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Climate Change Vulnerability and Adaptation in Southwest Oregon

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Cover photo: Red Buttes, Rogue River-Siskiyou National Forest. U.S. Forest Service

Climate Change Vulnerability and Adaptation in Southwest Oregon

Jessica E. Halofsky, David L. Peterson, and Rebecca A. Gravenmier,
Editors

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Abstract

Halofsky, Jessica E.; Peterson, David L.; Gravenmier, Rebecca A., eds. 2022. Climate change vulnerability and adaptation in southwest Oregon. Gen. Tech. Rep. PNW-GTR-995. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 445 p.

The Southwest Oregon Adaptation Partnership (SWOAP) is a science-management partnership with the U.S. Department of Agriculture, Forest Service (U.S. Forest Service)—Rogue River-Siskiyou and Umpqua National Forests, Pacific Northwest and Rocky Mountain Research Stations, and Pacific Northwest Region; U.S. Department of the Interior—Bureau of Land Management Medford and Roseburg Districts, and National Park Service Oregon Caves National Monument and Preserve; and University of Washington. 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 ecosystems to a warmer climate. The vulnerability assessment focused on water resources, fisheries, vegetation, wildlife, recreation, and ecosystem services.

The vulnerability assessment shows that the effects of climate change on hydrology in southwest Oregon will be significant, although not as pronounced as in other areas of the Pacific Northwest where more of the land area is covered by high mountains. 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 affect aquatic and terrestrial ecosystems, especially as frequency of extreme climate events (drought, low snowpack) and ecological disturbances (streamflow, wildfire, insect outbreaks) increase.

Distribution and abundance of coldwater 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 will be the primary facilitator of vegetation change, in some cases leading to altered structure and function of ecosystems, including more forest area in younger age classes and some low-elevation forests being displaced by other tree and shrub species. 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., riparian, old forest) will be the most vulnerable to more disturbance and large-scale shifts in flora.

The effects of climate change on recreation activities are difficult to project, although higher 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.

SWOAP resource managers developed adaptation options in response to the vulnerabilities of each resource, including both 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 is to accelerate restoration and fuel treatments in dry forests to reduce the undesirable effects of extreme events and high-severity wildfire. 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, climate-smart management, ecosystem services, fisheries, hydrology, infrastructure, recreation, science-management partnership, southwest Oregon, terrestrial ecosystems, vegetation, wildlife, wildfire.

Summary

The Southwest Oregon Adaptation Partnership (SWOAP) is a science-management partnership comprising U.S. Department of Agriculture, Forest Service (U.S. Forest Service)—Rogue River-Siskiyou and Umpqua National Forests, Pacific Northwest and Rocky Mountain Research Stations, and Pacific Northwest Region; U.S. Department of the Interior—Bureau of Land Management Medford and Roseburg Districts, and National Park Service Oregon Caves National Monument and Preserve; and University of Washington. These organizations worked together over a 2-year period to identify climate change issues relevant to resource management in southwest Oregon and to find solutions that can minimize undesirable effects of climate change and facilitate transition of ecosystems to a warmer climate.

Mean annual temperature for the region has increased by 0.05 to 0.13 °C per decade since 1895 (depending on the historical dataset used), while annual precipitation has not changed. Global climate models for a high-end greenhouse gas emission scenario (Representative Concentration Pathway 8.5; comparable to current emissions) project that warming will continue throughout the 21^{st} century. Compared to observed historical temperature, average warming is projected to increase 2.4 to 5.6 °C by the end of the 21^{st} century (2070–2099). Precipitation may increase slightly in the winter, although the magnitude is uncertain.

The effects of climate change on hydrology will be significant but differ by location. Snow residence time will not change much at low-elevation locations in the western portion of the assessment area (where it is already minimal) but is expected to decrease 6 to 8 weeks at high elevation in the Cascade Range in the northeastern portion of the assessment area. Because snow is not a large contributor to streamflow in much of southwest Oregon, only moderate decreases in low flows and moderate increases in winter flows are expected over much of the region. The most notable declines in summer low flows and increases in winter flows are expected in high-elevation Cascade streams and the northwestern Siskiyou Mountains

Vulnerability assessment and adaptation development for the SWOAP assessment area conclude the following:

Water Resources and Infrastructure

- Effects: Decreasing snowpack and declining summer flows will alter timing and availability of water supply, although the effects will be moderate compared to much of the Pacific Northwest where high mountains comprise a larger portion of the landscape. Low flows will affect water availability during late summer, the period of peak demand (e.g., for irrigation). Increased magnitude of peak streamflows in winter in the northeastern portion of

the assessment area 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: Sediment delivery to streams from roads can be reduced by disconnecting ditch lines from streams during watershed restoration, timber projects, vegetation management, and road management. Landslide risk can be reduced by stabilizing slopes, mapping landslide risk, locating or relocating roads in areas that are less vulnerable to landslides, and decommissioning roads in vulnerable locations. Streamflow projections that consider climate change can inform decisions on structure type and sizing at stream crossings, as well as decisions about travel management and restoration. Instream restoration techniques will improve hydrologic connectivity in floodplains and increase water storage capacity (e.g., adding wood to streams). Reintroducing or supporting populations of American beaver (*Castor canadensis*) may also help to slow water movement and increase water storage.

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 August stream temperature for 2080, proportion of total stream kilometers with temperature less than 17 °C will decrease (1) from 56 percent (current) to 17 percent (future) for coho salmon (*Oncorhynchus kisutch* Walbaum) (Oregon coast evolutionary significant unit [ESU]), (2) from 36 to 13 percent for coho salmon (southern Oregon–northern California coast ESU), (3) from 34 to 16 percent for spring Chinook salmon (*O. tshawytscha* Walbaum in Artedi), (4) from 36 to 12 percent for fall Chinook salmon, (5) from 56 to 22 percent for summer steelhead (*O. mykiss* Walbaum), (6) from 67 to 25 percent for winter steelhead, (7) from 77 to 52 percent for cutthroat trout (*O. clarkii clarkii* Richardson), and (8) from 36 to 12 percent for Pacific lamprey (*Entosphenus tridentatus* Richardson). Umpqua chub (*Oregonichthys kalawatseti* Markle, Pearsons & Bills) thermal habitat (much warmer than for other species) will decline slightly by 2080.
- Adaptation options: Adaptation strategies focus on maintaining and diversifying monitoring programs; restoring natural thermal, hydrologic, and wood regimes; restoring and maintaining habitat connectivity; and

detecting and removing nonnative species. Specific adaptation tactics include removing barriers to fish movement, increasing instream flow, increasing retention of cold water across the landscape, restoring stream structure and function, enhancing and protecting hyporheic zones, and protecting refugial habitats. Multiple objectives can be achieved by ensuring connectivity of floodplains and side channels and by restoring and maintaining riparian vegetation and American beaver habitat and colonies. Adaptation tactics will be most efficient if they are coordinated with existing stream management and restoration efforts conducted by the Forest Service and other agencies and landowners.

Vegetation

- Effects: Higher air temperature, through its influence on soil moisture, is expected to cause gradual changes in the abundance and distribution of vegetation species, with drought-tolerant species being more competitive. Ecological disturbance, mostly through increased occurrence of wildfire, will be the primary facilitator of vegetation change, and future forest landscapes may be dominated by younger age classes and smaller trees.

Moist forests—

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. Increased wildfire may lead to a more fragmented landscape of moist forest in younger age classes, with most areas continuing to be dominated by Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and other early-seral species.

Mesic forests—

Higher temperatures, more area burned by wildfire, and increasing drought may cause a transition of mesic forests to more xeric forests. Douglas-fir will likely continue to dominate most stands, and incense cedar (*Calocedrus decurrens* (Torr.) Florin) and sugar pine (*Pinus lambertiana* Douglas) will increase in abundance. More area burned and increased drought severity will likely favor hardwoods and shrubs, and more frequent severe fire will decrease old-forest patches and connectivity. Increasing summer drought stress will decrease growth and reduce vigor for many species in mesic forests.

Ultramafic forests and woodlands—

Increased drought stress may cause declines of some species that currently characterize serpentine soils, although many of these species have relatively high drought tolerance. Increased fire activity will likely favor shrubs over conifers. As fire frequency increases, shrub species will have an advantage over conifers that are not drought and fire tolerant. Increased abundance of invasive annuals, especially grasses, could promote more frequent fire as the grasses increase fuel continuity.

Dry forests—

Douglas-fir may be limited by drought on drier sites, but drought-tolerant species (ponderosa pine [*Pinus ponderosa* Lawson & C. Lawson)], incense cedar, oaks [*Quercus* spp.]) may become more dominant. Drought stress and higher fire frequency may cause dry forest to transition to woodlands or shrublands in the driest locations. High fuel loads may initially cause large, high-severity fires. Over time, low- and mixed-severity fires may reduce fuels, leading to lower intensity fires and a finer scale patch mosaic. Growth of most tree species will decrease, and tree mortality may increase in some locations because of interactions among drought, fire, and insects.

Woodlands—

Expansion of woodland types is likely with hotter, drier conditions; habitat for Oregon white oak (*Q. garryana* Douglas ex Hook.) and California black oak (*Q. kelloggii* Newberry) will persist, but sudden oak death could affect black oak. With more frequent fire, conifer encroachment could be reduced, favoring development of open oak woodlands, although current high fuel loads may cause high-severity fires. Nonnative annual grass species can establish following wildfire and thinning treatments and may limit the capacity of oak woodlands to adapt to changing climate and disturbance.

Shrublands—

With increasing fire frequency and summer water deficit, shrublands will likely expand in drier portions of southwest Oregon, including conversion of dry forest to dominance by shrub species following fire. Repeated fire could facilitate dominance of chaparral species where short intervals between severe fires combine with drought to limit forest establishment. Conversion to shrubland would likely occur where mature forest is killed by high-severity fire and frequent reburns, with each successive fire killing more regenerating conifers and potential seed trees. Drought conditions will further limit tree seedling regeneration.

Special habitats—

Wetlands, riparian areas, and groundwater-dependent ecosystems (GDEs) will be especially vulnerable to higher air temperature and altered hydrology; less water during summer will potentially reduce the duration and depth of standing water, thus increasing water temperature. Drying in riparian areas is likely to alter plant community composition. Fire exclusion has resulted in denser forests in some riparian areas and adjacent uplands, which may facilitate more wildfires, favoring hardwood species and shade-intolerant conifers. Some ephemeral montane wetlands may disappear, and some intermediate wetlands may become ephemeral.

Adaptation options—

Minimizing the incidence of high-severity, stand-replacing disturbance events and maintaining spatial diversity of forest stands and age classes will help increase resilience to fire, drought, and insects, thus supporting functional forest ecosystems. Reducing stand density with thinning in dry forests can decrease intertree competition and forest drought stress, thus increasing tree growth and vigor. Expanding fuel treatments in appropriate locations can help prevent stand-replacement fire over large areas. Favoring drought-tolerant genotypes and species may help increase survival following disturbances. To minimize negative effects of climate change on riparian areas and GDEs, managers can plan for more frequent flooding in winter and drier soils in summer, increase upland water storage, and manage water to maintain springs and wetlands.

Wildlife

- Effects: Ecosystem responses to climate change will affect animal species through altered food availability, competition, predator-prey dynamics, and availability of key habitat features (e.g., 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 foloowing:

Conifer forest—

Future distribution and characteristics of forest habitats will be determined by large-scale disturbance, particularly wildfire. High-severity fire can reduce spatial and structural heterogeneity at broad scales and may increase fragmentation and isolation of old-forest patches critical for northern spotted owls (*Strix* *occidentalis caurina*) and marbled murrelets (*Brachyramphus marmoratus*). Reduced availability of thermal microrefugia will increase vulnerability to thermal stress for salamanders, small mammals, and mesocarnivores. Repeated fires may cause a transition from forests to woodlands and shrublands. Fishers (*Pekania pennanti*), northern goshawks (*Accipiter gentilis*), northern spotted owls, northern flying squirrels (*Glaucomys sabrinus*), and olive-sided flycatchers (*Contopus cooperi*) will be sensitive.

Early-seral forest and brushfields—

Animals associated with early-seral, postfire habitats tend to be good dispersers with high reproductive rates, which may facilitate survival in a warmer climate. Species dependent on herbaceous vegetation may be sensitive to altered timing of forage availability and plant development. A longer growing season may affect timing of availability of forage and pollen resources. Altered plant phenology and timing of forage quality and quantity will be important for species that depend on these resources. Projected increases in net primary productivity may promote shrub and hardwood growth, providing habitat for shrub-associated species. Postdisturbance colonization by invasive plants may reduce plant species diversity, thus reducing food and fine-scale structural diversity. Pocket gophers and several bird species will be sensitive.

Oak woodlands, savannas, and grasslands—

Increased fire frequency may favor oaks and maintain open woodland habitat if large oak trees are able to survive initial fires in areas with high fuel loads. Increased growth of invasive annual grasses could reduce fire resilience and overall biodiversity, producing cascading effects through the food web. More frequent and severe fires could reduce the availability of snags, logs, and other structures that provide fine-scale thermal refugia. Increased susceptibility to sudden oak death in warmer, wetter conditions is another potential stressor. Amplified summer drought is unlikely to negatively affect native prairie and savanna communities.

Wetland, riparian, and open water—

Altered seasonal water availability and water temperature will affect aquatic insect populations that provide prey for insectivorous wildlife. Increased vulnerability to drying may also affect amphibian species restricted to shallow, fishless ponds. Distribution of cold, moving-water streams is expected to decrease, although groundwater-fed streams will be less sensitive than snowmelt-fed systems. Loss of riparian vegetation caused by increased frequency and intensity of wildfire or winter flooding could also contribute to increased stream temperatures and concurrent loss of nesting and resting structures for wildlife (shrubs, snags, and logs). Amphibians, American dippers (*Cinclus mexicanus*), and American water shrews (*Sorex palustris*) will be sensitive.

Subalpine forests, woodlands, and meadows—
Animal adaptations for cold, snowy environments will be disadvantageous in a warmer, snowless future, and warmer winters may alter thermoregulatory behaviors. Loss of snowpack will be highly negative for species that use subnivean habitats (e.g., meadow voles) or prey on species that use those habitats (e.g., bobcats [*Lynx rufus*]). Seasonal availability of plant and insect foods may be limited by water availability as summer drought increases. Longer duration of warmer weather may affect forage availability, altering migration timing and duration of residency for migrants that traverse large-elevation extents (e.g., deer and elk). Higher summer maximum temperatures may increase thermal stress for some animals. Future distribution of mountain meadows will be affected by tree establishment and disturbance processes. Phenological mismatches between vegetation and pollinators may be a particular concern for high-elevation herbaceous communities. Sensitive species include great gray owls (*Strix nebulosa*), varied thrushes (*Ixoreus naevius*), Vaux's swifts (*Chaetura vauxi*), and American martens (*Martes americana*) in forest habitats, and American pikas (*Ochotona princeps*), yellow-bellied marmots (*Marmota flaviventris*), and gray-crowned rosy finches (*Leucosticte tephrocotis*) in meadow habitats.

- Adaptation options: Thermal and other types of refugia (e.g., moisture, disturbance) will facilitate species persistence with climate change. Increasing spatial variability in stand structures (e.g., stem density and gaps) can increase the extent of refugia in the diverse physiography of southwest Oregon. Increasing habitat connectivity is critical for species that are mobile and can be attained by providing passage structures across highways, closing roads, and removing barriers to movement. Managing for late-successional forest habitat will help provide diverse, abundant food resources for some species. Fuel reduction and strategic placement of fuel breaks can help to lower fire severity and protect valued habitats. In wetland, riparian, and open-water habitats, reducing existing stressors will help increase resilience to drought and disturbance. In addition, thinning and prescribed fire in low-elevation dry forest will facilitate a transition to future conditions. Encouraging beaver colonization increases water retention and groundwater recharge. In high-elevation habitats, minimizing new stressors will increase resilience to climate change and help retain animal species associated with this habitat.

Recreation

- Effects: Summer recreation (e.g., 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 (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 the 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 [*Vaccinium* spp.], mushrooms) will be somewhat sensitive to the climatic conditions that support the distribution and abundance of items being collected.
- Adaptation options: Organizational flexibility and responsiveness to change will help adapt recreation management to climate change. Redirecting recreational use to optimize recreational opportunities as well as protecting areas that are vulnerable to damage by recreationists will help maintain the quality of recreation experiences in the future. Adaptation tactics focus on adjusting the capacity of recreation sites and increasing flexibility of the availability of those sites based on variable weather conditions from year to year. Access to some areas may need to be restricted in order to protect resources, especially when roads, trails, and facilities are not yet open (and may not be safe) in years when snow melts early. Efforts are needed to identify recreation sites that are likely to incur heavier use in a warmer climate, then ensure that infrastructure and staffing are sufficient to support that use, or alternatively disperse access to locations that can sustain more use. Flexibility in the seasonality of staffing, permitting, and concessionaire contracts will be needed to adjust to altered recreation demands and opportunities in the future.

Ecosystem Services

- Effects: Higher temperature and increased frequency and extent of disturbances will alter forest structure and growth, thus affecting timber supply, carbon sequestration, and access and availability of special forest products. Mortality of trees and other vegetation caused by drought and multiple stressors may 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. Grazing access to water sources and grazing effects on riparian areas may become more prominent issues as water becomes scarcer. The ability of forests to sequester carbon will likely decrease if a 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) that are valued by American Indian tribes and others.

- Adaptation options: The primary adaptation options for forest products are to create resilience by thinning dry forests to reduce competition and fuel ladders, removing surface fuels to prevent high-intensity wildfires, and managing the timing and location of harvests. Long-term stability of carbon sequestration can be maintained using this same approach. Productive grazing can be ensured by developing adaptive grazing strategies to respond to changing conditions, and mitigating impacts of fire, nonnative species, and drought. Adaptation options for native pollinators include protecting pollinator habitat, maintaining a diversity of native species, and increasing agency and public awareness of the importance of native pollinators. Sustainability of cultural resources can be improved by reducing nonclimate stressors, encouraging pre- and postdisturbance strategies to protect high-value resources, and applying traditional ecological knowledge where appropriate.

The SWOAP climate change vulnerability assessment and adaptation project achieved specific elements of national climate change strategies for federal agencies, providing a new scientific context for resource management, planning, and ecological restoration in southwest Oregon. The large number of adaptation options, many of which are a component of current management practice, provide a pathway for slowing the rate of deleterious change in resource conditions. Rapid implementation of adaptation in resource planning and management will help maintain critical structure and function of aquatic and terrestrial ecosystems in southwest 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]

Introduction

The Southwest Oregon Adaptation Partnership (SWOAP) (fig. 1.1) is a science-management partnership with the U.S. Department of Agriculture, Forest Service (U.S. Forest Service)—Rogue River-Siskiyou and Umpqua National Forests, Pacific Northwest and Rocky Mountain Research Stations, and Pacific Northwest Region; U.S. Department of the Interior—Bureau of Land Management Medford and Roseburg Districts, and National Park Service Oregon Caves National Monument and Preserve (box 1.1); and University of Washington. Initiated in fall of 2016, the SWOAP is a collaborative project with the goals of increasing climate change awareness, assessing climate change vulnerability, and developing science-based adaptation options to reduce adverse effects of climate change and ease the transition to new climate states and conditions (see http://adaptationpartners.org/swoap). Developed in response to Forest Service proactive climate change strategies (USDA FS 2008, 2010a, 2019c), and building on previous efforts in national forests (Halofsky and Peterson 2017; Halofsky et al. 2011, 2018a, 2018b, 2019; Hudec et al. 2019; Littell et al. 2012; Raymond et al. 2013, 2014; Rice et al. 2012; Swanston et al. 2011, 2016) and other regional efforts (Myer 2013), the partnership brings together resource managers, research scientists, and stakeholders to plan for climate change in southwest Oregon.

Biogeography of Southwest Oregon

The SWOAP assessment area (1.9 million ha) is in the southwestern corner of Oregon, from the crest of the Cascade Range to the Coast Range. The major rivers in the assessment area are the Rogue River and its two southern tributaries, the Applegate River and Illinois River, and the two forks of the Umpqua River upstream of their confluence. The assessment area spans across Coos, Curry, Douglas, Jackson, Josephine, Klamath, and Lane Counties in Oregon and a small portion of Siskiyou County in northern California (fig. 1.1).

The Rogue basin comprises five subbasins; the lower Rogue River, middle Rogue River, upper Rogue River, Illinois River, and Applegate River all drain to the Pacific Ocean. The Rogue River originates at Crater Lake National Park and drains more than 75 percent of the Rogue River-Siskiyou National Forest land area to the Pacific Ocean. Other wild and scenic rivers include the Chetco River, Elk River, Illinois

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[1] **Joanne J. Ho** was a research economist, University of Washington, School of Environmental and Forest Sciences, Box 352100, Seattle, WA 98159.

Box 1.1

Characteristics of Federal Management Units in the Southwest Oregon Adaptation Partnership

Rogue River-Siskiyou National Forest

- Total area: 697 346 ha
- Area of timber harvested (completed fiscal year [FY] 2017): 423 ha
- Area burned by wildfire (2017): 94 680 ha
- Livestock grazing: 14,994 animal unit months (AUMs)[a]
- Protected wilderness area: 229 000 ha
- Recreation activities: beach and dunes, camping, climbing, fishing, hunting, bicycling, hiking, horse riding, nature viewing, watersports (motorized and nonmotorized boating, rafting, swimming, tubing, waterskiing, windsurfing), winter sports (skiing and snowboarding, sledding/tubing, snowmobiling, cross-country skiing and snowshoeing)

Umpqua National Forest

- Total area: 397 858 ha
- Area of timber harvested (completed FY 2017): 277 ha
- Area burned by wildfire (2017): 25 944 ha
- Livestock grazing: 1,249 AUMs[a]
- Protected wilderness area: 43 382 ha
- Recreation activities: beach and dunes, camping, climbing, fishing, hunting, mountain biking and bicycling, hiking, horse riding, nature viewing, watersports (motorized and nonmotorized boating, rafting, surfing, swimming, tubing, waterskiing, windsurfing), winter sports (ice skating, mushing/skijoring, skiing and snowboarding, sledding/tubing, snowmobiling, cross-country skiing and snowshoeing)

Continued on next page

River, Klamath River, the north fork of the Smith River, River Styx, and Umpqua River. Many of these rivers are recognized for high water quality, providing habitat for fish, and natural scenic qualities for recreation. Aquatic species supported by these rivers and streams include Chinook salmon (*Oncorhynchus tshawytscha* Walbaum in Artedi), coho salmon (*O. kisutch* Walbaum, steelhead trout (*O. mykiss* Walbaum), coastal cutthroat trout (*O. clarkii clarkii* Richardson), Pacific lamprey (*Entosphenus tridentatus* Richardson), and Umpqua chub (*Oregonichthys kalawatseti* Markle, Pearsons and Bills).

Owing to its diverse climate and geology, the Rogue basin has some of the most botanically and genetically diverse flora in the nation, with 26 different conifer species and an abundance of rare and endemic plants. The Cascade Range features

Bureau of Land Management (BLM) Medford District

- Total area: 354 508 ha
- Timber harvest (2017): 26.3 million board feet (MMBF)
- Total value of special forest products harvested (2016): $28,810
- Area burned by wildfire (2017): 57 ha
- Livestock grazing (2017): 7,473 AUMs
- Areas of critical environmental concern: 11 812 ha
- Total recreation visits (2017): 1,191,348
- Wilderness areas: 13 480 ha

BLM Roseburg District

- Total area: 172 413 ha
- Timber harvest (2017): 46.3 MMBF
- Total value of special forest products harvested (2016): $65,786
- Area burned by wildfire (2017): 3119 ha
- Areas of critical environmental concern: 4108 ha
- Total recreation visits (2017): 888,671

Oregon Caves National Monument and Preserve

- Total area: 1843 ha
- Key natural features: cave/karst systems, rivers and streams
- Notable wildlife species: bats, corvids, northern spotted owl, Pacific marten, black bear, mountain lion
- Total recreation visits (2013): 72,717
- Recreation activities: cave tours, hiking, wildlife viewing, hunting

[a] An AUM (animal unit month) is the forage required to sustain one cow/calf pair (or its equivalent) for 1 month.

high-elevation, snow-capped volcanic peaks above conifer forests with meadows, lakes, and meandering streams. The Siskiyou region contains open oak woodlands and conifer forests in a landscape of complex geology, soils, and plant communities. Maritime forests dominate the coastal mountain range, where temperatures rarely exceed 24 °C in the summer, and snow is rare in the winter. Maritime climate effects diminish farther inland where summer temperatures often reach 27 to 32 °C.

