important but are typically difficult to quantify.

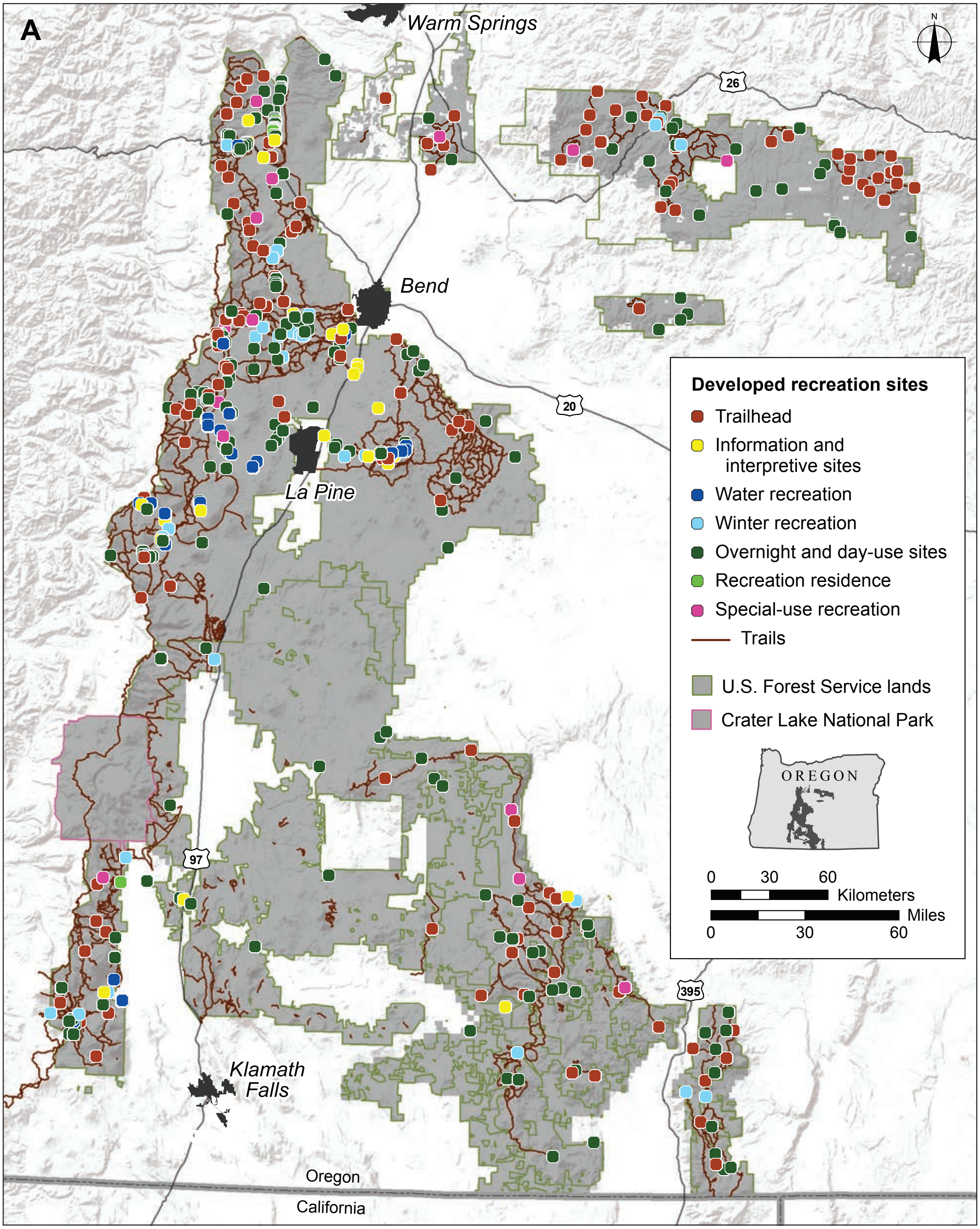

Figure 8.1—Recreation sites in national forest lands in the South-Central Oregon Adaptation Partnership assessment area for (A) all sites; (B) winter recreation and water recreation; (C) overnight and day use; and (D) trailheads, interpretive sites, and special-use recreation.

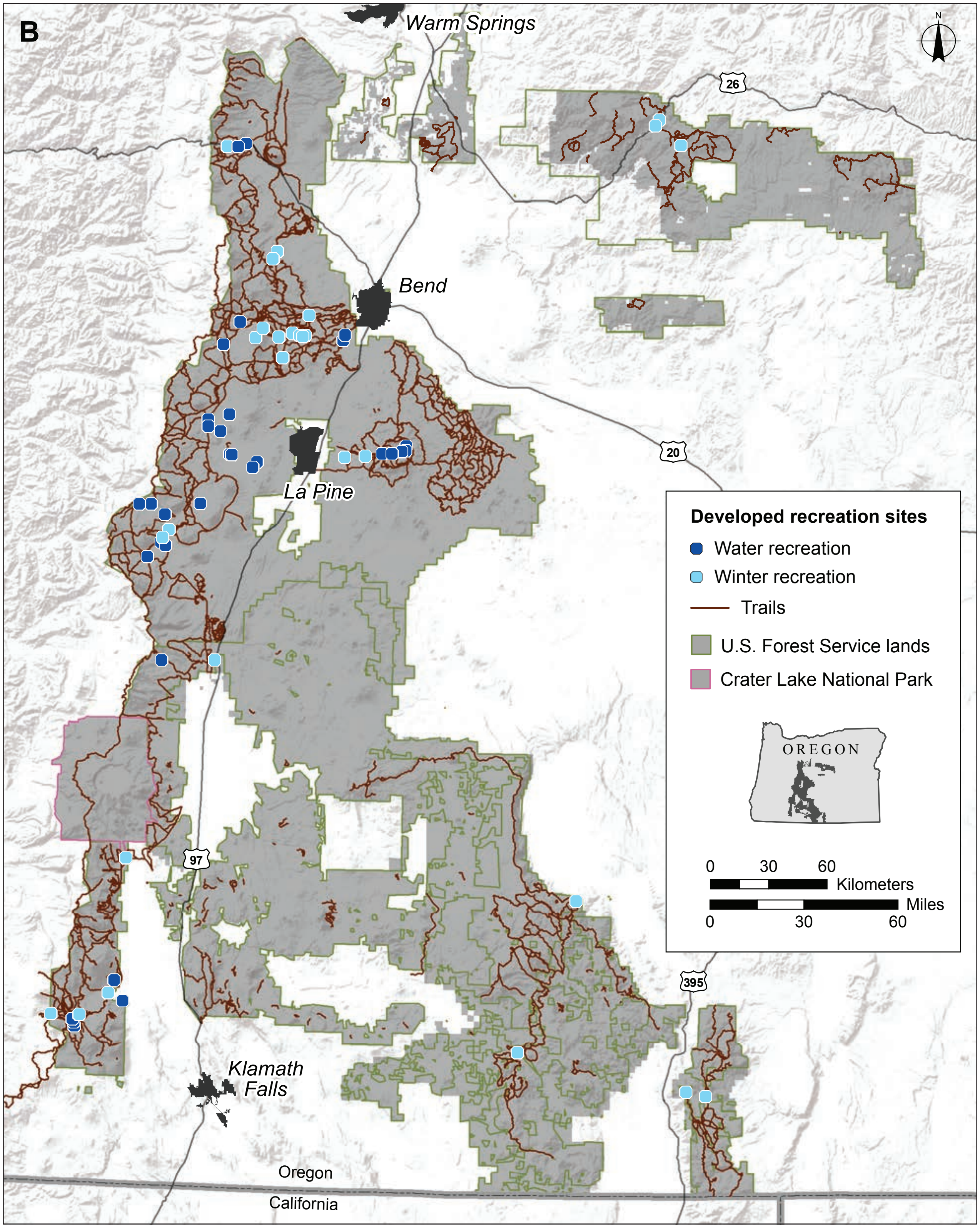

Figure 8.1 (continued)—Recreation sites in national forest lands in the South-Central Oregon Adaptation Partnership assessment area for (A) all sites; (B) winter recreation and water recreation; (C) overnight and day use; and (D) trailheads, interpretive sites, and special-use recreation.

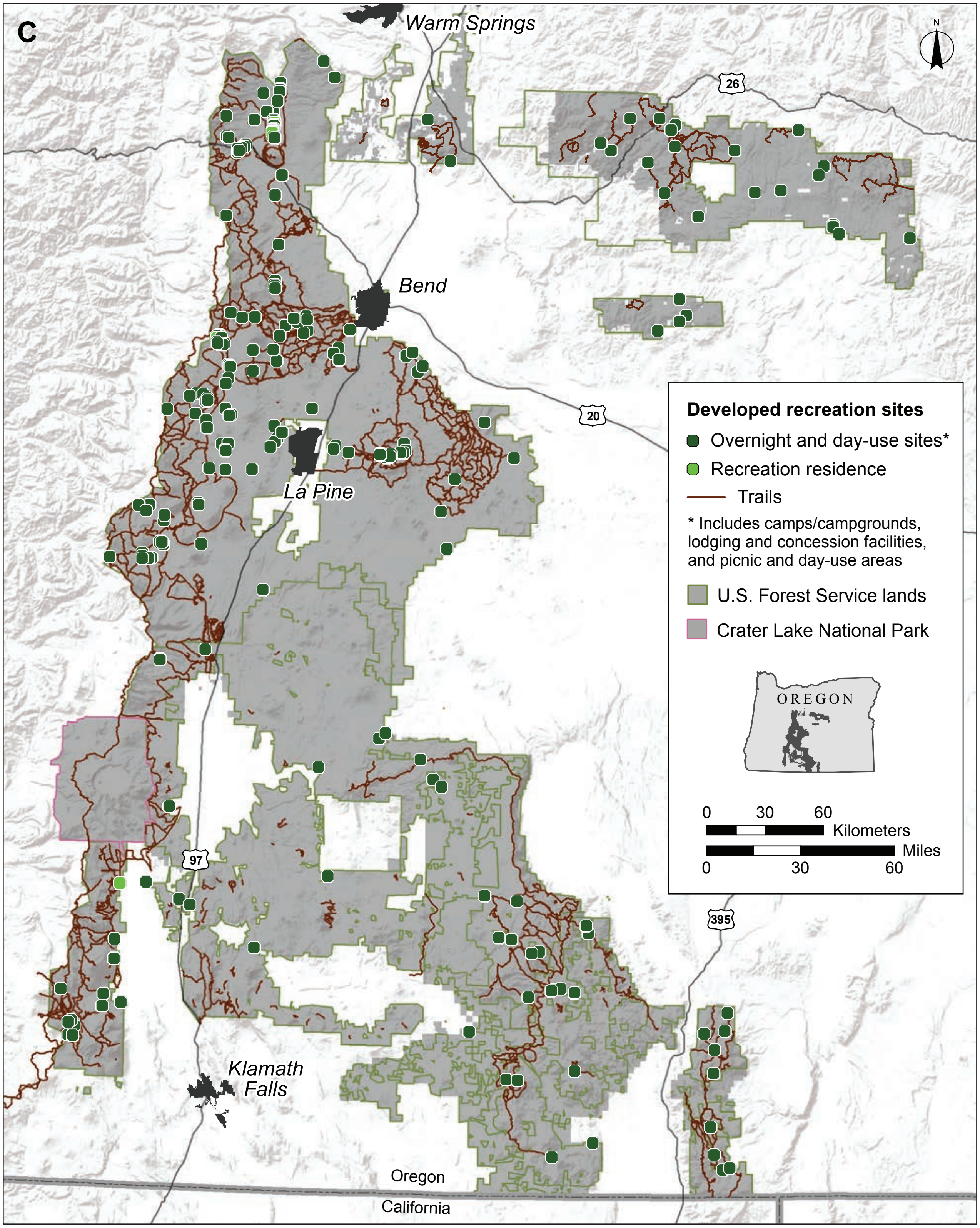

Figure 8.1 (continued)—Recreation sites in national forest lands in the South-Central Oregon Adaptation Partnership assessment area for (A) all sites; (B) winter recreation and water recreation; (C) overnight and day use; and (D) trailheads, interpretive sites, and special-use recreation.

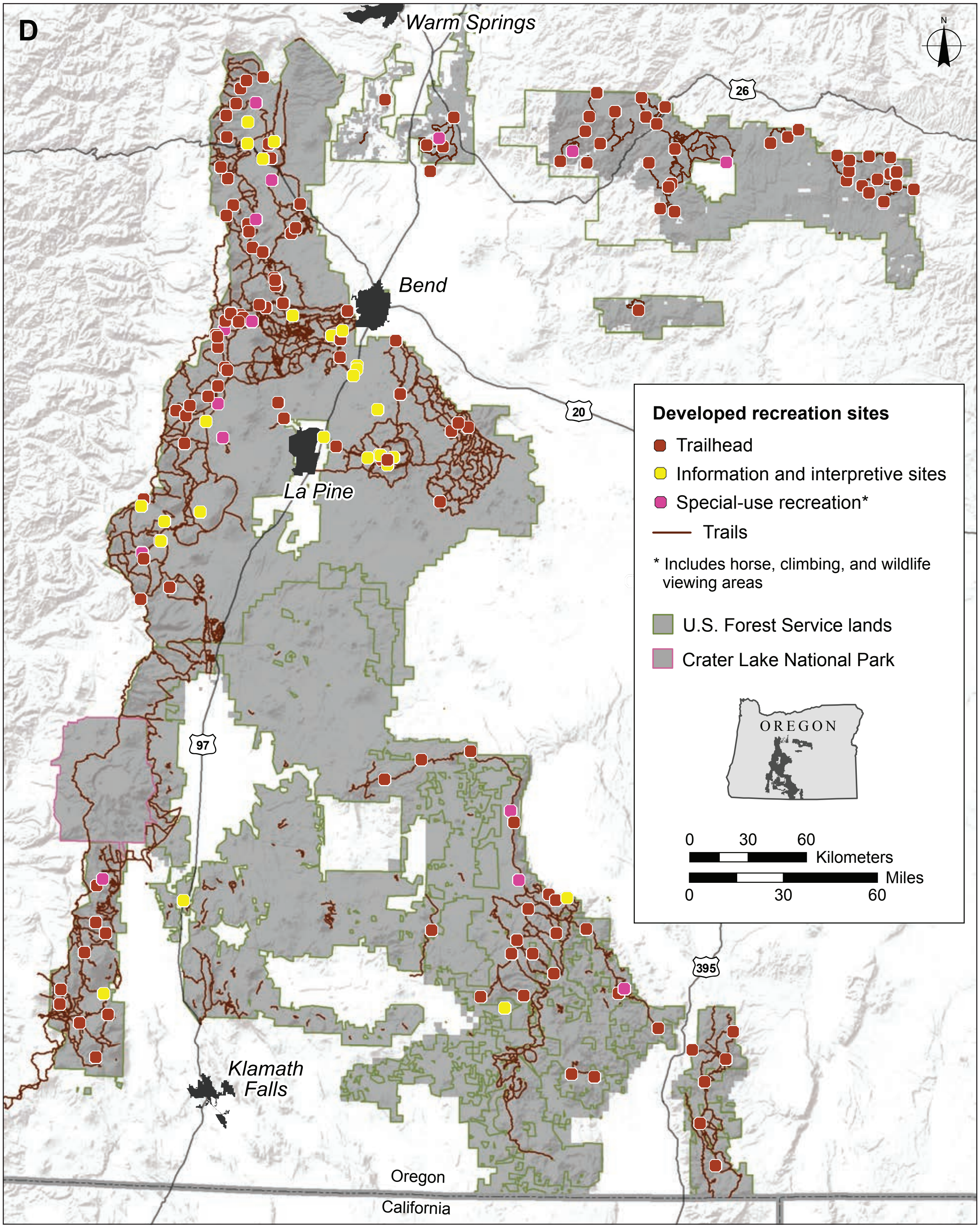

Figure 8.1 (continued)—Recreation sites in national forest lands in the South-Central Oregon Adaptation Partnership assessment area for (A) all sites; (B) winter recreation and water recreation; (C) overnight and day use; and (D) trailheads, interpretive sites, and special-use recreation.

Relations Between Climate Change and Recreation

The supply of and demand for recreation opportunities are sensitive to climate through (1) a direct effect of changes in temperature and precipitation on the availability and quality of recreation sites, and (2) an indirect effect of climate on the characteristics and ecological condition of recreation sites (Hand and Lawson 2018, Loomis and Crespi 2004, Mendelsohn and Markowski 2004, Shaw and Loomis 2008) (fig. 8.2).

Direct effects of altered temperature and precipitation patterns are likely to affect most outdoor recreation activities in some way. Direct effects are important for skiing and other snow-based winter activities that depend on seasonal temperatures and the amount, timing, and phase of precipitation (Englin and Moeltner 2004, Irland et al. 2001, Stratus Consulting 2009). Warm-weather activities are also sensitive to direct effects of climate change. Increases in minimum temperatures have been associated with increased national park visits in Canada, particularly during non-peak "shoulder" seasons (spring, autumn) (Scott et al. 2007). The number

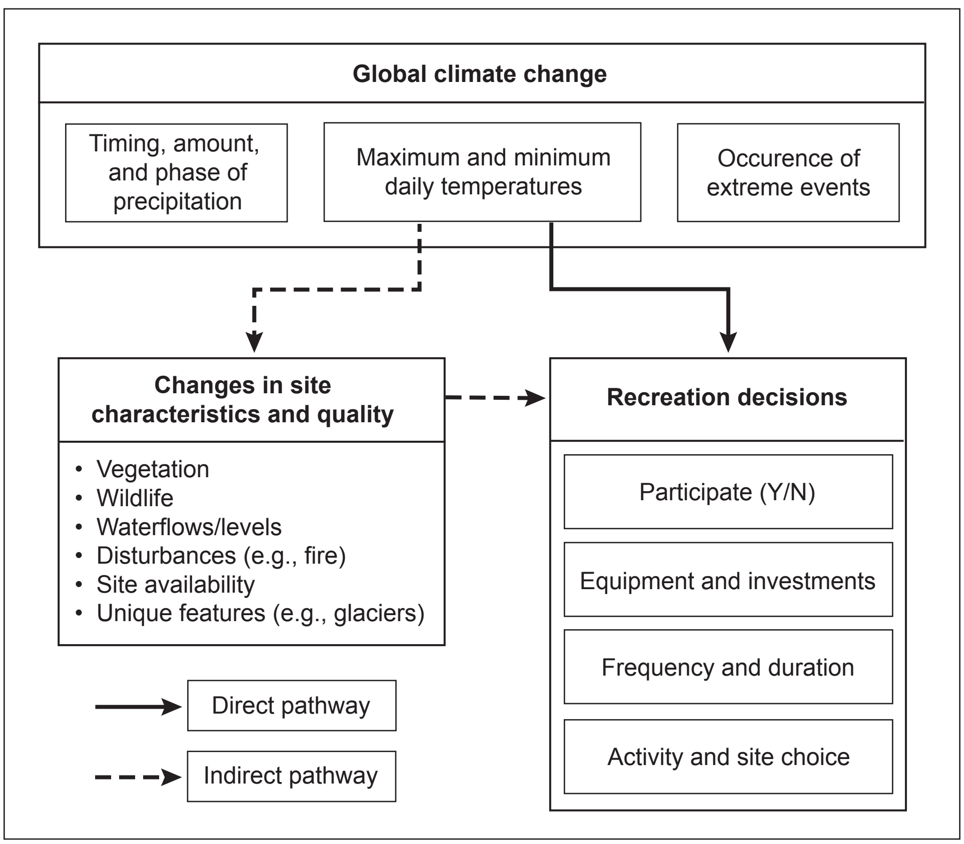

Figure 8.2—Direct and indirect effects of climate on recreation decisions (from Hand and Lawson 2016).

of projected warm-weather days is positively associated with expected visitation for U.S. national parks (Albano et al. 2013, Fisichelli et al. 2015). Temperature and precipitation may also directly affect the comfort and enjoyment that participants derive from engaging in an activity on a given day (Mendelsohn and Markowski 2004).

Indirect climate effects tend to be important for recreation activities that depend on additional ecosystem inputs, such as wildlife, vegetation, and surface water. Coldwater fishing in some locations in the Western United States is expected to decline in the future because of climate effects on temperature and streamflow that threaten coldwater fish habitat (Hunt et al. 2016, Jones et al. 2013) (chapter 5). Surface water area and streamflows are important for water-based recreation (e.g., boating), and forested area affects several outdoor activities (e.g., camping and hiking) (Loomis and Crespi 2004). Recreation visits to sites with highly valued natural characteristics, such as glaciers or popular wildlife species (chapters 4 and 7), may be reduced in some future climate scenarios if the quality of those characteristics is threatened (Scott et al. 2007). The indirect climate effect on disturbances, and wildfire in particular (chapter 7), may also play a role in recreation behavior, although the effect may be heterogeneous and vary over time (Englin et al. 2001). The recent update to the U.S. Forest Service (USFS) 2010 Resources Planning Act (RPA) assessment modeled the effects of climate change on different recreational activities (USDA FS 2016). Model results indicate that projected changes in recreation are expected to differ considerably (both positively and negatively) by geographic location and activity (table 8.2). For south-central Oregon, the number of participants in warm-weather activities in 2060 is projected to increase significantly (mostly as a result of population increase), but with minimal effects of climate change. Climate change is projected to have minimal positive and negative effects on most activities, with the exception of a significant increase in hunting participation.

Recreation Patterns in South-Central Oregon

Recreation is an important component of public land management in south-central Oregon. Recreational resources are managed to connect people with natural resources and cultural heritage, and to adapt to changing social needs and environmental conditions. Recreation managers aim to provide diverse recreation opportunities that span the recreation opportunity spectrum, from modern and developed to primitive and undeveloped (Clark and Stankey 1979) (box 8.1). For lands managed by the USFS, sustainable recreation serves as a guiding principle for planning and management purposes (USDA FS 2010, 2012b), and recreation is now considered an important ecosystem service as described in the 2012 planning rule. Sustainable recreation seeks to “sustain and expand benefits to America that quality recreation opportunities provide” (USDA FS 2010). Recreation has a central role in the mission of the National Park Service, with emphasis on providing access for park visitors for

Table 8.2—Modeled projections of the effects of climate change on recreation in South-Central Oregon Adaptation Partnership national forests[a] for 2060 (USDA FS 2016)

Recreation activity	Total number of participants	Projected change without climate change	Projected change with climate change	Net effects of climate change
	Millions	- - - - - - - -	*Percent*	- - - - - - - -
Visiting developed sites	31	68	67	-1
Visiting interpretive sites	26	72	71	-1
Birding	13	69	71	2
Nature viewing	31	66	65	-1
Day hiking	17	67	63	-4
Primitive area use	18	53	55	2
Motorized off-roading	9	47	49	-2
Motorized snow activities	1	80	78	-2
Hunting	3	9	19	10
Fishing	10	52	54	2
Developed skiing	5	91	96	5
Undeveloped skiing	1	55	53	-2
Floating	6	55	53	-2

[a] Data are from the "RPA Pacific Coast Region" in USDA FS (2016), which includes the Deschutes, Fremont-Winema, and Ochoco National Forests, and Crooked River National Grassland.

Note: Model output is based on an average of results for the A2, A1B, and B2 emission scenarios. Percentage changes for total number of participants are compared to 2008; net effects of climate change equal "with climate change" minus "without climate change."

not only enjoyment, but for broader cultural and educational opportunities related to the natural and historical environments (USDI NPS 2001). Collaboration with other agencies and stakeholders is a key for providing meaningful recreation experiences.

People participate in a wide variety of outdoor recreation activities in south-central Oregon. The National Visitor Use Monitoring (NVUM) program, conducted by the USFS to monitor recreation visitation and activity on national forests, identifies 27 different categories of recreation in which visitors may participate. These include a wide variety of activities and ways that people enjoy and use national forests and other public lands. The National Park Service monitoring program provides visitor counts at every unit but not activity characterization at every unit, so their visitor use statistics (https://irma.nps.gov/stats) differ from those of the USFS.