Geological composition in the assessment varies from granitics to metamorphosed peridotites (serpentine), ranging from 200 million years in age to the recent ice-age alluviums that are approximately 50,000 years old. The Cascade Range is composed of relatively recent (60 million years old) igneous rock, whereas the Coast Range is composed of sedimentary rocks.

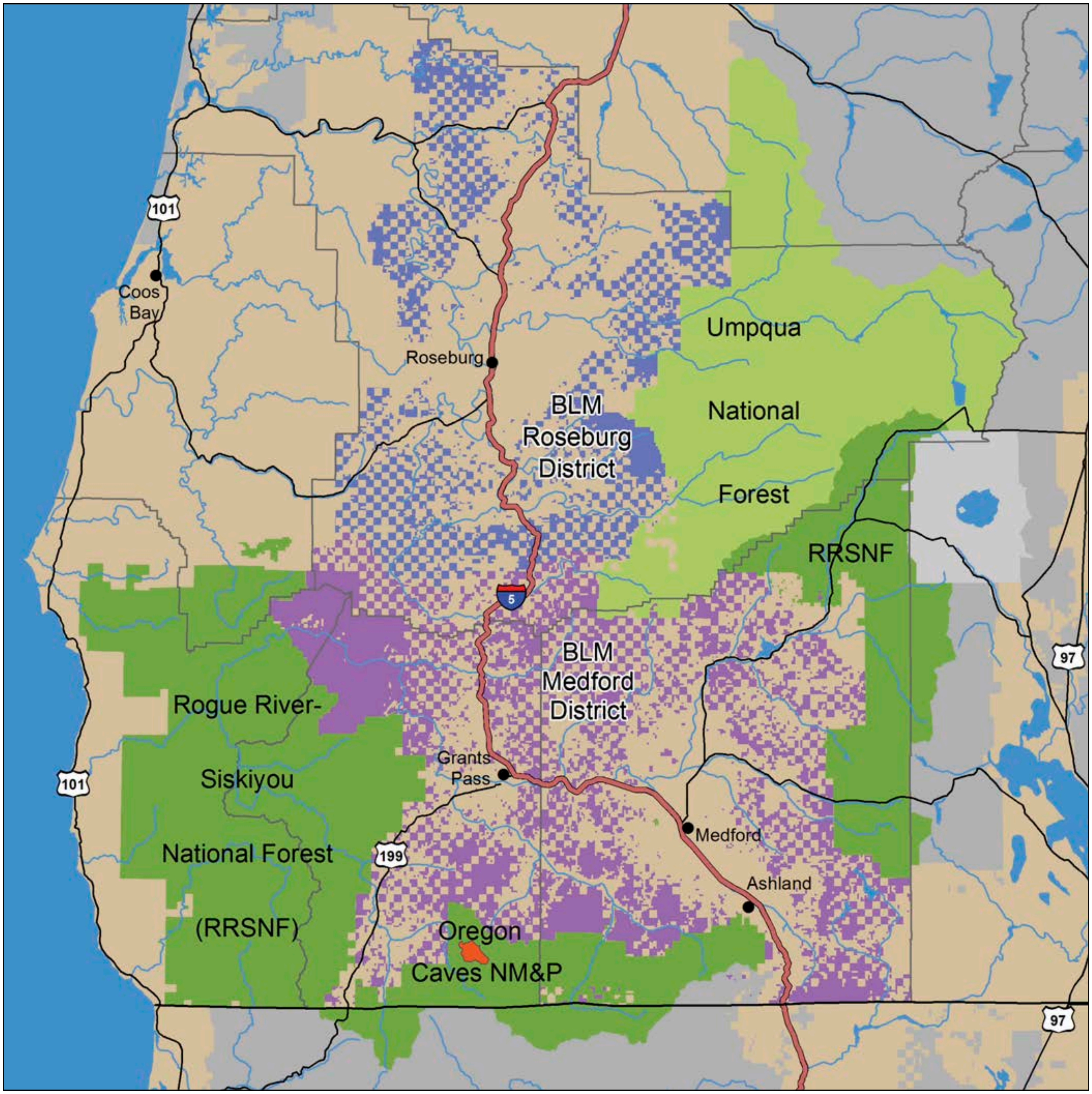

Figure 1.1—Assessment area for the Southwest Oregon Adaptation Partnership. BLM = Bureau of Land Management, NM&P = National Monument and Preserve.

Lower elevation forests consist of mixed conifer and hardwoods, transitioning upland into stands of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), white fir (*Abies concolor* (Gordon & Glend.) Lindl. ex Hildebr.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg), western redcedar (*Thuja plicata* Donn ex D. Don), Pacific silver fir (*A. amabilis* Douglas ex J. Forbes), Shasta red fir (*A. magnifica* A. Murray), and mountain hemlock (*Tsuga mertensiana* (Bong.) Carrière). Glaciers, whitewater rapids, volcanic basalt, and andesite monolithic spires are among iconic features of Umpqua National Forest, which has a diverse habitat that supports over 250 wildlife species, including elk (*Cervus elaphus* L.), deer, American black bear (*Ursus americanus* Pallas), mountain lion (*Puma concolor* L.), brown bat (*Myotis lucifugus*), pallid bat (*Antrozous pallidus* LeConte), Indiana bat (*M. sodalis*), northern long-eared bat [*M. spetentronalis*]), northern spotted owl (*Strix occidentalis caurina* Merriam), eagles, western osprey (*Pandion haliaetus* (Linnaeus)), and peregrine falcon (*Falco peregrinus anatum* Bonaparte).

In the southeastern portion of the assessment area, the BLM Medford District is largely composed of dry Douglas-fir-dominated forests (approximately 50 percent), with a mesic white fir and Douglas-fir forest component (approximately 30 percent), and some oak woodlands (approximately 5 percent). The BLM Roseburg District in the northwestern portion of the assessment area is composed of moist western hemlock and Douglas-fir forest (primarily in the northern portion) (approximately 35 percent), dry Douglas-fir forests (approximately 30 percent), and mesic Douglas-fir and white fir forests (approximately 25 percent). Oregon Caves National Monument and Preserve is composed of moist forest (approximately 10 percent), mesic white fir and Douglas-fir forests (approximately 70 percent), with high-elevation mountain hemlock forests and parkland in the eastern portion of the park.

Recent major fires in southwest Oregon include the Biscuit Fire in 2002, which burned nearly 200 000 ha. In 2017, the Chetco Bar Fire burned more than 77 000 ha, 40 000 ha of which was a reburn of the Biscuit Fire area (fig. 5.7). The 2018 Klondike Fire (70 000 ha) also burned over a portion of the Biscuit Fire. The 2017 High Cascade Complex fire burned 31 030 ha across Crater Lake National Park, Rogue River-Siskiyou National Forest, Umpqua National Forest, and Fremont-Winema National Forest. The Umpqua North Complex fire of 2017 burned 17 500 ha.

Land use in the SWOAP assessment area has evolved over time. Prior to the arrival of European settlers in the mid-19th century, human presence in southwest Oregon dates back more than 10,000 years. Ancestors of the Umpqua, Southern Molala, Yoncalla, and Cow Creek Bands of the Umpqua Tribe of Indians lived in and managed the landscape of southwest Oregon, using fire to create habitat for birds, mammals, and traditional plant foods. In 1856, these tribes were moved to reservations.

As the population of European settlers increased over time, the forests provided timber to build infrastructure that supported the Gold Rush and further developments in the region. Between 1960 and 1990, timber harvest ranged from 6.4 to 45.5 million board feet (MMBF) per year (fig. 8.1). The Northwest Forest Plan of 1994 curtailed timber production significantly in order to protect habitat for endangered species, bringing timber production in the area to no more than 1.1 MMBF (abbreviation for million board feet) per year from 1994 to 2016.

Recreation is currently a prominent use of public lands in southwest Oregon. The Rogue River, designated by the Wild and Scenic Rivers Act of 1968 as one of the first eight rivers in the National Wild and Scenic Rivers System, encompasses more than 6400 km of fish-bearing tributary streams (Myer 2013). Outdoor recreation participation in Oregon more than doubled between 1982 and 2009 for the activity of walking for pleasure. Viewing and photographing birds more than quadrupled in the same time period, while canoeing and kayaking also more than doubled (OPRD 2013). Other popular activities include rafting, wilderness exploration, lake and stream fishing, snowmobiling, horseback riding, and bicycling.

The population in the SWOAP assessment area for 2016 was 927,885 (22.8 percent of statewide population) (OSoS 2018). In 2017, outdoor recreation as an industry in the state of Oregon accounted for $16.4 billion in consumer spending, $5.1 billion in wages and salaries, and 172,000 direct jobs (OIA 2018). The Oregon wood products industry provided 58,000 jobs and an average annual wage of $49,200 in 2013 (OFIC 2018).

U.S. Forest Service Response to Climate Change

Climate change is an agencywide priority for the Forest Service, which has issued direction to administrative units for responding to climate change (USDA FS 2008) (table 1.1). In 2010, the Forest Service 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 Climate Change Performance Scorecard (2011–2016) for implementing the Forest Service climate change strategy (USDA FS 2010a). The overarching goal of the Forest Service 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 was reported annually from 2011 to 2016 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. Another version of the scorecard, with similar elements to the first version, is now being used.

The SWOAP built on previous efforts in ecosystem-based management to address climate change in the Western United States and tiered efforts in southwest Oregon to that broader context. Other efforts (table 1.2) have also

Table 1.1—U.S. Department of Agriculture, Forest Service (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 the strategic plan that 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 is 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 improvement in 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 2012 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 measureable 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.

Table 1.2—Climate change vulnerability assessments on Forest Service lands

Publication	Project	States	Federal lands[a]	Area	Vulnerability assessment?	Adaptation options?
				Million hectares		
Hayward et al. 2017	Assessment for south-central Alaska	Alaska	Chugach NF, Kenai Peninsula	9.2	Yes	No
Halofsky et al. 2011	Olympic Adaptation Partnership	Northwest Washington	Olympic NF, Olympic NP	0.6	Yes	Yes
Raymond et al. 2014	North Cascadia Adaptation Partnership	Northern Washington	Mount Baker-Snoqualmie NF, Okanogan-Wenatchee NF, North Cascades NP, Mount Rainier NP	2.4	Yes	Yes
Halofsky and Peterson 2017	Blue Mountains Adaptation Partnership	Oregon	Malheur NF, Umatilla NF, Wallowa-Whitman NF	2.1	Yes	Yes
Halofsky et al. 2019	South Central Oregon Adaptation Partnership	Oregon	Deschutes NF, Fremont-Winema NF, Ochoco NF, Crooked River National Grassland, Crater Lake NP	2.0	Yes	Yes
Halofsky et al. 2018a	Northern Rockies Adaptation Partnership	Montana, northern Idaho, South Dakota, northwest Wyoming	15 national forests, 3 national parks	74	Yes	Yes
Halofsky et al. 2018b	Intermountain Adaptation Partnership	Utah, Nevada, southern Idaho, northwest Wyoming	12 national forests, 22 National Park Service units	13.8	Yes	Yes
Hudec et al. 2019	Southwest Washington Adaptation Partnership	Washington	Gifford Pinchot NF	0.5	Yes	Yes
Rice et al. 2012	Assessment for Shoshone National Forest	Wyoming	Shoshone NF	1.0	Yes	No
Littell et al. 2012, Morelli et al. 2012	Assessment for eastern California	California	Inyo NF, Tahoe NF, Devils Postpile NM	0.5	Yes	Yes
Furniss et al. 2013	Watershed vulnerability assessments	Nationwide	11 national forests across the United States	NA	Yes	No
Butler et al. 2015	Central Appalachians	Northeastern and midwestern United States	Monongahela NF, Wayne NF, Cuyahoga Valley NP	101	Yes	No
Swanston et al. 2011, 2016	Climate Change Response Framework	Northern Wisconsin	Chequamegon-Nicolet NF	7.5	Yes	No
Janowiak et al. 2014	Northwoods Climate Change Response Framework Project	Northern Wisconsin, Michigan	Chequamegon-Nicolet NF, Ottawa NF	6.5	Yes	No

[a] NF = national forest, NP = national park, NM = national monument.

demonstrated the success of science-management partnerships to increase climate change awareness among resource managers and promote climate change adaptation on federal lands. These previous assessments were intended to help national forest managers identify where limited resources could be best invested to increase 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 SWOAP is focused on implementation of the principles and practices discussed in the guidebook.

Risks and vulnerabilities associated with climate change, and gaps in scientific knowledge and policy need to be assessed on a continual basis. Engaging employees, partners, and the general public in productive discussions about climate change and adaptation is an integral part of successfully responding to climate change. Furthermore, sharing climate change information, vulnerability assessments, and adaptation strategies across administrative boundaries will further enhance the success of climate change responses in southwest Oregon.

Southwest Oregon Adaptation Partnership Process

The Forest Service climate change strategy identifies 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 the Forest Service and BLM, several other agencies and organizations participated in the SWOAP workshop, including the National Park Service, Oregon Parks and Recreation Department, Confederated Tribes of Siletz Indians, Cow Creek Band of Umpqua Tribe, Southern Oregon Climate Action Now, Southern Oregon Forest Restoration Collaborative, and members of the public. This type of partnership enables a coordinated and complementary approach to adaptation that crosses jurisdictional boundaries. The SWOAP also provides a venue for agencies to learn from the practices of others so that the most effective adaptation options can be identified.

The SWOAP assessment area includes Rogue River-Siskiyou National Forest, Umpqua National Forest, BLM Medford and Roseburg Districts, and Oregon Caves National Monument and Preserve. Oregon Department of Forestry lands and private forest lands also occur within the assessment area but were not specifically included in analyses conducted for the assessment. The SWOAP process included the following:

- A vulnerability assessment of the effects of climate change on hydrology, water uses and infrastructure, fisheries, forest vegetation and disturbance, wildlife, recreation, and ecosystem services. These resource sectors were selected by resource specialists based on current management concerns and challenges.
- 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.
- Development of an enduring science-management partnership to facilitate ongoing dialogue and activities related to climate change.

Vulnerability assessments typically involve measures of 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 (e.g., Case and Lawler 2016, Luce et al. 2014, Potter and Crane 2010).

We used model output, scientific literature, and expert knowledge to assess exposure, sensitivity, and adaptive capacity, and to identify key vulnerabilities for the identified resource areas of concern. The process took place over 16 months and involved monthly phone meetings for each resource-specific assessment team. Each assessment team identified key questions to address, selected values to assess, and determined which climate change models and tools best informed the assessment. In some cases, assessment teams conducted spatial analyses or ran and interpreted models, selected criteria on which to evaluate model outputs, and developed maps of model outputs 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.

By working collaboratively with scientists and resource managers and focusing on a specific region, the SWOAP provides the scientific foundation for operationalizing climate change in forest management planning and project implementation (Peterson et al. 2011; Raymond et al. 2013, 2014; Swanston et al. 2016). After identifying and assessing vulnerabilities for each resource sector, scientists, land managers, and stakeholders convened at a workshop in April 2018 in Grants Pass, Oregon, to present and discuss findings of the vulnerability assessment and to elicit ideas for adaptation options. Facilitated dialogue was used to identify key sensitivities and adaption 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 for implementing these adaptation actions into projects, management plans, partnerships, and policies. Participants generally focused on adaptation options that could 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. Facilitators captured information generated during the workshops with worksheets adapted from Swanston et al. (2016).

This publication contains a chapter on climate in southwest Oregon, and one chapter for each of the resource sectors addressed in the vulnerability assessment: water resources and infrastructure, fish and aquatic habitat, forest vegetation and disturbance, wildlife habitats, recreation, and ecosystem services. Each chapter summarizes adaptation options generated at the workshop. A final chapter provides conclusions about the process and next steps for applications of the vulnerability assessment and adaptation information.

Resource managers and other decisionmakers can use this publication in several ways. First, the vulnerability assessment will provide information on climate change effects needed for forest planning, environmental effects analyses, conservation strategies, and monitoring. Second, climate change sensitivities and adaptation options developed at the broad scale provide the scientific foundation for finer scale assessments. We expect that over time, and as needs and funding align, appropriate adaptation options will be incorporated into plans for specific management units. Third, we anticipate that resource specialists will apply the information in this assessment to management projects, thus operationalizing climate-smart resource management and planning.

Adaptation planning is an ongoing and iterative process. Implementation of adaptation planning or actions may occur at any time, such as when managers revise national forest land management plans and other planning documents, or after the occurrence of extreme events and ecological disturbances (e.g., wildfire, flooding). We focus on adaptation options for the Forest Service, but information in this publication can be used by other land management agencies as well. Just as the SWOAP process has been adapted from previous vulnerability assessments and adaptation planning efforts, other national forests and organizations can further adapt the SWOAP process, thus propagating climate-smart management across large landscapes.

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Chapter 2: Climate Change in Southwest Oregon

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Historical and Current Climate in Southwest Oregon

The Southwest Oregon Adaptation Partnership (SWOAP) assessment area extends from the Pacific Ocean eastward to the crest of the Cascade Mountains and occupies about two degrees of latitude from the California border to the southern edge of the Willamette Valley. It includes two national forests (Rogue River-Siskiyou and Umpqua), two Bureau of Land Management (BLM) districts (Roseburg and Medford), and one national monument (Oregon Caves). Elevations across the assessment area range from near sea level to 2894 m on the summit of Mount McLoughlin, with most major cities located below 600 m. Typical elevations within the area's national forests are between 1000 to 1500 m (fig. 2.1A). The SWOAP assessment area covers two climate divisions classified by the National Centers for Environmental Information, Oregon climate divisions 1 and 3, though the majority of the region coincides with Oregon climate division 3 (Southwestern Valleys). The coastal foothills within the SWOAP region are covered by Oregon climate division 1 (Coastal Area).

A mediterranean precipitation pattern characterized by wet winters and very dry summers, Köppen's Cs climate classification, prevails in southwest Oregon (fig. 2.2). On both the Rogue River-Siskiyou and Umpqua National Forests, approximately 75 percent of annual precipitation occurs between October and March. Summers in the region are among the driest in the United States, with less than 5 percent of the annual precipitation falling between June and August. Annual precipitation on the Rogue River-Siskiyou National Forest averages more than 2000 mm, though this value varies from just over 600 mm near the Applegate Valley to more than 4000 mm on the windward slope of the Coast Range (figs. 2.1B and 2.2C). On the Umpqua National Forest, the annual average precipitation is lower at about 1400 mm, ranging from a minimum of 950 mm at low-elevation regions to slightly over 2100 mm at the highest elevations (figs. 2.1B and 2.2D).

Precipitation within the region is modulated in part by the interannual El Niño Southern Oscillation (ENSO) and the interdecadal Pacific Decadal Oscillation (PDO) (Redmond and Koch 1991). The PDO is thought to be a slow North Pacific response to ENSO forcing and not a single phenomenon, but rather, a response

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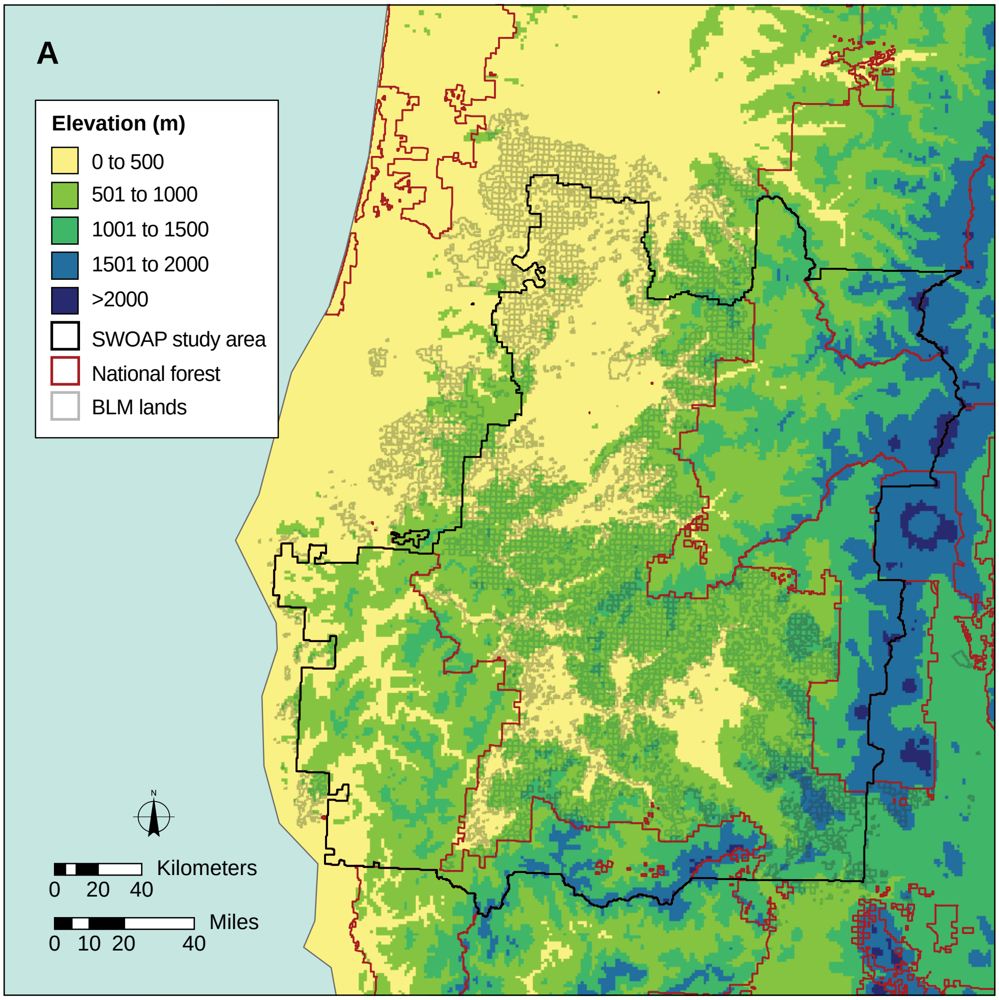

Figure 2.1—Southwest Oregon Adaptation Partnership (SWOAP) assessment area elevation and climate (1970–1999). Parameter-Elevation Regression on Independent Slopes Model (PRISM) data (Daly et al. 2008) were used to plot (A) elevation; (B) mean annual precipitation; (C) mean daily maximum temperature (TMAX) for June, July, and August (JJA); and (D) mean daily minimum temperature (TMIN) for December, January, and February (DJF). The SWOAP assessment area and national forest boundaries are overlaid. BLM = Bureau of Land Management.

to three distinct ocean-atmosphere feedbacks (Newman et al. 2016). Although tropical Pacific conditions are a primary control on regional precipitation, Miller and Goodrich (2007) demonstrated that there are important subregional patterns, each with distinct trends and teleconnection relationships. As such, the strength of precipitation-teleconnection relationships varies significantly across the Pacific Northwest (PNW). Some research suggests that the ENSO and PDO reinforce one another when they are in the same phase and dampen their impacts when they are out of phase (e.g., Mote et al. 2003), though PDO plus ENSO analysis is limited by the small number of observed PDO cycles.

The annual average temperature in the majority of the region's cities ranges from about 11 to 12 °C. Despite similar average temperatures between coastal

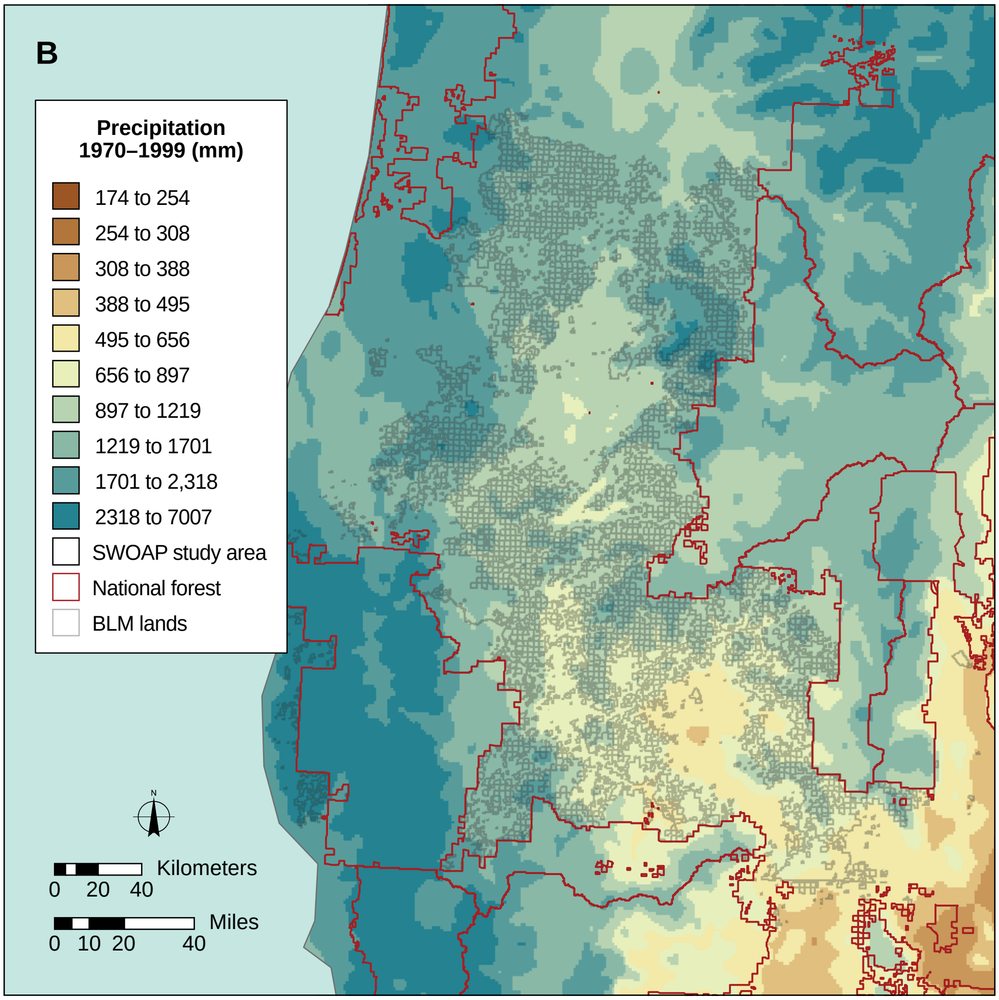

Figure 2.1—continued. Mean annual precipitation.

locations such as North Bend and inland locations such as Medford, temperature seasonality increases significantly away from the coast. Along the coast, the difference between average winter and summer temperatures is about 6 to 7 °C, whereas farther inland, temperature seasonality increases to over 15 °C at sites like Fish Lake and Medford.

Winter temperatures are generally mild with daytime temperatures at most locations ranging from 8 to 12 °C, though winter minimum temperatures commonly drop below freezing at all but the coastal locations (fig. 2.1D). At higher elevation locations on the Umpqua National Forest west of Crater Lake National Park, nighttime temperatures below freezing occur more than 200 nights per year. In contrast, coastal locations generally experience fewer than 15 days per year below freezing. The most populated cities of the SWOAP assessment area (Ashland, Grants Pass, Medford, and Roseburg) typically have between 40 and 100 days per year below 0 °C.

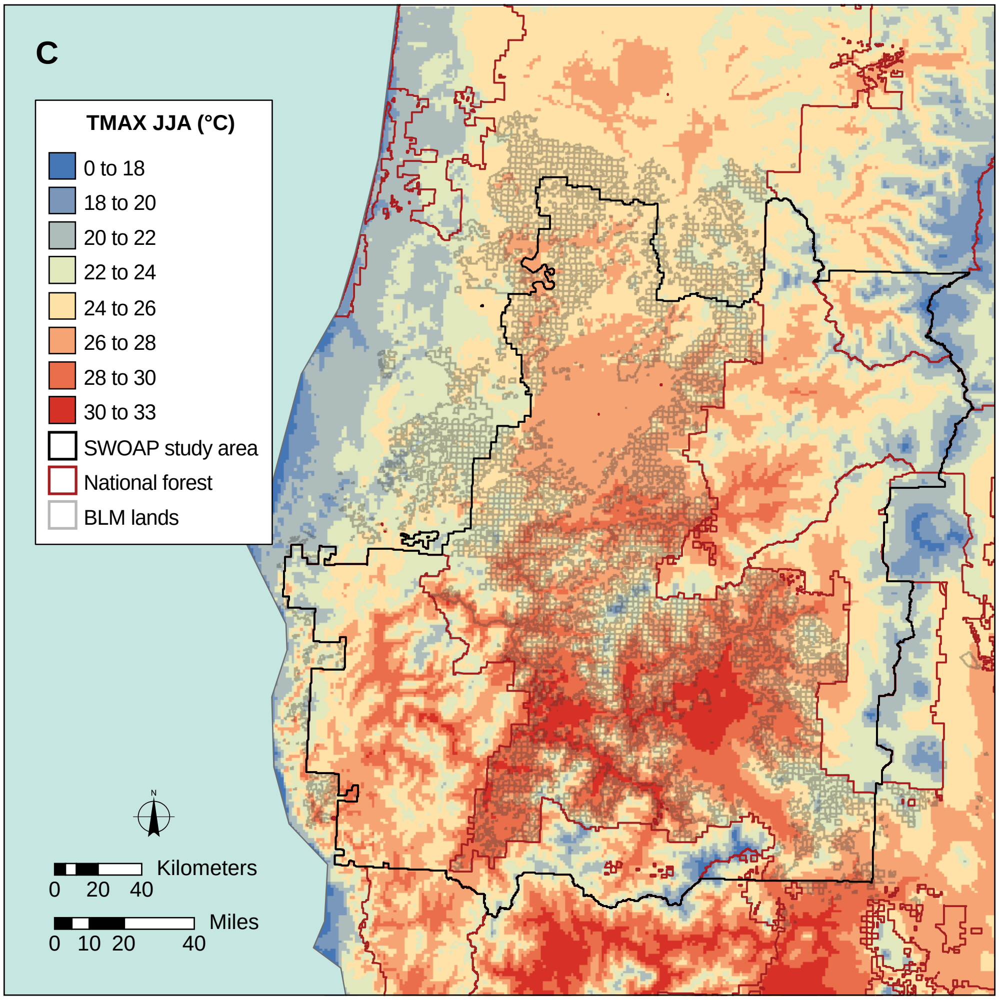

Figure 2.1—continued. TMAX JJA = mean daily maximum temperature for June, July, and August.

Summer temperatures vary significantly because of elevation and coastal proximity, with maximum temperatures averaging around 18 to 20 °C along the coast, while inland valley temperatures often exceed 30 °C at locations such as Cave Junction and Medford (fig. 2.1C). At higher elevation locations on the two national forests, the average summer maximum temperature is generally below 20 °C, similar to the regional coastal cities, which reflects the strong moderating influence of the relatively cold Pacific Ocean. The warm and sunny conditions that prevail during most of the summer in southwest Oregon lead to high fire danger.

Temperatures in the SWOAP assessment area have increased since 1895 (figs. 2.3 and 2.4). The mean annual temperature for the region, based on Parameter-Elevation Regression on Independent Slopes Model (PRISM) gridded climate data (Daly et al. 2008), has increased by 0.05 °C per decade, a rate less than half indicated by the average of U.S. Historical Climate Network (USHCN) (Menne et al. 2009) stations in the region (0.13 °C per decade) and in the Oregon climate division 3 (0.11 °C per decade) dataset. Although its developers specifically caution against

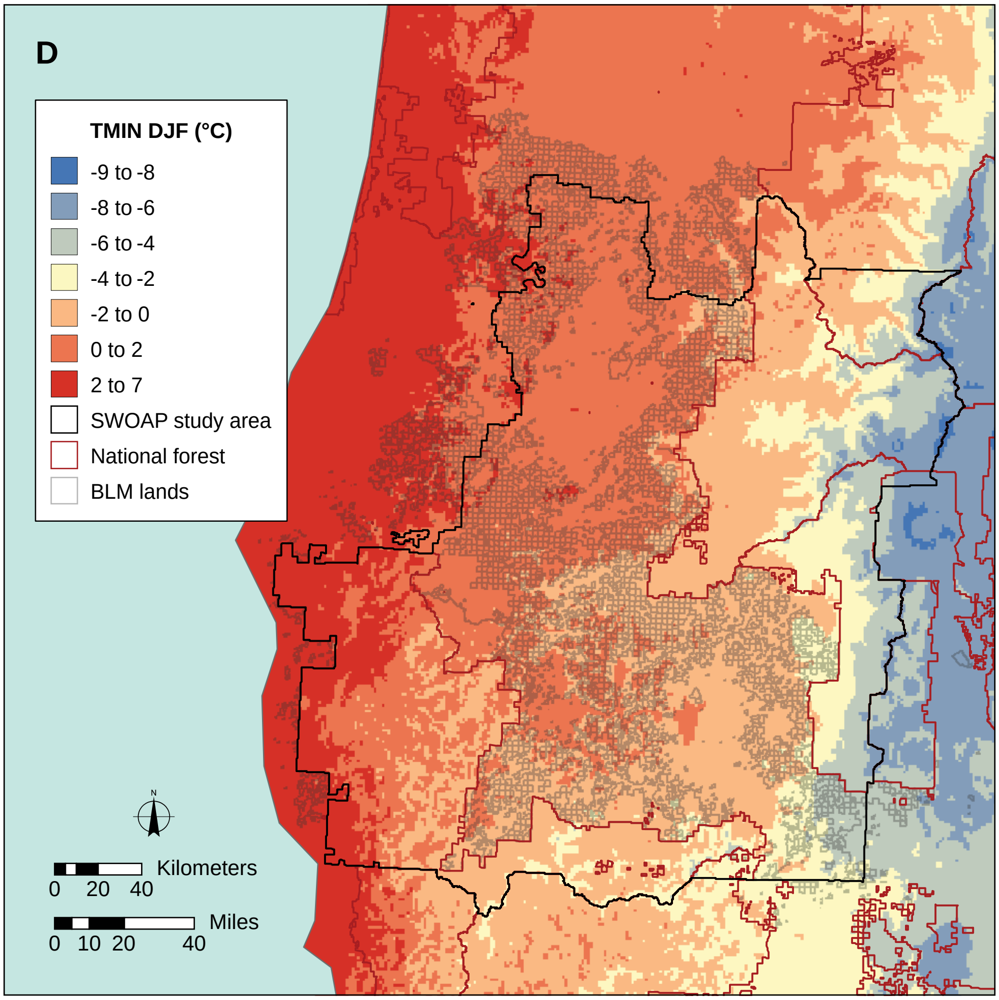

Figure 2.1—continued. TMIN DJF = mean daily minimum temperature for December, January, and February.

using PRISM for long-term trend analysis, we elected to include it for comparison to results from recent PNW climate change research (e.g., Abatzoglou et al. 2014). The likely explanation for the differing warming rates in the observed datasets is that the USHCN and climate division dataset have statistical adjustments to the original data resulting in lower temperatures in the early 20th century and higher temperatures in the latter half of the century. These adjustments are made to account for station moves, change of instrumentation, urban heat-island impacts, and other factors that would create biases. There is some uncertainty about the reliability of pre-1931 climate division data (Allard et al. 2015). Some of the SWOAP assessment area stations in the USHCN are created from data infill procedures, where missing original data are thus created from a nearest neighbor station that may be located relatively far away. We present here each of the temperature datasets to provide a range of observed temperature increase estimates for the SWOAP assessment area.

As with the annual temperature increase, there is variability among the observed datasets in the characterization of maximum and minimum temperature

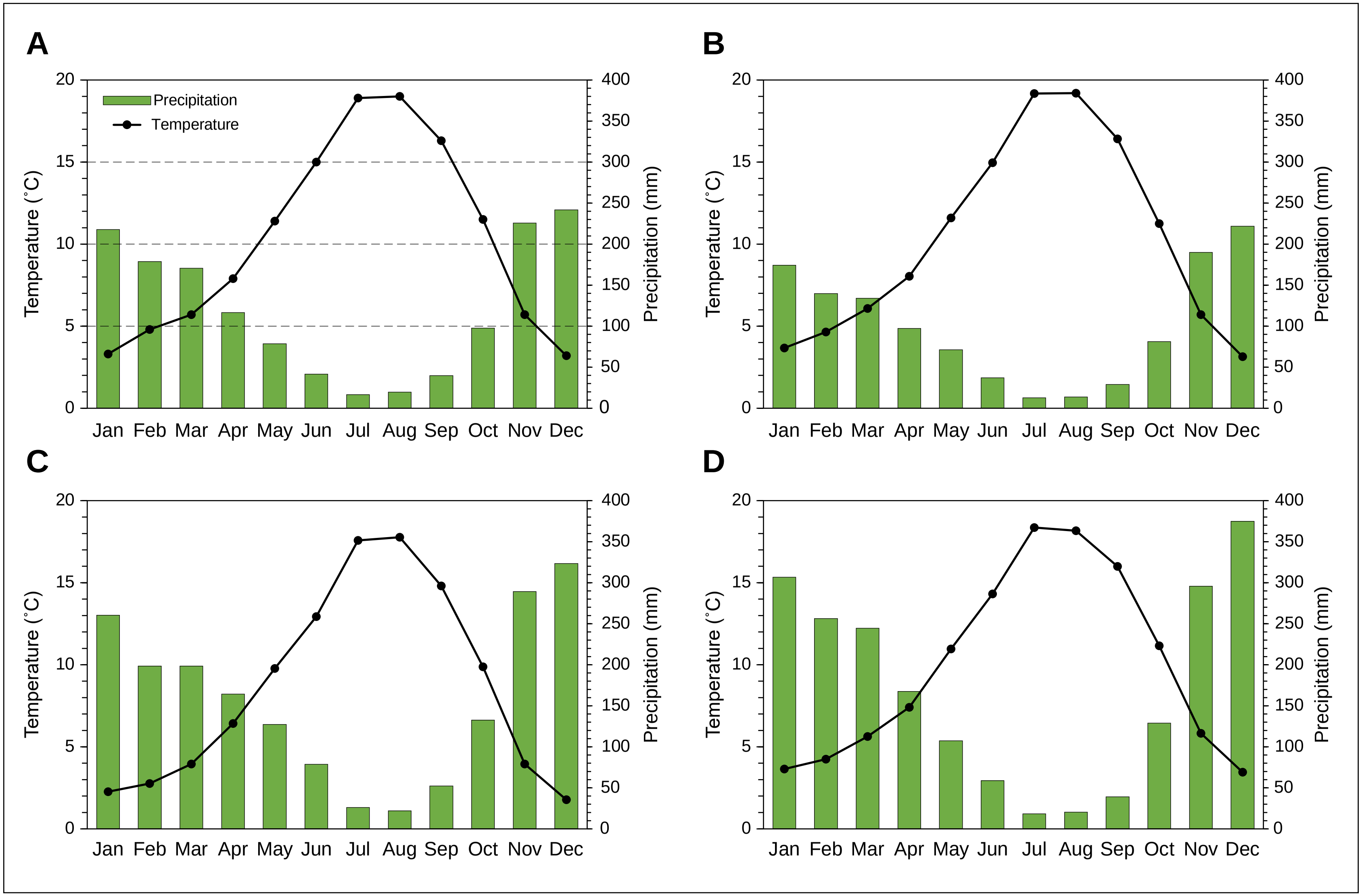

Figure 2.2—Mean monthly temperature and precipitation for 1970–1999 of the (A) Southwest Oregon Adaptation Partnership assessment area, (B) Oregon Climate Division 3, (C) Rogue River-Siskiyou National Forest, and (D) Umpqua National Forest. PRISM data were used for (A), (C), and (D).

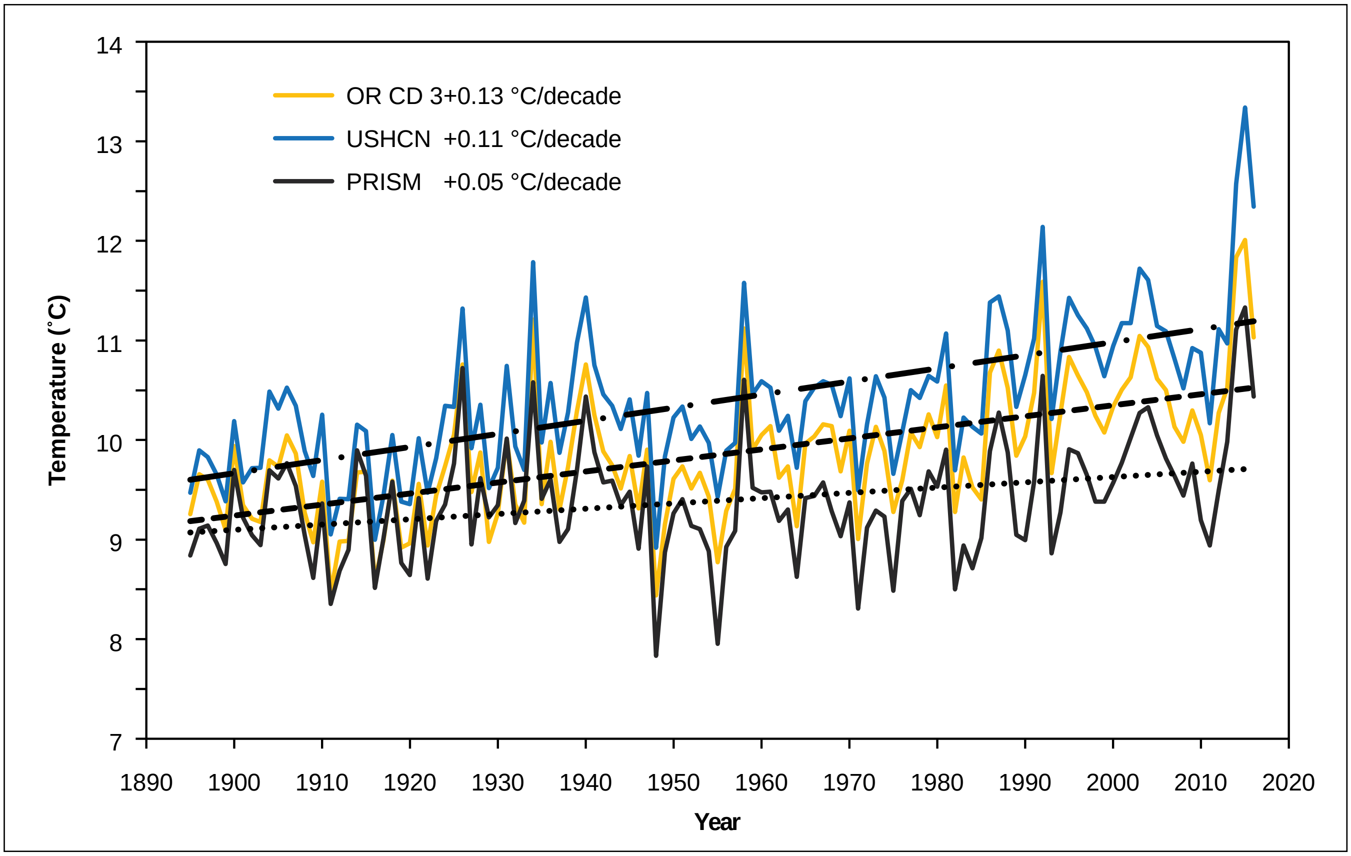

Figure 2.3—Historical annual temperature for the Southwest Oregon Adaptation Partnership assessment area. Historical values were calculated from Oregon Climate Division 3 (OR CD 3), the U.S. Historical Climate Network (USHCN), and PRISM data (Daly et al. 2008). A linear best fit was applied to each time series.

change (fig. 2.4). In the climate division dataset, maximum temperature increased more than minimum temperature in both SWOAP climate divisions. However, in the USHCN and PRISM datasets, minimum temperature increased more than maximum temperature. In the PRISM dataset, the minimum temperature increase is three to five times larger in magnitude than maximum temperature, which did not increase by a statistically significant amount on either national forest. Abatzoglou et al. (2014) found that minimum temperatures increased by more than maximum temperatures in the PNW since 1920 but observed similar trends for both during the past 50 years. Global climate change assessments also generally indicate that minimum temperatures have increased more than maximum temperatures worldwide (Vose et al. 2005), leading to a decrease in diurnal temperature range. Bumbaco et al. (2013) showed that the frequency of nighttime minimum temperatures exceeding the 99th percentile for June to September increased markedly in western Washington and Oregon over the past century, though trends in the frequency of maximum temperatures exceeding the 99th percentile were not observed.

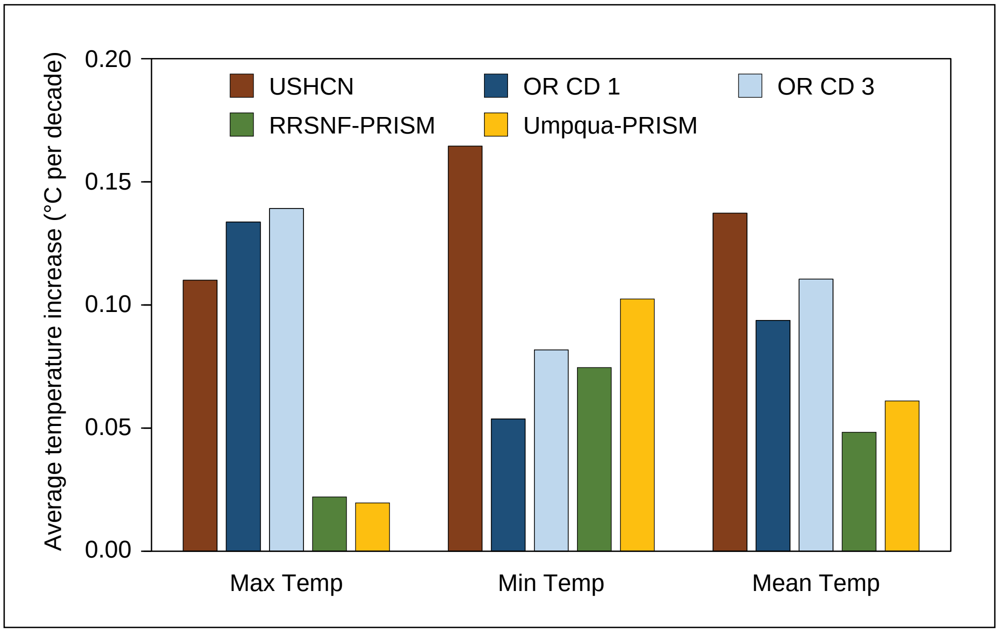

Figure 2.4—A comparison of maximum (Max), minimum (Min), and mean temperature trends in the U.S. Historical Climate Network (US HCN), National Climatic Data Center Oregon Climate Division 3 (OR CD 3) dataset, and PRISM product for 1895–2016. RRSNF = Rouge River-Siskiyou National Forest.

Seasonal temperature trends in the observed datasets are more consistent (fig. 2.5). Summer temperatures have increased the most in the region, ranging from 0.07 °C per decade on the Rogue River-Siskiyou National Forest in the PRISM dataset to 0.17 °C per decade in USHCN dataset. In each of the datasets, spring exhibited the least warming, with no statistically significant change in temperature on either forest in the PRISM dataset. This is consistent with Abatzoglou et al. (2014), who found that PNW spring temperatures actually declined from 1980 to 2012, though in that time period, the other three seasons each warmed at an accelerated rate compared to 1900–1980. However, the observed regional temperature datasets reveal that the fourth and fifth hottest spring seasons occurred in 2016 and 2015, respectively. Furthermore, 6 of the 10 hottest years recorded in the region have occurred since 2003, with the hottest summer (2015) and year (2015) also observed during that time.