To assess how recreation patterns may change in south-central Oregon, categories of outdoor recreation activities are identified that may be sensitive to climate changes (fig. 8.3). For the purposes of the recreation assessment, a recreation activity is sensitive to climate change if changes in climate or environmental conditions that depend on climate **would result in a significant change** in the demand for or supply of that recreation activity within the assessment area.

The 27 categories of recreation identified in the NVUM survey are grouped into five climate-sensitive categories of activities, plus an "other" category of

Box 8.1

The Recreation Opportunity Spectrum

The Recreation Opportunity Spectrum (ROS) is a classification tool used by federal resource managers since the 1970s to provide visitors with varying challenges and outdoor experiences (Clark and Stankey 1979, USDA FS 1990). The ROS classifies lands into six **management class categories** defined by setting and the probable recreation experiences and activities it affords:

Management class	Example location
Modern developed	Deschutes National Forest near Bend, Oregon
Rural	Ochoco National Forest near Prineville, Oregon
Roaded natural	Many locations
Semi-primitive motorized	East Fort Rock off-highway vehicle area near LaPine, Oregon
Semi-primitive nonmotorized	Three Sisters Wilderness, Cascades Lakes Highway near Bend, Oregon
Primitive	Sky Lakes Wilderness, Fremont-Winema National Forest

Setting characteristics that define ROS include:

- Physical: type of access, remoteness, size of the area
- Social: number of people encountered
- Managerial: visitor management, level of development, naturalness (evidence of visitor impacts and/or management activities)

The ROS is helpful for determining the types of recreational opportunities that can be provided. After a decision has been made about the opportunity desirable in an area, the ROS provides guidance about appropriate planning approaches and standards by which each factor should be managed. Decisionmaking criteria include (1) the relative availability of different opportunities, (2) their reproducibility, and (3) their spatial distribution. The *ROS Primer and Field Guide* (USDA FS 1990) specifically addresses access, remoteness, naturalness, facilities and site management, social encounters, and visitor impacts. The ROS can be used to:

- Inventory existing opportunities.
- Analyze the effects of other resource activities.
- Estimate the consequences of management decisions on planned opportunities.
- Link user desires with recreation opportunities.
- Identify complementary roles of all recreation suppliers.
- Develop standards and guidelines for planned settings and monitoring activities.
- Help design integrated project scenarios for implementing resource management plans.

In summary, the ROS approach provides a framework that allows federal land managers to classify recreational sites and opportunities and to allocate improvements and maintenance within the broader task of sustainable management of large landscapes.

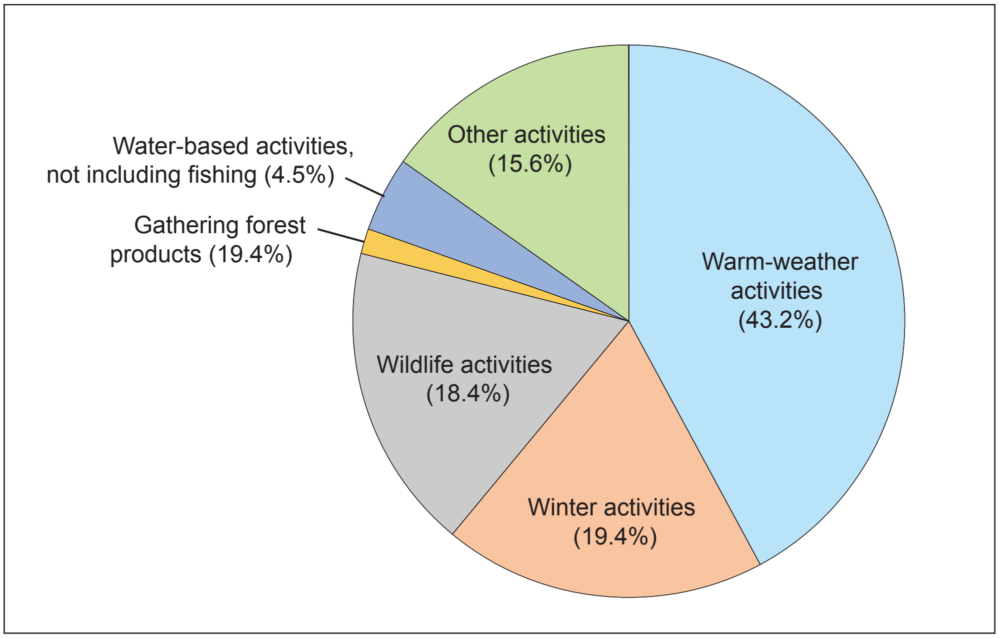

Figure 8.3—Percentage of total South-Central Oregon Adaptation Partnership national forest visits by climate-sensitive primary activity (USDA FS n.d.).

activities that are less sensitive to climate change. Each category includes activities that would likely be affected by changes to climate and environmental conditions in similar ways. Table 8.3 lists activities that comprise the climate-sensitive categories and summarizes their sensitivity to climate change. The categories were developed to capture the most common types of recreation in public lands in south-central Oregon that would be affected by climate change. In total, 18 NVUM recreation category activities were identified as sensitive to climate change. These 18 activities account for the primary recreation activities for 85 percent of visits to national forests in the South-Central Oregon Adaptation (SCOAP) assessment area.[2]

Warm-weather activities are the most popular and include hiking and walking, viewing natural features, developed and primitive camping, bicycling, backpacking, horseback riding, picnicking, and other nonmotorized uses. These were the main activity for 37.5 percent of national forest visits (654,000 visits per year). Of these, hiking and walking were the most popular and were the primary reason for 16.8 percent of visits (293,000 visits). Snow-based winter activities are also a large draw, and include downhill skiing, cross-country skiing, ski touring, and snowmobiling. They were the primary activity for 27.5 percent of all visitors (479,000 visits).

[2] White, E.M. 2017. Personal communication. Research social scientist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 3625 93rd Avenue, Olympia, WA 98512.

Table 8.3—Estimated participation in different recreational activities by visitors to Deschutes, Fremont-Winema, and Ochoco National Forests

Activity	National forest visitors who participated in this activity as their main activity[a]		Relationship to climate and environmental conditions
	Percent	*Number*	
Warm-weather activities:	37.5	653,625	Participation typically occurs during warm weather; dependent on availability of snow- and ice-free sites, dry weather with moderate daytime temperatures, and air quality unimpaired by smoke from wildfires.
Hiking/walking	16.8	292,824	
Viewing natural features	6.3	109,809	
Developed camping	3.6	62,748	
Bicycling	4.6	80,178	
Other nonmotorized	3.7	64,491	
Horseback riding	0.5	8,715	
Picnicking	0.8	13,944	
Primitive camping	0.4	6,972	
Backpacking	0.8	13,944	
Winter activities:	27.5	479,325	Participation depends on timing and amount of precipitation as snow, and cold temperatures to support consistent snow coverage. Inherently sensitive to climatic variability and interannual weather patterns.
Downhill skiing	19.7	343,371	
Snowmobiling	0.9	15,687	
Cross-country skiing	6.9	120,267	
Wildlife activities:	13.3	231,819	Wildlife availability is a significant input for these activities. Temperature and precipitation are related to habitat suitability through effects on vegetation, productivity of food sources, species interactions, and water quantity and temperature (for aquatic species). Disturbances may affect amount, distribution, and spatial heterogeneity of suitable habitat.
Hunting	1.7	29,631	
Fishing	9.7	169,071	
Viewing wildlife	1.9	33,117	
Gathering forest products	1.3	22,659	Activity depends on availability and abundance of target species (e.g., berries, mushrooms), which are related to patterns of temperature, precipitation, and snowpack. Disturbances may alter availability and productivity of target species in current locations and affect opportunities for species dispersal.
Water-based activities:[b]	5.5	95,865	Participation requires sufficient waterflows (in streams and rivers) or levels (in lakes and reservoirs). Typically considered a warm-weather activity and depends on moderate temperatures and snow- and ice-free sites. Some participants may seek water-based activities as a heat refuge during periods of extreme heat.
Nonmotorized water activities	4.1	71,463	
Motorized water activities	1.4	24,402	

[a] Source: USDA FS (n.d.). Includes data from Deschutes, Ochoco, and Fremont-Winema National Forests, Round 3 of the National Visitor Use Monitoring program. Recreation surveys were administered for these forests in 2013. Visits to Crooked River National Grassland are included in visits to Deschutes National Forest and not reported separately.

[b] Does not include fishing.

Wildlife-related activities, including hunting, fishing, and viewing wildlife, were the primary activity for 13.3 percent of visits (232,000 visits). Of these, fishing was the most popular with 9.7 percent of visits (169,000 visits). Gathering forest products such as berries and mushrooms was the primary activity for 1.3 percent of visits (23,000 visits). Motorized and nonmotorized water activities (other than fishing) comprised 5.5 percent of visits (96,000 visits). Crater Lake National Park has nearly 476,000 visits annually, 77 percent of which occured during the summer (box 8.2). Most summer visitors participate in sightseeing, hiking, and camping, whereas winter visitors participate in cross-country skiing and snowmobiling.

Nonlocal visitors spend $106 million per year (based on expenditures within 80 km of national forest boundaries; 2014 dollars) (USDA FS, n.d.). Table 8.4 summarizes expenditures by visitors to national forests in the SCOAP assessment area. We focus on spending by nonlocal visitors because these individuals spend money in local communities that would not have been spent otherwise. Lodging expenses comprise 30 percent of total expenditures, followed by gas and oil (18.5 percent), restaurants (16.5 percent), and groceries (14.5 percent). The remaining expenditure categories of other transportation, activities, admissions and fees, and souvenirs comprise 21 percent of all spending. It should be noted that economic contribution (spending as a result of recreational activity), as currently calculated by federal agencies, differs from economic impact (including the multiplier effect of such spending), and that the USFS estimates of local spending tend to be conservative.[3] Therefore, the data cited here are just one quantifiable means of describing the economic significance of recreation activities.

[3] Activities in the "Other" category were judged to be less sensitive to climate changes and tend to be less frequently listed as a primary recreation activity in south-central Oregon. Although participation in many of these activities is likely linked to climate in some way, other factors are likely to be more important determinants of participation (e.g., maintenance of infrastructure for visiting interpretive sites).

Box 8.2

Climate Change and Recreation in Crater Lake National Park

An exceptionally scenic caldera lake that formed after the collapse of Mount Mazama about 7,700 years BP, the subalpine and montane forests that surround it, and deep snowpacks make Crater Lake National Park a popular tourist and recreation destination. Crater Lake, the deepest lake in the United States, has pristinely clear waters. Recreational opportunities include hiking, bicycling, camping, boat tours, wildlife viewing, cross-country and backcountry skiing, and snowboarding. The park sees almost a half-million visitors on average each year, with the vast majority visiting during warm-weather months. Average annual recreation visitation and overnight stays at Crater Lake National Park during 2010–2014 were:

Summer (June–September)	367,637 (77.3 percent)
Shoulder season (May, October)	61,949 (13.0 percent)
Winter (November–April)	45,946 (9.7 percent)
Total	475,532

Some of the park features that draw recreational visitors may be sensitive to climate-related changes. For example, clear water that remains at a relatively constant level depends on precipitation, particularly in the form of winter snow. Winter recreation is also snow dependent. Although the park tends to receive a large snowpack even in drier years, low snowfall totals may limit winter recreation opportunities at the beginning and end of the season.

Warmer temperatures may result in longer seasons available for warm-weather recreation activities, but could also alter the distribution and range of certain plant and animal species that comprise the park's unique natural landscape, such as whitebark pine (*Pinus albicaulis* Engelm.) and American pika (*Ochotona princeps* Richardson). Increased frequency and intensity of wildfire resulting from climate change may also affect recreation through road and area closures. Although visitors may have increased opportunities to visit the park during the snow-free season, projected increases in fire-season length may limit visitation in certain years.

Table 8.4—Estimated total annual expenditures by non-local and local visitors to Deschutes, Fremont-Winema, and Ochoco National Forests, by spending category

	Nonlocal spending[a b]		Local spending	
Spending category	Total annual expenditures	Spending for each category	Total annual expenditures	Spending for each category
	Thousands of dollars (2014)	*Percent*	*Thousands of dollars (2014)*	*Percent*
Lodging	20,822	28.0	1,702	6.8
Restaurant	14,469	19.4	3,276	13.1
Groceries	9,807	13.2	5,240	21.0
Gasoline, oil	11,414	15.3	8,255	33.1
Other transportation	441	0.6	84	0.3
Activities	6,803	9.1	1,398	5.6
Admissions, fees	5,544	7.4	2,601	10.4
Souvenirs	5,187	7.0	2,371	9.5
Total	74,488		24,927	

[a] Nonlocal refers to trips that required traveling more than 80 km.
[b] Source: Calculations based on national forest visitation data (USDA FS, n.d.) and estimates of forest-level visit segment shares and per-visit expenditures (White 2017). Includes data from Deschutes, Fremont-Winema, and Ochoco National Forests, Round 3 of the National Visitor Use Monitoring program. Recreation surveys were administered for these forests in 2013. Expenditures for Crooked River National Grassland are included in visits to Deschutes National Forest and not reported separately. See White (2017) for a description of how to estimate forest-level expenditure summaries.

Assessing Climate Change Effects on Recreation

This section provides an assessment of the likely effects of climate on climate-sensitive recreation activities in the SCOAP assessment area. Two sources of information are used to develop assessments for each category of recreation activity. First, reviews of existing studies of climate change effects on recreation and studies of how recreation behavior responds to climate-sensitive ecological characteristics are used to draw inferences about likely changes for each activity category. Second, projections of ecological changes specific to the SCOAP assessment area, as detailed in the other chapters contained in this publication, are paired with the recreation literature to link expected responses of recreation behavior to specific expected climate effects.

Current conditions reflect wide variation in interannual and intra-annual weather and ecological conditions. Temperature, precipitation, waterflows and levels (chapters 3 and 4), wildlife distributions (chapter 7), vegetative conditions, and wildfire activity (chapter 6) may exhibit wide ranges of variation. Recreationists are likely already accustomed to some extent to making decisions with a significant uncertainty about conditions at the time of participation. Recreation in south-central Oregon is affected by several existing challenges and stressors. Increasing population near urban areas, particularly in proximity to public lands, can strain visitor services and facilities because of increased use; projected population increases in the future may exacerbate these effects (Bowker et al. 2012). Increased use from population growth can also reduce site quality because of congestion at the most popular sites (Yen and Adamowicz 1994).

The physical condition of recreation sites and natural resources is affected by both human and natural forces. Recreation sites and physical assets need maintenance. Deferred or neglected maintenance may increase congestion at other sites that are less affected, or increase hazards for visitors who continue to use degraded sites. Moreover, deferred or neglected maintenance can diminish user experience and cause unintended resource damage (e.g., adjacent aquatic resources). Unmanaged recreation can create safety hazards and contribute to natural resource degradation (USDA FS 2010). This stressor may interact with others, such as population growth and maintenance needs, if degraded site quality or congestion encourages users to engage in recreation that is not supported or appropriate at certain sites or at certain times of the year. Natural hazards and disturbances may create challenges for providing recreation opportunities. For example, wildfire affects recreation demand (because of altered site quality and characteristics) but may also damage physical assets or exacerbate other natural hazards such as erosion (chapters 4 and 6).

The overall effect of climate change on recreation activity is likely to be an increase in participation in warm-weather activities and a potential increase in the benefits derived from recreation, a function of warmer temperatures and increased season length (Fisichelli et al. 2015). In contrast, lower snowpack is expected to decrease the available season for winter activities such as skiing and snowmobiling (Mendelsohn and Markowsi 2004, Wobus et al. 2017). However, these general inferences mask potential variation in the effects of climate on recreation between types of activities and geographic locations.

Warm-Weather Activities

Warm-weather activities such as hiking, camping, and nature viewing are the most common recreation activities in south-central Oregon, and the primary activities in more than 40 percent of all visits to national forests in south-central Oregon. Warm-weather recreation is sensitive to the length of appropriate season (Fisichelli et al. 2015), depending on the availability of snow- and ice-free trails and sites, and the timing and number of days with temperatures within minimum and maximum comfort range (which may vary with activity type and site). The number of warm-weather days was a significant predictor of expected visitation behavior in Rocky Mountain National Park (Colorado) (Richardson and Loomis 2004), and minimum temperature was a strong predictor of monthly visitation patterns in Waterton Lakes National Park (Alberta, Canada) (Scott et al. 2007).

Overall demand for warm-weather activities is expected to increase owing to a direct effect of climate change on season length. Temperatures are expected to increase 3 to 7 °C across the region by the year 2100 (chapter 3), which is expected to result in earlier availability of snow- and ice-free sites and an increase in the number of warm-weather days in spring and autumn. For example, higher minimum temperatures are associated with increased number of hiking days (Bowker et al. 2012). This was borne out in south-central Oregon in spring 2015, when wilderness use increased significantly above the average, because of very early snow-free access.[4] Also in 2015, early hiking and mountain biking on muddy trails caused significant damage in places (fig. 8.4).

However, if season length increases, access to popular recreation sites may be limited, because many federal recreation and maintenance employees are hired for 3 to 4 summer months only (including volunteer workers), precluding earlier accomplishment of tasks such as clearing trails and opening campgrounds. In addition, extreme summer

[4] Information on recreation in 2015 is based on observations provided by federal recreation managers who participated in the South-Central Oregon Adaptation Partnership.

Figure 8.4—Trail use by hikers and mountain bikers, particularly before trails are officially open, can cause significant damage when trails are muddy and have standing water.

temperatures can dampen participation during the hottest weeks of the year (Bowker et al. 2012, Richardson and Loomis 2004), although it is unclear if that will occur in south-central Oregon. Extreme heat may shift demand to cooler weeks at the beginning or end of the warm-weather season, or shift demand to alternative sites (e.g., higher elevations, lakes) that are less exposed to extreme temperatures and dusty conditions.

Indirect effects of climate change on forested area may have a negative effect on warm-weather recreation, primarily through wildfire impacts, if site availability and quality are compromised. Wildfires have a heterogeneous and temporally nonlinear effect on recreation (Englin et al. 2001). The presence of recent wildfires has differential effects on activities such as hiking and mountain biking, although recent wildfire activity tends to decrease the number of visits (Hesseln et al. 2003, 2004; Loomis et al. 2001). The severity of fire may also matter. High-severity fires are associated with decreased recreation visitation, often as a result of large-scale closures of federal lands, whereas low-intensity fires are in some cases associated with slight increases in visitation (Starbuck et al. 2006). Recent fires are associated with initial losses of benefits for camping (Rausch et al. 2010) and backcountry recreation activities (Englin et al. 1996) that are attenuated over time. In a study in Yellowstone National Park, visitation was lower following months with high wildfire activity, although there was no discernable effect of previous-year fires (Duffield et al. 2013).

Potential increases in the likelihood of extreme wildfire activity may reduce demand for warm-weather activities in certain years because of degraded site desirability, impaired air quality from smoke, and limited site access caused by fire management activities. This was illustrated in south-central Oregon in late summer 2015, when widespread wildfire and associated smoke reduced access to and quality of recreation. South-central Oregon is expected to experience increased area burned by wildfire, average fire size, and fire severity (chapter 6), which tend to have a negative impact on recreation visitation and benefits derived from recreation.

Flooding and high peak flows of rivers and smaller streams are expected to increase as a result of decreased snowpack (chapter 4). Flooding will be most prominent in the lower reaches of streams, including floodplains, where many recreational facilities, trailheads, and roads are located (fig. 8.5). This may damage recreational infrastructure and roads, as well as restrict access to facilities for long periods of time. Approximately 29 km of recreation trails (hiking, horse, off-highway vehicle) are within 90 m of streams in which bankfull stream depth is expected to increase by over 30 percent (compared to historical) by 2040, increasing to 206 km by 2080. Recreation sites most at risk to flooding by 2040 include Pikes Crossing (forest camp), Corral Creek (campground), and Skyliner Lodge, increasing to 23 sites by 2080.

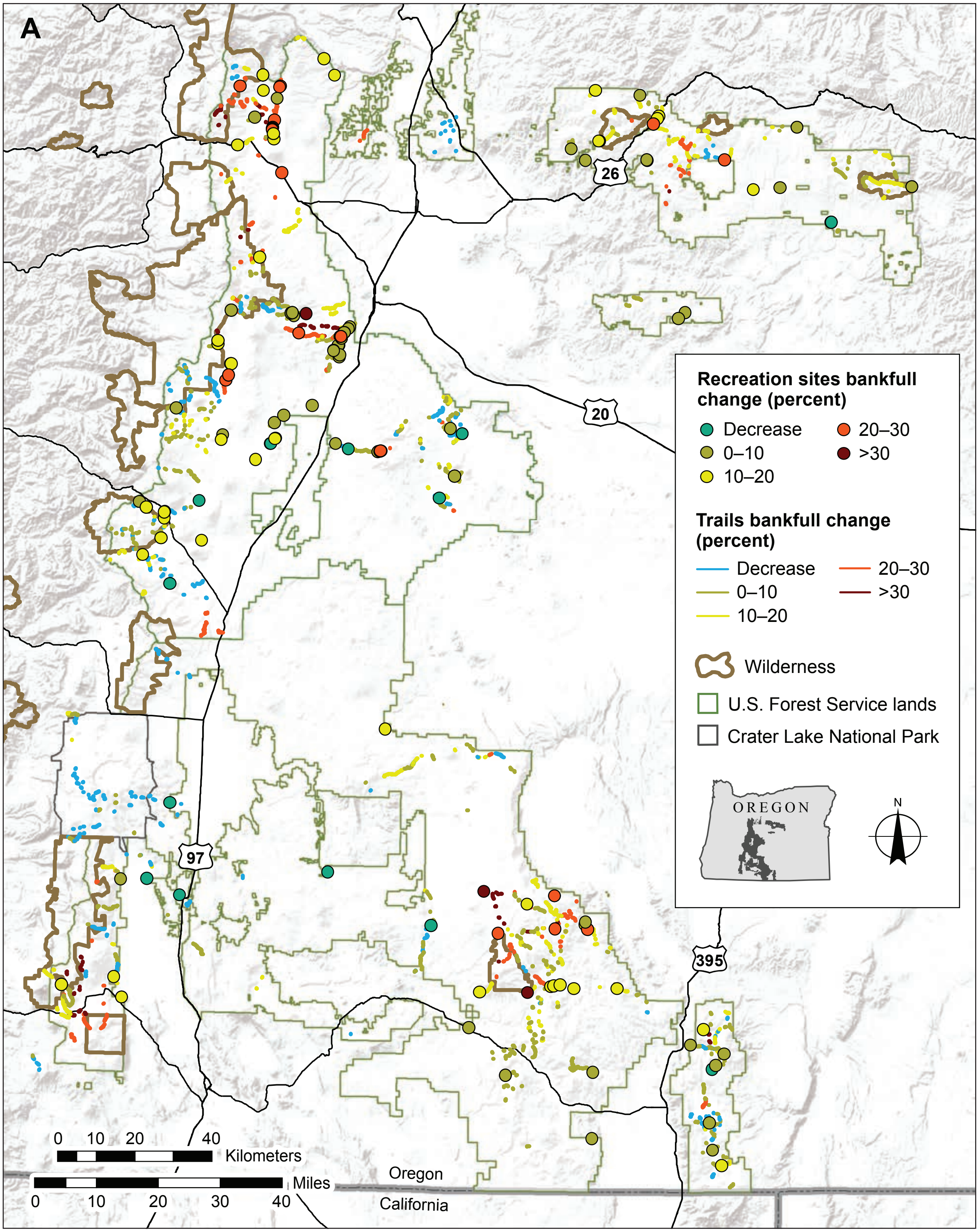

Figure 8.5—Summer recreation is sensitive to climate change in locations where flooding will increase on streams within 90 m of Forest Service or National Park Service recreation sites or trails: (A) percentage change in bankfull flow ($m^3 s^{-1}$) between historical data and 2040; (B) percentage change in bankfull flow ($m^3 s^{-1}$) between historical data and 2080.