There is no significant long-term trend in annual precipitation on either forest or in Oregon climate division 3 (fig. 2.6). This broadly matches observations from Mote et al. (2003) and Abatzoglou et al. (2014) for the greater PNW. There is some indication of a minor increase in SWOAP spring precipitation in recent decades, which mirrors a primary finding of Abatzoglou et al. (2014), who noted that spring precipitation increased during the period 1901–2012. They also found that summer and autumn precipitation decreased since 1901, a result not revealed in the SWOAP data. Luce et al. (2013) suggested that orographic precipitation in the PNW has decreased since 1950 owing to a weakening of tropospheric westerly winds, but there is a notable lack of high-elevation observational data within the SWOAP

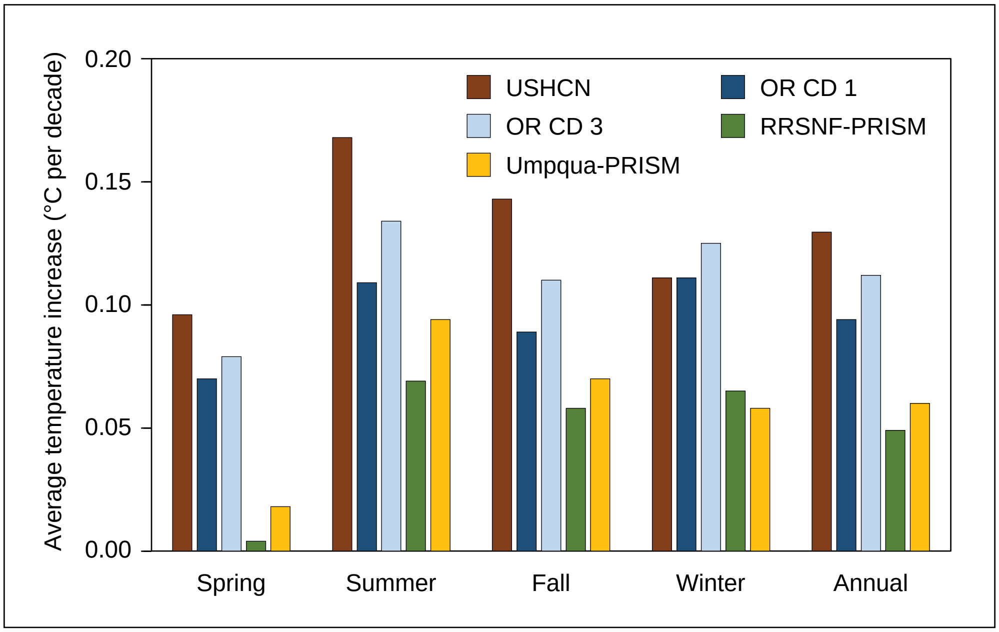

Figure 2.5—A comparison of seasonal mean temperature trends in the U.S. Historical Climate Network (USHCN), National Climatic Data Center Oregon Climate Division 3 (OR CD 3) dataset, and PRISM product for 1895–2016. RRSNF = Rogue River-Siskiyou National Forest.

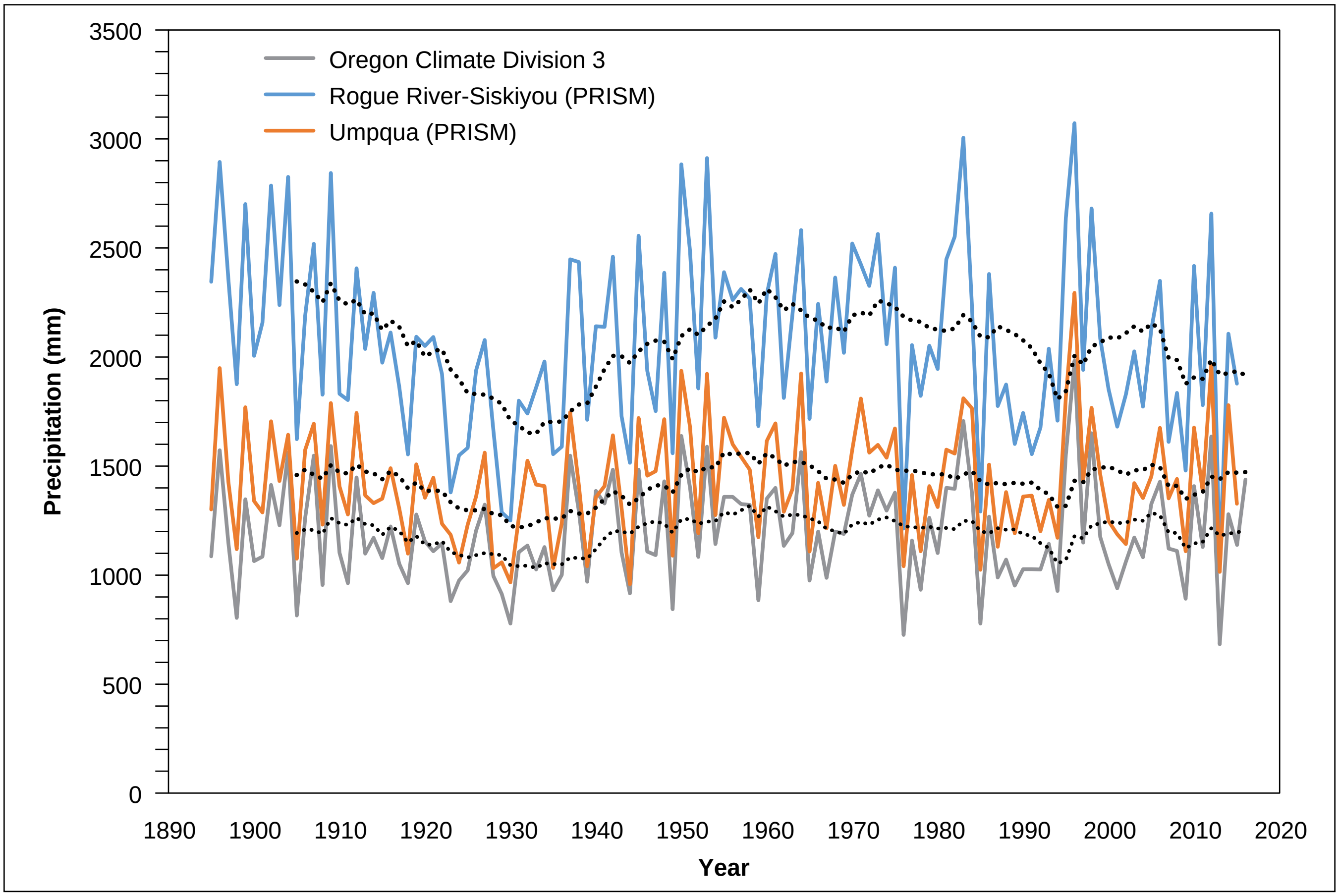

Figure 2.6—Historical annual precipitation for the Southwest Oregon Adaptation Partnership assessment area. Historical values were calculated from PRISM (Daly et al. 2008). The dotted lines represent 11-year moving average values.

assessment area to assess this finding. Throughout the SWOAP assessment area, the driest period was during the mid-1920s to mid-1930s when a warm phase of the PDO occurred. The highest annual average precipitation occurred during the 30-year period 1941–1970 when a cold phase of the PDO prevailed.

Another way to examine long-term moisture trends is to assess drought with the Palmer Drought Severity Index (PDSI), a standardized index that uses precipitation and temperature data to estimate water availability. The index ranges from -10 (dry) to 10 (wet) with values less than -3 indicative of severe drought. The PDSI for Oregon climate division 3 (Southwestern Valleys) exhibits considerable interannual and interdecadal variability (fig. 2.7). Overall, there is no long-term trend toward either wetter or drier conditions, though the highest (wettest) and lowest (driest) 36-month running mean PDSI values have each occurred in the past 20 years. In the SWOAP assessment area, the most recent 27-year period (1987–2013) was characterized by increased drought severity compared to the period 1960 to 1986 (fig. 2.8). This suggests an intensification of the hydrologic cycle, consistent with global assessments (Durack et al. 2012). However, there were no droughts in the previous 120 years thought to be as

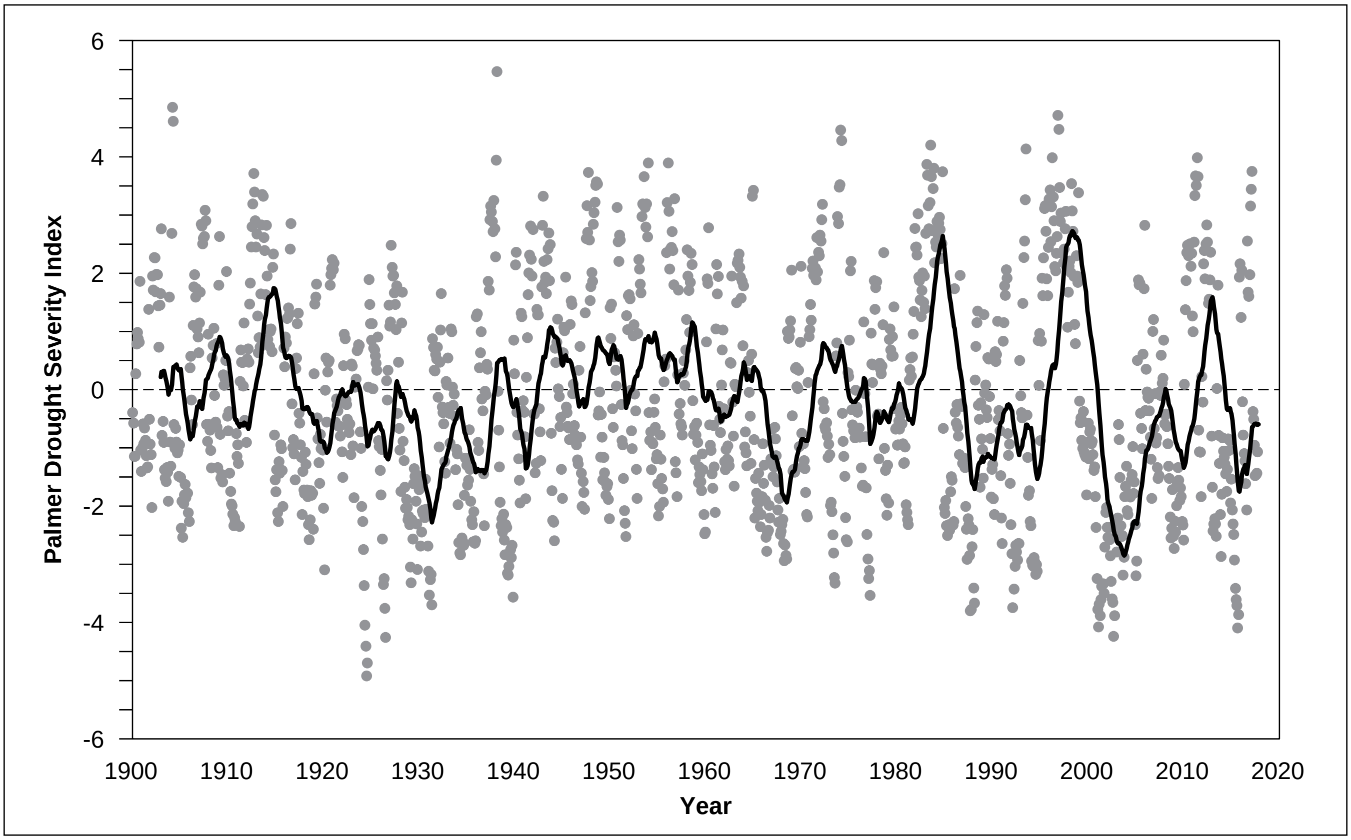

Figure 2.7—Historical Palmer Drought Severity Index for Oregon Climate Division 3—Southwestern Valleys. The solid line represents a 3-year moving average value.

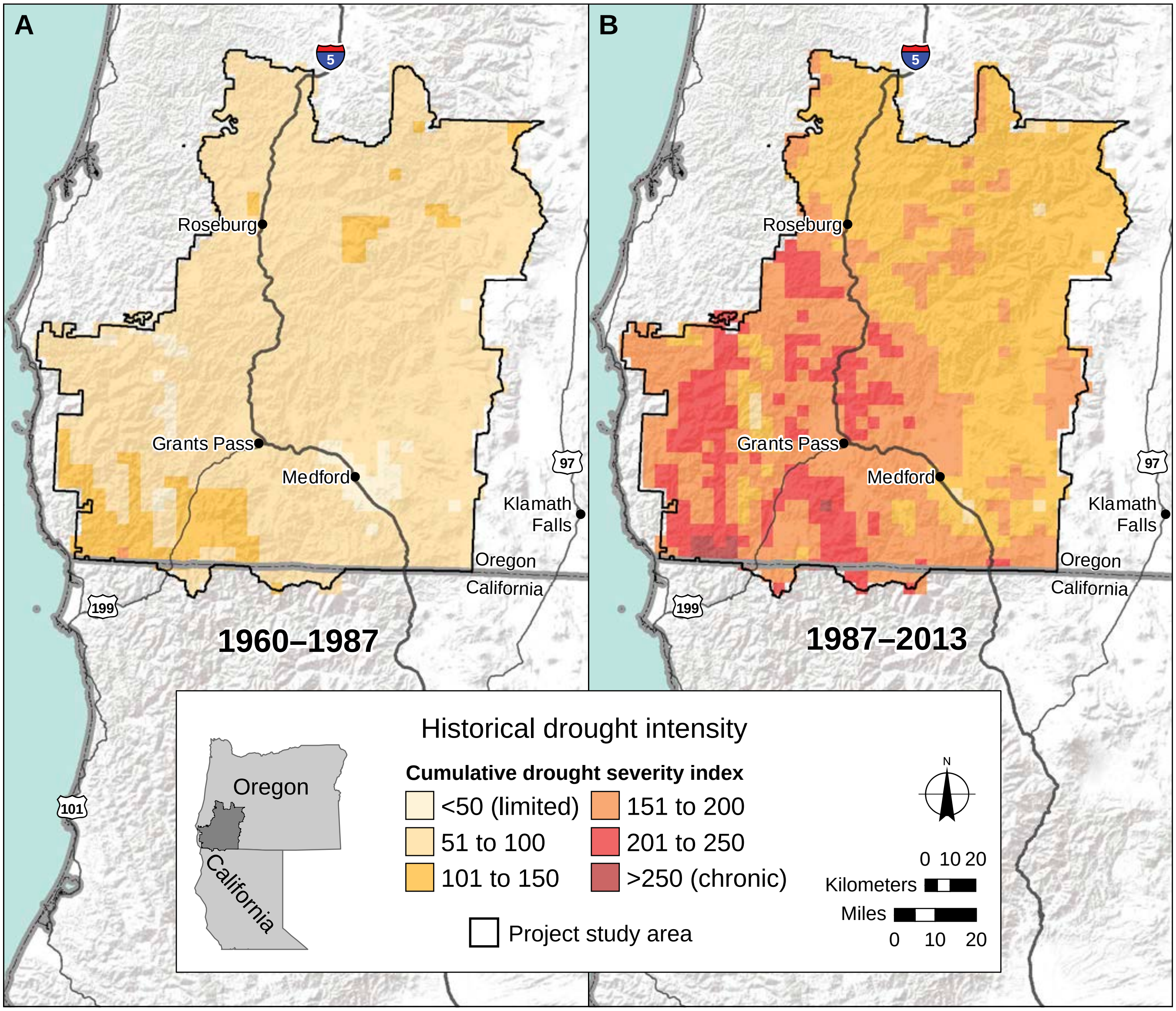

Figure 2.8—A comparison of Cumulative Drought Severity Index in the Southwest Oregon Adaptation Partnership assessment area for two 27-year periods, 1960–1986 and 1987–2013.

severe as the mega-droughts that occurred during the 16th century (Stahle et al. 2007). Moreover, Cook et al. (2004) suggested that the 20th century was a relatively wet period for western North America in the context of the past 1,200 years.

April 1 snow water equivalent (SWE) is a common measure of snowpack used by water resource managers across the Western United States (McCabe and Legates 1995). This information is collected by real-time Snow Telemetry (SNOTEL) stations and non-real-time snow course/aerial survey monitors. The SNOTEL era began in 1979, while snow-course data within the region extend back to the mid-1930s. There is no statistically significant trend in April 1 SWE at Rogue River-Siskiyou National

Forest and Umpqua National Forest locations as indicated by the SNOTEL data (fig. 2.9). However, snow course data for the SWOAP assessment area indicate declining April 1 SWE since 1950 (Mote 2003). The differing snow trends based on the period of record analyzed is consistent with results from Stoelinga et al. (2010) who found that for the PNW as a whole, snowpack had declined since the 1930s, but had actually increased from 1976 to 2007. Mote et al. (2005) also documented a substantial decline in PNW snowpack from 1950 to 1997, but reported that Oregon Cascades snowpack had increased modestly from 1916 to 1997, suggesting that regional snowpack trends are sensitive to the starting year of record and specific location examined.

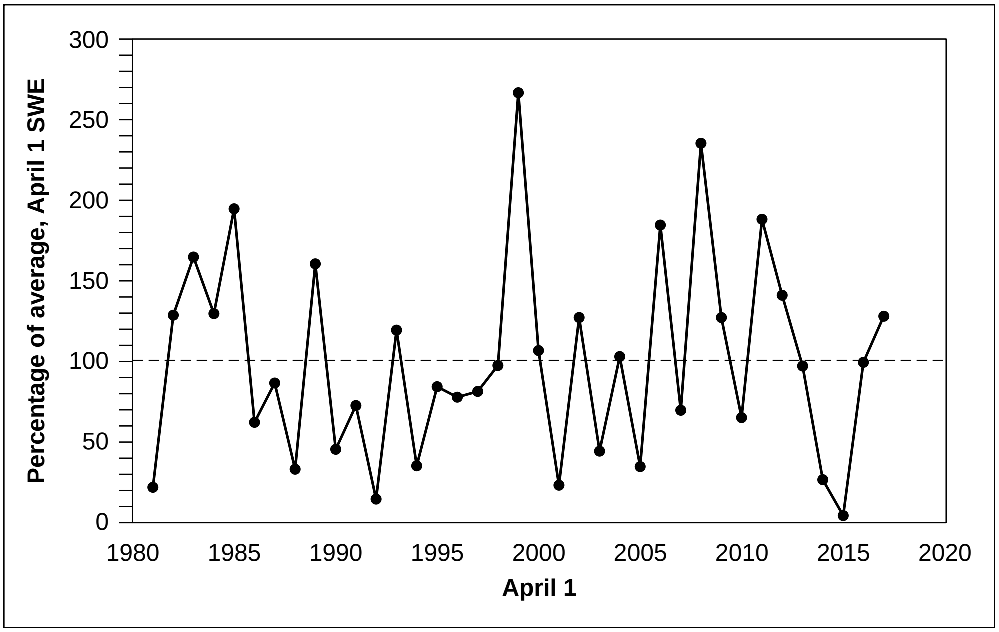

Figure 2.9—Percentage of average April 1 snow-water equivalent (SWE) in the Southwest Oregon Adaptation Partnership assessment area based on 1981–2010 values from nine SNOTEL stations: Bigelow Camp, Billie Creek Divide, Cold Springs Camp, Diamond Lake, Fish Lake, Fourmile Lake, King Mountain, Sevenmile Marsh, and Summit Lake.

Note that the mid-20th century years were among the wettest and coldest during the 20th century in southwest Oregon and greater PNW. Thus, studies that assess snowpack trends starting from 1950 may overestimate 20th century snowpack decline in the PNW. Regardless, the consecutive snow drought years of 2014 and especially 2015 are thought to be a preview of future snowpack conditions in the PNW (Sproles et al. 2017). Moreover, there is strong evidence that snowmelt season is occurring 1 to 3 weeks earlier throughout the Western United States and the PNW on account of higher spring temperatures (Stewart et al. 2005). Future regional warming is expected to accelerate this trend throughout the PNW (Mote et al. 2003).

The finding of no statistically significant change in regional April 1 SWE since 1980 is supported by both Siler et al. (2018) and Yan et al. 2019) who each report that Cascade Mountains snowpack during the past 40 years has been stable despite recent warming trends. Siler et al. (2018) concluded that atmospheric circulation patterns driven by natural climatic variability explain April 1 snowpack resiliency despite significant winter warming since 1980. They suggest snowpack will experience an accelerated decline once the offsetting influence of natural atmospheric circulation variability diminishes. Although moderated spring temperature trends and atmospheric circulation patterns have stabilized regional April 1 snowpack, Yan et al. (2019) show that annual peak SWE decreased significantly with a concomitant increase in rain-on-snow events throughout the Cascades.

Projected Future Climate in South-Central Oregon

To investigate a range of possible future climates for the SWOAP assessment area, we examined the National Aeronautics and Space Administration NEX-DCP30 downscaled climate dataset. NEX-DCP30 comprises climate projections produced by 31 global climate models (GCMs) from the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al. 2012) for two climate change scenarios: Representative Concentration Pathways (RCPs) 4.5 and 8.5 (van Vuuren et al. 2011). NEX-DCP30 uses a statistical downscaling method called bias correction-spatial disaggregation to downscale GCM output to 30 arc-second resolution (approximately 800 m) for the conterminous United States, using PRISM as a reference climate dataset (Thrasher et al. 2013). RCP 4.5 and RCP 8.5 represent possible trajectories of change to Earth's atmosphere in its radiative forcing, ending with +4.5 and +8.5 watts per square meter (W m^{-2}), respectively, by year 2100. 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 with no climate change mitigation, high population growth, and continued increase in greenhouse gas emissions to the end of the 21st century.

Temperature projections for RCP 4.5 initially track closely to RCP 8.5 (fig. 2.10A) but diverge around the year 2040, with significantly more warming for the RCP 8.5 scenario by the end of the century. Projected changes to precipitation are similar for RCP 4.5 and RCP 8.5, with high interannual variability and a negligible long-term trend (fig. 2.10B). The long-term future of Earth's climate depends on events and decisions yet to be made by society. RCPs, therefore, are only possible pathways, and are not associated with probabilities of occurrence. For the remainder of this report, we focus on the RCP 8.5 scenario as a high emissions benchmark.

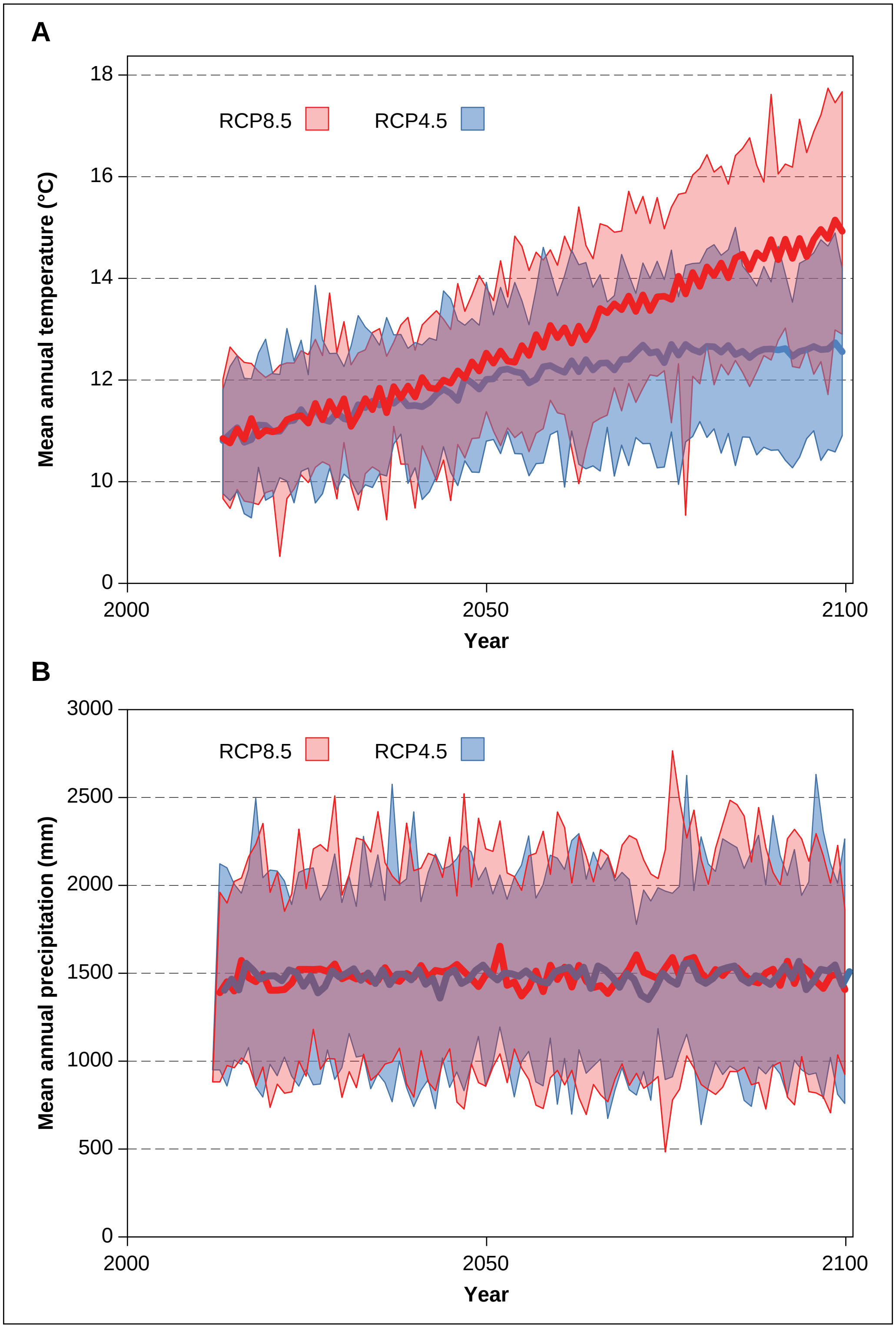

Figure 2.10—A comparison of Representative Concentration Pathway (RCP) 4.5 and RCP 8.5 climate change scenarios for the Southwest Oregon Adaptation Partnership assessment area. (A) Projected annual temperature and (B) precipitation were calculated from 31 global climate models in the NASA NEX-DCP30 downscaled climate dataset (Thrasher et al. 2013). Red and blue lines are fitted to the annual time series.

The GCMs under RCP 8.5 simulate a substantial increase in mean annual temperature for the SWOAP assessment area. For the 1970–1999 period, PRISM data indicate a mean annual temperature of 10.1 °C for the region. By the 2070–2099 period, the mean annual temperature increases to 14.3 °C in the model ensemble average, ranging from 12.5 °C in the GISS-E2-R model to 15.7 °C in the IPSL-CM5A-LR model. The rate of temperature increase in the model ensemble average for the period 2013–2099 is 0.50 °C per decade, which is between 4 and 10 times greater than that indicated in the historical record shown in figure 2.4.

The GCMs simulate future patterns of warming that mirror observed seasonal trends documented in figure 2.5. The model ensemble average shows more warming in summer (+ 5.2 °C) and fall (+ 4.5 °C) than in winter (+ 3.7 °C) and spring (+ 3.5 °C). Although slightly less warming is projected for winter and spring, the anticipated temperature increase would greatly affect regional snowpack and water resources (Li et al. 2017) and would likely extend the length and severity of the fire season (Gergel et al. 2017).

There is strong agreement among the GCMs in the seasonality of increasing temperatures, as 30 of the 31 models show the largest temperature increase during summer, with a range of 3.3 to 7.4 °C. To place the average projected summer temperature increase in context, a 5.2 °C increase for Medford would make thermal conditions during summer similar to those currently observed in Bakersfield, California, located over 800 km to the southeast. A summer temperature increase on the upper end of the model projections would render the summer climate of Medford comparable to the western Mojave Desert in southern California. The ensemble average increase of 3.7 °C in winter would make the winter climate of Medford like that currently observed in Sacramento, California. Another way to think about a 3.7 °C winter temperature increase is to consider the elevation difference this represents. Assuming an average lapse rate of 6 °C per kilometer, a 3.7 °C temperature increase in winter represents 617 m of elevation, meaning that temperatures currently observed at 1000 m in elevation would now occur above 1600 m in elevation. This would result in more rain at high elevations, less winter snowpack, more winter flooding events, and lower summer streamflow.

The average annual temperature increase of 4.2 °C projected by the GCMs would greatly affect the number of days below freezing and the length of the freeze-free period. Using climate summary data from the Western Regional Climate Center (WRCC 2019), we examined the historical relationship between average annual minimum temperature and freeze data in the SWOAP assessment area. The data show that for every degree Celsius increase, there are 24 fewer days with a minimum temperature below freezing (fig. 2.11). A similar relationship exists with

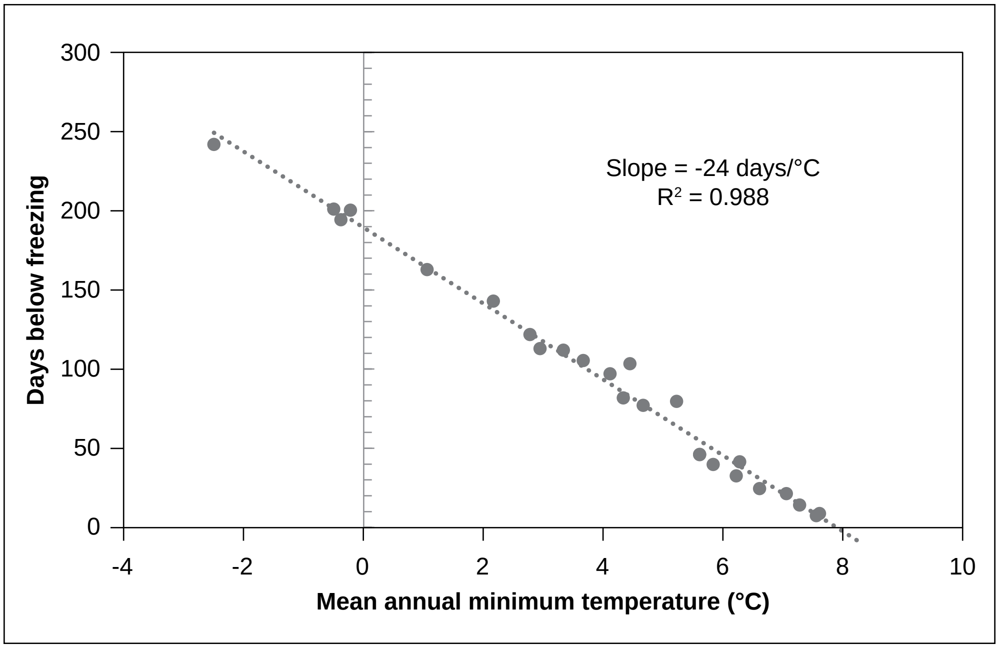

Figure 2.11—Days below freezing at 23 stations within the Southwest Oregon Adaptation Partnership assessment area versus their respective mean annual minimum temperatures (°C). Data are from the Western Region Climate Center (WRCC 2019).

the freeze-free data, where each degree increase translates into 23.5 more days between freeze events. The regression line in figure 2.11 suggests that freezing days decrease to zero if the average annual minimum temperature of a location exceeds 7.9 °C. Therefore, a 4.2 °C annual temperature increase would mean that Roseburg, with a current annual average minimum temperature of 6.5 °C and an average of 36 days below freezing per year (WRCC 2019), would become a location with few to no freezing days.

A 4.2 °C annual temperature increase would mean that Roseburg, with a current annual average minimum temperature of 6.5 °C and an average of 36 days below freezing per year (WRCC 2019), would become a location with few to no freezing days.

Precipitation projections for the SWOAP assessment area are less clear, though the majority of the models (20 out of 31) indicate an increase in 2070–2099 precipitation compared to the 1970–1999 baseline. Eleven of the models suggest precipitation will decrease over the region. However, when comparing the 1970–1999 period with the modeled 2070–2099 values, only 1 of the 11 projected decreases is statistically significant at the 95 percent level using a difference of means student's t-test comparison. In contrast, eight of the models indicate a greater than 10 percent increase in annual precipitation compared to 1970–1999 that is statistically significant at the 95 percent level. The models generally project either no change in annual precipitation or a slight increase. Because of the large projected temperature increases, the modeled precipitation increases would still lead to a net water loss compared to 1970–1999 given higher evapotranspiration rates. The GCMs generally show an increase in the seasonal amplitude of precipitation, with more winter precipitation (December through February) and less precipitation during the growing season (April through October).

There is considerable variability in modeled climate for the SWOAP assessment area among the 31 GCMs (fig. 2.12). Thirty of the 31 GCMs used in this report were evaluated and ranked by Rupp et al. (2013) for their ability to reproduce various characteristics of the recently observed climate of the PNW (table 2.1). The GCMs ranked higher by Rupp et al. (2013) generally project warmer and wetter climates under RCP 8.5 (fig. 2.12). The GCMs in the lowest quartile of the rankings projected less warming by the end of the century.

Table 2.1—Ranking of global climate models (GCM) that comprise NEX-DCP30 (Thrasher et al. 2013) according to their skill for simulating historical climate of the Pacific Northwest region (Rupp et al. 2013)[a]

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

[a] ACCESS1-0 was not evaluated in Rupp et al. (2013).

To examine a range of possible climate change effects within the SWOAP assessment, we selected projections from five GCMs as case studies (table 2.2). The case studies cover a variety of future climate states, while giving preference to GCMs ranked better in their ability to simulate past climate of the PNW (Rupp et al. 2013). CESM1(CAM5), which we classify as the “near mean” model, was selected as the GCM that simulates a future climate nearest the mean of the 31 GCMs, with an annual temperature increase of 4.5 °C and no statistically significant change in mean annual precipitation. BNU-ESM (termed the “hot” model)

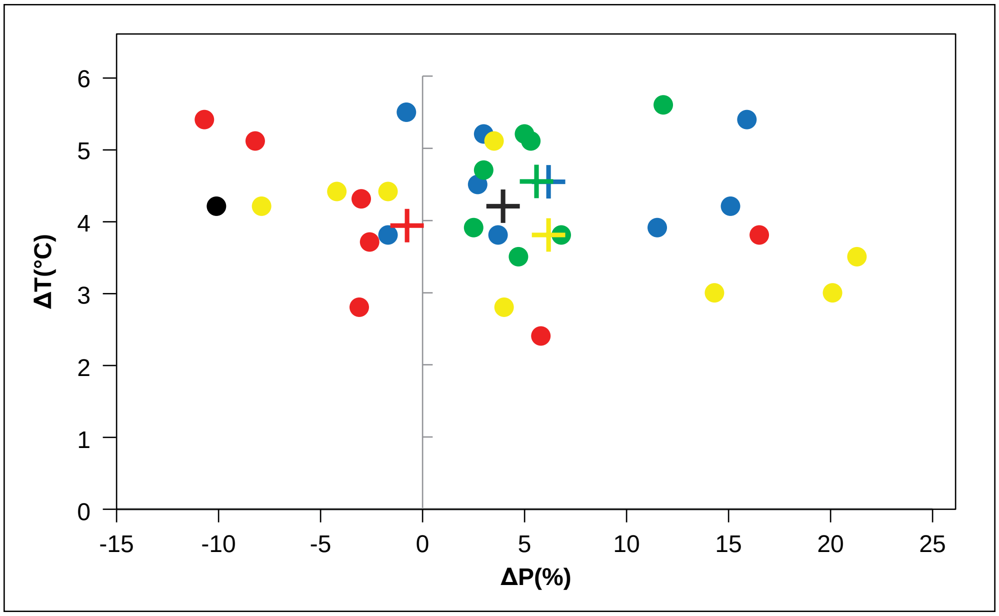

Figure 2.12—Projected change in average annual temperature (ΔT) and average annual precipitation (ΔP) in Representative Concentration Pathway 8.5 from 31 global climate models (GCMs) between the 2070–2099 and the 1970–1999 periods for the Southwest Oregon Adaptation Partnership assessment area. ΔT and ΔP were calculated using the NASA NEX-DCP30 downscaled 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 dots 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) and is represented by the black dot.

Table 2.2—Five downscaled global climate model (GCM) outputs selected for analysis

GCM	Rank[a]	ΔT[b]	ΔP	Representative case[c]
		°C	*Percent*	
CESM1(CAM5)	1	*4.5*	*2.7*	Near mean
CanESM2	11	5.4	15.9	Hot-wet
BNU-ESM	24	5.1	3.5	Hot
MIROC-ESM-CHEM	38	5.4	-10.7	Hot-dry
MRI-CGCM3	29	2.8	4.0	Cool

[a] Rank is from Rupp et al. (2013) and reflects overall model performance for simulating historical climate of the Pacific Northwest.

[b] ΔT and ΔP were calculated as the difference between the climate of 1970–1999 and 2070–2099 for the Southwest Oregon Adaptation Partnership assessment area under the Representative Concentration Pathway 8.5 climate change scenario.

[c] Representative case indicates the relative position of the GCM among the 31 GCMs.

projected a temperature increase larger than the ensemble average (+5.1 °C) without a significant change in mean annual precipitation. BNU-ESM may overestimate winter precipitation because of data processing errors,[2] although it is not a particularly "wet" outlier GCM in the 28-member ensemble, even with this error. CanESM2 (termed the "hot and wet" model) simulated a 5.4 °C temperature increase and a statistically significant 16 percent increase in mean annual precipitation for the SWOAP region. MIROC-ESM-CHEM (termed the "hot and dry" model) indicated a 5.4 °C temperature increase and an 11 percent decrease (not statistically significant) in mean annual precipitation. MRI-CGCM3 (termed the "cool" model) is cooler than the ensemble mean with a projected 2.8 °C temperature increase and no statistically significant change in annual precipitation.

By the end of the century, all five of the selected GCMs simulate significant warming in every month of the year, with the largest temperature increase during summer (fig. 2.13A). The hot-wet CanESM2 model projects a 7.4 °C summer temperature increase for the SWOAP assessment area, with increases of 7.9 °C and 8.2 °C in July and August, respectively. An 8 °C summer temperature increase would transform the region into one with summer temperatures that are currently experienced in the American Southwest. Such an increase would also result in the highest elevations of the SWOAP assessment area experiencing summer temperatures comparable to current summer conditions in Ashland and Medford. Even the cool MRI-CGCM3 model simulates a 3.7 °C temperature increase during summer, which would pose significant challenges to water resources and greatly increase fire risk.

The five case study models generally indicate drier growing-season (spring and summer) conditions, though an interesting outlier is the CanESM2 model which simulates a 41 percent increase in summer precipitation compared to the 1970–1999 average (fig. 2.13B). The CanESM2 model projects a 54 percent increase in July precipitation and a 144 percent increase in August precipitation, suggesting that the GCM is simulating possible monsoonal impacts for the region. Notably, only one other model of the 31 GCMs shows a greater than 50 percent increase in August precipitation. Another similarity among the case studies is that winter precipitation is projected to increase, particularly in January, with the five models ranging from a 9 percent (MIROC-ESM-CHEM) to 62 percent (CanESM2) increase.

Elevation differs widely throughout the SWOAP region, from less than 200 m to more than 2500 m. Effects of climate change on temperature and precipitation may vary by elevation (e.g., Diaz and Eischeid 2007, Wang et al. 2013) with higher

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[2] Rupp, D. 2019. Personal communication. Assistant professor, College of Earth, Ocean and Atmospheric Science, Oregon State University, CEOAS Administrative Building, Corvallis, OR 97331.

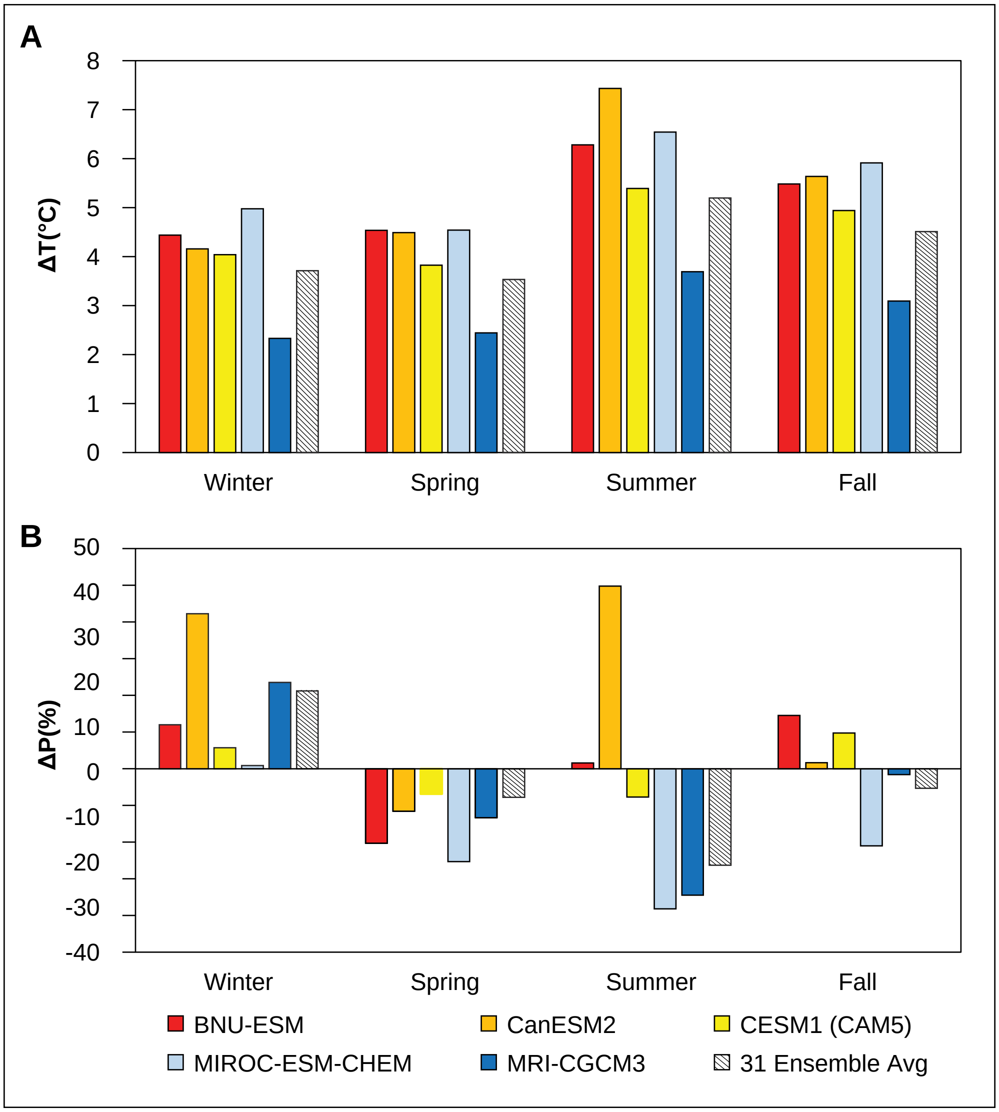

Figure 2.13—(A) Projected seasonal mean temperature and (B) mean precipitation under the Representative Concentration Pathway 8.5 climate change scenario (van Vuuren et al. 2011) for five selected global climate models (colored bars). Future projections were calculated from the NASA NEX-DCP30 downscaled climate dataset (Thrasher et al. 2013).

elevation locations often thought to be warming more rapidly. However, long-term, high-elevation weather stations are rare in the Western United States. Moreover, there is evidence that the SNOTEL network—one of the primary sources of temperature data in remote mountainous regions—produces inflated high-elevation temperature trends over the past 30 years (Oyler et al. 2015).

Although the evidence for elevation-dependent warming over the past century is equivocal, the CMIP5 models generally suggest mountainous regions throughout the world will warm faster than nonmountainous locations at the same latitude, especially during winter (Rangwala et al. 2013). An important caveat to simulated climate in mountainous regions is that GCMs do not explicitly simulate the effects of elevation and topography, with the large and rugged Cascade Range reduced to a smooth and relatively small topographic feature in the models. Some anticipated effects of climate change in the region—more warming farther inland than near the coast, and amplified winter-through-spring warming at higher elevations owing to changes in snow albedo feedback (e.g., Rupp et al. 2017)—may not be captured by our downscaling method.

Historical (1970–1999) temperature, growing season length, and precipitation for the SWOAP assessment area derived from the PRISM dataset agree well with the historical simulation (1970–1999) from the five selected GCMs (figs. 2.14A, 2.14C, and 2.14E). The projected change in mean annual temperature varies minimally among the elevation bands with the exception of the MIROC-ESM-CHEM model, which simulates a 5.9 °C temperature increase above 2100 m compared to 5.0 °C closer to sea level. Each of the other case study GCMs analyzed show less than 0.5 °C difference in warming by elevation. Projected change in mean annual precipitation varies considerably among the five case study models (fig. 2.14D). The BNU-ESM, CESM1(CAM5), and MRI-CGCM3 each indicate negligible change in mean annual precipitation with little variability by elevation. The hot-dry MIROC-ESM-CHEM model projects a weakening of orographic precipitation, with a 10 percent decrease below 300 m and a 15 percent decrease above 1500 m. In contrast, the hot-wet CanESM2 model shows a strengthening of orographic precipitation, with a 10 percent increase simulated below 600 m and a 20 percent increase above 2100 m.

Despite projected temperature increases ranging from 3.0 to 5.4 °C in the five case study models, there is no change in growing season length below 1000 m, as no month currently has a mean monthly temperature below freezing at that elevation level (fig. 2.14F). At the 1500-m level, the models all show the growing season increasing by 1 month to become a 12-month growing season. The models indicate a much larger change in growing season above 1800 m. In the 2100- to 2500-m elevation band, the hot-dry MIROC-ESM-CHEM model projects the growing season to increase by 4.5 months to become almost year-round at 11.3 months. The cool MRI-CGCM3 simulates the least change to SWOAP assessment area growing season, though it still shows a 2-month increase above 1500 m.

Along with significant changes in growing season length in each model (fig. 2.15), growing degree-days (GDD) and wet growing degree-days (WGDD) both increase substantially under the RCP 8.5 climate change scenario (figs. 2.16B and 2.16D). GDD is a general index of energy available for plant growth and is calculated as the product of the temperature above zero and the number of days (McMaster and Wilhelm 1997). For example, if every day of a month were 10 °C, then GDD would be 10 degrees times 31 days for 310 GDD. WGDD in an index of

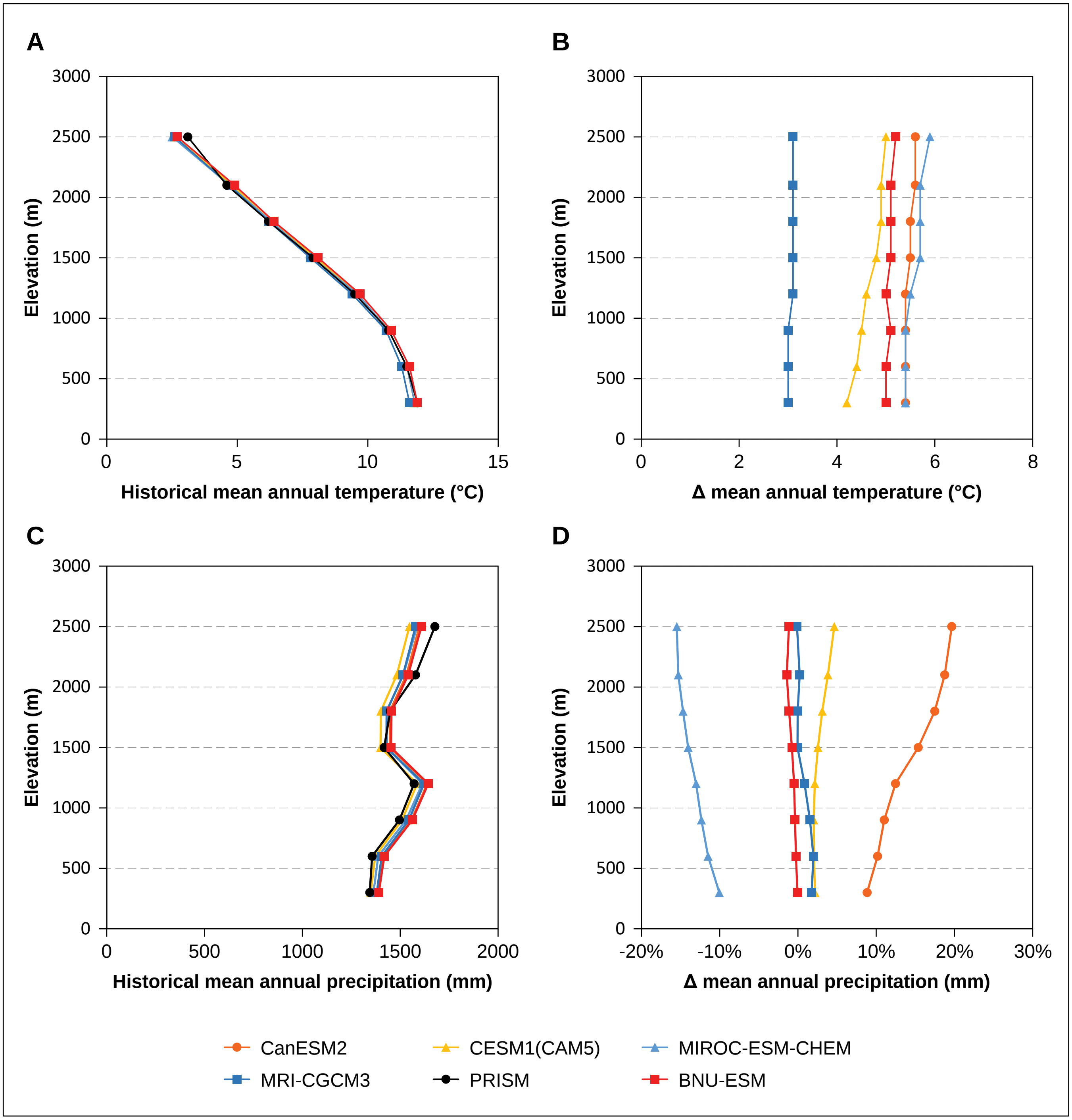

Figure 2.14—(A) Historical mean annual temperature, and (B) projected change; (C) historical mean annual precipitation, and (D) projected change; and (E) historical growing season length, and (F) projected change for the Southwest Oregon Adaptation Partnership (SWOAP) assessment area for five selected 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. 2008), and future projections were calculated using the NASA NEX-DCP30 downscaled climate dataset (Thrasher et al. 2013) for the RCP 8.5 climate change scenario (van Vuuren et al. 2011). For a given climate model, projected changes were calculated relative to the historical values in the given model, not relative to PRISM. The SWOAP assessment area was divided into elevation bands in 300-m increments.