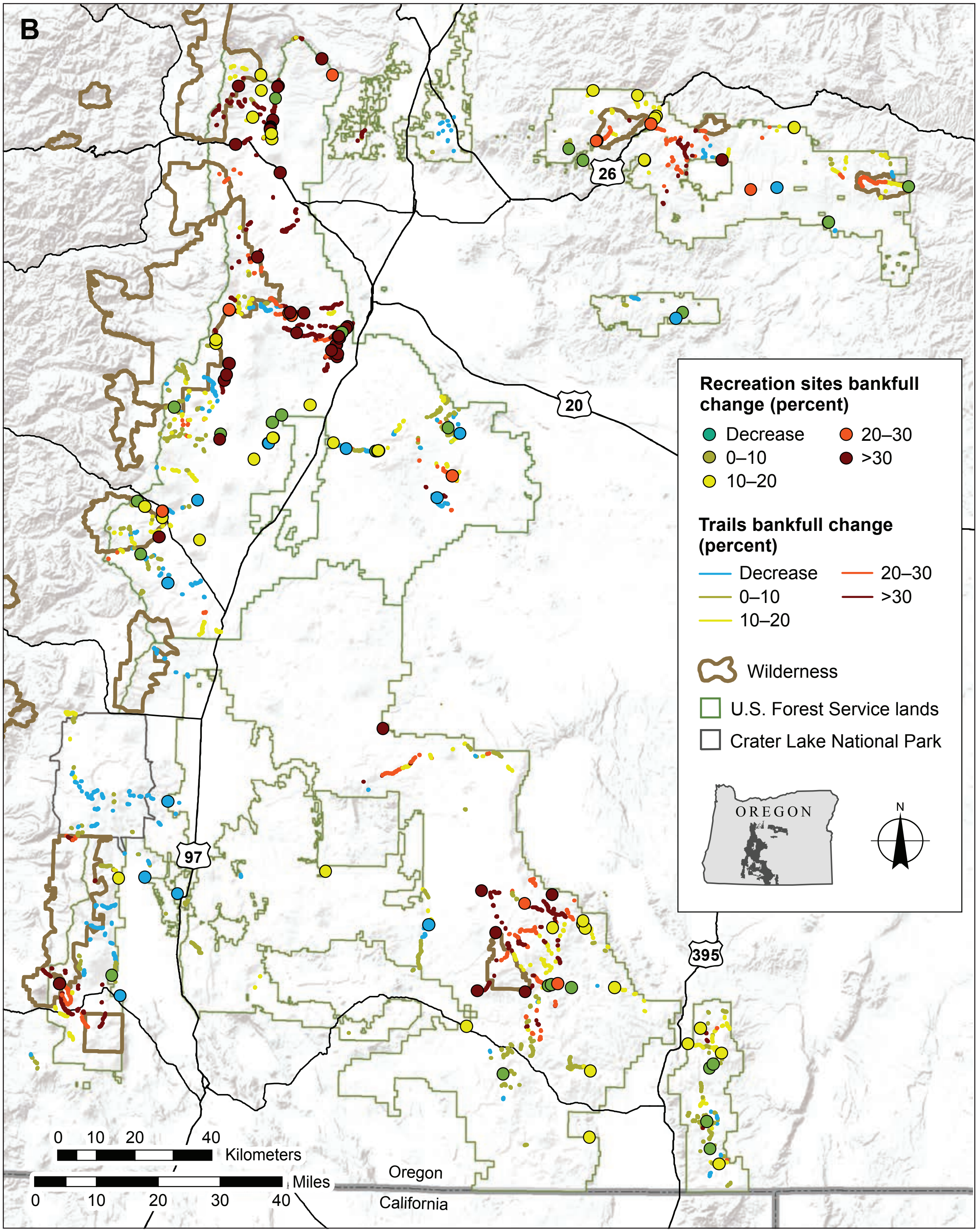

Figure 8.5 (continued)—Summer recreation is sensitive to climate change in locations where flooding will increase on streams within 90 m of Forest Service or National Park Service recreation sites or trails: (A) percentage change in bankfull flow ($m^3 s^{-1}$) between historical data and 2040; (B) percentage change in bankfull flow ($m^3 s^{-1}$) between historical data and 2080.

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

Adaptive capacity among recreationists is high because of the large number of potential alternative sites. Some recreationists can alter the timing of visits and alter capital investments (e.g., appropriate gear), although some may be constrained by work schedules, family schedules, and finances. However, benefits derived from recreation may decrease even if substitute activities or sites are available (Loomis and Crespi 2004). For example, some alternative sites may involve higher costs of access (because of remoteness or difficulty of terrain). Although the ability of recreationists to substitute sites and activities is well established, there remains little understanding of how people substitute across time periods or between large geographic regions (e.g., choosing a site in south-central Oregon instead of the Southwestern United States) (Shaw and Loomis 2008). It is also unclear how much flexibility exists in scheduling outfitters and recreation concessionaires and if special-use permitting can be modified to accommodate seasonal changes.

In summary, projected climate scenarios are expected to result in a moderate increase in warm-weather recreation activity and benefits derived from these activities. Longer warm-weather seasons will likely increase the number of days when warm-weather activities are viable and increase the number of recreation sites accessible during shoulder seasons. This increased activity may degrade the condition of some trails, facilities, and infrastructure. The effects of a longer season may be offset somewhat by negative effects on warm-weather activities during extreme heat and increased wildfire activity. The likelihood of effects on warm-weather recreation is high; the primary driver of climate-related changes to warm-weather recreation is through direct effects of temperature changes on the demand for warm-weather recreation. Indirect effects on recreation, primarily through wildfire effects, may be harder to project with certainty and precision, particularly at a fine-grained geospatial scale.

Cold-Weather Activities

South-central Oregon has many winter recreation sites that exhibit a wide range of characteristics and attract visitors from the Pacific Northwest and beyond. Mount Bachelor Ski Area, located in Deschutes National Forest, is a major attraction for downhill skiers and snowboarders and provides significant revenue for businesses in nearby Bend, Oregon, and elsewhere (box 8.3). Other national forest sites and Crater Lake National Park support cross-country skiing, snowshoeing, snowmobiling, and backcountry touring and camping.

Snow-based recreation is highly sensitive to variations in temperature and the amount and timing of precipitation as snow. Seasonal patterns of temperature and snowfall determine the likelihood of a given site having a viable season and the length of viable seasons (Scott et al. 2008). Lower temperatures and the presence of new snow are associated with increased demand for skiing and snowboarding (Englin and Moeltner 2004).

Climate change is expected to have a generally negative effect on snow-based winter activities, although a wide range of effects at local scales is possible because of variations across the region in site location and elevation. Approximately 360 km of snow trails (cross-country ski, snowmobile, snowshoe) in the SCOAP assessment area are considered to be highly sensitive to reduced snowpack (fig. 8.6). Sno-Parks in the highly sensitive category include Corbett, Lower Three Creek, Summit, Swampy Lakes, and Upper Three Creek.

Warmer projected winter temperatures for the region are expected to reduce the proportion of precipitation as snow, even if the total amount of precipitation does not deviate significantly from historical norms (chapter 4). The rain-snow transition zone (where precipitation is more likely to be snow rather than rain for a given time of year) is expected to move to higher elevations, particularly in late autumn and early spring (Klos et al. 2014). This places lower elevation sites at risk of shorter or nonexistent winter recreation seasons, potentially changing types and patterns of recreation. However, the highest elevation areas in the region are projected to remain snow-dominated in future climate scenarios (see chapter 4).

Studies of the ski industry in North America uniformly project negative effects of climate change (Scott and McBoyle 2007, Wobus et al. 2017). Overall warming is expected to reduce expected season length and the likelihood of reliable winter recreation seasons. Climatological projections for the SCOAP assessment area (see chapter 3) are consistent with studies of ski area vulnerability to climate change in other regions, where projected effects of climate change on skiing, snowboarding, and other snow-based recreation activities is negative (Dawson et al. 2009, Scott et al. 2008, Stratus Consulting 2009, Wobus et al. 2017). Low-elevation access areas will probably become less available, and those locations with adequate snow may face more recreation pressure (figs. 8.6 and 8.7).

Snow-based recreationists have moderate capacity to adapt to changing conditions given the relatively large number of winter recreation sites in the region. A recent

Box 8.3

Mount Bachelor, a Recreation Icon

Mount Bachelor is one of the most prominent geological features of south-central Oregon. Formed 11,000 to 15,000 years BP as a shield volcano, it was later capped with a stratovolcano as eruptions became more explosive over time. Composed mainly of basalt and basaltic andesite, it last erupted 8,000 to 10,000 years BP and is covered with ash from the eruption of Mount Mazama (currently occupied by Crater Lake) about 7,700 years BP.

Mount Bachelor is a popular and economically important recreation site, especially for downhill skiing. Located within Deschutes National Forest about 35 km west of Bend, Oregon, the ski area operates under a U.S. Forest Service special-use permit. Often termed simply "the Mountain," Mount Bachelor Ski Area contains the largest skiable area (316 ha) in the state.

Based on data for 2010–2011, the total economic impact of the snow sports industry in Oregon was $675 million; every $1,000,000 spent generated an additional $900,000 of spending elsewhere in Oregon, and every 10 jobs in the snow sports industry linked to another four jobs (Runberg 2013). Mount Bachelor plays a large part in this economic assessment, hosting around 500,000 skier visits per year (based on data since 2004). It is also an increasingly popular destination for summer recreation (hiking, mountain biking, riding the ski lift), expanding the season for visitation and buffering the potential effects of climate change on reduced snowpack (and less skiing).

Although national statewide ski area visitations have steadily increased over the past 50 years, Mount Bachelor's capacity is limited by parking availability and current infrastructure. The Master Development Plan, approved by the Forest Service in 2013, allows for potential expansion of infrastructure and recreational activities. The area covered by the special-use permit has increased, and expansion will optimize visitation numbers based on parking, lodge, lift, and ski area capacity. An increase in recreational activities during the summer will encourage more visitation in snow-free months (Ecosign Mountain Resort Planners 2010).

Karl Helser

Mount Bachelor ski resort, northern view.

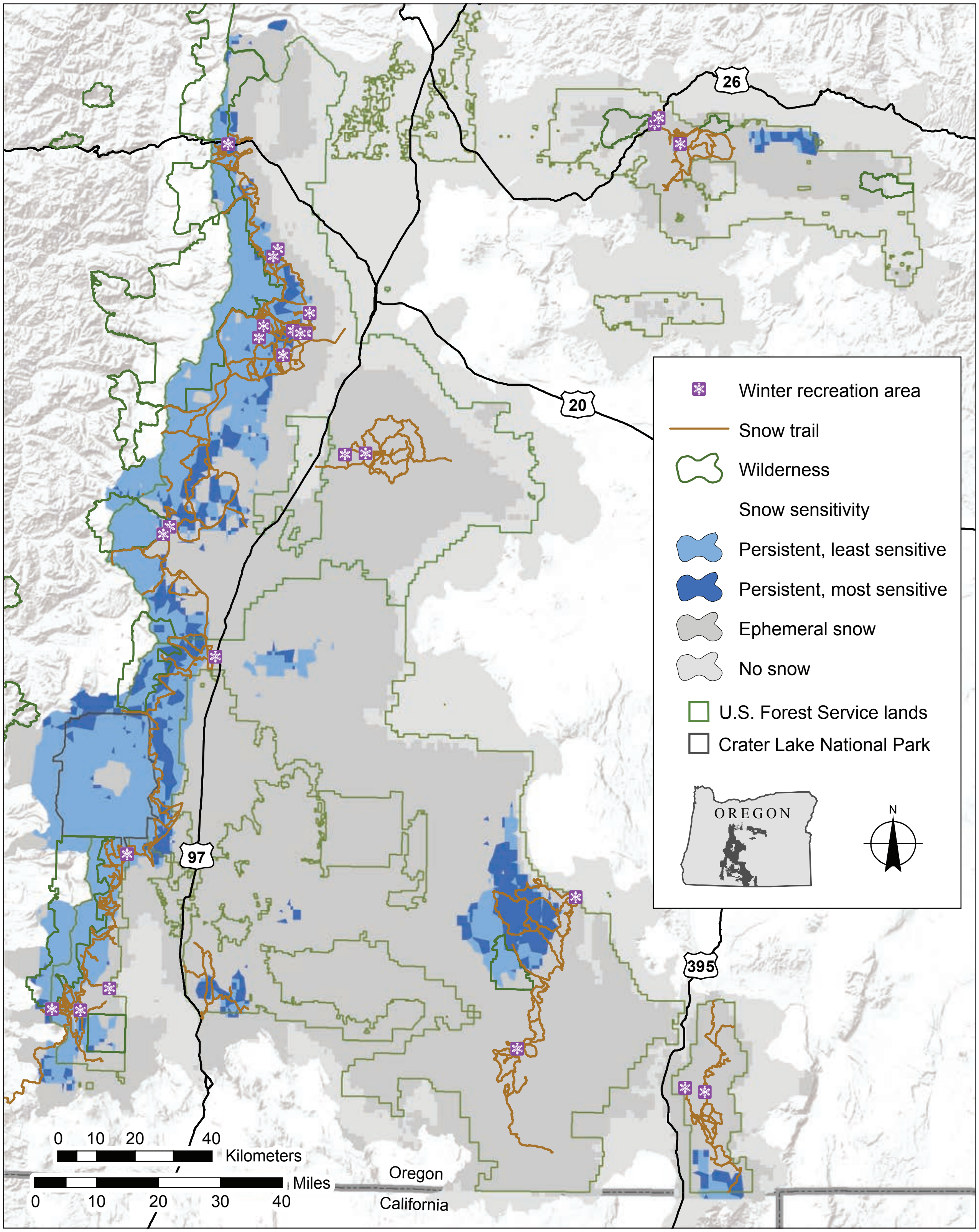

Figure 8.6—Winter recreation is sensitive to climate change in locations where the utility of recreation sites will be reduced by decreasing snowpack.

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Figure 8.7—Locations with adequate snow for winter recreation (e.g., sno-parks) may face increasing use and reduced quality of the recreational experience.

survey in Oregon showed that downhill skiers are willing to travel an average of 110 km to reach a ski area (Community Planning Workshop 2012), although this distance may be flexible if favorable snow conditions become scarcer. For example, during the winter of 2014–2015, which was characterized by very low snowpack levels across the region, Mount Bachelor Ski Area had more snow than any other ski area in the Pacific Northwest. Consequently, Mount Bachelor had a normal number of visits (483,000, compared to the past 10-year average of 505,000), generating significant revenue for the Bend, Oregon, area in an otherwise disastrous year for the downhill ski industry and other snow-based activities in the Northwest (box 8.4). In addition, like other large ski resorts, Mount Bachelor has the capability to make snow to supplement low snowpack. Although interregional substitution patterns for winter recreation, including increased expense and distance traveled, are poorly quantified (Shaw and Loomis 2008), changes in south-central Oregon sites relative to other regions may affect future visitation.

For undeveloped or minimally developed site activities (cross-country skiing, backcountry skiing, snowshoeing), recreationists may seek higher elevation sites with higher likelihoods of viable seasons (fig. 8.8). This would not be possible for snowmobiling when higher elevations are within designated wilderness. Although developed downhill skiing sites are fixed improvements, potential adaptations include additional investments in snowmaking, higher elevation development, and new run development (Scott and McBoyle 2007), as well as promoting the use of ski areas during multiple seasons for warm-weather activities (e.g., mountain biking, zip lines).

Box 8.4

The Winter of 2014–2015 in South-Central Oregon: A Preview of the Effects of Climate Change on Recreation?

Climate scientists considered the winter of 2014–2015 in the Pacific Northwest to be a preview of later in the 21st century because it had the characteristics projected by climate models for the year 2060. Average temperatures during the winter were 3 to 9 °C above the mean. Total precipitation from October 2014 through March 2015 was near normal, but most precipitation fell as rain at low to moderate elevations—exactly as projected by climate models.

Federal land managers in south-central Oregon, who are familiar with how climate and weather interact with natural resources, observed many distinctive effects of the unusually warm weather and low snowpack. Many typical activities on federal lands and in surrounding communities changed (use type and patterns of use). The summary below includes facts, observations, and comments collected from federal employees and community members in May 2015 about the winter of 2014–2015. Note that not all effects of this unusual winter are necessarily negative for resource values or personal values. Quotes are included to provide personal perspectives.

- Recreation use was different, with more road driving and hiking relative to skiing (cross-country, backcountry, alpine). "I never got to go cross-country skiing (glad I didn't invest in new backcountry skis this year)." "I was able to hike more instead of going cross-country skiing."
- Lack of snow meant the Digit Point campground at Miller Lake was free of snow much earlier, and because it is a year-round fishing lake, people have been fishing there since the end of February. The road was damaged, and because there were no seasonal staff available yet, garbage accumulated and other damage occurred at the lakeside.
- Camping in open-access campgrounds and dispersed camping sites saw increased early pressure prior to seasonal staff being available.
- No snowmobile trails or Sno-Parks were open for snowmobiling in Fremont-Winema National Forest.
- Warner Canyon Ski Area did not open for the 2013–2014 and 2014–2015 winters because there was not enough snow.
- The Chemult Dog Sled Races were canceled for the 2013–2014 and 2014–2015 winters because there was not enough snow.
- Lack of snow meant no high school cross-country ski races for the Oregon Interscholastic Ski Racing Association, which uses the Sno-Park every year. This resulted in no additional revenue for the town of Chemult from race participants and visitors.
- No ice fishing or ice skating occurred because of the lack of lake and reservoir ice.
- Boat users requested docks on lakes to be installed several months earlier than normal, and staff was not available to accommodate the requests.
- "I biked nearly all winter without studs on my tires!"


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Figure 8.8—For many backcountry skiers, a satisfactory experience includes sufficient snow cover, scenic vegetation, and solitude—an interaction of physical, biological, and social factors.

In summary, the magnitude of climate effects on snow-based winter activities is expected to be high. Warmer temperatures are likely to shorten winter recreation seasons, reducing opportunities for winter activities at lower elevation. Developed sites may have limited ability to adapt to these changes unless additional adjacent areas are available and feasible for expanded development. The likelihood of effects is expected to be high for snow-based recreation, although variation across sites is likely because of differences in location and elevation. Climate models generally project warming temperatures and a higher elevation rain-snow transition zone, which would leave additional sites exposed to the risk of shorter seasons.

Wildlife Activities

Wildlife recreation activities involve terrestrial or aquatic animals as a primary component of the recreation experience. Wildlife recreation can involve consumptive (e.g., hunting) or nonconsumptive (e.g., wildlife viewing, birdwatching, catch-and-release fishing) activities. Distinct from other types of recreation, wildlife activities depend on the distribution, abundance, and quality of desired target species. These factors influence activity "catch rates," that is, the likelihood of catching or seeing an individual of the target species. Sites with higher catch rates can reduce the costs associated with a wildlife activity (e.g., time and effort tracking targets) and enhance overall enjoyment of a recreation day for that activity (e.g., more views of highly valued species).

Participation in wildlife activities is sensitive primarily to climate-related changes that affect expected catch rates. Catch rates are important determinants of site selection and trip frequency for hunting (Loomis 1995, Miller and Hay 1981), substitution among hunting sites (Yen and Adamowicz 1994), participation and site selection for fishing (Morey et al. 2002), and participation in nonconsumptive wildlife recreation (Hay and McConnell 1979). Changes to habitat, food sources, or streamflows and water temperature (for aquatic species) may alter wildlife abundance and distribution, which in turn influence expected catch rates and wildlife recreation behavior. The current trend of declining hunting and fishing licenses in Oregon (Darling 2014) may reduce demand for animal harvest.

Wildlife recreation may also be sensitive to other direct and indirect effects of climate change. The availability of highly valued target species affects benefits derived from wildlife activities (e.g., bull trout [*Salvelinus confluentus* Suckley] for coldwater anglers) (Pitts et al. 2012), as does species diversity for hunting (Milon and Clemmons 1991) and nonconsumptive activities (Hay and McConnell 1979). Temperature and precipitation are related to general trends in participation for multiple wildlife activities (Bowker et al. 2012, Mendelsohn and Markowski 2004), although the precise relationship may be activity specific or species specific. Some activities (e.g., big game hunting) may be enhanced by cold temperatures and snowfall at particular times to aid in field dressing, packing out harvested animals, and tracking, although the overall effects of snow level will probably differ by location and target species.

Warmer temperatures projected for south-central Oregon may increase participation in terrestrial wildlife activities because of an increased number of days that are desirable for outdoor recreation, although extreme heat in summer would have a negative effect. In general, warmer temperatures are associated with greater participation in hunting, birdwatching, and viewing wildlife (Bowker et al. 2012).

However, hunting that occurs during discrete seasons (e.g., elk [*Cervus elaphus* L.] and deer hunts managed by state seasons) may depend on weather conditions during a short period of time. The desirability of hunting during established seasons may decrease as warmer weather persists later into the fall and early winter and the likelihood of snow cover decreases, reducing harvest rates. In addition, the potential for conflicts with warm-weather recreation may increase, because hunting is not generally compatible with other forms of recreation.

The effects of changes in habitat for target species are likely to be ambiguous because of complex relationships among species dynamics, vegetation, climate, and disturbances (primarily wildfire and invasive species). Overall vegetative productivity may decrease in the future, although this is likely to have a neutral effect on game species populations, depending on the size, composition, and spatial heterogeneity of forage opportunities in the future (see chapter 6). Similarly, the effects of disturbances on harvest rates of target species are ambiguous because it is unknown exactly how habitat composition will change in the future.

Higher temperatures will likely decrease populations of native coldwater fish species as climate refugia become limited to higher elevations (see chapter 5). This change favors increased populations of fish species that can tolerate warmer temperatures. However, it is unclear whether shifting populations of species will affect catch rates, because relative abundance of fish may not necessarily change if warmwater species become more common. It is unclear if a shift from coldwater species to warmwater species will affect preferences and behavior by anglers (Hunt et al. 2016).

Increased interannual variability in precipitation and reduced snowpack will result in higher peak flows in winter and lower low flows in summer, creating stress for fish populations during different portions of their life histories (chapter 5). The largest patches of habitat for cold-water species will be at higher risk of fragmentation, particularly at low elevation. Increased incidence and severity of wildfire may increase the likelihood of secondary erosion events that degrade waterways and fish habitat and could affect infrastructure (e.g., docks, boat launches) used for fishing. These effects could degrade the quality of individual sites in a given year or decrease the desirability of angling as a recreation activity relative to other activities. Some anglers will be able to shift activities to different sites and different target species.

In summary, the magnitude of climate effects on activities involving wildlife is expected to be low for terrestrial wildlife activities and moderate for fishing. Ambiguous effects of vegetative change on terrestrial wildlife populations and distribution suggest that conditions may improve in some areas and decline in others.

Overall, warming tends to increase participation, but may create timing conflicts for activities with defined regulated seasons (e.g., big game hunting). Anglers may experience moderate negative effects of climate change on benefits derived from fishing. Opportunities for coldwater species fishing will likely decrease, although warmwater tolerant species may become more common, mitigating reduced benefits from fewer coldwater species. Warmer temperatures and longer seasons encourage additional participation, but indirect effects of climate on streamflows and reservoir levels could reduce opportunities in some years. The likelihood of climate-related effects on wildlife recreation is expected to be moderate for both terrestrial and aquatic wildlife activities. Uncertainties exist about the magnitude and direction of indirect effects of climate on terrestrial habitat and the degree to which changes in available target species affect participation.

Gathering Forest Products

Forest product gathering accounts for a relatively small portion of primary visit activities in south-central Oregon, although it is relatively more common as a secondary activity. A small but avid population of enthusiasts for certain types of products supports a small but steady demand for gathering as a recreational activity. Small-scale commercial gathering likely competes with recreationists for popular and high-value products (e.g., huckleberries [*Vaccinium* spp.], mushrooms, Christmas trees, boughs), although resource availability may be sufficient to accommodate both types of gathering at current participation levels. Special-use permits are required for some products. In 2015, national forests in the SCOAP assessment area issued more than 21,000 such permits, of which 45 percent were for Christmas trees, 35 percent for firewood, and 13 percent for mushrooms.