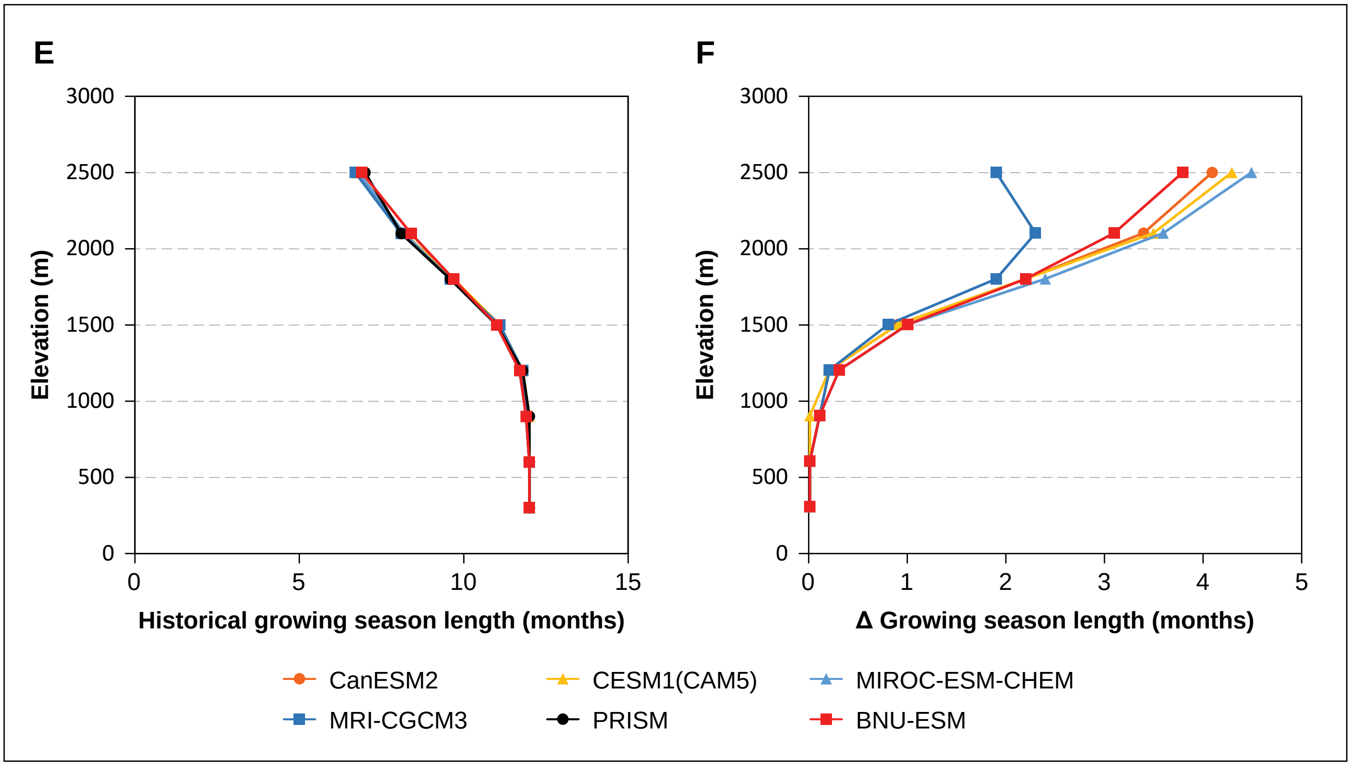

Figure 2.14—continued.

energy available for plant growth while there is significant moisture available, and it is calculated the same way as GDD, except only months with precipitation greather than 76 mm were included. The threshold of 76 mm is the average May precipitation for the SWOAP assessment area for the 1970–1999 period. GDD are projected to increase most in absolute value during the summer, ranging from +135 GDD in the cool MRI-CGCM3 model to +255 GDD in the hot-wet CanESM2 model. In percentage terms, the largest change in all models occurs in winter, with all but the cool MRI-CGCM3 model showing more than a doubling of GDD for 2070–2099.

There is some disagreement between historical WGDD in PRISM and the five selected GCMs stemming from precipitation differences among the GCMs (fig. 2.16C). Overall, the GCMs show a bias toward drier spring and summer conditions and wetter conditions in fall to early winter relative to PRISM. For example, between July and August, PRISM indicates that the SWOAP region averages 43 WGDD, whereas the near mean CESM1(CAM5) model simulates just 6 WGDD for the historical period. However, between October and December, all five models show about 10 percent more WDGG for the historical period than the PRISM dataset. While all of the models show a large increase in WGDD, differences in projected temperature and precipitation lead to considerable variability in WGDD

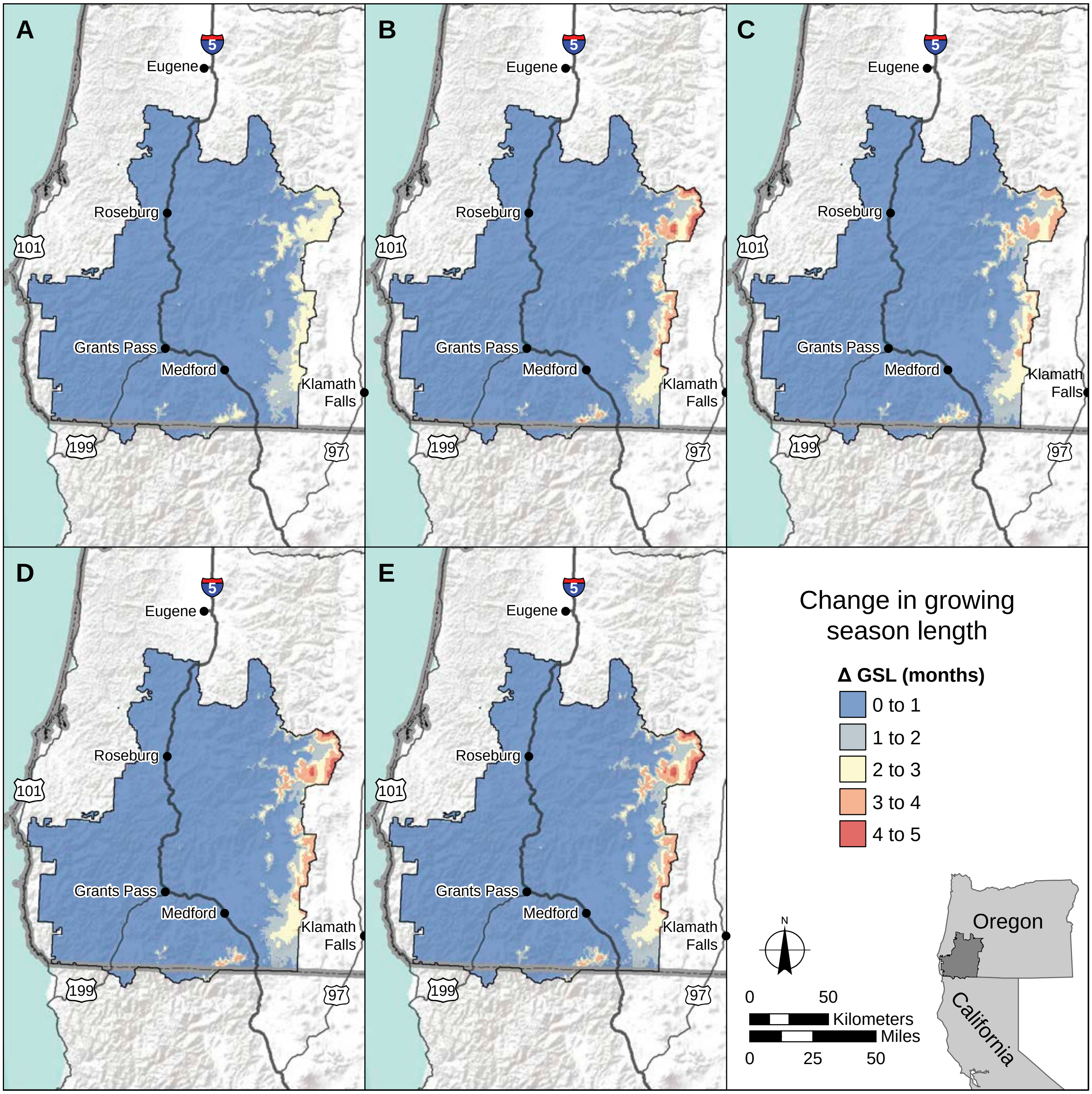

Figure 2.15—Change in growing season length (GSL) from historical (1970–1999) to end of century (2070–2099) under the Representative Concentration Pathway 8.5 climate change scenario (van Vuuren et al. 2011) for five selected global climate models for the Southwest Oregon Adaptation Partnership assessment area. Growing season included all months with mean daily minimum temperatures greater than 0 °C.

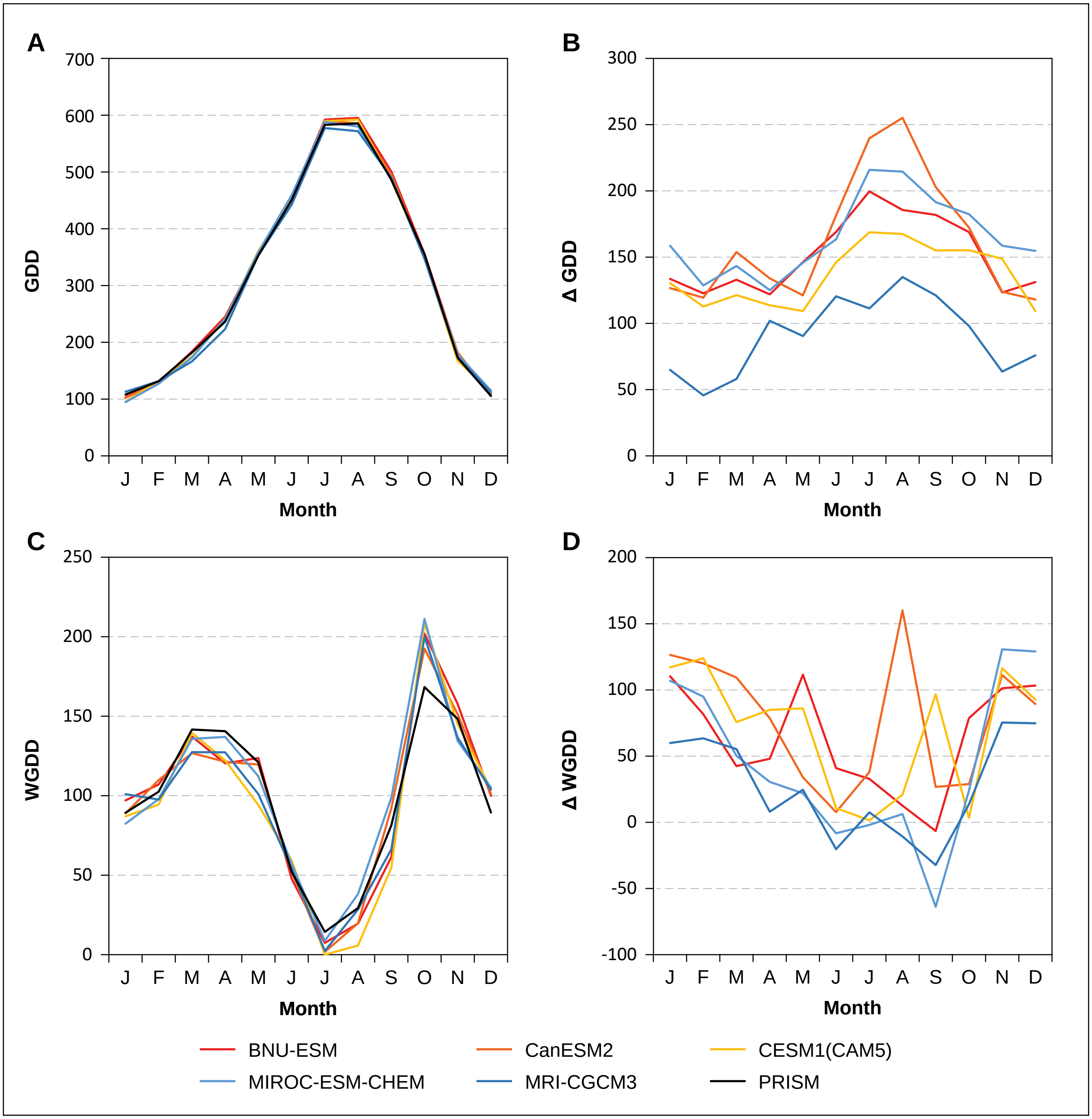

Figure 2.16—(A and B) Monthly growing degree-days (GDD) and (C and D) wet growing degree-days (WGDD) by elevation for five selected global climate models for the Southwest Oregon Adaptation Partnership assessment area. Historical values (A and C) for GDD and WGDD were calculated from PRISM data (Daly et al. 2008) 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. For a given climate model, projected changes were calculated relative to the historical values in the model, not relative to PRISM.

projections (fig. 2.16D). The near mean CESM1(CAM5) simulates the largest change, with an extra 931 WDGG per year, a 79 percent increase.

All of the models show an increase in WGDD during fall, winter, and spring, whereas all but one (the hot-dry MIROC-ESM-CHEM) simulate an increase during summer. The hot-wet CanESM2 model indicates more than a doubling of August precipitation, leading to an additional 160 WGDD for the month, the largest monthly change in WGDD among the five selected models. The largest projected decreases in WGDD occur in September, with the hot-dry MIROC-ESM-CHEM and cool MRI-CGCM3 simulating 64 and 32 fewer WGDD, respectively.

The RCP 8.5 climate change scenarios suggest generally more favorable climate for plant growth by the end of the century, though warmer summer temperatures may produce increased drought stress. Accordingly, we examined historical and projected future climatic water deficit (CWD), which represents the amount by which potential evapotranspiration (PET) exceeds actual evapotranspiration (AET), a key indicator of drought stress (Stephenson 1998). Estimates of AET and PET for the SWOAP assessment area were obtained from MC2 dynamic global vegetation model simulations performed with PRISM and the five selected GCMs. CWD was calculated as an annual value, averaged by elevation bands (fig. 2.17). There is good agreement at all elevations between the simulated historical values of CWD and those based on PRISM (fig. 2.17A). Under RCP 8.5, CWD is projected to increase by at least 52 percent to as much as 274 percent, depending on the elevation band and GCM. Overall, the models simulate about a doubling of the historical CWD values by the end of the century. The largest percentage increases are projected for areas above 2100 m, where increases range from a low of 141 percent in the cool MRI-CGCM3 to 274 percent in the hot-dry MIROC-ESM-CHEM.

Summary and Conclusions

The average annual temperature within the SWOAP assessment area has already increased by 0.6 °C (PRISM) to 1.5 °C since 1895. Under the RCP 8.5 scenario, the 31 GCMs analyzed show that temperatures are projected to continue to increase throughout the 21st century. The model ensemble average shows a 4.2 °C annual temperature increase, with individual models ranging from 2.4 to 5.6 °C by the end of the century (2070–2099). There is considerable variability among the GCMs in both the magnitude of temperature increase and changes in precipitation. All of the GCMs suggest an increase in annual mean temperature, with 30 of 31 models showing the most warming in summer and least in winter. Overall, the models

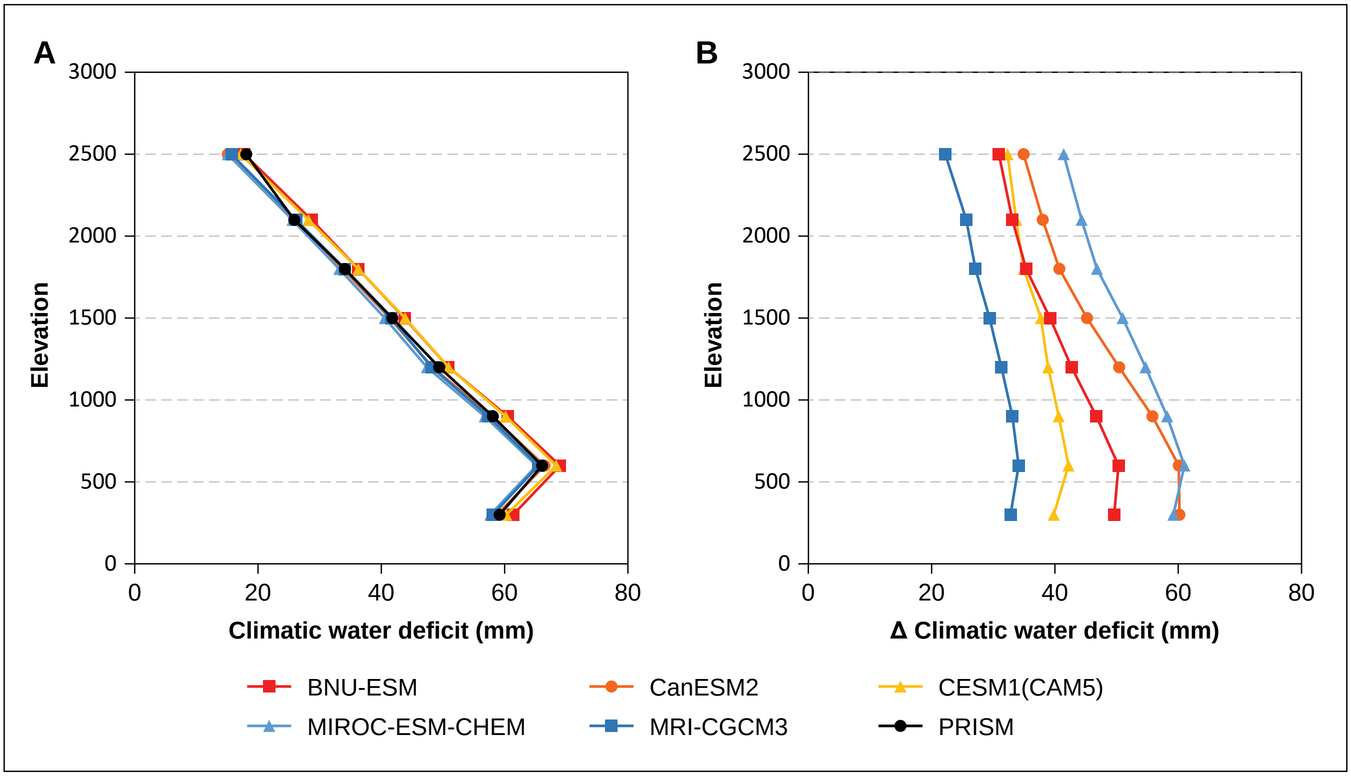

Figure 2.17—(A) Historical climatic water deficit (CWD) and (B) the change in CWD for five selected global climate models (GCMs) for the Southwest Oregon Adaptation Partnership assessment area. Data for the historical period were calculated from PRISM data (Daly et al. 2008) and from MC2 dynamic global vegetation model simulations for 1970–1999. Future projections (B) represent the Representative Concentration Pathway 8.5 climate change scenario (van Vuuren et al. 2011) for 2070–2099.

generally project a slightly wetter climate in the SWOAP assessment area, or no significant change in precipitation. However, seasonal amplification of precipitation is a common theme in the model results, with wetter winters and drier summers simulated by most of the GCMs.

Because of rising temperatures, the growing season is expected to increase markedly above 1800 m in elevation. Even at the highest elevations of the SWOAP region, the growing season is projected to become year-round or nearly so under 4 °C of warming. In addition, warmer temperatures will result in more precipitation falling as rain instead of snow at high elevations, a substantial decline in mountain snowpack, an earlier snowmelt season, and decreases in summer streamflow. Higher temperatures more favorable for plant growth may be offset by increased drought stress from a doubling of CWD expected from climate change. In each season, projected climate changes would transform the SWOAP assessment area climate to one with no modern period analog.

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Chapter 3: Climate Change Effects on Water Resources and Infrastructure in Southwest Oregon

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Introduction

Climate change will likely affect physical hydrologic processes and the many resource values influenced by those processes, including water availability, infrastructure, and fish. Specifically, climate change is likely to alter the amount, timing, and type of precipitation (e.g., Holden et al. 2018, Luce et al. 2013; chapter 2); snowpack storage volumes; and timing and rate of snowmelt (Hamlet et al. 2005, Luce et al. 2014a, Lute and Luce 2017, Musselman et al. 2017, Safeeq et al. 2013). These changes, in turn, reduce summer streamflow (Kormos et al. 2016) and increase stream temperatures (Isaak et al. 2012, 2016; Luce et al. 2014b). Peak flow changes are also likely (Hamlet and Lettenmaier 2007, McCabe et al. 2007, Safeeq et al. 2015), with important consequences for some fish species (Wenger et al. 2011), geomorphic processes (e.g., Goode et al. 2012), and infrastructure. Finally, changes in the amount and timing of precipitation will affect vegetation (chapter 5), further altering water supplies (Adams et al. 2012, Vose et al. 2016b).

In this chapter, we describe hydrologic processes and regimes in the Southwest Oregon Adaptation Partnership (SWOAP) assessment area, historical trends in hydrologic parameters (snowpack, peak streamflow, and low streamflow), and projected effects of climate change on those hydrologic parameters. We then describe a vulnerability assessment for water use and infrastructure in the SWOAP assessment area. We conclude the chapter with adaptation options to reduce the negative effects of climate change on hydrology, water use, and infrastructure.

Topographic and Geologic Setting

The rugged topography of southwest Oregon, combined with diverse geology, frame a variety of hydrologic processes and sensitivities to climate change. The region sits at the juncture of three major mountain ranges: the Cascade Range in the eastern portion, the Oregon Coast Range in the northwestern corner, and the

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Siskiyou subrange of the Klamath Mountains in the southwestern portion. The landscape is characterized by ridges, canyons, and valleys, with most human settlement being in a few wide valleys.

The region comprises two well-known river basins that originate in the southern Cascades (the Rogue and the Umpqua) as well as several coastal rivers. Several reaches and tributaries of the Rogue and Umpqua are designated as wild and scenic rivers, along with three rare coastal river designations for the Chetco, Elk, and Smith Rivers. These rivers are known for excellent water quality and abundant fish populations.