Forest product gathering is sensitive primarily to climatic and vegetative conditions that support the distribution and abundance of target species. Participation in forest product gathering is also akin to warm-weather recreation activities, depending on moderate temperatures and the accessibility of sites where products are typically found. Vegetative change caused by warmer temperatures and increased interannual variation in precipitation may alter the geographic distribution and productivity of target species (chapter 6), as well as access to those species. Increased incidence and severity of wildland fires may eliminate sources of forest products in some locations, but in some cases, fires may encourage short- or medium-term productivity for other products (e.g., mushrooms, huckleberries). Long-term changes in vegetation that reduce forest cover may reduce viability of forest product gathering in areas that have a high probability of vegetative transition to less productive vegetation types.

Recreationists engaged in forest product gathering may have the ability to select different gathering sites as the distribution and abundance of target species changes, although these sites may increase the costs of gathering. Those who engage in gathering as a secondary or tertiary activity may choose alternate activities to complement primary activities. Commercial products serve as an imperfect substitute for some forest products such as Christmas trees. Beyond recreation, collecting traditional "first foods" and plant materials on federal lands is an important activity for many American Indians.

In summary, the magnitude of climate effects on forest product gathering is expected to be low. This activity is a less common recreation activity in the region, although it may be more often a secondary or tertiary activity. Longer warm-weather seasons may expand opportunities for gathering in some locations, although these seasonal changes may not correspond with greater availability of target species. The likelihood of effects is expected to be moderate, although significant uncertainty exists regarding direct and indirect effects on forest product gathering. Vegetative changes caused by climate change and disturbances may alter abundance and distribution of target species, although the magnitude and direction of these effects are unclear.

Water-Based Activities, Not Including Fishing

Separate from fishing, water-based activities comprise a relatively small but important portion of primary recreation activity participation on federal lands. Lakes and reservoirs provide opportunities for both motorized and nonmotorized boating and swimming, although boating may commonly be paired with fishing. Upper reaches of streams and rivers are generally not desirable for boating and floating. Existing stressors include the occurrence of drought conditions that reduce water levels and site desirability in some years, and disturbances that can alter water quality (e.g., erosion events following wildland fires, damage from flooding).

Availability of suitable sites for non-angling, water-based recreation is sensitive to reductions in water levels caused by warming temperatures, increased variability in precipitation, and decreased precipitation as snow. Sensitivity will be lower in areas with a significant contribution from groundwater. Lower surface-water area is associated with less participation in boating and swimming activities (Bowker et al. 2012, Loomis and Crespi 2004, Mendelsohn and Markowski 2004), and streamflow magnitude is positively associated with number of days spent rafting, canoeing, and kayaking (Loomis and Crespi 2004). Demand for water-based recreation is also sensitive to temperature. Warmer temperatures are generally associated with higher participation in water-based activities (Loomis and Crespi 2004, Mendelsohn and Markowski 2004), although extreme heat may dampen participation for some activities (Bowker et al. 2012).

Increasing temperatures, reduced storage of water as snowpack, and increased variability of precipitation are expected to increase the likelihood of reduced water levels and greater variation in water levels in lakes and reservoirs on federal lands (see chapter 4), which is associated with reduced site quality and suitability for certain activities. The susceptibility of lakes to reduced water quantity may differ, depending on the reliability of the water source (springs [e.g., Crane Prairie, Wickiup, and Billy Chinook reservoirs] versus streams [Prineville and Ochoco reservoirs]). Warmer water promotes algal blooms in lakes, already a management issue in south-central Oregon, reducing dissolved oxygen, decreasing clarity, and harming some aquatic species, humans, and pets (fig. 8.9). Meeting the demands for streamflows of downstream water users with senior water rights may make dealing with low water levels upstream more complex in drought years (e.g., increased demand by agricultural users could lower reservoir levels). In addition, competition for water is expected to increase for other uses, such as hydroelectric power, which may lead to raising dam levels and altering storage levels as management norms.

Warmer temperatures are likely to lead to increased demand for water-based recreation as the viable season lengthens. Extreme heat encourages some people to seek water-based activities as a climate refuge, although extreme heat also discourages participation in outdoor recreation in general (Bowker et al. 2012). However, projected population growth and economic factors will probably affect the demand for water-based recreation more than climate change (Bowker et al. 2012).

In summary, climate change is expected to have a moderate effect on water-based recreation. Increasing temperatures and longer warm-weather seasons are likely to increase demand, although the incidence of extreme temperatures may dampen this effect in certain years. Fewer opportunities for water-based recreation because of lower streamflows and reservoir levels may also offset increased demand to some extent. Climate change effects are expected to occur with moderate likelihood. Climate model projections tend to agree on a range of warming temperatures and longer seasons, although changes in precipitation are uncertain. Changes in the timing of snowmelt may increase the likelihood of negative effects to water-based activities (through lower summer flows and reservoir levels) that offset increases caused by warmer temperatures.

U.S. Forest Service

Figure 8.9—Algal blooms, shown here in Haystack Reservoir (Crooked River National Grassland), are encouraged by extended periods of warm weather, resulting in undesirable conditions for recreation.

Conclusions

Several recreation activities are considered highly sensitive to changes to climate and ecosystem characteristics (table 8.5). However, recreation in south-central Oregon is diverse, and the effects of climate are likely to differ widely between different categories of activities and across geographic areas within the region. Overall, participation in climate-sensitive recreation activities is expected to increase in the region, primarily because longer warm-weather seasons will make more recreation sites available for longer periods of time.

Increased demand for warm-weather activities is likely to be countered by decreased opportunities for snow-based winter activities. Receding snow-dominated areas and shorter seasons in the future are likely to reduce opportunities (in terms of available days and sites) for winter recreation. Recreation use in high-use and lower elevation areas may be disproportionately affected by reduced snow.

Table 8.5—Summary of climate change assessment ratings for recreation by activity category

Activity category	Likelihood of climate effect	Magnitude of climate effect	Direct effects	Indirect effects
Warm-weather activities	High	Moderate (+)	Warmer temperature (+) Higher likelihood of extreme temperatures (-)	Increased incidence, area, and severity of wildfire (+/-) Increased smoke from wildfire (-)
Snow-based winter activities	High	High (-)	Warmer temperature (-) Reduced precipitation as snow (-)	
Wildlife activities	Moderate	Terrestrial wildlife: low (+) Fishing: moderate (-)	Warmer temperature (+) Higher incidence of low streamflow (fishing -) Reduced snowpack (hunting -)	Increased incidence, area, and severity of wildfire (terrestrial wildlife +/-) Reduced cold-water habitat, incursion of warm-water tolerant species (fishing -)
Gathering forest products	Moderate	Low (+/-)	Warmer temperature (+)	More frequent wildfires (+/-) Higher severity wildfires (-)
Water-based activities, not including fishing	Moderate	Moderate (+)	Warming temperatures (+) Higher likelihood of extreme temperatures (-)	Lower streamflows and reservoir levels (-) Earlier season low flows (-) Increased incidence of water quality degradation (e.g., algal blooms) (-)

Note: Positive (+) and negative (-) signs indicate expected direction of effect on overall benefits derived from recreation activity.

Allocation of skiing and other activities to a smaller portion of the landscape (as at-risk snow disappears) may increase crowding and create challenges for managing a limited number of suitable sites.

Beyond these general conclusions, the details of changes to recreation patterns in response to climate changes are complex. Recreation demand is governed by several economic decisions with multiple interacting dependencies on climate and weather. For example, decisions about whether to engage in winter recreation, which activity to participate in (e.g., downhill or cross-country skiing), where to ski, how often to participate, and how long to stay for each trip depend to some degree on weather and ecological characteristics. On the supply side, site availability and quality depend on climate, but the effect may differ greatly from one location to another. Thus, climate effects on recreation depend on spatial and temporal relationships between sites, climate and ecological characteristics, and human decisions.

The effects of climate on site quality and characteristics that are important for some recreation decisions (e.g., indirect effects of climate on vegetation, wildlife habitat, and species abundance and distribution) are uncertain. The exact effect of climate on target species for wildlife recreation or other quality characteristics may be difficult to project or heterogeneous across the region, yet these characteristics play a large role in recreation decisions for some activities. Another source of uncertainty is how people will adapt to changes when making recreation decisions. Substitution across time and space is difficult to predict (Shaw and Loomis 2008). This may be important in the future if some sites exhibit relatively little effect from climate change compared with sites in other regions. For example, winter recreation sites in south-central Oregon may experience shorter or lower quality seasons in the future, but may still experience an increase in demand if nearby alternative sites have even worse conditions.

Substitution is likely to be an important adaptation mechanism for recreationists. Many recreation activities that are popular in the region may have several alternate sites, or timing of visits can be altered to respond to climate changes (although this may be difficult for snow-based recreation). However, substitution may represent a change in economic effects even if it appears that participation changes little (Loomis and Crespi 2004); the new substitute site may be more expensive to access, or lower quality than the preferred site prior to climate change.

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Chapter 9: Climate Change and Ecosystem Services in South-Central Oregon

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Introduction

Ecosystem Services Defined

Ecosystem services are the benefits that people receive from nature. They are critical building blocks of human societies. A global analysis of human dependence on natural systems known as the Millennium Ecosystem Assessment (MEA) found that 60 percent of these goods and services are declining faster than they can recover (MEA 2005). This is partly because relationships between ecological conditions and flows of benefits are poorly understood or have been inadequately considered in resource decisionmaking. The MEA drew attention to these critical goods and services by highlighting their importance in four primary categories: **provisioning services** such as food, fiber, energy and water; **regulating services** including erosion and flood control, water purification and temperature regulation; **cultural services** such as spiritual connections with the land, history, heritage and recreation; and **supporting services,** or the foundations of systems such as soil formation, nutrient cycling, and pollination.

Ecosystem Services and Climate Change

Climate change effects on ecological systems will affect the ability of those systems to provide ecosystem services over time. Effects on different parts of ecosystems, individual species, and species interactions will have implications for water availability

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and quality, regulation of flows and flood prevention, pollinator and plant relationships, and forest products, among other benefits (Montoya and Raffaelli 2010, Mooney el al. 2009). A greater incidence of extreme events, and state or "regime" shifts, could significantly change the ability of systems to provide goods and services on which people rely (Mooney at al. 2009, Seidl et al. 2016). It is important to understand the biological underpinnings of ecosystem services to mitigate climate change effects, increase resilience, and adapt over time (Seidl et al. 2016). This chapter builds on other chapters in this document that specify climate change effects on components of ecosystems, including vegetation, hydrology, and habitats.

Ecosystem Services and the U.S. Forest Service

Efforts to integrate ecosystem services into U.S. Forest Service (USFS) policy and practice have increased over the past several years. In 2013, the USFS associate deputy chiefs chartered the agency's National Ecosystem Services Strategy Team. This national group is composed of scientists and managers from the National Forest System, State and Private Forestry, and the Pacific Northwest Research Station, and is tasked with finding opportunities to incorporate ecosystem services into Forest Service programs and operations. This team is taking the lead in responding to a presidential memorandum issued in October 2015 that instructed federal agencies to incorporate ecosystem services into decisionmaking, and requires each agency to formalize a plan for doing so (Office of the President of the United States, 2015).

In addition, the 2012 planning rule (36 C.F.R. 219) requires national forests to take ecosystem services into consideration when revising land management plans. From an operational standpoint, climate change vulnerability assessments are intended to inform the plan revision process by analyzing potential climate change impacts relevant to land management. By including ecosystem services in climate change vulnerability assessments, the information gathered can more easily be incorporated once plan revision begins.

Approach

The ecosystem services included in this assessment were selected in consultation with staff from Deschutes, Fremont-Winema, and Ochoco National Forests and Crooked River National Grassland. The chapter authors focused on a subset of services based on their importance in and around the South-Central Oregon Adaptation Partnership (SCOAP) assessment area, the ability to make meaningful conclusions about the effects of climate change on these services, and data availability. This mirrors the criteria outlined in the USFS 2012 planning rule directives, which advise managers to focus on key ecosystem services in revision of national forest land management plans that (1) are important outside the planning area, and (2) are those that USFS decisionmaking can affect. It was important that ecosystem services covered in this chapter be representative of all four categories (provisioning, regulating, cultural, and supporting), in an attempt to more thoroughly describe the suite of benefits the SCOAP assessment area provides. Assessments for each ecosystem service drew from vulnerability assessments described in chapters in this report, including climate (chapter 3), hydrology, water use and infrastructure (chapter 4), aquatic habitat (chapter 5), vegetation (chapter 6), wildlife (chapter 7), and recreation (chapter 8).

Forest Products

Forest products have long been an important provisioning service provided by the National Forest System. The national forests within the SCOAP assessment area provide a host of wood products, including timber, biomass, and firewood. Broadly speaking, climate change is expected to affect timber and forest products through changes in vegetation structure and growth, as well as altered disturbance regimes. Increased physiological stress associated with higher temperatures and altered precipitation patterns is expected to result in increased tree mortality in some locations (Allen et al. 2010). Increased frequency or severity of heat-related disturbances, such as insect outbreaks and wildfire, are also anticipated to cause widespread mortality (Seidl et al. 2008). Within the SCOAP assessment area, as in much of the Western United States, wildfire activity is expected to increase as a result of climate change (Westerling et al. 2008).

Increased mortality rates will alter the productivity of forests at broad scales, potentially reducing the amount of merchantable timber and other harvested forest products. Conversely, increased carbon dioxide (CO_2) concentrations and longer growing seasons could increase forest productivity, although experimental results conflict as to the magnitude of this effect (Kirilenko and Sedjo 2007). Across the SCOAP assessment area landscape, productivity is expected to generally increase, although the magnitude and location depends on the climate model and emissions scenario chosen (chapter 6). These broad projected changes in productivity could have implications for timber productivity (see chapter 6 for details). In addition to changes in mortality and productivity rates, climate change may induce species range shifts, altering species composition patterns that have been relied on to produce timber (Gonzalez et al. 2010). Within the assessment area, subalpine forest types are expected to be displaced by moist and dry coniferous forest types (see chapter 6). Again, this could have implications for timber and nontimber forest products, although uncertainty in projections for individual species is high.

Biophysical changes will have implications for local and global socioeconomic conditions as well, affecting industries and communities that are dependent on timber and nontimber forest harvests. Local changes in supply and demand will be affected by climate change and global market fluctuations. Increased supply associated with stimulated production could lower commodity prices (Kirilenko and Sedjo 2007). Demand for timber will likely continue to grow slowly, while demand for biofuels may grow as nearby local economies seek alternative sources of energy.

Current Levels of Use

Currently, forest products from the SCOAP assessment area are important for both commercial and noncommercial uses. The number of permits sold for nontimber forest products (table 9.1) reveals the variety of ways in which the forest is being utilized. Across all forests, firewood, Christmas trees, and mushroom hunting are among the most popular activities. Table 9.1 shows the number of permits sold from 2014 to 2015.

Table 9.1—Special forest products permits sold for all South-Central Oregon Adaptation Partnership national forests for fiscal years 2014 and 2015

	Deschutes FY15	Deschutes FY14	Fremont-Winema FY15	Fremont-Winema FY14	Ochoco FY15	Ochoco FY14
Mushrooms	1,376	1,280	1,038	1,466	430	130
Berries	0	0	0	0	1	0
Boughs	77	76	38	28	38	26
Firewood	3,402	3,096	2,534	2,261	1,528	1,465
Post and poles	122	121	141	96	13	18
Christmas trees	6,463	5,861	2,281	2,388	887	927
Cones	221	766	169	290	6	2
Biomass	77	91	0	0	0	0
Decorative dead wood	56	26	0	0	0	2
Transplants	313	323	33	27	32	22
Miscellaneous botanical	4	12	0	0	4	0
Burl	0	1	0	0	0	0
Beargrass	0	0	0	0	0	0
Edible ferns	0	0	0	0	0	0
Salal	0	0	0	0	0	0
Miscellaneous convertible	0	0	0	0	0	0
Miscellaneous non-convertible	0	0	2	2	3	2

Climate change will likely affect these special forest products both through access and availability. Each individual plant species that provides these products will respond uniquely to climate change, affecting the quantity, quality, and seasonality of the goods listed above. The magnitude and pace of these changes is uncertain, and will be further obscured by high year-to-year variation.

Access to these forest products will also be affected by shifting demography and recreation patterns, as well as impacts to infrastructure. User group conflicts, particularly in years of low production of highly sought after products, will likely continue and may increase if yields are low for several years in a row. For instance, conflict mediation by Deschutes National Forest staff was necessary between commercial and recreational mushroom harvesters in years of particularly low matsutake mushroom (*Tricholoma matsutake* [S. Ito & S. Imai] Singer) production caused by below-normal precipitation. Shifting recreational patterns, discussed in chapter 8, will also likely affect special forest product gathering. This could mean more intense gathering in the shoulder (spring and autumn) seasons when staffing and infrastructure might not be in place to support those activities.

Grazing

Forage for livestock is a significant ecosystem service provided by the SCOAP assessment area. The 2012 agricultural census indicated that the six counties served by national forests in the assessment area (Crook, Deschutes, Grant, Jefferson, Klamath, Lake, and Wheeler Counties) represented approximately 23 percent of Oregon cattle and calf sales. Rangeland management for cattle, sheep, and horses or mules (including the Big Summit Wild Horse Herd) is particularly significant on the Ochoco and Fremont-Winema National Forests, which administer 67 and 74 active allotments, respectively (see table 9.2 for specific data and use history). The Oregon Department of Agriculture's *Oregon Agriculture 2016 Facts and Figures* brochure ranked cattle and calves as Oregon's number one agricultural commodity, with $914,324,000 in estimated value.

As noted in chapter 6, changes in winter and spring precipitation could translate into substantial impacts on the composition and distribution of rangeland vegetative species, with subsequent implications for forage availability and quality. Grazing itself, as well as many other historical activities, has been associated with the spread and dominance of nonnative grasses in some locations. Cheatgrass (*Bromus tectorum* L.), medusahead (*Taeniatherum caput-medusae* [L.] Nevski), and North Africa grass (*Ventenata dubia* [Leers] Coss.) are invaders that alter fire regimes and dramatically effect ecosystem structure and function (see box 6.5). Cheatgrass has been associated with higher fine-fuel amounts, greater fuel continuity, and

Table 9.2—Fiscal year 2014 range allotment data for South-Central Oregon Adaptation Partnership national forests and grassland

		Deschutes National Forest	Ochoco National Forest	Crooked River National Grassland	Fremont-Winema National Forest
Number of active allotments		8	49	16	74
Number of vacant allotments		12	4	2	9
HMs and AUMs by livestock class (based on 2015 authorized use):					
Cattle (bull)	HMs	341		326	
	AUMs	512		494	
Cattle (mature cow)	HMs	197		1,357	1,192
	AUMs	197	1,357	1,192	
Cattle (mature cow with nursing calf)	HMs	13,394	29,651	8,716	70,871
	AUMs	17,679	39,141	11,504	93,553
Cattle (yearling [9–18 months])	HMs		132	1,124	676
	AUMs		92	787	474
Sheep (ewe with lamb or nanny with kid)	HMs		11,614		2,748
	AUMs		3,485		824
Sheep (mature sheep or goat)	HMs				4,412
	AUMs			882	
Horse or mule	HMs		60	85	
	AUMs		72	102	
Authorized use history:					
1999		8,550	40,290	22,917	86,240
2000		9,581	38,896	22,917	82,887
2001		11,350	39,986	15,584	91,910
2002		11,061	40,546	22,112	105,831
2003		10,668	49,765	24,325	79,412
2004		12,524	16,850	12,215	86,815
2005		11,898	47,173	37,495	86,306
2006		6,939	45,666	40,978	81,442
2007		15,301	39,836	26,585	79,710
2008		10,105	52,474	1,699	79,522
2009		8,084	38,390	17,084	70,528
2010		12,264	36,635	14,657	75,332
2011		8,652	36,927	35,916	74,905
2012		9,408	37,309	17,851	75,201
2013		12,180	39,296	17,990	74,305
2014		13,747	37,048	10,828	71,777
2015		18,388	42,790	14,244	96,925

AUM = animal unit month; HM = head months.

lower fuel moisture, increasing the burn readiness of sites (Davies and Nafus 2013). Future changes in climate, such as increased May temperatures and March precipitation, suggest that cheatgrass, and possibly other nonnative annual grasses, will increase in extent in south-central Oregon.

Changes in rangeland management may be needed as rangeland and grazed forest land conditions change. Some studies suggest that dormant season (winter) grazing could reduce the spread of nonnative species and wildfire probability (Davies et al. 2015). Although altered plant species composition and distribution would be expected for lands currently grazed, most models indicate that plant community types in those areas will increase in acreage across the assessment area. Depending on precipitation trends, some rangeland species may increase in abundance, and others will decrease or remain relatively static. Adaptive management may also be necessary to manage sites that become increasingly sensitive to climate change, such as riparian areas, wetlands, springs, and other groundwater-dependent ecosystems. Sustainable ranching practices in the SCOAP assessment area will enhance the conservation of open and undeveloped space (and associated ecosystem services).

Geology and Minerals

The geology of south-central Oregon forms the foundation of the area's soils, vegetation, and hydrologic function, as well as related ecosystem services. Volcanic features of the Cascade Range, including Newberry National Volcanic Monument, attract visitors to the region. Historical volcanic activity resulted in deposits of mercury and gold, actively mined to this day. The silica-rich hydrothermal waters associated with the volcanic activity disseminated out in the fractures and air pockets to become the agate and thunder eggs sought after by the public. The minerals resource is extensive, encompassing geothermal potential at Newberry on Deschutes National Forest; oil and gas leases on Crooked River National Grassland; gold, thunder egg, opal, and sunstone mines on Deschutes, Fremont-Winema, and Ochoco National Forests; and numerous mineral material permits across the national forests and grassland.

Mineral Resources

Crooked River National Grassland accounts for the majority of the USFS Pacific Northwest Region's leasable mineral revenues, which totaled $33,007 in 2015. This total is less than 1 percent of the national total of leasable mineral revenues for that year. Locatable mineral activity is primarily on Ochoco National Forest. Table 9.3 displays the plans of operation, notices of intent, and non-plans (minor mining activity that does not require a formal Plan of Operations) being administered by the respective forests.

Table 9.3—Locatable mining on the Deschutes, Fremont-Winema, and Ochoco National Forests and the Crooked River National Grassland

Forest or grassland	Plans of operation	Notice of intent	Non-plans
Deschutes	1	0	0
Fremont-Winema	1	0	0
Ochoco and Crooked River	4	15	7

National Forest System (NFS) lands provide many mineral commodities. Within south-central Oregon, mineral material (gravel, cinders, stone, pumice, and sand) is used for forest projects like surfacing roads, restoring streams, hardening water developments for range, enhancing campgrounds, and constructing trail-heads. The area also issues mineral material permits for landscape rock, crushed aggregate, and pit run to public, state, county, and municipalities.

In 2015, the USFS Pacific Northwest Region accounted for 3.9 percent of the mineral material production in the NFS. The region issued 417 contracts with a disposal volume of 141,000 metric tons and a value of $150,650. The forests within the SCOAP assessment area accounted for 82 percent of the contracts, 62 percent of the value, and 76 percent of the volume (table 9.4). This is a significant portion of the mineral material production within the region.

Mineral resources on NFS lands are an attraction for recreation, and Oregon gems are recognized nationally. Rockhounding has been a key recreation activity since the early 1960s. There are four well-attended rockhound fairs held annually in Prineville, Lakeview, Sisters, and Madras.

Table 9.4—Mineral material summary for 2015

	Sales			Free use			In-service	
National forest	Number of contracts	Metric tons	Value	Number of contracts	Metric tons	Value	Metric tons	Value
			Dollars			*Dollars*		*Dollars*
Deschutes	58	284	685	8	50 378	55,532	56 265	176,285
Fremont-Winema	0	0	0	1	39 689	27,125	5 298	3,650
Ochoco and Crooked River National Grassland	1	3	21	18	16 380	10,360	9 413	6,829
Totals	59	287	706	27	106 447	93 017	70 976	186 764

Geothermal Energy

Geothermal energy provides electric power generation and space heating, as well as support for manufacturing. Currently, there are about 21 000 ha with active geothermal leases on Deschutes National Forest on the flanks of Newberry Volcano outside the Newberry National Volcanic Monument. In 1976, the Newberry Known Geothermal Resource Area was formed. Throughout the 1980s, more than two dozen exploration wells were drilled across the Newberry Volcano (those within the monument area were withdrawn with its establishment in 1990). In June 1994, an environmental impact statement for a plan of operation of a 33-megawatt power plant was signed, but by 1996 the project was suspended indefinitely. The next formal project began in 2008 to drill two deep exploration wells on the west flank. These deep wells encountered hot dry rock, and this project was suspended in 2009. In 2012, a decision was signed to allow the Newberry Volcano Enhanced Geothermal Systems Demonstration Project. Although this project was partially successful, Department of Energy funding ended in 2015, and no power was produced. As of 2016, geothermal energy development at Newberry is at a lull.