Although the mountains stretch across the length and breadth of this region, they do not reach the high elevations of many other ranges in the Western United States. To the west of Interstate-5 Highway and U.S. Highway 199, the southern Oregon Coast Range and Siskiyou Mountains comprise rugged topography with deep canyons, and ridges in the 900- to 1200-m range and a few peaks just over 1500 m. Snow is frequent above 900 m, but the smaller rivers and streams with headwaters in this subregion are dominated by rainfall-driven runoff. To the east in the Cascade Mountains, and to the south in the northeastern Siskiyous, the mountains are higher; many high ridges range from 1500 to 1800 m, and the highest peaks range from 2400 to 2900 m. Lower elevations in the Cascade Range have shallow, brief snowpacks, whereas higher elevations have deep, late-lying snowpacks. Rivers with most of their headwaters in these higher mountains tend to have snowmelt-dominated hydrographs or mixed hydrographs, with both winter and spring peak flows.

The geology of the region is varied and complex owing to a variety of origins. To the east, the Cascades are composed of a mix of volcanic rocks from basalt flows, to andesite, to deep deposits of pumice. West of the Cascades, there is a mix of sedimentary, metamorphic, and igneous rocks yielding high diversity across small spatial scales. The sedimentary rocks are primarily marine in origin and range from extensive friable siltstones and mudstones, which are known for both shallow and deep-seated slope instability, to massive sandstones and conglomerates forming high bluffs and cliffs in some locations. Metamorphic rocks include schists, slates, phyllites, and marble. The bulk of the igneous rocks in the western half of the region are intrusive and range from ultramafic peridotite and serpentinite deposits to small felsic granitic plutons, although there are some areas with extrusive volcanics. A good portion of the coastal bedrock is a melange formation from material accumulated from the seabed as the North American Plate has advanced westward over the Juan de Fuca Plate under the Pacific Ocean. Much of this material is structurally weak.

The geomorphology of the region has a mixed origin. The direct signature of tectonic and volcanic processes is still clear in many places, most obviously in and around Crater Lake (formed by a major eruption about 7700 years ago) and the High

Cascades. A few valleys have been influenced by alpine glaciers. In the western half of the region, interactions of bedrock properties with fluvial and mass wasting processes influence the geomorphology. Specific local bedrock properties are key to geomorphic process.

The hydrologically important contrasts in geologic setting are the relatively porous bedrocks and deep ash deposits from recent volcanism in the Cascades relative to the comparatively tight, though highly fractured, bedrocks of the rest of the region, with a few specific exceptions (e.g., the marble of the Oregon Caves area). The highly porous rocks of the High Cascades provide greater storage and therefore greater storage times for rainfall and snowmelt in those areas. These long storage times support a longer recession from spring and winter high-flow periods and, consequently, higher summer baseflows. The landscape in these areas is relatively undissected by streams, and some channel heads are formed by large spring systems sustained by large groundwater aquifers. In contrast, the older and less permeable bedrocks to the west have shallower waterflow paths and less storage. This results in a greater degree of dissection and higher stream densities, where streams typically run low by the end of summer because of a lack of deep groundwater contributions. However, much of the rock in this western portion is strongly fractured because of its tectonic history, leading to a moderate amount of baseflow support. Deep storage associated with individual fractures sustains many localized springs, which contribute to regional biodiversity and rare indigenous flora.

These geological differences in hydrogeology are reflected spatially as differences in the recession constant k, as calculated by Safeeq et al. (2013, 2014) and used in the streamflow analysis described below (fig. 3.1). The k constant has units of fraction per day, and places with high k constants drain more rapidly relative to their total storage, whereas places with lower k values drain more slowly relative to their total storage. Much of the region has moderate storage levels that are very sensitive in ratio terms to shifts in timing of water input (e.g., earlier snowmelt) (Stewart et al. 2005). The deep aquifers of the High Cascades are less sensitive in terms of percentage changes to a shift in timing but can be sensitive in terms of absolute flow. Some of the locally deepest aquifers or springs, including some of the localized ones in the western portion of the region, have long enough storage times that shifts in snowmelt timing have nearly no effect on baseflow. However, they can be very sensitive to trends in annual precipitation (e.g., Luce et al. 2013).

With this context, the water resource responses to climate change across the SWOAP assessment area are 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 assessment area.

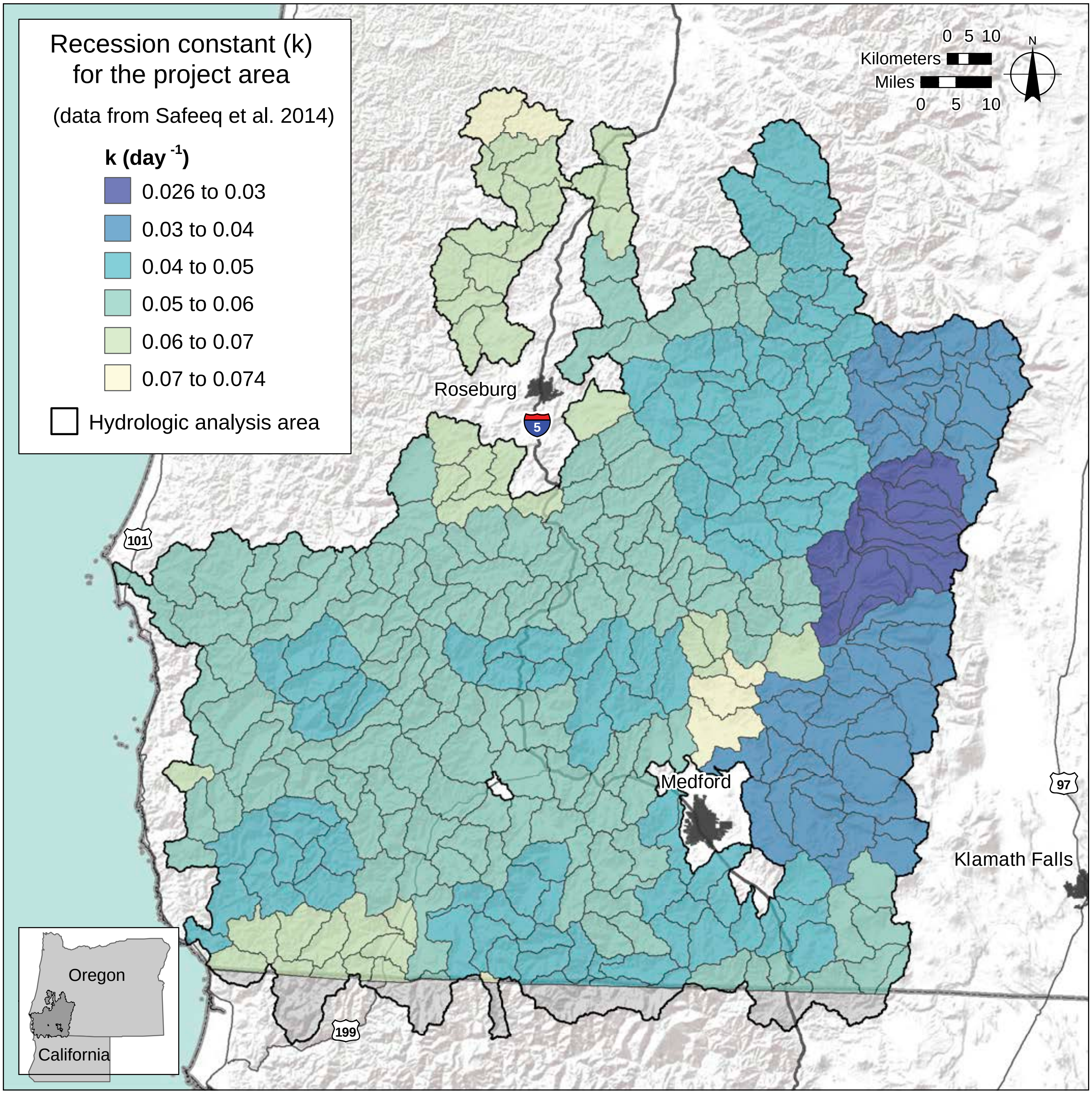

Figure 3.1—Relative geologic storage of water across the Southwest Oregon Adaptation Partnership assessment area. The inverse of the k value (i.e., 1/k) is the number of days it takes for the flow rate to fall to 1/e from an "initial" flow rate (e is Euler's number used in natural logarithms and has a value of about 2.71828). Small k values have a longer recession, in this case on the order of 1 month, whereas the higher k values reflect about a 2-week recession to 1/e times the original flow. The longest recessions are seen in the younger volcanics of the High Cascades in the vicinity of Crater Lake, Diamond Lake, and the upper Rogue River basin. Data unavailable for California.

Streamflow Response Calculations

Climate-induced changes were estimated using the Variable Infiltration Capacity (VIC) model (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 developed by the Climate Impacts Group at the University of Washington (https://cig.uw.edu/news-and-events/datasets/wus/) (Littell et al. 2014). 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 important for calibration (Mattheusen et al. 2000), the large calibration units do little to inform local groundwater behavior. Given the importance of groundwater to low flows in portions of the SWOAP assessment area, 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) (fig. 3.1). Specifically, the 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 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.

The VIC model uses a potential evapotranspiration estimate generated from the downscaled climate information when calculating future evapotranspiration. Such approaches are known to overestimate increases in evapotranspiration because they use temperature information as a proxy for actual energy balance information (e.g., Milly and Dunne 2017). The VIC model uses the Penman-Monteith approach, which is one of the more accurate approaches, but estimates about twice as much increase in evapotranspiration in the Columbia River basin as the energy balance suggests could be sustained (Milly and Dunne 2017). Based on energy balance changes driven by increased carbon dioxide, increases in evaporation from land areas are not expected to exceed a few millimeters per month (Luce et al. 2016, Milly and Dunne 2017, Roderick et al. 2014).

Snowpack: Current Conditions and Projected Changes

One of the principal changes expected in the hydrology of Western U.S. mountains is less snow accumulation and earlier snowmelt (Barnett et al. 2008). Snowpack storage can be regarded in two ways: how deep the snow is, and how long it lasts. The depth of snow can be represented by snow water equivalence (SWE) and duration by snow residence time (SRT) (Luce et al. 2014a). The SWE on April 1st is considered a useful metric of storage for the coming spring runoff and irrigation season. The SRT is the length of time that any new snow will last. It is generally about half of the total duration that snow is on the ground. SRT in the range of a few weeks is generally associated with rapid accumulation and melt cycles, indicating transient snowpacks often associated with rain-on-snow events (Nolin and Daly 2006).

There are strongly contrasting expectations of snow changes in the eastern versus western portions of the SWOAP assessment area (figs. 3.2 through 3.4). In the low-elevation western portions, snow is already mostly absent or ephemeral, and warming temperatures are expected to change average SRTs and April 1st SWE little in absolute terms, simply because there is not much snow to lose. Snow is “warm” over much of this area, being close to its freezing point, but precipitation is high because these are the first mountains encountered by moisture from the Pacific Ocean. Some of the snowpacks on ridges and peaks in the western portion of the assessment area can be a meter deep, although this may not be apparent in figures 3.2 through 3.4. Higher ridges and peaks in the western portion are likely to maintain some snow in winter through the 21st century, although it will be shallower and not last as long. At mid-elevations in the Cascades, and probably the higher elevation ridges and peaks of the western mountains, the more transient or ephemeral snowpacks will be largely eliminated with climate change by the 2080s, and places with moderately persistent snowpacks will become more transient in nature. In the High Cascades, in the northeast corner of the region, the average SRT declines on the order of 6 to 8 weeks, or about 35 to 40 percent of the current SRT, by the 2080s. In short, precipitation will spend less time as snow.

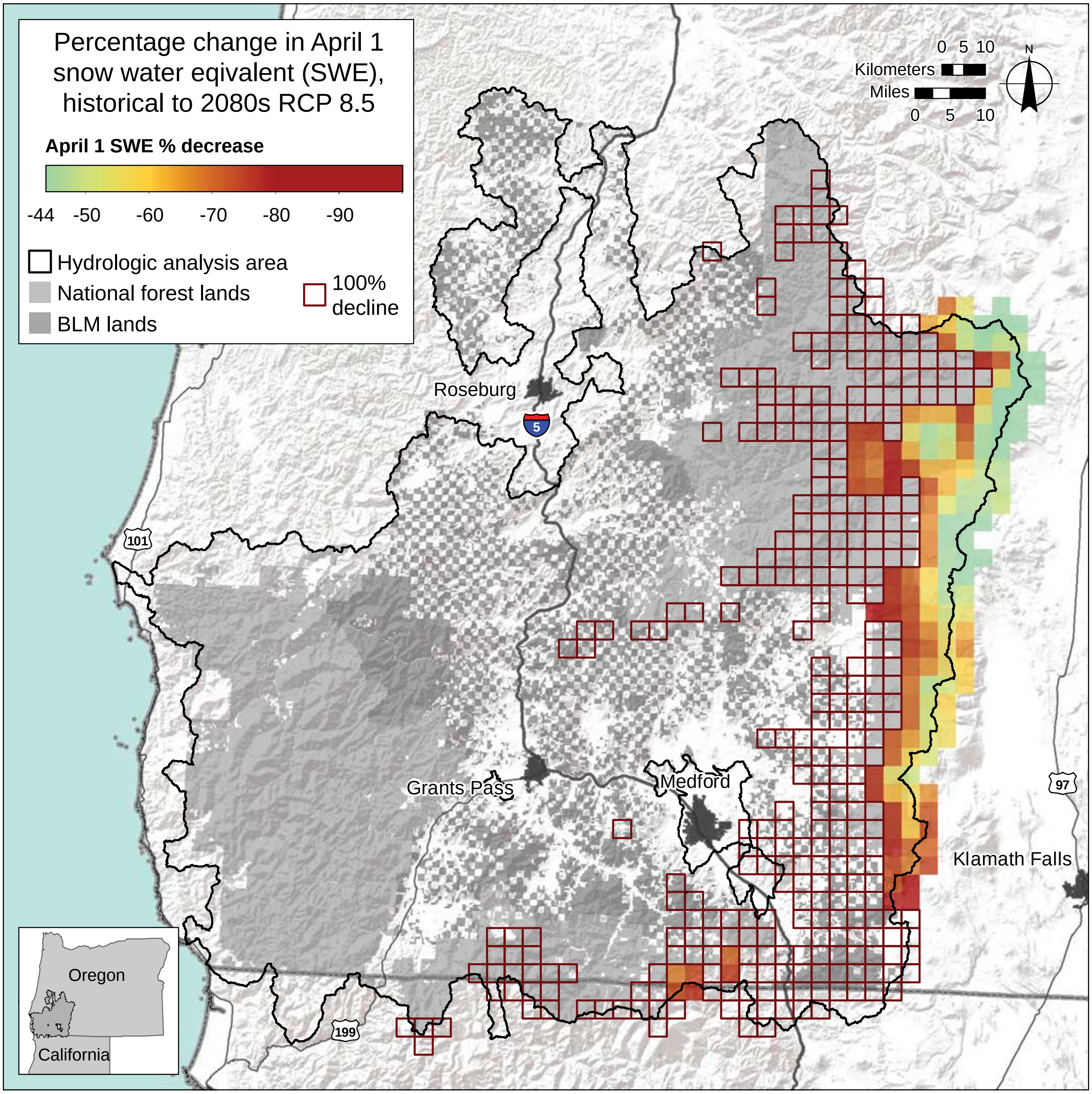

Figure 3.2—Projected declines in April 1 SWE between a historical period (1991–2011) and 2080, based on a 3 °C increase in December–March average temperature at Natural Resources Conservation Service Snow Telemetry stations in the Southwest Oregon Adaptation Partnership assessment area (from Luce et al. 2014). RCP = Representative Concentration Pathway, BLM = Bureau of Land Management.

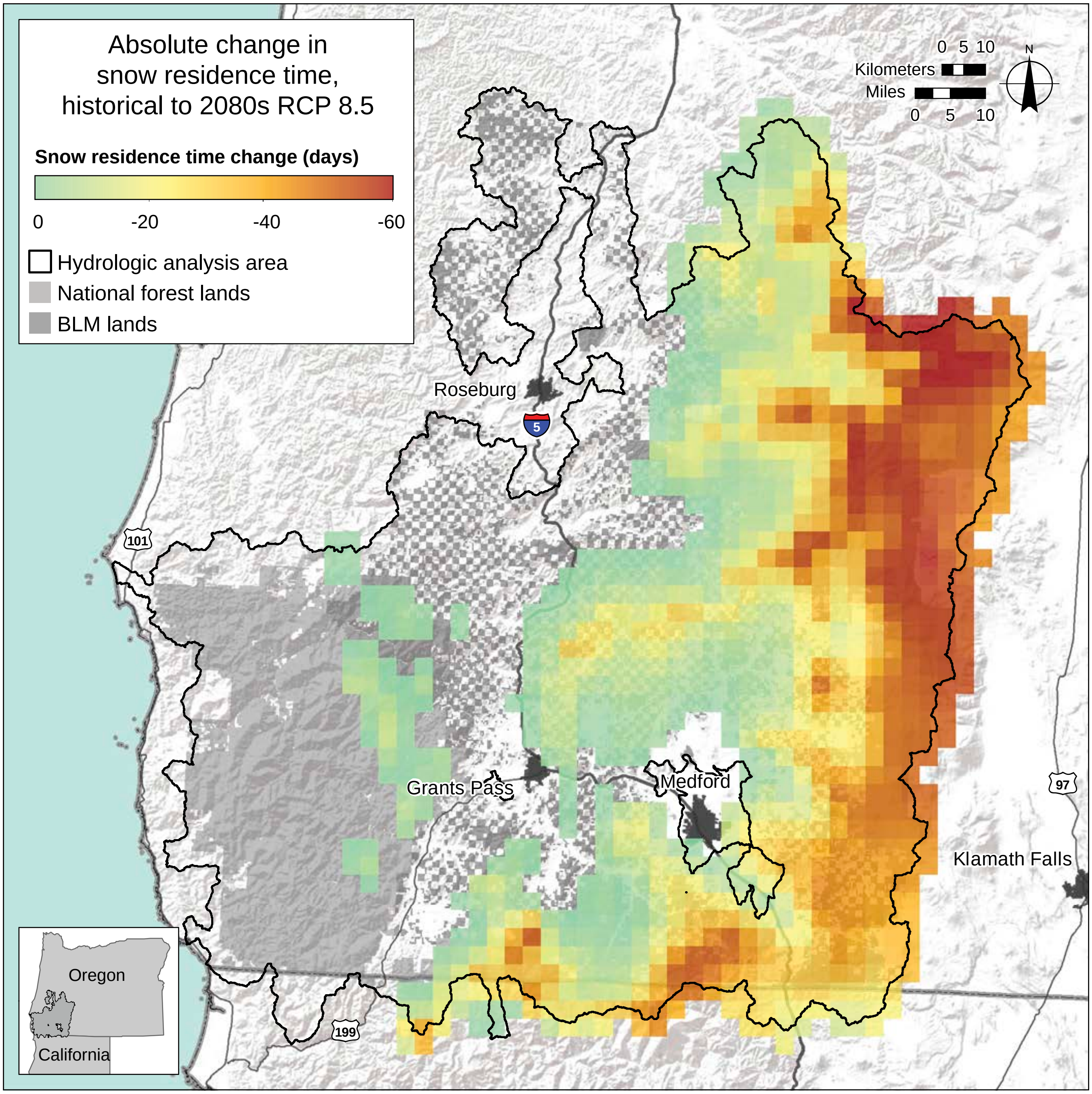

Figure 3.3—Projected (absolute) change in snow residence time (days) between a historical period (1991–2011) and 2080, based on a 3 °C increase in December–March average temperature at Natural Resources Conservation Service Snow Telemetry stations in the Southwest Oregon Adaptation Partnership assessment area (from Luce et al. 2014). RCP = Representative Concentration Pathway, BLM = Bureau of Land Management.

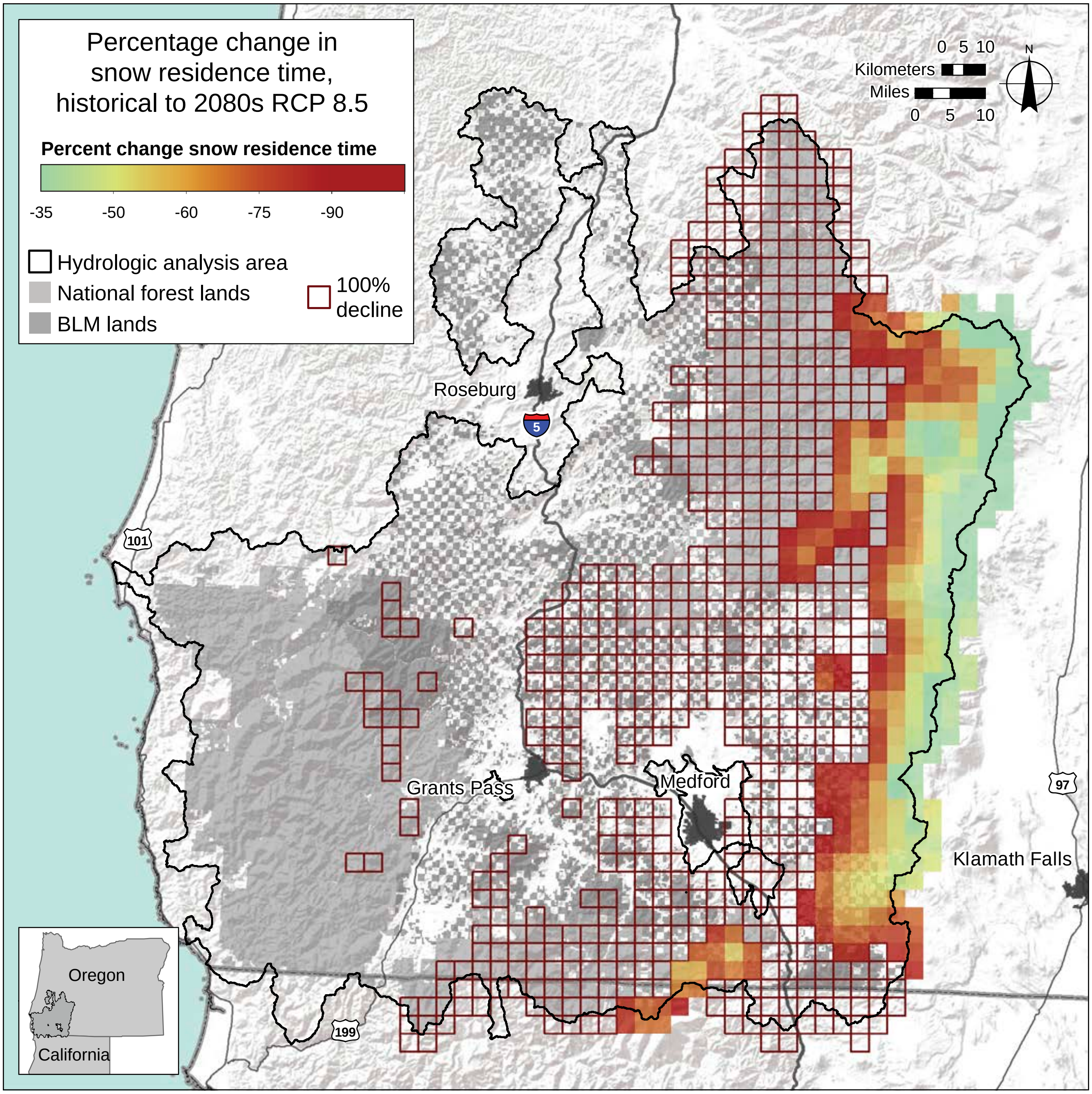

Figure 3.4—Projected percentage change in snow residence time between a historical period (1991–2011) and 2080, based on a 3 °C increase in December–March average temperature at Natural Resources Conservation Service Snow Telemetry stations in the Southwest Oregon Adaptation Partnership assessment area (from Luce et al. 2014). RCP = Representative Concentration Pathway, BLM = Bureau of Land Management.