Climate Change Effects

In general, minerals and geology will be unaffected by increased temperatures. However, the glaciers in the Three Sisters and Mount Jefferson Wilderness areas will continue to retreat. Snow levels are expected to decrease, which will affect groundwater levels and possibly mineral resources.

If rain events become more severe as projected, then mass wasting and erosion of slopes could worsen (chapter 4). The special geologic area known as Balancing Rocks, located above the Metolius arm of Lake Billy Chinook, may change rapidly with increased mass wasting and erosion. The majority of the special geological features within the SCOAP assessment area will remain unchanged.

Mineral resources are not directly affected by changes in vegetation or precipitation. However, activities related to mineral resources will be affected. Placer mining occurs along streams, which may be affected by climate change. Mineral material use will most likely increase, as roads are affected by higher peak flows and require repair. Mineral and geologic resources will be needed for stream restoration, road reconstruction, and bridge abutments. Available water to support geothermal lease development may become scarcer. Higher intensity short-term events (e.g., floods) could result in less infiltration and more runoff.

As mentioned in chapter 6, groundwater-dependent ecosystems may be stressed as groundwater is pumped from local aquifers to compensate for longer, drier summers. Wells to obtain groundwater to support recreation, livestock, or other forest management activities may need to be drilled deeper. Groundwater recharge could diminish if streams lose volume.

Vulnerability in aquatic systems is relevant to management of mineral resources. As streamflows are reduced, concentrations of mining activity may occur where gold placers exist. Monitoring resources and educating the mining public about changes to streams and riparian areas where placer mining is occurring could prevent degradation.

Demand for mineral resources could be affected by shifts in energy resource markets. If fossil fuel extraction is less favorable because of concerns about CO_2 emissions, oil and gas leases on Crooked River National Grassland may not be developed. Conversely, geothermal energy exploration and development near Newberry Crater may increase to fill the energy gap.

Carbon Sequestration

Carbon sequestration refers to the long-term storage of carbon by forests in biomass and soils. It is a dynamic process and one that involves both carbon uptake (via photosynthesis) and carbon release (via decomposition and disturbance). Carbon sequestration is referred to as a regulating ecosystem service—it buffers climate effects by helping to mitigate CO_2 levels in the atmosphere. In this way, carbon storage in forests is becoming more valuable as the impacts of greenhouse gas emissions are becoming more fully understood and experienced (USDA FS 2015a).

Currently, the forests of North America are a net carbon sink, meaning they are absorbing more carbon than they are releasing (Pan et al. 2011). The NFS accounts for about 20 percent of all forest land area in the United States and about 25 percent of all carbon stored, with a net increase in total stock over time (USDA FS 2015a). Typically, management activities (e.g., prescribed fire, fuel reductions, thinning) represent a short-term carbon loss through the removal or burning of biomass (Birdsey and Pan 2015, Nunery and Keeton 2010). However, these short-term losses may help increase forest carbon sequestration in the long run by mitigating large-scale disturbance or improving overall forest health (Stephens et al. 2012). In addition, forest products removed from the forest can be reservoirs of long-term carbon storage (Skog 2008).

Box 9.1

Forest Carbon Principles

To integrate carbon management with planning processes and climate change responses, the U.S. Forest Service has created these six guiding principles for dealing with carbon on national forests:

- Emphasize ecosystem function and resilience.
- Recognize carbon sequestration as one of many ecosystem services.
- Support diversity of approaches in carbon exchange and markets.
- Consider system dynamics and scale in decisionmaking.
- Use the best information and methods to make decisions about carbon management.
- Strive for program integration and balance.

In response to a growing need for guidance on carbon management and stewardship, the USFS created a set of preliminary "carbon principles" (box 9.1) (USDA FS 2015a). These principles are general and are meant to assist all USFS programs and authorities in thinking about ways to approach carbon stewardship. The second of these six principles recognizes carbon as one of many ecosystem services, and carbon sequestration should be considered in context with other ecosystem services (USDA FS 2015a). Carbon storage is one of many objectives of any national forest plan or project action. This information is provided to help national forests and their stakeholders determine the state of the carbon resource, and how carbon stewardship might be blended with other ecosystem service goals in planning and management.

The USFS champions the concept 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 national forests. This involves protecting existing carbon stocks as well as building resilience in stocks through adaptation, restoration, and reforestation. Carbon stewardship is an aspect of sustainable land management. Carbon estimates are most useful at very large spatial scales; baseline carbon estimates at the national forest scale do not fully inform needs for project-specific applications, although assessment of carbon stocks at the national forest scale may guide project-specific and National Environmental Policy Act analysis.

Baseline Carbon Estimates

National Forest System units are required to identify baseline carbon stocks and to consider this information in management. The USFS has developed a nationally consistent carbon assessment framework that is used by all national forests. Estimates of total ecosystem carbon storage and flux have been produced for all national forests, relying on consistent methodology and plot-scale data from the Forest Inventory and Analysis (FIA) program (USDA FS 2015a). Carbon stores reflect the amount of carbon stored in all forms of biomass as well as soil. Carbon flux reflects the year-to-year balance of carbon going into or being pulled from the atmosphere (Woodall et al. 2013). Box 9.2 provides baseline carbon stock and flux (stock change) estimates for the SCOAP assessment area. Carbon stock change measures the interannual change in carbon stock caused by tree growth, disturbance, and management. Negative stock changes indicate that carbon is being removed from the atmosphere (i.e., net carbon sink), whereas positive values mean carbon is being released (i.e., net carbon source).

Box 9.2

Current Carbon Stocks of SCOAP Forests

Deschutes National Forest—
Carbon is steady, averaging about 100 Tg, with slight annual declines (~1 Tg) since 2005.

Ochoco National Forest—
Carbon is steady, averaging about 50 Tg, with slight annual declines (~1 Tg) since 2005.

Fremont National Forest—
Carbon is steady, averaging about 60 Tg, with no demonstrable change since 2005.

Winema National Forest—
Carbon is steady, averaging about 75 Tg, with no demonstrable change since 2005.

Harvested Wood Products

Sequestration through tree growth and biomass accumulation is not the only way in which carbon is stored in forests. Harvested wood products (HWP), such as lumber, panels, and paper, can account for a significant amount of carbon storage after wood is removed from the forest. Estimates of this contribution are important for both national-level accounting and regional reporting (Skog 2008). Products derived from the harvest of timber from national forests extend the storage of carbon or substitute for fossil fuel use (via biofuels). Estimates at the regional level are presented in figure 9.1 for both HWP still in use and in solid waste disposal sites. Storage in HWP peaked in 1995 at 143 Mg C, with total storage of 131 Mg C in 2013, the most recent estimate available.

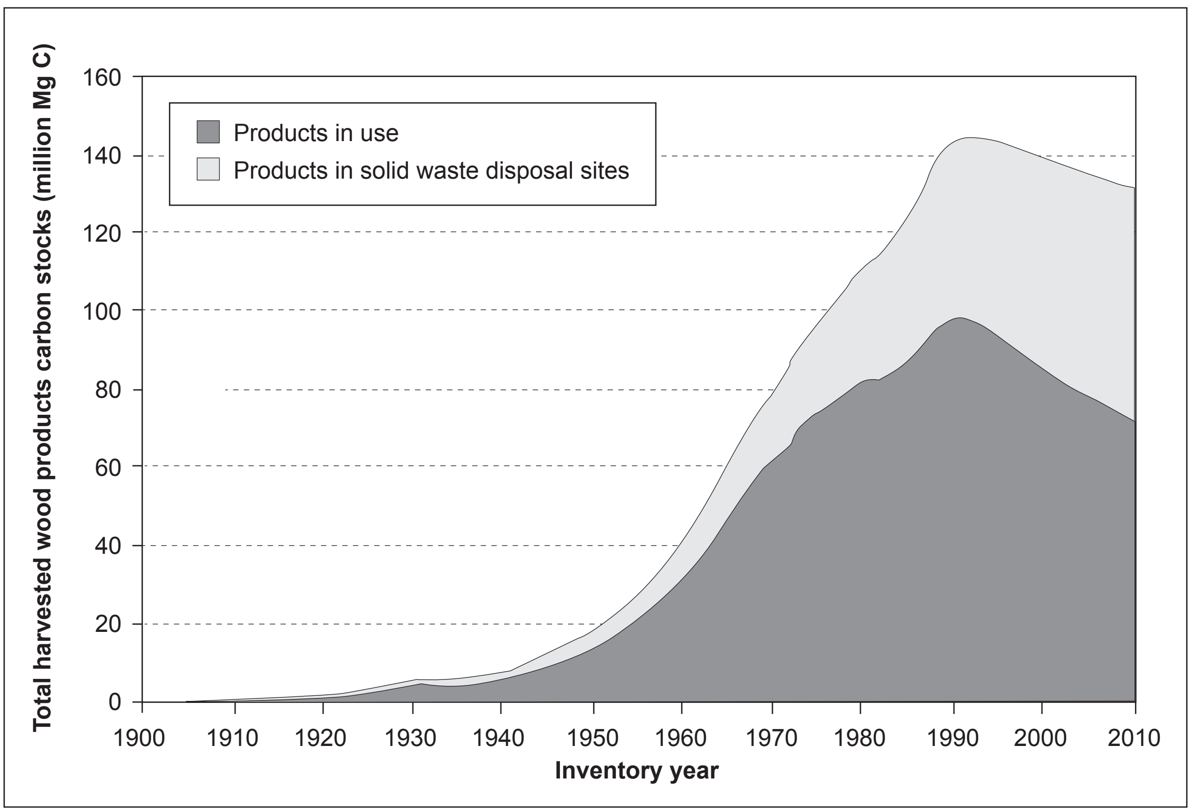

Figure 9.1—Carbon (C) stored in harvested wood products still in use and in solid waste disposal sites for the U.S. Forest Service Pacific Northwest Region. This carbon is not included in the baseline carbon estimates for the individual national forests, as it is typically located offsite. Analysis is from Butler, E.; Stockmann, K.; Anderson, N. [et al.]. 2014. Estimates of carbon stored in harvested wood products from the U.S. Forest Service Pacific Northwest Region, 1909–2012. Unpublished report. On file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula, MT.

Climate Change Effects

Part of the challenge in understanding future trends in carbon sequestration is the high level of uncertainty associated with anticipated climate change. Trends in forest carbon stocks throughout the West will be affected by direct physiological climate impacts (e.g., increased CO_2 concentrations), and indirect climate-mediated impacts (e.g., increased disturbances and shifts in species or age composition) (Vose et al. 2012). During the national forest plan revision process, more detailed carbon stock and flux estimates will be produced for each forest.

Pollinators

Pollination is considered a supporting ecosystem service, an underlying process to help create and maintain functioning ecosystems. Humans benefit from pollination because many plant products or crops we consume (fruits, seeds, nuts) or value (biotic diversity) are a direct product of thriving pollinator communities, which rely on high-quality habitat. In this way, national forests provide an indirect service by providing habitat to pollinators, which in turn provide a service to society (figs. 9.2 and 9.3).

U.S. Forest Service

Figure 9.2—Bumblebee collecting pollen.

U.S. Forest Service

Figure 9.3—Bumblebee on wildflower.

Pollination as Ecosystem Service

Pollination by animals is a vital ecosystem service, and is essential to the reproduction of many crops and nearly all wild plants (Klein et al. 2007). Although pollination is generally provided by wild and managed insects, birds and mammals play a role as well. Globally, pollinators are responsible for the reproduction of 65 percent of the world's wild plants, and about 35 percent of crops depend on pollination for reproduction (Klein et al. 2007, Wratten et al. 2012). In the United States, honeybee pollination adds more than $15 billion worth of agricultural crops annually (Pollinator Health Task Force 2015). Pollinators also support the viability of first foods and sustain cultural practices. In addition, wild insects may pollinate crops more efficiently than managed ones, and diverse pollinator assemblages provide better pollination services than a single species (Garibaldi et al. 2013, Ricketts 2004).

Although pollinators provide value to agriculture, they also have significant ecological and cultural value. Wildflowers in particular benefit from pollinators, which help these plant species reproduce and maintain genetic diversity. A 2014 presidential memorandum on pollinator health prompted the creation of the Pollinator Health Task Force jointly led by the U.S. Environmental Protection Agency and U.S. Department of Agriculture (Pollinator Health Task Force 2015). One of this task force's three overarching goals was to restore or enhance 2.8 million ha of land for pollinators over the next 5 years through federal actions and public-private partnerships (Pollinator Health Task Force 2015). This goal is explicitly linked to the ecological necessity of healthy pollinator populations for the maintenance of native plant communities.

Pollinators in the SCOAP Assessment Area

Native and managed pollinators play many important roles in the SCOAP assessment area (see box 7.5). In addition to the pollination services they provide, charismatic and threatened species such as monarch butterflies (*Danaus plexippus* L.) and western bumblebees (*Bombus occidentalis* Greene.) help galvanize public interest in USFS lands and stewardship (figs. 9.4 and 9.5). With respect to monarchs in particular, citizen science efforts led by the USFS to monitor monarch occurrence and habitat has led to a new understanding of the vital role that south-central Oregon can play in monarch conservation, revealing a much larger monarch presence than previously thought.

The USFS monitoring and outreach efforts have also been successful because of partnerships with conservation and education groups such as the recently established Monarch Advocates of Central Oregon (MACO). Moreover, early USFS outreach and education efforts led directly to the formation of this partner group. Partnerships with MACO and other organizations throughout south-central Oregon are

U.S. Forest Service

Figure 9.4—Monarch butterfly.

examples of a key strategy outlined in the recent USFS publication, *Conservation and Management of Monarch Butterflies: A Strategic Framework* (USDA FS 2015b). Monitoring efforts will be increasingly necessary for understanding how climate change is affecting pollinators within the SCOAP assessment area, particularly given concerns related to plant phenology changes and habitat loss. Citizen science efforts via successful partnership networks are the most promising and effective strategy for assessing climate effects on a variety of pollinators in south-central Oregon.

The juxtaposition of agricultural and public lands is important to pollinators in south-central Oregon, especially in Crooked River National Grassland and portions of Ochoco National Forest that adjoin agricultural lands. The principal crops in the SCOAP assessment area are legumes such as alfalfa (grown for livestock feed) and vegetable seed crops. Native bees and other pollinators may collect nectar from commercial crops, and consequently, agricultural management may influence native pollinator populations. Therefore, it is important to monitor pollinator populations and to continue to support them through appropriate revegetation activities on public lands.

Bureau of Land Management

Figure 9.5—Wood River wetland provides a habitat for plants such as hardstem bulrush, wocus (yellow water lily), common cattail, bigleaf lupine, and many sedges and grasses. The Klamath people have historically gathered wocus seedpods and still prepare them for food today.

Climate Change Effects

Climate change is expected to affect pollinator populations in both direct and indirect ways (VanBergen 2013). Increasing temperature with climate change will directly influence thermoregulation in pollinators, affecting insect physiology (e.g., changes in body size and lifespan) and behavior (e.g., changes in foraging behavior) (Scaven and Rafferty 2013). Climate change is expected to have significant effects on plant phenology (Miller-Rushing and Primack 2008, Panchen et al. 2012). Potential mismatches in timing of flowering and pollinator emergence may affect plant reproduction, especially when either the flowers or pollinators are short lived (Fagan et al. 2014). However, evidence suggests that native bees (as opposed to managed bees) are more likely to adapt their phenology to compensate for warming temperatures, keeping pace with host-plant flowering (Bartomeus et al. 2011). In response to climate change, pollinator species might shift their range in order to find new food sources. However, such migration may be impeded in areas of low habitat connectivity, potentially reducing population sizes and increasing the likelihood of local extinction (VanBergen 2013).

Cultural Values

Cultural ecosystem services include connections between people and the land that may be intangible, such as spiritual enrichment, heritage, identity, and aesthetic experiences. They also include practices such as harvesting of first foods for American Indian tribes (fig. 9.5), rituals in sacred places, and recreation activities for the general public. People often develop connections to specific locations, features, or landscapes. Memories, interactions, and history play a role in attachment to the land and sense of place (Eisenhauer et al. 2000, Kruger and Jakes 2003). For example, the Three Sisters Mountains and Metolius Basin are iconic features that people strongly associate with south-central Oregon. Mount Mazama and the creation of Crater Lake play a critical role in the history of the Klamath people. Specific places and experiences can influence where people live, work, and recreate (Smith et al. 2011).

The effects of climate change on ecological structures, processes, and functions will affect culturally important natural resources, places, and traditions, as well as connections between people and the land (Hess et al. 2008, Lynn et al. 2011). For example, the Big Marsh and surrounding watershed on the Crescent Ranger District of Deschutes National Forest represents a culturally important site for solitary recreation, family traditions, wildlife viewing, and collection of matsutake mushrooms (see box 9.3). Disruptions to hydrologic processes or increased vulnerability to insects and disease can affect related habitats and uses. Products such as matsutake mushrooms that require freezing temperatures might also be negatively affected as the climate warms.

Climate change effects on recreation use are likely to be complex (chapter 8). Overall, receding snow and shorter seasons in the future are likely to reduce the opportunities (in terms of available days and sites) for winter recreation. This may be offset by increased warm-weather activities. Perceptions of fire and its impact on the landscape might also shift uses into new areas, particularly if burned forests are perceived negatively. As recreation opportunities change, so do the ways people connect with forests and grasslands, affecting the physical, mental, and spiritual nature of recreation activities.

Some populations may be more deeply affected by climate change than others because of geographic location, the degree of association to climate-sensitive environments, and unique cultural, economic, or political characteristics (Lynn et al. 2011). American Indian tribes may be particularly vulnerable to climate shifts because of their cultural connections with ecosystems and specific plant and animal species, as well as their dependence on resources for subsistence (Cordalis and Suagee 2008, Lynn et al. 2011).

Box 9.3

Identifying the Cultural Importance of the Big Marsh Landscape

The Big Marsh project area encompasses an approximately 12 000-ha watershed in the southwestern portion of the Crescent Ranger District of the Deschutes National Forest. The focal point of the planning area, Big Marsh, is one of the largest high-elevation wetland or marsh complexes in the continental United States. Forest Service staff collaborated with The Nature Conservancy to gather information from community members and stakeholders about the importance of Big Marsh from diverse perspectives. A 2-day workshop was convened with scientific and resource experts, local citizens familiar with the Big Marsh planning area, and Forest Service partner organizations: the U.S. Fish and Wildlife Service, Oregon Department of Fish and Wildlife, Oregon Hunters Association, Walker Rim Riders Snowmobile Club, Rocky Mountain Elk Foundation, Oregon State University, and Northwest Forest Workers Center. In addition to identifying the significance of the watershed for habitat, water supplies, and forest products, participants emphasized the uniqueness of Big Marsh and the importance of the solitary and peaceful recreation opportunities it offers. Many individuals also associated the marsh with mental and spiritual renewal or long-standing family traditions. Identification of these cultural values influenced restoration proposals and strengthened public engagement in the planning process.

Tribes reserve treaty rights to hunt, fish, and gather on NFS lands. First foods play a vital role in the physical, mental, and spiritual health of native communities. Access to these foods may become less predictable as composition and distribution of culturally important species shifts. For example, salmon have spiritual, physical, and economic significance for many Pacific Northwest tribes. Climate change may affect the timing and magnitude of streamflow (chapter 4), increase stream temperatures (chapter 5), and cause higher levels of sediment resulting from disturbance. This may affect salmon at all stages of their life cycle (Lynn et al. 2011). Shifts in hydrology could also affect lake and pond habitat for the yellow pond-lily (also called wocus lily) (*Nuphar polysepala* Engelm.), which is significant for the Klamath tribes. Yellow pond-lily seeds are used as a food source and ground into flour. Decreases in summer flows could threaten pond-lily persistence.

Extreme weather and shifts in phenology may also influence the consistency and yield of berry species (CIER 2007, Lynn et al. 2013). Climate-change adaptation actions that increase resilience to wildfire can benefit berry species populations, as well as access to first-food sites. For example, hazardous fuels treatments serve multiple purposes, including reducing tree competition and stress, as well as increasing shade for huckleberries. Interconnected forest and meadow restoration treatments also increase the vigor of common camas (*Camassia quamash* [Pursh] Greene), a traditional food source (Lynn et al. 2013).

Climate change adaptation can be informed by tribal connections with the land and experience of harvesting first foods under a variety of conditions over time. This history forms the basis of traditional ecological knowledge (Berkes et al. 2000, Lynn et al. 2011). Tribes have adapted to past climate stressors, including conducting sustainable harvests during past regional reductions in salmon populations and habitat quality (Lynn et al. 2013). This knowledge and resilience to change are critical in adaptation planning.

Conclusions

Ecosystem services are social benefits derived from the natural landscape. The landscape's capacity to provide these services is directly related to their ecological condition. Changes in temperature, the nature and timing of precipitation, and the frequency and extent of disturbance regimes will alter the structures, processes and functions of south-central Oregon forests and grasslands (box 9.4).

Forest species composition will likely change, which may affect how local timber supply can respond to market demands. As wildfires, drought, and insect outbreaks become more prevalent with climate change, tree mortality may become a greater concern for **timber productivity**. Special forest products collected commercially and recreationally and for other cultural uses may also be affected as climate change alters the timing and location as well as the quality and availability of these products.

Livestock forage availability and quality will likely be affected by winter and spring precipitation and changes in vegetation composition. Nonnative grasses will likely increase in abundance in rangeland ecosystems. Conflicts may intensify between livestock access to water sources and protection of riparian areas, wetlands, springs, and other groundwater-dependent ecosystems.

Mineral resources and geology of the SCOAP assessment area are unlikely to be affected by increased temperatures, although glaciers are expected to continue to retreat. Changes in groundwater supply may affect mineral resources. In addition, climate-change adaptation actions, including stream restoration and deepening wells in search of groundwater sources, could affect mineral resources.

Box 9.4

Invasive Species, Climate Change, and Ecosystem Services

Climate change has the potential to alter ecological processes in ways that increase the societal and environmental impacts of nonnative invasive species (Pyke et al. 2008). A species is considered to be invasive if it meets two criteria: (1) it is not native to the ecosystem under consideration and (2) its introduction causes, or is likely to cause, economic or environmental harm or harm to human health (Executive Order 13112).[2] As native plant communities are disrupted by changing climatic conditions, invasives may become more competitive, with subsequent cascading effects on biotic and abiotic components of ecosystems (Charles and Dukes 2007, Hellmann et al. 2008). Invasive species have broad climatic tolerances and large geographic ranges. They are effective at overcoming barriers to dispersal, tolerating changing environmental conditions, and acquiring resources (Pyke et al. 2008). As ecosystem structures and systems change, so do the processes and functions that sustain ecosystem services (Charles and Dukes 2007, Pejchar and Mooney 2009).

The Forest Service National Strategic Framework for Invasive Species Management (Framework) states that "exotic species invasions and variations in climate patterns represent two of the greatest challenges to maintaining the ecosystem services provided by natural systems" (USDA FS 2013). The Framework identifies several threats posed by invasives to ecosystem services including "clean water, recreational opportunities, sustained production of wood products, wildlife and grazing habitat, and human health and safety." These effects can result in considerable cost. The Framework highlights an estimate of damage from invasive species worldwide at more than $1.4 trillion per year, or 5 percent of the global economy (Pimentel et al. 2001).

Provisioning services—
Changes in species and community structures can cause declines in economically valuable species, such as those used for fiber, food, forage or fuel (see "Forest Products" and "Grazing" sections). Invasive species that have deeper roots, higher evapotranspiration rates, or greater biomass than natives have also been shown to change water flow for drinking and irrigation (Pejchar and Mooney, 2009). Invasives may also outcompete native forage species. Invasion of exotic plants into Western U.S. rangelands have decreased range productivity from 23 to 75 percent, depending on local context (Eviner et al. 2012). Reduction in biodiversity caused by invasives may also influence genetic resources, medicines and pharmaceuticals, with subsequent impacts on human health (Charles and Dukes 2007).

Regulating and supporting services—
Interference by invasives in ecosystem functions may influence pollination, water purification, pest control, natural hazards, and climate regulation, with implications for system resilience and ecosystem services. Nonnative pollinators may displace native species. They could also enable range expansion in pollinator-limited invasives and distract

[2] Executive Order 13112 (February 3, 1999). https://www.federalregister.gov/documents/1999/02/08/99-3184/invasive-species.

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pollinators away from natives (Charles and Dukes 2007, Pejchar and Mooney 2009). Shifts in species composition could be detrimental for fish and wildlife habitat, including for vulnerable species like the sage-grouse. Altered species assemblages may also impact climate regulation by causing changes in fire regimes and carbon sequestration. Cheatgrass, for example, is dramatically changing the vegetation and fauna of many natural systems. In some cases, it facilitates more frequent fire, which displaces shrubs and native vegetation that provide wildlife habitat (Pimentel et al. 2004). Changes in plant assemblages may also affect carbon and other nutrients stored in vegetation and soils, with implications for site productivity (Eviner et al. 2012, Pejchar and Mooney 2009).

Invasives generally have a negative effect on water regulation. They can alter channel morphology, decrease water holding capacity, and thereby increase flood risk (Charles and Dukes 2007, Eviner et al. 2012, Pejchar and Mooney 2009). Water quality may also be compromised by erosion if invasives alter soil properties or if their root structures decrease soil stability. Changes in wetland species composition and function could also alter water filtration, storage, and flow regulation. Reed canary grass (*Phalaris arundinacea* L.), for example, compromises water storage capacity in marsh systems and also reduces habitat for the yellow rail (*Coturnicops noveboracensis* Gmelin), a migratory bird with a limited range in the Western United States.

Cultural services—
Invasive species may affect several cultural ecosystem services, including recreation opportunities, aesthetics, and plant-based cultural resources such as special forest products. Terrestrial invasive plants like Japanese knotweed (*Fallopia japonica* [Houtt.] Ronse Decr.) may affect recreation and tourism by forming dense stands that crowd out native species, thereby impeding accessibility and potentially reducing wildlife and rare-plant viewing (Charles and Dukes 2007). Both aquatic and terrestrial plants can interfere with watercraft, lower water quality, and reduce the abundance and diversity of fish and wildlife that attract visitors (Eiswerth et al. 2005 as cited by Smith et al. 2011). The presence of invasives and shifts in disturbance regimes can influence scenic views and aesthetics, as well as cultural or spiritual experiences in forests and grasslands (Charles and Dukes 2007).

The importance of context in understanding invasive species impacts on ecosystem services—
Interactions between invasive species, ecological structures and functions, and ecosystem services are complex and may differ with space and time. Understanding the species or assemblages that are key service providers or degraders, and how they respond to changing climatic conditions, will aid vulnerability assessments (Eviner et al. 2012). Site-specific knowledge can assist in understanding the vulnerability of systems to invasion and their subsequent ability to provide ecosystem services that are critical to human well-being.

Carbon sequestration, the long-term storage of carbon by forests, is a dynamic process that involves carbon uptake through photosynthesis and carbon release through decomposition and wildfires. Sequestration occurs with tree growth and biomass accumulation, as well as harvesting of wood products that remove the carbon from forests to be sequestered in places beyond the forest. The ability of forests to sequester carbon will change with tree physiological responses to climate change, shifts in forest composition and structure, and changing disturbance regimes.

Native and managed **pollinators** provide an important ecosystem service to forests and nearby agricultural lands. Increasing temperatures will likely influence pollinator thermoregulation, which in turn affects their physiology and behavior. Climate change is expected to affect plant phenology, and mismatches in timing of flowering and pollinator emergence may affect plant reproduction. Native bees may be more adaptive to such changes compared to managed bees. Pollinators may shift their range to find new food sources, although low habitat connectivity may inhibit such shifts.

National forests provide many **cultural values**, including spiritual enrichment, heritage, sense of place, identity, and aesthetic experiences. National forests also provide first-foods harvesting by American Indian tribes, sacred places for rituals, and recreation activities for the general public. Climate change is likely to alter these experiences by affecting ecological structure, process, and function. For example, disturbances and changes to hydrologic regimes may alter access to harvest sites, recreational sites, and other locations of importance. Climate change will also likely affect salmon populations, which have spiritual, physical, and economic significance to Pacific Northwest tribes.

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Chapter 10: Adapting to Climate Change in South-Central Oregon

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Introduction

Adaptation, or an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects (McCarthy et al. 2001), can help to reduce harm, or transition organisms and systems to new conditions in a warmer climate. Federal agencies with responsibility for land and water management are mandated to consider climate change in planning and projects and to begin preparing for the effects of climate change. The processes and tools for developing adaptation options have, to date, differed within and among federal agencies (Halofsky et al. 2015). However, as outlined in Peterson et al. (2011), key steps in the process include (1) **review**—learn basic climate change science and integrate it with knowledge of local resource conditions and issues; (2) **rank**—evaluate the sensitivity of specific natural resources to climate change; (3) **resolve**—develop and implement adaptation strategies and tactics; and (4) **observe**—monitor the effectiveness of adaptation options and make adjustments as needed.

Step 3, resolve, is used to develop adaptation options that promote sustainable resource management in a changing climate. This step encompasses several types of management strategies, characterized as "resistance, resilience, response, and realignment" (Millar et al. 2007). The **resistance** strategy includes actions that forestall impacts and protect highly valued resources. The **resilience** strategy includes actions that improve the capacity of systems to return to desired conditions after disturbance. The **response** strategy employs tools to facilitate transition of systems from current to new desired conditions, and the **realignment** strategy uses restoration practices to enable persistence of ecosystem processes and functions in a changing climate. Adaptation actions are often complementary with other land management actions such as ecosystem restoration.

The South-Central Oregon Adaptation Partnership (SCOAP) incorporated all four steps in the adaptation process. An initial meeting with leadership and managers from Deschutes, Fremont-Winema, and Ochoco National Forests involved review of basic climate change information set in a local context. That meeting was followed by a vulnerability assessment process that evaluated potential effects of climate change on hydrology, water use, and roads (chapter 4); fish and aquatic

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habitat (chapter 5); vegetation (chapter 6); wildlife (chapter 7); recreation (chapter 8); and ecosystem services (chapter 9). These assessments set the stage for hands-on development of adaptation options (the "resolve" step) by resource managers in a workshop setting. Managers engaged in facilitated discussion and completed worksheets, adapted from Swanston and Janowiak (2012), that identified key climate change vulnerabilities and related adaptation strategies (overarching approaches for resource planning and management) and tactics (on-the-ground management actions). Managers were encouraged to identify several types of strategies focused on resilience, response, and realignment. They also identified where tactics could be applied and opportunities for implementation of tactics, where applicable.

This chapter describes the adaptation strategies and tactics developed in the workshop for each of the six resource areas covered in the vulnerability assessment. Chapter 11 describes next steps for implementation and monitoring. This chapter does not reflect all of the possible adaptation strategies and tactics that are available or beneficial in response to future climate change vulnerabilities identified in the previous chapters for the SCOAP assessment area. Rather, the adaptation options described here reflect what the workshop teams for each resource area deemed the most important.

Adapting Management of Water Use and Roads to Climate Change

Adaptation Options for Water Use

Climate change will likely lead to lower snowpack, earlier runoff, and lower summer streamflows in south-central Oregon (chapters 3 and 4). Lower soil moisture and low flows in late summer, combined with increasing demand for water, will likely reduce water availability for aquatic resources, recreation, and other uses, particularly in areas less influenced by groundwater. However, actions within national forests can potentially reduce water use. A key adaptation strategy for national forest managers is to improve water conservation and align water availability on the landscape with demand (table 10.1). For example, consumptive uses, such as livestock in grazing allotments, may need to be reduced with decreased water availability in summer. Sources of water could be reexamined and diversified, with less use of surface water. Over the long term, increasing water conservation and reducing user expectations of water availability (e.g., through education) are inexpensive and complementary adaptation tactics for maintaining adequate water supply.

Vulnerability assessments for individual communities will likely provide better information on where and when water shortages may occur and can facilitate development of adaptation tactics customized to specific locations. However, because

Table 10.1—Water resource adaptation options for south-central Oregon

Sensitivity to climatic variability and change: Low summer flows will become lower. Less water will be available during times of peak demand, stressing the water delivery system.

***Adaption strategy/approach*—**Improve water conservation and address demands for water.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Diversify sources of water; rely less on surface water; consider low-volume wells; find better source locations for livestock and other uses	Align consumptive uses (such as stocking rates in allotments) with available water resources	Design stream crossings that have a low-flow channel; make an inset floodplain to maintain summer connectivity in the stream network
Where can tactics be applied?	Where low flow estimates jeopardize beneficial use	—	—

Sensitivity to climatic variability and change: Higher and earlier peak flows will lead to higher risk of damage to transportation infrastructure (roads and trails) and to stream channel function.

***Adaption strategy/approach*—**Increase resilience of road system infrastructure to peak flows. Focus on stream crossings, and roads within 90 m of channels.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Increase size of drainage structures; plan for greater than 100-year flood events; install more bridges and open bottom culverts; put venting fill in floodplains	Plan for more road decommissioning and rerouting; review historical closures and decommissioning sites for adequacy	Reduce hydrologic connectivity of roads to the stream system by outsloping, and increasing rolling dips and cross culverts; improve surfacing, especially at approaches to road crossings
Where can tactics be applied?	Prioritize roads where modeling shows highest increase in peak flows, and where rain-on-snow events are likely to occur	Forestwide; prioritize areas that are most vulnerable to peak flows and damage from peak flows	Forestwide

Sensitivity to climatic variability and change: Increased winter soil saturation leads to higher risk of landslides, which will affect the road system and access, and affect streams, water quality, and human safety.

***Adaption strategy/approach*—**Increase resilience to landslides by protecting roads and structures from higher landslide frequency. Reduce management activities that increase landslide potential.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Locate/relocate roads in areas less vulnerable to landslides	Redesign roads to avoid oversteep cut and fills, and improve water drainage; design debris catches on major access roads	Use seasonal road closures to keep visitors away during the most hazardous times of year
Where can tactics be applied?	Identify landslide-prone areas	Identify landslide-prone areas	Identify landslide-prone areas

Table 10.1—Water resource adaptation options for south-central Oregon (continued)

Sensitivity to climatic variability and change: Increased peak flows make recreational facilities, historic sites, cultural sites, and points of diversion (PODs) more vulnerable. Potential increased use of these facilities during shoulder seasons may increase safety hazards.

Adaption strategy/approach—Protect recreation facilities, historic sites, cultural sites, and PODs from peak flows, and improve public safety.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Restore watershed function by reconnecting stream channels to floodplains, dispersing flow, and reducing the intensity of flood events near campgrounds and other facilities	Relocate recreation facilities; move or structurally modify PODs where they are vulnerable; move sites and features (e.g., outhouses, picnic tables) to higher ground	Identify potential areas for early warning systems to notify visitors of dangers; prioritize inventory of sites to implement warning system
Where can tactics be applied?	Wherever applicable; prioritize in areas where increased peak flows are anticipated	Wherever applicable; prioritize in areas where increased peak flows are anticipated	Recreation sites that are highly vulnerable

— = No information.

discussions of water use and water rights are often contentious, open dialogue and full disclosure of data and regulatory requirements can foster the development of proactive, realistic, and fair management options (Clifton et al. 2017).

Actions related to biological components of mountain landscapes may also reduce the effects of climate change on water resources. Thinning and hazardous fuels treatments in low-elevation coniferous forest reduce the risk of high-severity fire and associated impact to soils, erosion, and water quality in streams. Similarly, restoration techniques that maintain or modify biophysical properties of hydrological systems can increase climate change resilience. For example, stream restoration techniques that improve floodplain hydrologic connectivity increase water storage capacity, and adding wood to streams improves channel stability and complexity, slows water movement, improves aquatic habitat, and increases resilience to both low and high flows. Reintroducing or supporting populations of American beaver (*Castor canadensis* Kuhl) may help to slow water movement and increase water storage in some locations (Pollock et al. 2014, 2015).

Adaptation Options for Roads and Infrastructure

Climate change adaptation options for roads and infrastructure were developed after consideration of the effects of climate-related stressors, including sensitivity of road design and maintenance to increasing flood risk, effects of higher peak streamflows on road damage at stream crossings, and safety hazards associated with an increase in extreme disturbance events (table 10.1). The following adaptation strategies were developed to address these stressors: (1) increase resilience of road system infrastructure to flood events, focusing on stream crossings and roads within 90 m of a stream channel; (2) increase resilience to landslides by protecting roads and structures from higher landslide frequency, while reducing management activities that increase landslide potential; (3) increase resilience of functioning stream conditions to low flows at stream crossings; and (4) increase resiliency and protect recreation facilities, historic and cultural sites, and points of diversion (PODs) to peak flows, and improve public safety.

The concept of Q_{100} (the peak flow anticipated in a 100-year flood event) is a key factor currently used for road management and stream crossing design. But with increasing peak flow events in a changing climate, it may be necessary to plan for greater than 100-year flood events. Managers may want to consider increasing the size of drainage structures and installing more bridges in open bottom culverts (table 10.1). Managers may also want to reduce hydrologic connectivity of roads to the stream system, and thus flood damage, by out-sloping, and increasing rolling dips and cross-drainage culverts. National forests in the SCOAP assessment area have a large backlog of culverts and road segments in need of repair, replacement, or upgrading, but capacity and funding limitations hinder these efforts. However, extreme events that damage roads and infrastructure may provide an opportunity for upgrades that increase resilience to climate change. The Federal Highway Administration Emergency Relief for Federally Owned Roads program is the principal source of storm-damage repair funds. At present, use of these funds is generally limited to in-kind replacement, but in some cases, matching funds can be raised or upgrades can be funded with sufficient justification and documentation of the environmental impacts and future trends for disturbance. The latest climate change projections could be included as justification for betterments.

Adapting road management to climate change may require further reductions in the road system, as actions to increase resilience will not be possible on all road segments given current funding limitations. Managers will need to plan for more road decommissioning and rerouting (table 10.1). Review of historical closures and decommissioning sites may be helpful to determine what was effective in the past and what may be most effective in the future. The U.S. Forest Service (USFS) travel analysis process (USDA FS 2005) already addresses some climate change vulnerabilities through decommissioning and increasing resilience of roads, culverts, and bridges to storms, but incorporating climate change in this process will help to further enhance resilience to increased flood and landslide potential. For example, priority for decommissioning may be given to roads that are in basins with higher risk of increased peak flows and flooding, in areas of high landslide risk, in floodplains of large rivers, or on adjacent low terraces. Information on locations in the transportation system that currently experience frequent flood damage (Strauch et al. 2014) can be combined with spatially explicit data on projected changes in flood or landslide risk and current infrastructure condition to provide indicators of where damage is most likely to continue and escalate with changes in climate (e.g., figs. 4.11 through 4.13).

With warming temperatures, there may be more demand for public access to national forests and parks during times of greater flood and landslide risk (chapter 8), thus increasing public safety hazards. In flood-prone portions of south-central Oregon, managers may consider locating or relocating roads to areas less vulnerable to floods and landslides (e.g., out of floodplains) (table 10.1). Roads can be designed to avoid overly steep cuts and fills and to improve water drainage. Managers can use seasonal road closures to keep visitors away during the most hazardous times of year as well as implement an early warning system to notify visitors of potential dangers. Greater control of seasonal use, combined with better information about current conditions, especially during early spring and late autumn, will ensure better public safety. Partnerships with recreation user groups may generate opportunities to convey this message to a larger audience, thus enhancing public awareness of hazards and the safety of recreation users.

Management of recreation facilities and historical and cultural resources may also need to be modified with increased risk of flooding and landslides. To reduce the intensity of flooding near campgrounds and other facilities, watershed restoration practices such as reconnecting stream channels to floodplains can be implemented (table 10.1). Recreation facilities such as campgrounds could be moved to higher ground to minimize flood impacts. However, the high cost of relocating buildings and inability to move historical sites from floodplains will require that adaptation options focus on resistance through prevention of flood damage, though that will become increasingly difficult over time as flood risk continues to increase. Eventually, infrastructure may need to be relocated to allow river channels to migrate and accommodate the changing hydrologic regime.

Adapting Fisheries and Fish Habitat Management to Climate Change

There are well-documented strategies and tactics for increasing fish population resilience to changing climate in streams of the Western United States (e.g., ISAB 2007, Luce et al. 2012, Mantua and Raymond 2014, Rieman and Isaak 2010). Resource managers used this information as a basis for developing adaptation strategies and tactics for streams in the SCOAP assessment area (table 10.2). Strategies focused on storing more water on the landscape, increasing resilience to disturbance, maintaining and restoring riparian and wetland vegetation complexity, and maintaining and restoring natural thermal conditions in streams.

Table 10.2—Fish and aquatic habitat adaptation options for south-central Oregon

Sensitivity to climatic variability and change: Climate change will result in changes in streamflow regimes.

***Adaption strategy/approach*—**Increase residence time, and store water on the landscape.

	Specific tactic—A	**Specific tactic—B**	**Specific tactic—C**
Tactic	Restore fluvial processes; increase shallow groundwater storage and riparian vegetation	Support beavers; reintroduce beavers; reduce trapping	Protect springs
Where can tactics be applied?	Critical habitat and priority watersheds	Where tactic A is successful; suitable but unoccupied habitat.	—
	Specific tactic—D	**Specific tactic—E**	**Specific tactic—F**
Tactic	Thin dry forests to reduce evapotranspiration	Improve grazing management	Improve efficiencies in regulated water use; conserve water
Where can tactics be applied?	Overstocked stands; juniper stands; high-elevation wetlands with encroaching lodgepole pine	Reduce pressure on riparian areas by providing more upland forage	Basinwide

Sensitivity to climatic variability and change: Some disturbance processes will increase in frequency and extent with climate change.

Adaption strategy/approach: Increase resilience to all disturbances.

	Specific tactic—A	**Specific tactic—B**	**Specific tactic—C**
Tactic	To increase resilience to fire, improve habitat; create riparian complexity; create fuel breaks near riparian zones; implement fish-friendly vegetation treatments	To increase resilience to floods, reconnect floodplains; improve hydrologic function of watersheds	Decontaminate gear and recreational gear to avoid spreading fish diseases; coordinate with state managers on fish stocking (vector, density); maintain genetic diversity of native fish populations and increase habitat connectivity to increase population resilience to disease
Where can tactics be applied?	—	—	Watersheds that support species of concern

Sensitivity to climatic variability and change: Change in riparian and wetland vegetation will alter aquatic food webs, stream shade, organic matter inputs, water chemistry, and cover from predators.

***Adaption strategy/approach*—**Maintain and restore riparian and wetland complexity.

	Specific tactic—A	**Specific tactic—B**	**Specific tactic—C**
Tactic	Retain riparian buffers along streams; protect riparian areas from grazing; diversify riparian vegetation composition and structure with plantings; add large wood to streams	Maintain complex wetland habitat with diverse species and structure; promote beavers; control nonnative species; reduce conifer encroachment	Restore fluvial processes in context of water management; maintain moist areas along streams to increase floodplain connectivity
Where can tactics be applied?	—	—	—

— = No information.

Responding to Shifts in Timing and Magnitude of Streamflow

Increasing temperatures will result in more precipitation falling as rain rather than snow and reduced snowpack in the SCOAP assessment area (chapter 4). This will lead to shifts in the timing and magnitude of streamflows, with higher winter peak flows and lower summer low flows in some parts of the SCOAP assessment area, causing stress for some fish species (chapter 5) (Mantua et al. 2010). Storing more water on the landscape could help to mitigate effects of lower summer flows (table 10.2). Specifically, managers can protect springs, increase shallow groundwater storage, and increase soil water storage in floodplains and on hillslopes by maintaining or restoring riparian vegetation (table 10.2). Promoting American beaver populations and beaver-related overbank flow processes could help increase water storage (Pollock et al. 2014, 2015). Minimizing negative effects of roads and grazing may also help offset increases in sediment yield with climate change (Goode et al. 2012). Finally, increasing water conservation may help to maintain summer flows and minimize stress on fish. Adaptation tactics will be most efficient if they can be coordinated with existing stream management and restoration efforts conducted by the Forest Service and other landowners and stakeholders (Rieman et al. 2015).

Responding to the Effects of Increased Disturbance

Climate change will likely increase the frequency of disturbance events, such as flooding (chapter 4), disease outbreaks (chapter 5), and wildfire (chapter 6), which will affect streams and aquatic habitat. Increased area burned will contribute to erosion and sediment delivery to streams (Goode et al. 2012). Depending on the timing and magnitude, sediment delivery can negatively affect some life-history stages of anadromous fish. Large debris flows can also negatively affect aquatic habitat.

To increase aquatic system resilience to wildfire, managers can work to maintain and restore hydrologic function by reconnecting floodplains and improving aquatic habitat and connectivity (table 10.2). Wildfire use plans can help to address fire effects on streams and reduce disturbance-related sediment input from roads. Restoring and revegetating burned areas, often a component of the Burned Area Emergency Rehabilitation program, can help to store sediment and maintain channel geomorphology following fire.

Increasing resilience of vegetation to wildfire may also help reduce fire severity and effects on aquatic systems. Hazardous fuel treatments that reduce forest stand densities and surface fuels are an adaptation tactic that is already widely used in uplands of dry forest ecosystems (Halofsky and Peterson 2016). Managers may want to prioritize hazardous fuel treatments near riparian areas to decrease riparian fire severity and impacts to streams.

Responding to Increased Stream Temperatures

Increasing stream temperatures and decreasing summer flows with warming climate will likely be problematic for coldwater-adapted fish species, particularly in streams with little groundwater influence and at the downstream extents of population distributions, where some species are near their thermal tolerances in summer (Isaak et al. 2012). Management actions to maintain and restore natural thermal conditions will likely be most effective in buffering against increasing stream temperatures. Specific tactics include restoring the functionality of stream channels and floodplains to retain cold water as well as riparian vegetation for shade. It will also be important to maintain or increase habitat connectivity, ensuring that passages for aquatic organisms are effective so that aquatic organisms can access cold-water refugia in the summer (Isaak et al. 2012). Management actions will be more effective when informed by stream temperature data collection and long-term monitoring (Isaak et al. 2016). The NorWeST stream temperature database, which includes the SCOAP assessment area, could provide information for monitoring network design.

To summarize, adapting to the effects of climate change on aquatic habitats will require a diversity of adaptation strategies and tactics, as described here. Most fish species and populations will have the capacity to adapt and track their habitats (Eliason et al. 2011), but others may require management interventions to persist. Stream restoration, already a common practice, will need to consider future biophysical conditions and how they will be affected by warming (Beechie et al. 2013). All management activities will need to be prioritized and conducted in the areas most likely to increase resilience of fish species and their habitat. As many species and populations adjust their phenologies and distributions to track changing climate, Forest Service lands will likely play an increasingly important role in providing future habitats.

Adapting Forest Vegetation Management to Climate Change

Increasing temperatures with climate change will lead to more precipitation falling as rain rather than snow, earlier snowmelt, and lower snowpacks (Elsner et al. 2010). Areas in alpine and subalpine vegetation types will likely decrease in the SCOAP assessment area, and frequency of drought and fire will likely increase (chapter 6). To maintain areas of subalpine habitat, managers suggested identifying, mapping, and protecting subalpine refugia (sensu Morelli et al. 2016) (table 10.3). Managers could consider excluding fire from likely refugia, such as on north-facing slopes and in areas with cold air drainage. Tracking tree species regeneration and distribution

Table 10.3—Forest vegetation adaptation options for south-central Oregon

Sensitivity to climatic variability and change: Significant loss of subalpine forest may occur with climate change.

***Adaption strategy/approach*—**Identify and address threats to refugia in subalpine forests (dominated by whitebark pine and mountain hemlock).

	Specific tactic—A	Specific tactic—B	Specific tactic – C
Tactic	Assemble existing datasets to identify and map climate change refugia, and revisit periodically	Exclude fire in potential subalpine refugia	Thin subalpine forest to increase resilience to fire and insects
Where can tactics be applied?	—	Cold air drainages; north-facing slopes; subalpine forests with disease resistance and multiple age classes	Prioritize cold air drainages; north-facing slopes; forests with multiple age classes, disease resistance and genetic diversity; areas with sufficient access

	Specific tactic—D	Specific tactic—E	Specific tactic—F
Tactic	Monitor subalpine forests and try to determine causes of changes	Inform the public about changes in subalpine forest and management approaches	Control for nonnative species in subalpine forest; promote understory diversity
Where can tactics be applied?	In current transitional zones	—	—

Sensitivity to climatic variability and change: Increased drought and disturbance will affect already overstocked dry forests.

***Adaption strategy/approach*—**Conduct active management in drought- and disturbance-susceptible dry forest.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Conduct more intensive thinning in dry forests	Conduct prescribed burns and allow frequent fire in dry forests; promote persistence of healthy trees; favor early-seral species	Promote drought- and disturbance-tolerant ponderosa pine and Jeffrey pine
Where can tactics be applied?	Thin more at lower elevations	—	On pumice soils

Sensitivity to climatic variability and change: Climate change will result in increased risk of fire, insect outbreaks, and drought in mesic forests.

***Adaption strategy/approach*—**Minimize stand-replacing disturbance events.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Favor early-seral species that are more tolerant of drought and defoliator outbreaks	Promote structural heterogeneity of fuels	Favor retention of old forest and complex structures
Where can tactics be applied?	—	—	—

— = No information.

in subalpine habitats will help managers determine how species are responding to climatic changes and how to adjust management accordingly (e.g., guidelines for planting) (Halofsky and Peterson 2016). Finally, communicating with the public about expected changes in subalpine forest and management response will likely help increase public support for active management in these high-risk habitats.

The frequency of disturbances such as fire, drought, and insect outbreaks will likely increase in mesic forests of south-central Oregon with warming (chapter 6). Minimizing the incidence of high-severity, stand-replacing disturbance events may help increase the resilience of mesic forests (table 10.3). Promoting the structural heterogeneity of fuels may help prevent stand-replacement fire over large areas. Favoring species and genotypes more tolerant of drought and defoliating insects may also help increase survival after these disturbances.

In the Pacific Northwest, wildfire exclusion, combined with extensive even-age timber management and other land uses, has resulted in dry forests at risk to wildfire, insects, and disease (Hessburg et al. 2015, 2016). A warmer climate will likely exacerbate these issues. The frequency and extent of wildfire will increase with warming in most dry forest and shrubland ecosystems (Rogers et al. 2011, Westerling et al. 2006), including those in the SCOAP assessment area (chapter 6). In dry, fire-prone forests, reducing stand density and conducting prescribed fires are primary actions for increasing forest resilience to climate change (Halofsky and Peterson 2016). Reducing stand density with thinning in dry forests can decrease forest drought stress and increase tree growth and vigor by reducing competition (Roberts and Harrington 2008). Reducing forest stand density, along with hazardous fuels treatment, can also increase forest resilience to wildfire (Hessburg et al. 2015, 2016; Stephens et al. 2013). Managers at our adaptation workshop suggested conducting more intensive thinning treatments involving greater reductions in forest stand density in dry forests, particularly at lower elevations (table 10.3). However, there must be a balance between thinning to reduce drought pressure but keep enough canopy to retain shade and help retain soil moisture (Brooks and Mitchell 2011). Reintroducing fire, through prescribed fire and managed wildfire, could also help reduce stand density and fuel levels and increase forest resilience to drought and other disturbances. Promoting persistence of vigorous trees, particularly of drought- and disturbance-tolerant species, will help promote long-term forest health (table 10.3). Managers may want to consider expanding species and genotypic diversity in plantings to increase resilience to disturbance.

Adapting Rangeland Vegetation Management to Climate Change

In a changing climate, lower elevation woodlands, shrublands, and grasslands in the SCOAP assessment area will likely be affected by changing fire regimes, increased drought, and increased establishment of invasive species (chapter 6). To control nonnative species in rangelands, managers suggested proactive management tactics such as early detection, rapid response for new invasions, incorporation of nonnative species prevention in all projects, and conducting outreach to educate employees and the public about invasives (table 10.4). Increasing collaboration among landowners and managers will also be necessary to effectively control nonnatives (Hellmann et al. 2008). Thus, managers also suggested establishing an interagency collaborative weed management program and creating new cooperative weed management areas.

Expansion of western juniper (*Juniperus occidentalis* Hook.) is a current issue that will likely continue under changing climate in south-central Oregon (Creutzburg et al. 2015) (see chapter 6). To control expansion of juniper, managers could use mechanical treatments at lower elevations, particularly in less-resilient areas, and prescribed fire or managed wildfire in higher elevation sagebrush steppe (table 10.4). When considering use of fire, managers may also want to consider risk of annual grass expansion. Given limited budgets, managers will need to prioritize areas for treatments where they will get the most return on investment. However, they will also have to consider other management priorities and concerns, such as sage-grouse priority areas, and grazing allotments. Development and application of climate-informed state-and-transition models (Halofsky et al. 2013) may help managers understand the potential effects of climate change and prioritize management actions.

Warmer temperatures and drier summer conditions will likely lead to an increase in fire frequency and severity (Rogers et al. 2011). To increase resilience of native sagebrush and grass ecosystems in south-central Oregon, managers suggested promoting early-season native species, and monitoring of postfire conditions to ensure implementation of appropriate postfire actions (e.g., the most effective seed mixture) (table 10.4). Grazing management will also be important in maintaining and increasing resilience of rangelands to climate change, and thus it will likely be necessary to develop flexible and perhaps novel grazing management plans. For example, removal of livestock from damaged ranges when native perennials are vulnerable (July–August), especially at lower elevations, may aid in supporting native ecosystem resilience.

Table 10.4—Rangeland vegetation adaptation options for south-central Oregon

Sensitivity to climatic variability and change: Climate change may lead to increased establishment and abundance of nonnative plant species.

***Adaption strategy/approach*—**Prevent nonnative species establishment and spread.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Establish an interagency collaborative weed management program; use existing weed management areas and create new cooperative weed management areas	Include nonnative species prevention strategies in all projects; promote education and outreach within and outside agency	Use early detection, rapid response approach to nonnative plants
Where can tactics be applied?	Public, tribal, and private lands within and adjacent to the SCOAP assessment area	Public, tribal, and private lands within and adjacent to the SCOAP assessment area	Public, tribal, and private lands within and adjacent to the SCOAP assessment area

Sensitivity to climatic variability and change: Expansion of western juniper will likely continue under changing climate.

***Adaption strategy/approach*—**Control expansion of western juniper.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Identify current and future critical areas to optimize return on investment of resources	Mechanically control juniper	Use prescribed fire and managed wildfire to control juniper
Where can tactics be applied?	Areas with Phase I encroachment; Crooked River National Grassland; at lower elevations across the the SCOAP assessment area	At lower elevations; in less resilient areas	In higher elevation sagebrush-steppe; locations with intact bunchgrass understory

Sensitivity to climatic variability and change: Higher temperatures will result in increased fire frequency and possibly severity.

***Adaption strategy/approach*—**Increase resilience of native sagebrush-grass ecosystems.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Monitor postfire effects (beyond the scope of suppression and Burned Area Emergency Response) and implement appropriate actions	Develop flexible, novel grazing management plan	Promote early-season native species
Where can tactics be applied?	Public, tribal, and private lands within and adjacent to the SCOAP assessment area; monitor on representative sites	Public, tribal, and private lands within and adjacent to the SCOAP assessment area; specific to allotments	Public, tribal, and private lands within and adjacent to the SCOAP assessment area

Adapting Management of Riparian Areas and Groundwater-Dependent Ecosystems to Climate Change

Key climate change vulnerabilities for riparian areas and groundwater-dependent ecosystems (GDEs) include shifts in the hydrologic regime (changes in timing and magnitude of flows, lower summer flows and higher, more frequent winter peak flows); changes in plant phenology and synchronicity of events with warming and changes in timing, type (rain versus snow) and quantity of precipitation, leading to altered water supply during the growing season; and changing biotic productivity and diversity in springs and wetlands. To minimize adverse effects of climate change on riparian areas and GDEs, managers can plan and prepare for more frequent and severe flood events; increase upland water storage; manage water to maintain springs and wetlands; improve soil quality and stability; increase resilience of riparian and wetland plant communities by preserving biodiversity; and manage for resilience of groundwater dependent springs and wetlands by considering the broader forest landscape, including uplands (table 10.5).

Adaptation strategies and tactics to address effects of hydrologic changes on riparian areas and GDEs had many similarities to those developed for water use and infrastructure and aquatic habitat (see previous sections). For example, maintaining or restoring stream channel form helps to increase hydrologic function and store water, which is beneficial for riparian and wetland vegetation, water quality, and aquatic habitat. Restoring and protecting riparian vegetation by managing livestock and recreation use similarly help to protect aquatic habitat and water quality by increasing water storage and providing shade to streams.

Other adaptation tactics were specific to riparian vegetation. For example, managers suggested that an assessment of riparian area health be conducted to help prioritize management actions (table 10.5). Monitoring and controlling nonnative plants in flood-prone areas, including the 100-year floodplain, could help ensure the functionality of riparian zones. Riparian zones will likely burn more frequently with warming climate, and thus in some riparian areas, managers may want to reintroduce fire to help facilitate the transition to future conditions.

GDEs are located in places where appropriate geological, hydrological, and biological conditions co-occur, and have existed at the same locations for thousands of years. GDEs cannot migrate to accommodate changing climatic conditions. Therefore, the primary options for protecting GDEs are to maintain aquifers that support them and to control management-induced stressors. Another strategy to increase resilience of GDEs is to manage for their functionality in the context of the broader landscape (table 10.5), because the structure and function of GDEs are influenced by surrounding vegetation and hydrology (Dwire and Mellmann-Brown 2017). Managers may want to devise a protocol to assess spring flows and volumes. Assessing the health of systems and determining whether they are resilient to potential changes in water supply during the growing season can help to prioritize areas for management (table 10.5). Maintaining

Table 10.5—Riparian area and groundwater-dependent ecosystem adaptation options for south-central Oregon

Sensitivity to climatic variability and change: Climate change will result in shifts in the hydrologic regime, including changes in timing and magnitude of flows, lower summer flows and higher, more frequent winter peak flows.

***Adaption strategy/approach*—**Plan and prepare for more frequent and severe flood events.

	Specific tactic—A	**Specific tactic—B**	**Specific tactic—C**
Tactic	Assess the health and resilience of the system; prioritize management areas based on assessment	Refine and revise stream health protocol to capture flow regime change	Monitor for and control undesirable nonnative species in flood-prone areas, including the 100-year floodplain
Where can tactics be applied?	Across the SCOAP area; consider all vegetation management projects and stream restoration projects	Across the SCOAP area	Across the SCOAP area

Sensitivity to climatic variability and change: Climate change will result in shifts in the hydrologic regime, including changes in timing and magnitude of flows, lower summer flows and higher, more frequent winter peak flows.

***Adaption strategy/approach*—**Increase upland water storage.

	Specific tactic—A	**Specific tactic—B**	**Specific tactic—C**
Tactic	Use riparian shrub planting and protection and riparian aspen restoration and management to increase water storage	Maintain or restore stream channel form	Protect riparian vegetation by adjusting livestock and recreation season of use, use numbers, and duration of use
Where can tactics be applied?	Prioritize based on watershed condition framework; consider all vegetation management projects and stream restoration projects	Prioritize based on watershed condition framework; consider all vegetation management projects and stream restoration projects	Prioritize based on watershed condition framework; consider all vegetation management projects and stream restoration projects

Sensitivity to climatic variability and change: Climate change will result in shifts in the hydrologic regime, including changes in timing and magnitude of flows, lower summer flows and higher, more frequent winter peak flows.

***Adaption strategy/approach*—**Conduct education and outreach with involved parties.

	Specific tactic—A	**Specific tactic—B**	**Specific tactic—C**
Tactic	Collaborate with watershed councils	Collaborate with recreation specialists to ensure public safety and habitat protection during flood seasons	Increase communication networks for recreation safety and awareness
Where can tactics be applied?	On a watershed basis	Flood season; flood-prone areas; high-use areas	—

water in springs and improving soil quality and stability can also help increase their resilience to climate change. Related tactics include using fencing to reduce ungulate impacts, and maintaining water on sites through water conservation techniques such as float valves, diversion valves, and hose pumps.

Table 10.5—Riparian area and groundwater-dependent ecosystem adaptation options for south-central Oregon (continued)

Sensitivity to climatic variability and change: Climate change will result in shifts in the hydrologic regime, including changes in timing and magnitude of flows, lower summer flows and higher, more frequent winter peak flows.

Sensitivity to climatic variability and change: Climate change will result in changes in plant phenology and synchronicity of events.

***Adaption strategy/approach*—**Increase resilience of riparian and wetland plant communities by preserving biodiversity.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Inventory and monitor plants in riparian and groundwater-dependent ecosystem areas	Identify important habitat by linking functional resilience of current vegetation to climate change scenarios and phenology; compare proportion of functional structural groups currently on the landscape with appropriate functional structural groups for future scenarios	Through Tactic B, identify locations appropriate for introducing or managing natural wildfire or mechanical work; embrace disturbance
Where can tactics be applied?	—	—	Consider all vegetation management projects and stream restoration projects

Sensitivity to climatic variability and change: Climate change will result in shifts in the hydrologic regime, including changes in timing and magnitude of flows, lower summer flows and higher, more frequent winter peak flows.

***Adaption strategy/approach*—**Conduct education and outreach with involved parties.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Collaborate with watershed councils	Collaborate with recreation specialists to ensure public safety and habitat protection during flood seasons	Increase communication networks for recreation safety and awareness
Where can tactics be applied?	On a watershed basis	Flood season; flood-prone areas; high-use areas	—

Sensitivity to climatic variability and change: Climate change will result in changes in plant phenology and synchronicity of events.

***Adaption strategy/approach*—**Increase resilience of riparian and wetland plant communities by preserving biodiversity.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Inventory and monitor plants in riparian and groundwater-dependent ecosystem areas	Identify important habitat by linking functional resilience of current vegetation to climate change scenarios and phenology; compare proportion of functional structural groups currently on the landscape with appropriate functional structural groups for future scenarios	Through Tactic B, identify locations appropriate for introducing or managing natural wildfire or mechanical work; embrace disturbance

Table 10.5—Riparian area and groundwater-dependent ecosystem adaptation options for south-central Oregon (continued)

Sensitivity to climatic variability and change: Climate change will result in shifts in the hydrologic regime, including changes in timing and magnitude of flows, lower summer flows and higher, more frequent winter peak flows.

Where can tactics be applied?	—	—	Consider all vegetation management projects and stream restoration projects

Sensitivity to climatic variability and change: Changes in timing, type (rain versus snow), and quantity of precipitation may alter water supply during the growing season, thus altering biotic productivity and diversity in springs and wetlands.

***Adaption strategy/approach*—**Manage water to maintain springs and wetlands; improve soil quality and stability.

	Specific tactic—A	**Specific tactic—B**	**Specific tactic—C**
Tactic	Monitor recreation usage and manage impacts	Reduce ungulate trampling with fencing and livestock use changes	Maintain water on site through water conservation techniques such as float valves, diversion valves, and hose pumps; take advantage of new technology and techniques
Where can tactics be applied?	High-elevation trails and popular destinations	Incorporate in updates of the livestock allotment management plan	—
	Specific tactic—D	**Specific tactic—E**	**Specific tactic—F**
Tactic	Encourage spring development project designs that will ensure water flows for native species and habitat; prioritize Oregon spotted frog habitat	Develop a national groundwater protection program; focus efforts on priority areas based on level 1 monitoring results	Preserve cold-water refugia
Where can tactics be applied?	—	—	Consider all vegetation management projects and stream restoration projects

Sensitivity to climatic variability and change: Changes in timing, type (rain versus snow), and quantity of precipitation may alter water supply during the growing season, thus altering biotic productivity and diversity in springs and wetlands.

***Adaption strategy/approach*—**Manage for resilience of groundwater-dependent springs and wetlands by considering the broader forest landscape, including uplands.

	Specific tactic—A	**Specific tactic—B**	**Specific tactic—C**
Tactic	Assess the health of the system (is it resilient to potential changes in the water supply during the growing season?); prioritize areas for management based on the results of the assessment	Devise a GDE protocol to assess spring flows and volumes	Control nonnative species in GDEs; use early detection, rapid response
Where can tactics be applied?	Areas with other water uses (range, recreation)	GDEs	—

— = No information.
GDE = groundwater-dependent ecosystem.

Adapting Wildlife Habitat Management to Climate Change

With changing climate in south-central Oregon, key sensitivities for wildlife habitat include habitat type conversions, increasing temperatures that exceed the physiological thresholds of faunal species, loss of habitat structure and spatial heterogeneity, changes in riparian and wet habitats, and loss of snowpack (chapter 7). Primary adaptation strategies to address these sensitivities include (1) reducing repeat disturbances that can result in a habitat type conversion; (2) providing thermal refugia and opportunities for wildlife movement; (3) increasing resilience of late-successional habitat and structure (shrub and forest) and surrounding habitat; (4) maintaining spatial patterns that are resilient to disturbance, provide habitat diversity, and maintain landscape permeability; (5) identifying, retaining, and restoring riparian and wetland habitat for wildlife; and (6) developing mitigation measures and strategies to compensate for loss of snowpack location and duration (table 10.6). Application of these strategies are described for specific habitat types (as identified in chapter 7) below. For all habitat types, monitoring will be critical to identify changes in habitat conditions and allow for adjustments in management.

In low-elevation shrub-steppe, prescribed fire and thinning could be used to maintain native woodland, shrub, and bunchgrass habitat structures for a mosaic of landscape patterns. As described in the previous section, control of nonnative species will be critical, as will management of other stressors (e.g., motorized recreation and overgrazing) (table 10.6). Coordination with adjacent land managers will be important to address potential land use conversion pressures and maintain landscape permeability and connectivity for range shifts and seasonal migration (Mawdsley et al. 2009). In these dry and warm habitat types, identification and protection of wet areas, water sources, and thermal refugia (e.g., cliffs, talus, and deep soils) will also be beneficial to wildlife.

Open, large-tree ponderosa pine (*Pinus ponderosa* Douglas ex P. Lawson & C. Lawson) forests are likely to be an ongoing high priority for management because of current high levels of fuel loading relative to historical conditions and proximity to the wildland-urban interface. Thinning and prescribed fire can be used to facilitate transition from mixed-conifer to open pine structure in appropriate settings (e.g., southern exposure, upper slope positions). A significant challenge will be promoting the development of large-tree and open understory conditions in capable areas where large trees of fire-resilient species are not currently present (Stine et al. 2014). Establishment of ponderosa pine and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) may require planting in areas where the seedbed is now dominated by shade-tolerant species (Hessburg et al. 2015, Merschel et al. 2014, Spies et al.

2012). However, careful consideration of future stocking rates will be important. The lowest, hottest settings may experience increased summer drought stress under projected future conditions. Creating more open conditions with fewer trees may be desirable for long-term sustainability in areas where increased seasonal drought stress is anticipated. Retention of thermal micro-refugia for smaller animals will to some extent depend on retaining large woody structures (living and dead, standing and down). Diverse understory food plants and shrub patches are an important component of this habitat type, and control of nonnative plants can help to maintain understory diversity.

Table 10.6—Wildlife adaptation options for south-central Oregon

Sensitivity to climatic variability and change: Habitat type or species conversions may occur with climate change (e.g., loss of big sagebrush after fire that never returns to big sagebrush).

***Adaption strategy/approach*—**Reduce repeat disturbances that can result in a habitat type or species conversion.

	Specific tactic—A	**Specific tactic—B**	**Specific tactic – C**
Tactic	Protect native bunchgrass and shrub-steppe habitats; decrease fuel continuity to reduce likelihood of widespread fire; use methods that reduce adverse impact of treatments (e.g., invasion by annual grasses following prescribed fire or wildfire); control nonnative plants; remove invading conifer trees; manage motorized recreation, grazing, and other stressors	Identify the best remaining areas of habitat types; maintain and restore a diversity of types and seral stages across the landscape; monitor ecotones	Use rapid response to nonnative species, including feral animals; use citizen science to report new invasions; educate the public on identification and control of nonnative species
Where can tactics be applied?	Remove conifers at the early stage of encroachment	—	—

Sensitivity to climatic variability and change: Increasing temperatures may exceed physiological thresholds of animal species.

***Adaption strategy/approach*—**Provide thermal refugia and opportunities for movement.

	Specific tactic—A	**Specific tactic—B**
Tactic	Maintain thermal and security refugia	Maintain landscape permeability for animal movement; provide passage structures across major highways; close roads; maintain elevational connectivity
Where can tactics be applied?	Talus and rimrock areas; protect deep soils from compaction; maintain or create large snags and down wood for thermal refugia and moisture retention	Areas identified in connectivity assessments

Table 10.6—Wildlife adaptation options for south-central Oregon (continued)

Sensitivity to climatic variability and change: Increased temperatures and changing disturbance regimes may result in loss of habitat structure and spatial heterogeneity.

***Adaption strategy/approach*—**Increase resilience of late-successional habitat and structure (shrub and forest) and surrounding habitat.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Protect, maintain, and recruit legacy structures (e.g., large trees, snags, down wood); remove duff from the base of legacy trees prior to prescribed fire; reduce fuels before prescribed fire or wildfire; develop burn prescriptions with the intent of protecting legacy trees	Identify areas on the landscape that are more likely to maintain late-successional forest; identify fire refugia via topography and aspect	Maintain a landscape that is likely to support mixed-severity fire; consider use of prescribed fire that mimics mixed-severity fire; use mechanical treatments to reduce landscape-level contiguous fuels prior to prescribed fire; use managed wildfire
Where can tactics be applied?	Post-disturbance environments	—	Use prescribed fire in areas with a variety of topographic settings (aspect, topographic position); mechanical treatments may be necessary to protect legacy structures, spotted owl habitat areas, or on landscapes with no topographic diversity

Sensitivity to climatic variability and change: Increased temperatures and changing disturbance regimes may result in loss of habitat structure and spatial heterogeneity.

***Adaption strategy/approach*—**Maintain spatial patterns that are resilient to disturbance, provide structural diversity, and maintain landscape permeability.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Maintain a landscape that is likely to support mixed-severity fire; consider use of prescribed fire that mimics mixed-severity fire; use mechanical treatments to break up contiguous fuels prior to prescribed fire; use managed wildfire	Develop landscape connectivity and permeability patterns for animal movement at multiple scales	Develop stand- and project-level prescriptions to maintain heterogeneity; maintain high-quality early-seral habitats across the landscape with legacies
Where can tactics be applied?	Use topographic patterns to inform where on the landscape to maintain different structures and patterns	Use topographic patterns to inform where on the landscape to maintain different structures and patterns	Use topographic patterns to inform where on the landscape to maintain different structures and patterns

In wetland, riparian, and open water habitats, reducing existing stressors will likely help increase resilience to climate change (e.g., limiting direct disturbance impacts from road construction and recreation sites). Managers may want to consider relocating roads and recreation developments away from floodplains to reduce their effects on riparian, wetland, and aquatic habitats. Shading riparian vegetation provides important microclimate for wildlife. Tactics to maintain riparian vegetation

Table 10.6—Wildlife adaptation options for south-central Oregon (continued)

Sensitivity to climatic variability and change: Climate change will affect riparian and wet habitats.

***Adaption strategy/approach*—**Identify, retain, and restore riparian and wetland habitat for wildlife.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Maintain and restore alpine wetlands for amphibian habitat; deepen wetlands to retain water; remove introduced fish; restore floodplain function; reintroduce beaver	Maintain and restore streamside and riparian habitats; manage grazing, recreation and other anthropogenic stressors in sensitive areas to maintain wildlife habitat; maintain riparian vegetation to provide wildlife habitat and stream shading; reintroduce beaver	Maintain and restore aspen habitat; remove encroaching conifers; manage grazing in sensitive areas to maintain wildlife habitat
Where can tactics be applied?	—	—	—

Sensitivity to climatic variability and change: Increased temperatures will result in loss of snowpack.

***Adaption strategy/approach*—**Develop mitigation measures and strategies to compensate for loss of snowpack location and duration.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Use methods that retain snowpack and associated moisture; use tree retention to slow the loss of snow; retain snowmelt through meadow and wetland restoration	Reduce impacts from winter recreation as recreation is concentrated into smaller areas	Maintain thermal and security refugia
Where can tactics be applied?	Alpine meadows and wetlands areas that capture and retain snowmelt; maintain vegetation on north slopes to maintain snowpack	In areas of potential high visitor use; in areas with high erosion potential; protect critical habitats and refugia	In talus and rimrock areas and high-elevation grasslands; protect deep soils from compaction; maintain large down wood for thermal refugia and moisture retention

— = No information.

include managing grazing, removing nonnative species, and protecting riparian areas from high-intensity fire. Promoting connectivity of riparian habitat conditions along stream networks can help provide for animal movement and range shifts. Encouraging beaver colonization can help maximize water retention and groundwater recharge.

In mid-elevation, old, structurally complex forest, restoration of sustainable landscape patterns may require a combination of mechanical treatments, prescribed fire, and managed wildfire (Halofsky et al. 2014). Mechanical treatments combined with prescribed fire can be used in the wildland-urban interface and around key ecological features (e.g., northern spotted owl [*Strix occidentalis caurina*] nest sites) where precise and predictable outcomes are required. Mixed-severity prescribed fire, and wildfire under appropriate conditions, can be used to establish broader scale sustainable landscape patterns (table 10.6). Topography is a particularly strong driver of moisture gradients in this type, and restoration activities to address resilient landscape patterns should be based on this topographic context (Hessburg et al. 2016).

Managing for habitat connectivity has widely been cited as a primary adaptation strategy; however, the issues associated with highly contiguous landscape patterns that are susceptible to large-scale disturbances highlights some challenges. Managers could consider strategies that reduce contagion for large-scale disturbance processes while maintaining landscape permeability for important ecological flows, including animal movement. Some management activities, including prescribed burns or mechanical treatments that retain stand structural heterogeneity (e.g., Lehmkuhl et al. 2015), could address highly contagious fuel patterns while still providing opportunities for forest-associated species to move through the landscape. Overall, it will be important for managers to develop strategies for this type that balance disturbance risk reduction and old forest conservation management objectives under intensifying disturbance regimes.

Mid-elevation early-seral habitats are likely to experience the greatest increase in abundance under climate change with increases in fire frequency and severity. It will be important to consider the ecological values of postdisturbance landscapes in climate adaptation planning, and carefully evaluate postdisturbance activities based on ecological and silvicultural considerations for desired future conditions at the site. Managers may consider promoting tree regeneration with species that may do well under future climatic conditions, but it will be necessary to develop realistic expectations for forest regeneration, and some sites may permanently shift to grassland or shrubland. Managers can improve wildlife habitat value of early-seral forest by identifying and implementing strategies to recruit and retain biological legacies and by considering habitat connectivity and landscape permeability patterns for animal movement at multiple scales.

In high-elevation habitats, including cold forests, woodlands, whitebark pine (*Pinus albicaulis* Engelm.) communities, meadows, grasslands, and barren areas, prescribed fire and wildfire can be used in appropriate settings to reduce the risk of large-scale, high-intensity fire being carried into high elevations from adjacent warmer types. These treatments, along with manual tree removal, can also be used to reduce tree encroachment and maintain structure of high-elevation woodlands and meadows. As described above, identifying and protecting climate and disturbance refugia can help maintain high-elevation habitats for wildlife (table 10.6). Managers may want to consider methods that retain snowpack and associated moisture, such as using tree retention to slow the loss of snow and restoring meadows and wetlands. As snow-based recreation is concentrated into smaller areas, efforts to reduce impacts from recreation may be needed.

Adapting Recreation Management to the Effects of Climate Change

Climatic warming is expected to reduce snow-based recreation season length and the likelihood of reliable winter recreation seasons in south-central Oregon. Some areas, especially at lower elevations, may become unsuitable for snow-based recreation because of warmer temperatures and increased likelihood of rain (chapter 3). High-elevation sites (including downhill ski resorts) will likely experience more variability in season length. To provide recreation opportunities in the future, recreation management will need to transition to address shorter average winter recreation seasons and changing use patterns (table 10.7). National forests and parks may want to invest in temporary or mobile structures to adapt to variability in seasonal changes. For example, the sno-park system could be based on snow levels, shifting both within and between years. Similarly, forests and parks may want to divest in low-elevation sno-parks and ski resorts that are unlikely to have consistent snow in the future.

In contrast, climate change is expected to lengthen the season for warm-weather activities as snow- and ice-free sites become accessible earlier, and temperatures are higher during the autumn and spring shoulder seasons. Risks of disturbances such as flooding and landslides are higher in the autumn and spring shoulder seasons, and increased recreation use during the shoulder seasons may pose risks to public safety. To protect the public, managers could conduct safety education sessions; develop fire, flood, and geohazard evacuation plans; enforce public use restrictions; and place gates in areas of concern (table 10.7). Managers may also engineer road and trail systems for wet-weather movement (e.g., graveled trails for use in the shoulder season) to both increase access and protect the roads and trails. Managers can consider how use in the shoulder seasons is managed, adjusting timing of actions such as road and trail openings and closures and special-use permits. Managers may establish defined season of use for all-terrain vehicles and mountain bikes during shoulder seasons, or rather than date-specific closures, continuously monitor and use weather- or condition-specific closures.

Capacity of recreation sites may need to be adjusted to provide sustainable recreation opportunities to meet increased demand in shoulder and summer seasons. For example, some campgrounds may need to be enlarged (table 10.7). Water-based recreation will also likely become more popular as recreationists seek relief from high summer temperatures. Tactics to address increased demand for water-based recreation include increasing the length of boat ramps (to allow for access with lower water levels), managing lake and river access capacity, and managing public expectations on site availability through, for example, a phone application or cameras. A sustainable recreation plan could help managers strategically invest and divest in particular sites based on changing use patterns and ecological carrying capacity. Some uses may need to be limited in some areas. Monitoring will be critical to assess changes in use patterns and identify demand shifts.

Table 10.7—Recreation adaptation options for south-central Oregon

Sensitivity to climatic variability and change: Ice- and snow-based recreation is highly sensitive to variations in temperature and the amount and timing of snow.

***Adaption strategy/approach*—**Transition recreation management to address shorter average winter recreation seasons and changing use patterns.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Invest in temporary or mobile structures to adapt to higher variability in seasonal changes (e.g., adjustable sno-park system based on snow levels, portable toilets in lieu of permanent toilets); divest in infrastructure that cannot be nimble or easily respond to variability	Place gates in areas of concern to close roads for resource protection; coordinate with engineering	Establish defined season of use for all-terrain vehicles and mountain bikes during shoulder seasons; monitor conditions; rather than date-specific closures, use weather or condition-specific closures; revise old closure orders
Where can tactics be applied?	Divest or alter design/use in low-elevation sno-parks or ski areas that are at risk of closing	Areas with resource sensitivity (e.g., in soils, wildlife, cultural resource areas, road conditions)	Information needs to be available in multiple formats (e.g., applications, website, at districts, posted at sites in field)

	Specific tactic—D	Specific tactic—E	Specific tactic—F
Tactic	Adjust recreation opportunities during shoulder season; add language to concessionaire contracts to allow for seasonal flexibility; communicate to users (use phone application)	Engineer road and trail systems for wet weather movement (e.g., graveled trail open during shoulder season, roads to access targeted areas)	Conduct safety education; be weather smart
Where can tactics be applied?	Existing permits	High-demand areas and where we may want to focus use; distribute recreation use to lower use areas	Forestwide

Sensitivity to climatic variability and change: Increasing length of snow-free season will increase demand for summer recreation access. Season of use will change (use may decrease because of more fire, smoke, and public use restrictions).

***Adaption strategy/approach*—**Maintain safe access at the beginning and end of the summer recreation season. Provide sustainable recreation opportunities in response to changing demand.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Assess changes in use patterns and identify demand shifts; identify use thresholds and site capacity in relation to other resources; address user conflicts as use becomes concentrated in smaller areas	Adjust timing of actions such as road and trail openings and closures and special-use permits based on resource concerns	Adjust capacity of recreation sites (e.g., enlarge campgrounds, collect additional fees, and install infrastructure such as fences, signs, and gates); develop a strategy to invest and divest based on a sustainable recreation plan
Where can tactics be applied?	Coordinate on regional level (not just by forest); consider hotter and drier conditions (users go where there is water); develop internal strategy that addresses conflicting uses	In areas where user days are decreasing, look for opportunities to shift use to other areas; engage public on adapting stewardship to changing landscape needs and pace of change	Work with engineering and roads

Table 10.7—Recreation adaptation options for south-central Oregon (continued)

Sensitivity to climatic variability and change: Increasing length of snow-free season will increase demand for summer recreation access. Season of use will change (use may decrease because of more fire, smoke, and public use restrictions).

***Adaption strategy/approach*—**Maintain safe access. Use risk management at developed sites.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Plan for fire, flood, geohazard evacuation and safety; enforce public use restrictions to ensure public safety	Develop vegetation management plans for campgrounds; develop hazard tree management strategies	Address risks from large streamflow events and geohazards (e.g., on access roads to campgrounds and trails, streams, lakes, steep slopes)
Where can tactics be applied?	Annual fire plans and public use restriction planning; landscape-level planning for safety procedures; evacuation procedures for recreation sites; put natural disaster plans in place ahead of time	Focus on high-risk areas (e.g., where there are forest health issues)	Where there are recurring failures in water system or where erosion begins to occur; adapt facilities near streams and lakes (e.g., adjust based on floodplain and more frequent floods)

Sensitivity to climatic variability and change: Lower water levels in summer will result in a decrease in suitable sites for water-based recreation, coupled with increasing demands.

***Adaption strategy/approach*—**Increase flexibility in water-based recreation site management and facility design.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Increase length of boat ramps	Manage shoreline and dry lake areas	Use flexibility in opening and closing facilities based on ice, weather conditions; add language to concessionaire contracts to allow for seasonal flexibility; communicate to users (use phone application)
Where can tactics be applied?	Existing boat ramps	Reservoirs and lakes	Existing permits

	Specific tactic—D	Specific tactic—E
Tactic	Manage lake and river access capacity	Manage public expectations on site availability; develop a third-party application that could inform people when recreation sites are full; use cameras at key recreation sites
Where can tactics be applied?	Forestwide at existing facilities and at public-created access sites; high use at some sites may be acceptable	High-use areas; recognize that use will shift

Table 10.7—Recreation adaptation options for south-central Oregon (continued)

Sensitivity to climatic variability and change: Lower water levels in summer will result in a decrease in suitable sites for water-based recreation, coupled with increasing demands.

***Adaption strategy/approach*—**Proactively manage for risks to public health and safety.

	Specific tactic—A	Specific tactic—B	Specific tactic—C
Tactic	Increase education on the health risk of algal blooms in lakes and impacts of algal blooms on water-based recreation	Evaluate facilities (Forest Service, resorts, recreation residences) near water edges and shorelines (e.g., septic systems, vault toilets, pit toilets)	Develop clear communication campaigns using social science research to address increased dispersed uses near waterline (e.g., human waste, dog waste, trash)
Where can tactics be applied?	Use pamphlets, websites, applications	All existing recreation facilities	Conduct a regional and subregional campaign

Sensitivity to climatic variability and change: Decreased or degraded habitat for aquatic and wildlife species.

***Adaption strategy/approach*—**Manage conflicts between river use and aquatic and wildlife species.

	Specific tactic—A	Specific tactic—B
Tactic	Determine and manage capacity for human use based on river designation and management objectives	Coordinate with the state to prepare for changing needs for recreational access
Where can tactics be applied?	Primarily Wild and Scenic Rivers and rivers that may be designated	Statewide

Sensitivity to climatic variability and change: Climate change will create uncertainty related to the seasonality and availability of noncommercial forest products (e.g., berries, mushrooms, Christmas trees, boughs, firewood).

Adaption strategy/approach: Adjust to changes in seasonality and availability of noncommercial forest products.

	Specific tactic—A	Specific tactic—B
Tactic	Coordinate with other resources to look for habitat enhancement and restoration opportunities	Work with partners to monitor forest products to gather information about status and trends
Where can tactics be applied?	—	Regional, subregional, and forest levels

— = No information.

Adapting Management of Ecosystem Services to Climate Change

Among the climate change vulnerabilities discussed for ecosystem services (chapter 9), those that pose the highest concern include the protection of habitat for pollinators, the availability of first foods as a cultural value, and nontimber forest products, such as matsutake mushrooms (*Tricholoma matsutake* [S. Ito & S. Imai] Singer). Many of these vulnerabilities stem from likely climate change impacts on other resources.

Increasing temperatures will likely have an effect on the thermoregulation of pollinators and may lead to a mismatch in the timing of emergence of flowers and pollinators (Fagan et al. 2014). Another possible indirect effect of climate change on pollinators is habitat loss and fragmentation with nonnative species and vegetation type shifts, leading to a reduction in forage resources or an increase in pests and diseases. Thus, maintaining a diversity of native species with overlapping flowering phenology that together span the growing season, and taking pollinators into consideration when developing management strategies for vegetation and GDEs, may help to increase pollinator resilience to climate change.

To (further) manage for the availability of first foods and nontimber forest resources, one first needs to understand (1) how climate change affects the availability of first food and nontimber forest products, (2) the overlap between commercial and recreational use versus tribal use, and (3) the effects of climate change on social interactions. This will help guide decisions on how to manage for first foods and nontimber forest products under a changing climate. Monitoring can help track changes in special forest products and different uses over time. Managers can use the information from monitoring efforts to adaptively manage special forest products, inform permitting, and ensure sustainable harvest.

Conclusions

The SCOAP vulnerability assessment and workshop process resulted in a list of high-priority climate change adaptation strategies and tactics for natural resource management for south-central Oregon. Many of the strategies and tactics were focused on increasing ecosystem resilience, although some were aimed at facilitating transition of ecosystems or management to a changing climate (e.g., transition recreation management to account for changing use patterns with climate change). Adaptation strategies and tactics that have benefits to more than one resource will generally have the greatest benefit (Peterson et al. 2011b). For example, reintroducing American beaver could have benefits for both water quantity and fish habitat. Management activities focused on reducing fuels and restoring hydrologic function are already standard practices on state and federal lands in south-central Oregon, suggesting that many current resource management actions will also be appropriate in a changing climate.

Implementation is the next challenging step for the SCOAP (see chapter 11). The locations where actions are implemented may be different or strategically targeted in the context of climate change. For example, fuel treatments may be targeted around high-value, late-seral habitat, which in the future may decrease in area with increased fire. Although implementing all adaptation options described here may not be feasible, managers can choose from the menu of strategies and tactics, and expand upon it in coming years.

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Chapter 11: Conclusions

Joanne J. Ho[1]

The South-Central Oregon Adaptation Partnership (SCOAP) provided significant contributions to assist climate change response on national forests and national parks in south-central Oregon. The effort synthesized the best available scientific information to assess climate change vulnerability, develop adaptation options, and catalyze a collaboration of land management agencies and stakeholders seeking to address the effects of climate change. The vulnerability assessment and corresponding adaptation options provided information to support national forests and national parks in implementing respective agency climate change strategies described in the U.S. Forest Service (USFS) National Roadmap for Responding to Climate Change (USDA FS 2010a) and Climate Change Performance Scorecard (USDA FS 2010b) (see chapter 1), and the National Park Service (NPS) Climate Change Response Strategy (USDI NPS 2010). The SCOAP process enabled the three national forests in the region to respond with "yes" to the climate change scorecard questions in the organizational capacity, engagement, and adaptation dimensions. In addition, the SCOAP process enabled Crater Lake National Park to make progress toward implementing several components (communication, science, and adaptation goals) of the NPS Climate Change Response Strategy (USDI NPS 2010).

Relevance to Agency Climate Change Response Strategies

In this section, we summarize the relevance of the SCOAP process to the climate change strategy of federal agencies and the accomplishments of participating national forests, national grasslands, and national parks. Information presented in this report is also relevant for other land management agencies and stakeholders in south-central Oregon. This process can be replicated and implemented by any organization, and the adaptation options are applicable in south-central Oregon and beyond. Like previous adaptation efforts (e.g., Halofsky and Peterson 2017, Halofsky et al. 2011, Raymond et al. 2014), a science-management partnership was critical to the success of the SCOAP. Those interested in using this approach are encouraged to pursue this partnership as the foundation for increasing climate change awareness, assessing vulnerability, and developing adaptation plans.

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Communication, Education, and Organizational Capacity

Organizational capacity to address climate change requires building institutional capacity in management units through training and education for employees. Training and education were built into the SCOAP process through workshops and webinars that provided information about the effects of climate change on water resources, fish and aquatic habitat, vegetation, wildlife, recreation, and ecosystem services. The workshops introduced climate tools and processes for assessing vulnerability and planning for adaptation.

Partnerships and Engagement

The SCOAP science-management partnership and process were as important as the products that were developed, because these partnerships are the cornerstone for successful agency responses to climate change. We built a partnership that included three national forests, the Pacific Northwest Regional office, the USFS Pacific Northwest and Rocky Mountain Research Stations, and the University of Washington, and is relevant for future forest plan revision and restoration projects conducted by the national forests in collaboration with stakeholders.

The SCOAP process encouraged collaboration between USFS and NPS, supporting a foundation for a coordinated regional response to climate change. By working with partners, we increased our capability to respond to climate change. Responding to such a challenge requires using an all-lands approach, which this partnership fostered.

Assessing Vulnerability and Adaptation

The SCOAP vulnerability assessment used the best available science to identify sensitivity and vulnerability of multiple resources in the SCOAP assessment area. Adaptation options developed for each resource area can be incorporated into resource-specific programs and plans. The identification of key vulnerabilities and adaptation strategies can also inform future forest plan revision efforts.

The science-management dialogue identified a set of key management practices that are useful for increasing resilience and reducing stressors and threats. This set of adaptation strategies and tactics does not reflect the full suite of possible actions and represents only the key strategies and tactics identified by workshop participants. Although implementing all options developed in the SCOAP process may not be feasible, resource managers can still draw from the menu of options as needed. Some adaptation strategies and tactics can be implemented on the ground now, whereas others may require changes in policies and practices or can be implemented when management plans are revised or as threats become more apparent. Additional beneficial practices not identified in the SCOAP process will very likely be identified in the future.

Science and Monitoring

Where applicable, the SCOAP products identified information gaps or uncertainties important to understanding climate change vulnerabilities to resources. These information gaps guide where monitoring and research would decrease uncertainties inherent to management decisions. Working across multiple jurisdictions and boundaries will allow SCOAP participants to increase collaborative monitoring and research of climate change effects and effectiveness of implementing adaptation strategies and tactics that increase resilience or reduce stressors and threats.

Throughout the SCOAP process, the best available science was used to understand projected changes in climate and effects on natural resources. This science can be incorporated into large landscape assessments such as forest and grassland planning assessments, environmental analysis for National Environmental Policy Act (NEPA) projects, or project design and mitigations.

Implementation

Implementation of climate-smart management will likely be motivated by extreme weather and large disturbances, and facilitated by changes in policies, programs, and land management plan revisions. It will be especially important for ongoing restoration efforts to incorporate climate change adaptation to ensure effectiveness. Implementation will be most effective if landowners, management agencies, and American Indian tribes work together across landscapes.

In many cases, similar adaptation options were identified for more than one resource sector, suggesting a need to integrate adaptation planning across multiple disciplines. Adaptation options that yield benefits to more than one resource are likely to have the greatest benefit (Halofsky et al. 2011, Peterson et al. 2011, Raymond et al. 2014). However, some adaptation options involve tradeoffs and uncertainties that need further exploration. Assembling an interdisciplinary team to tackle this issue will be critical for assessing risks and developing risk management options.

Integration of the information in this assessment in everyday work through "climate-smart thinking" is critical, and can be reflected in resource management and planning, as well as for management priorities such as safety. Flooding, wildfire, and insect outbreaks may all be exacerbated by climate change, thus increasing hazards faced by federal employees and the public. Resource management can help minimize these hazards by reducing fuels, modifying forest species composition, and restoring hydrologic function. These activities are commonplace, demonstrating that much current resource management is already climate smart. This assessment can improve current management practice by helping to prioritize and accelerate implementation of specific options and locations for adaptation.

Implementing adaptation options will often be limited by human resources, funding, and conflicting priorities. However, the magnitude and likelihood for some changes to occur in the near future (especially water resources and fisheries) are high, as are the consequences for ecosystems and human values, and some adaptation options may be precluded if they are not implemented soon. This creates an imperative for timely action for the integration of climate change as a component of resource management and agency operations.

The climate change vulnerability assessment and adaptation approach developed by the SCOAP can be used by the USFS, NPS, and other organizations in many ways. From the perspective of federal land management, this information can be integrated within the following aspects of agency operations:

- **Landscape management assessments and planning:** Provide information on key resource vulnerabilities, departure from desired conditions, and best science on potential effects of climate change on resources for inclusion in planning assessments. The adaptation strategies and tactics inform development of desired conditions, objectives, standards, and guidelines for land management plans, and general management assessments.
- **Resource management strategies:** Incorporate SCOAP best science into conservation strategies, fire management plans, infrastructure planning, and state wildlife action plans.
- **Project NEPA analysis:** Provide best available science for documentation of resource conditions, effects analysis, and alternatives development. Adaptation strategies and tactics provide mitigation and design tactics at specific locations.
- **Monitoring plans:** Identify knowledge gaps that can be addressed by monitoring in broad-scale strategies, plan-level programs, and project-level data collection.

Agencies can use climate change vulnerability information and adaptation strategies and tactics in:

- **National forest land management plan revision process:** Provide a foundation for understanding key climate change vulnerabilities for the assessment phase of forest plan revision. Information from vulnerability assessments can be applied in assessments required under the 2012 planning rule (USDA FS 2012), describe potential climatic conditions and effects on key resources, and help identify and prioritize resource vulnerabilities to climate change in the future. Climate change vulnerabilities and adaptation strategies can inform forest plan components such as desired conditions, objectives, standards, guidelines, and land use allocations.

- **Resource management strategies:** Incorporate information into forest restoration plans, conservation strategies, fire management plans, infrastructure planning, and state wildlife action plans.
- **Project design and implementation:** Provide mitigation and design tactics at specific locations.
- **Monitoring evaluations:** Provide periodic evaluation of monitoring questions.

We are optimistic that climate change awareness, climate-smart management and planning, and implementation of adaptation in south-central Oregon will continue to evolve. We anticipate that in the near future:

- Climate change will become an integral component of business operations.
- The effects of climate change will be continually assessed on natural and human systems.
- Monitoring activities will include indicators to detect the effects of climate change on species and ecosystems.
- Agency planning processes will provide opportunities to manage across boundaries.
- Restoration activities will be implemented in the context of the influence of a changing climate.
- Management of carbon will be included in adaptation planning.
- Institutional capacity to manage for climate change will increase within federal agencies and local stakeholders.
- Resource managers will implement climate-informed practices in long-term planning and management.

This assessment provides the foundation for implementing adaptation options that help reduce the adverse effects of climate change and transition resources to a warmer climate. We hope that, by building on existing partnerships, the assessment will foster collaborative climate change adaptation in resource management and planning throughout south-central Oregon.

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U.S. Equivalents

When you know:	Multiply by:	To get:
Kilometers (km)	0.621	Miles
Square meters (m^2)	10.76	Square feet
Hectares (ha)	2.47	Acres
Cubic meters (m^3)	35.3	Cubic feet
Metric tons	1.102	Tons
Teragrams (Tg)	1,102,311.3	Tons

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