Low-Flow Changes

Winters in the Pacific Northwest (PNW) have warmed over the past 50 years (chapter 2), and precipitation has declined in the mountains during this period as well (Luce et al. 2013), resulting in smaller snowpacks that melt out earlier in the year with less recharge to aquifers. As a result, summer flows have been decreasing, and fractions of annual flow occurring earlier in the water year have been increasing (Kormos et al. 2016, Leppi et al. 2011, Luce and Holden 2009, Safeeq et al. 2013, Stewart et al. 2005). In addition to shifted timing, Luce and Holden (2009) showed declines in some annual streamflow quantiles in the PNW between 1948 and 2006. They also 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 PNW. Overall, these driest 25 percent of years have the lowest summer flows as well. Furthermore, summer precipitation has declined in much of the West (Holden et al. 2018), which is not usually thought to substantially affect water supply, but it can support baseflows (Chang et al. 2012), particularly in coastal systems where snowpack in minimal.

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 these factors into account. Summer streamflows might be reduced compared to 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.

Snow is not a large contributor to streamflow in much of the assessment area, so only small decreases in low flows are expected over much of the assessment area (fig. 3.5). There is some snow support of baseflows, but declines in summer precipitation (e.g., Holden et al. 2018) may contribute to summer flow decreases in low-snow areas. The most notable declines in summer low flows are expected in High Cascade streams, rivers to which they are a tributary (Rogue and Umpqua), and the northwestern Siskiyou Mountains. The largest declines are projected in the higher

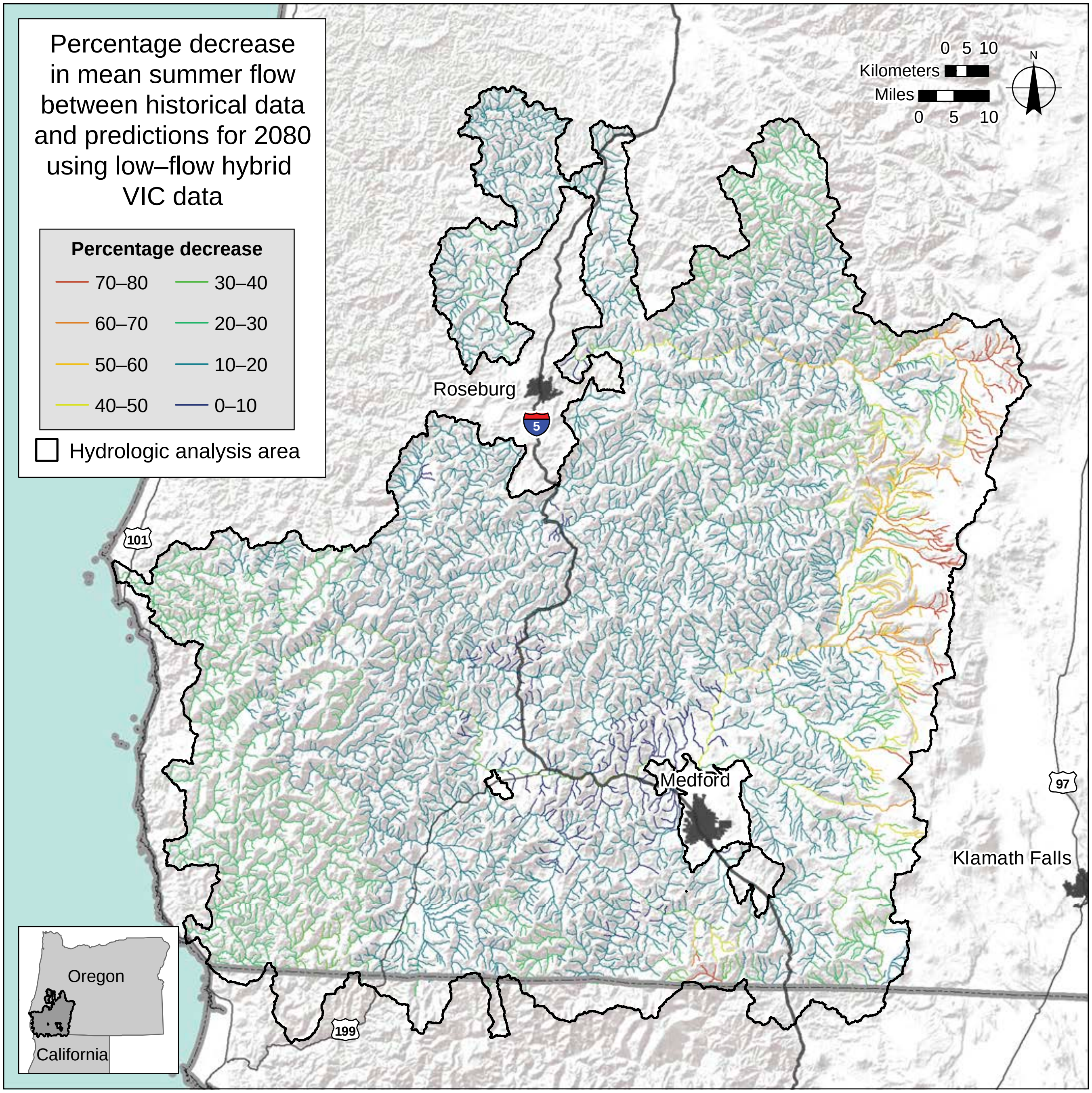

Figure 3.5—Projected percentage decrease in low flows between a historical period (1970–1999) and the 2080s under the A1B greenhouse gas emissions scenario (moderate scenario similar to RCP 4.5). Projections are based on Variable Infiltration Capacity (VIC) model projections of surface water input changes filtered by geologically based unit hydrograph. Data unavailable for California.

mountains where the snowpack changes are large. Although fractional changes in SRT are large in many areas, the greatest changes in low flows come from places with lower fractional (fig. 3.4) but large absolute (fig. 3.3) changes in SRT.

Climate change effects are not immediately obvious in the low-flow decline map (fig. 3.5) because of the limited area with large snowpack changes in the assessment area, and the correlation between spatial patterns in snow loss and spatial patterns in geologic hydraulics. The long residence time of the geologies of the High Cascades in the area west of Crater Lake provide little reduction in the percentage of decline (see figs. 3.1 and 3.5). Some aspects of climate change are not incorporated in the modeling; for example, low flows are also likely to be affected by changing vegetation. Increases in fire and insect mortality associated with increasing drought (e.g., Kolb et al. 2016, Littell et al. 2016, Vose et al. 2016a) may initially increase water yield by decreasing canopy interception and transpiration, but if such disturbances keep forests in earlier seral stages, an increase in the water demand from the vegetation for transpiration may make low flows even lower (Perry and Jones 2017).

Peak-Flow Changes

Flooding regimes in the PNW 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 in southwest Oregon 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 (Cannon et al. 2010, Istanbulluoglu et al. 2004, Moody and Martin 2009).

Flooding can be exacerbated by rain-on-snow events, because rainfall runoff is augmented by rapid snowmelt (Harr 1986) and because 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 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 in the rain-on-snow zone will tend to strongly increase flooding in basins where there is a large snow collection area (generally where the current rain-on-snow zone occurs at low elevations in the basin). In basins in which there is a small snow collection area, the upward shift in the rain-on-snow zone may only modestly increase the fractional contributing basin area with rain-on-snow, or potentially shrink the total area available for rain-on-snow-driven runoff as the upper part of the basin translates into the rain-dominated zone.

In the latter half of the 20th century, increased temperatures led to earlier runoff 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 in amount of precipitation in the winter months, common floods are expected to increase in magnitude (e.g., Goode et al. 2013, Wenger et al. 2011), and extreme hydrologic events (e.g., those currently rated as having 100-year recurrence intervals) may become more frequent (Hamlet et al. 2013).

Peak-flow increases are small across much of the assessment area (fig. 3.6), but large in those areas where snowpack changes are large, particularly where there is a shift from seasonal snowpacks to more intermittent snowpacks in the mid- to high-elevation Cascades. Although much of the western set of coastal mountains do not show substantial increases in peak flows at the scale of small river basins, changes from seasonal to more intermittent snowpacks along higher ridges may yield increased slope instability because of higher melt and rainfall rates.

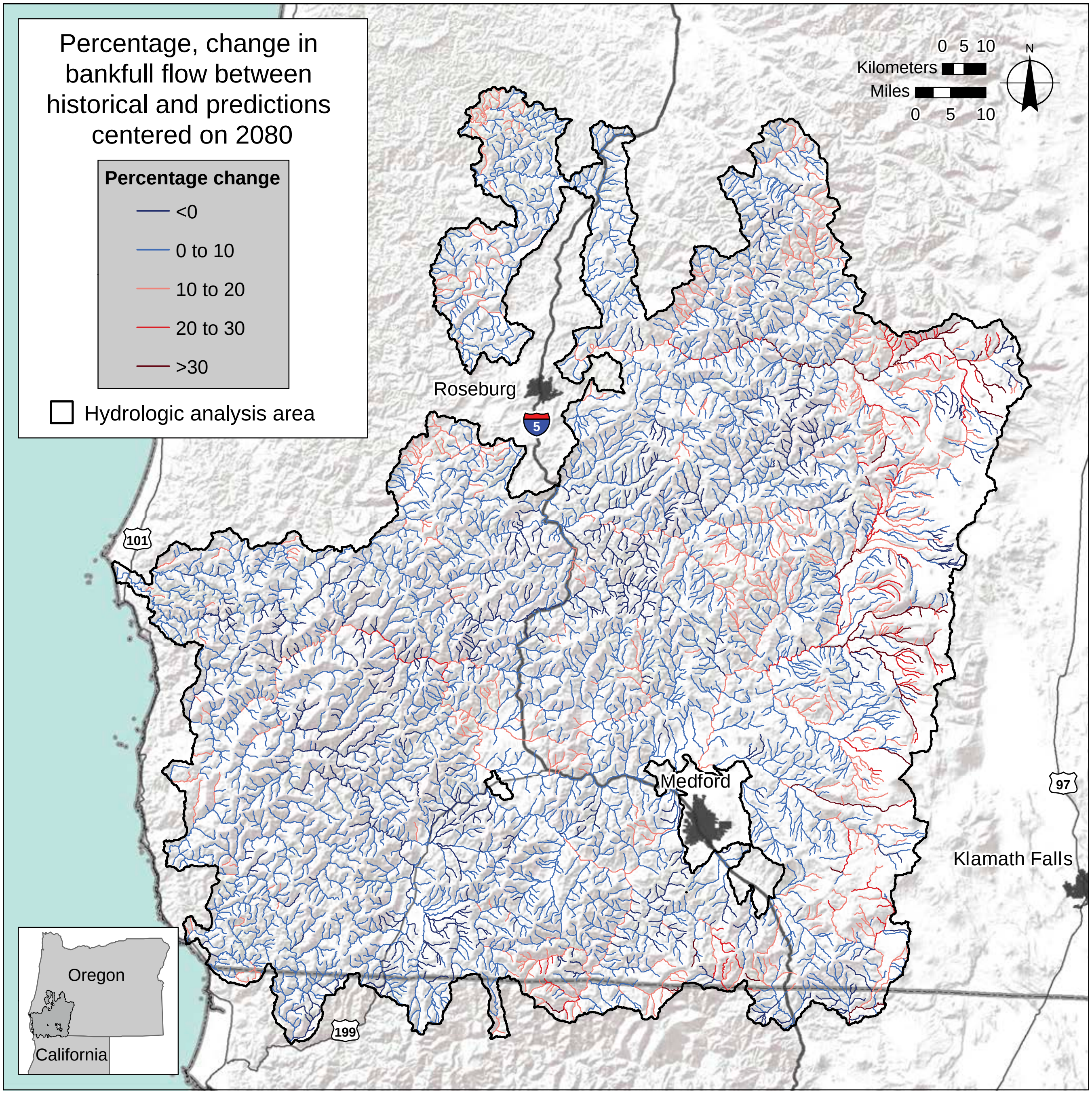

Figure 3.6—Projected percentage increase in bankfull flow (1.5-year event) between a historical period (1970–1999) and the 2080s under the A1B greenhouse gas emissions scenario (moderate scenario similar to RCP 4.5). Projections are based on Variable Infiltration Capacity model projections of surface water input changes filtered by geologically based unit hydrograph.

Water Resources and Uses

Water originating on public lands in southwest Oregon, such as the headwaters of the Umpqua and Rogue Rivers, plays an important role in providing water for ecosystems and humans. For example, these lands provide water to municipalities, manufacturing, agriculture, and many other human uses.

There are 391 certified water rights in the name of the United States in the SWOAP assessment area (table 3.1). Of the administrative units considered here, the Bureau of Land Management (BLM) Medford District holds the most of these water rights. Some of the largest use categories include domestic, forest management, fire protection, livestock, road maintenance, and wildlife (table 3.2). More than 25 municipalities rely directly on federal lands for municipal water supply, including Ashland, Brookings, Canyonville, Cave Junction, Coquille, Cottage Grove, Creswell, Dorena, Drain, Elkton, Glendale, Glide, Gold Beach, Gold Hill, Grants Pass, Medford, Milo, Myrtle Creek, Powers, Riddle, Rogue River, Roseburg, Shady Cove, Sutherlin, Tokatee Village, Tri-City, Winston, and Yoncolla (fig. 3.7).

Table 3.1—Summary of certified water rights in the Southwest Oregon Adaptation Partnership hydrologic assessment area[a]

	Rogue River-Siskiyou National Forest	Umpqua National Forest	BLM Medford District	BLM Roseburg District	Oregon Caves National Monument and Preserve	Other federal	Other	Total
Number of water rights by units	54	45	202	82	2	6	10,903	11,295

BLM = Bureau of Land Management.

[a] A single water right can have more than one point of diversion.

Source: Data are from Oregon Department of Water Resources.

There are more than 500 points of diversion (PODs) in streams on public lands in the SWOAP assessment area (fig. 3.8). The largest concentration of these PODs is in the Upper Jenny Creek and Keene Creek subwatersheds on the BLM Medford District. In some cases, a water right has multiple points of diversion (table 3.3).

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 allocation among users could affect allocation during severe droughts.

Table 3.2—Summary of water rights use type by Southwest Oregon Adaptation Partnership administrative unit (number of water rights in a category/total number of water rights on a unit)[a]

	Rogue River-Siskiyou National Forest	Umpqua National Forest	BLM Medford District	BLM Roseburg District	Oregon Caves National Monument and Preserve
Aesthetics	0	0	1/202	0	0
Agriculture	0	0	0	1/82	0
Domestic	23/54	31/45	3/202	0	2/2
Fire protection	1/54	7/45	116/202	4/82	2/2
Fish culture	3/54	0	1/202	0	0
Forest management	0	0	5/202	58/82	0
Greenhouse	0	0	1/202	0	0
Irrigation	8/54	1/45	8/202	1/82	0
Livestock	9/54	8/45	119/202	0	0
Manufacturing	0	2/45	9/202	1/82	0
Multipurpose	0	0	4/202	0	0
Pond maintenance	3/54	0	4/202	22/82	0
Power development	2/54	0	0	0	0
Recreation/campsite	11/54	4/54	2/202	0	0
Road maintenance	0	0	96/202	2/82	0
Storage	1/54	1/45	3/202	20/82	0
Temperature control	1/54	0	0	0	0
Wildlife	8/54	8/45	142/202	0	0

BLM = Bureau of Land Management.

[a] A water right can have multiple use types, and there is significant overlap.

Source: Data are from Oregon Department of Water Resources

In national forests, water is generally available for campgrounds and administrative sites and for other appropriated uses (e.g., livestock and wildlife). However, in dry years, availability may be limited at some sites, especially in late summer. Climate change could increase the frequency of water shortages on national forest sites in the future.

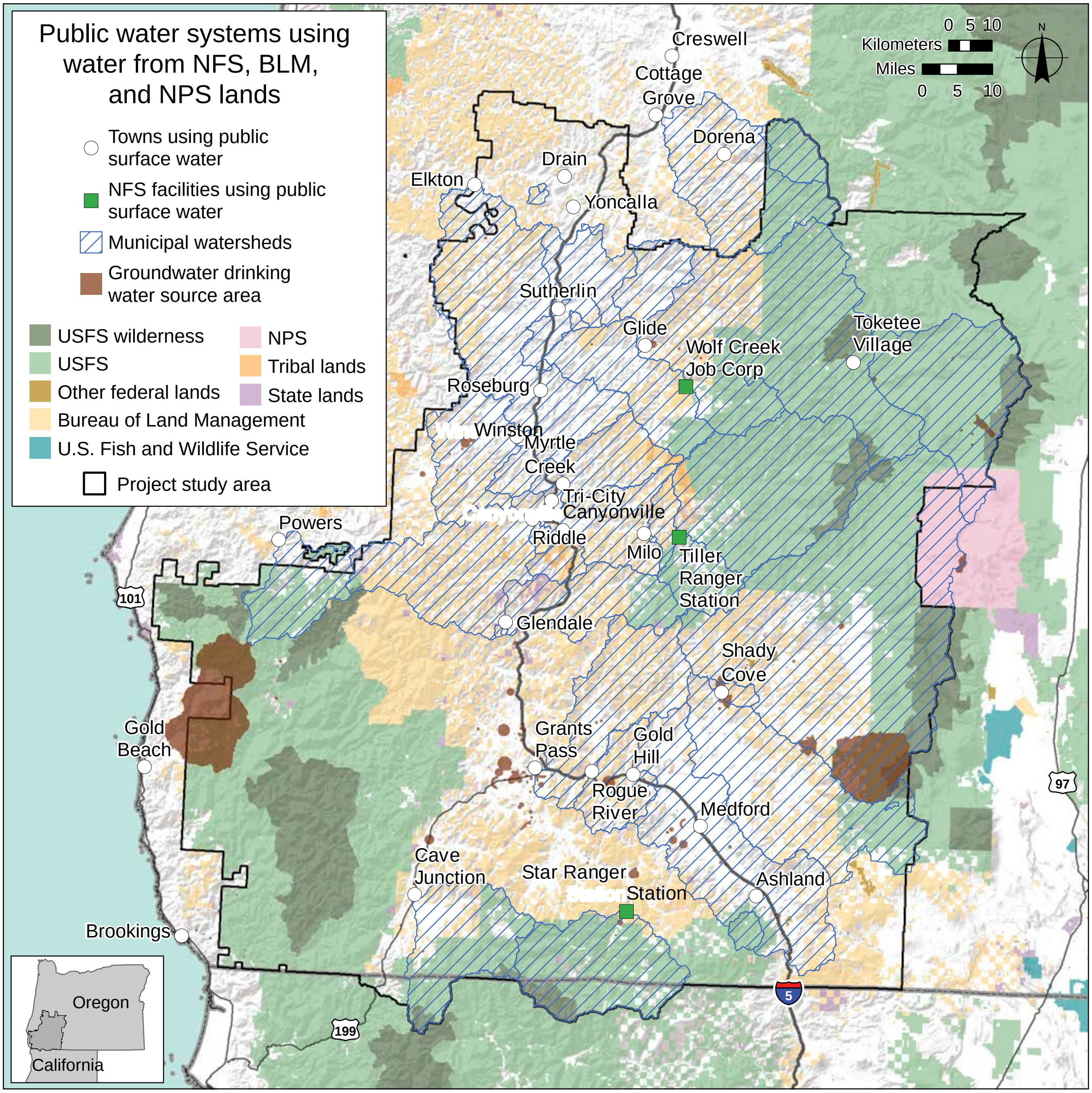

Figure 3.7—Public water systems using water from National Forest System (NFS), Bureau of Land Management (BLM), and National Park Service (NPS) lands. USFS = U.S. Forest Service.

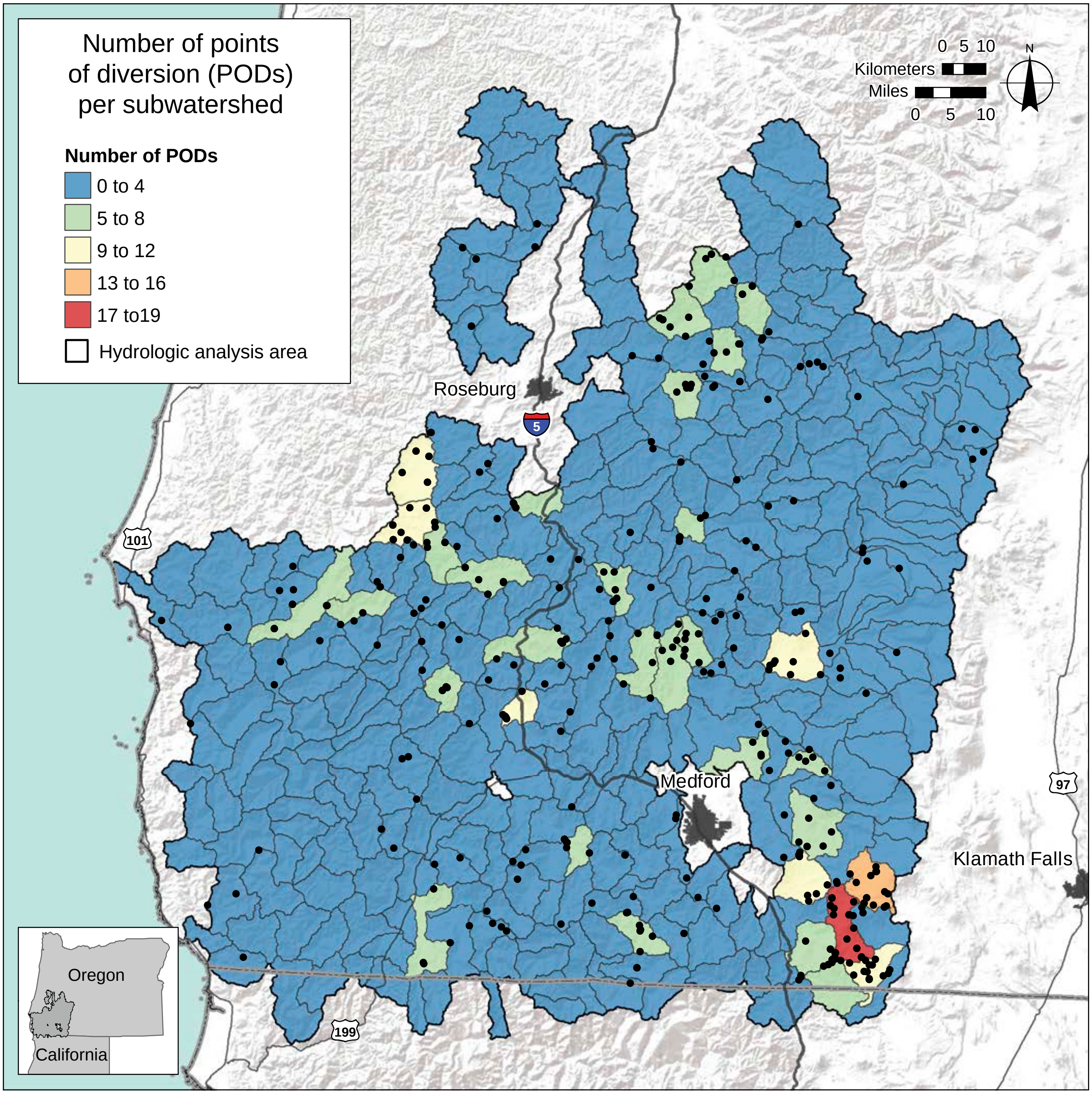

Figure 3.8—Number of points of diversion in the name of the United States, classified by subwatershed. PODs in the name of the United States are those for which the water right is held by the federal government and managed by a federal agency. No state or private PODs are shown.

Table 3.3—Points of diversion (POD) managed by Southwest Oregon Adaptation Partnership administrative units (within the project hydrologic assessment area)[a]

		Rogue River-Siskiyou National Forest	Umpqua National Forest	BLM Medford District	BLM Roseburg District	Oregon Caves National Monument and Preserve
Unique PODs	On unit	42	41	188	79	2
	On other unit or private	12	5	16	5	0
Total		54	46	204	84	2

BLM = Bureau of Land Management.

[a] Only PODs for certified water rights are reported·

Source: Data are from Oregon Department of Water Resources.

Climate Change Effects on Water Uses

Changes in snowpack and streamflow will likely alter the quality and availability of water in southwest Oregon. Shifts in the timing and magnitude of streamflow may alter the ability to meet water demand during summer in some locations (i.e., those that show the greatest decreases in summer low flows) (fig. 3.5). Decreases in summer flows are projected to be greatest in High Cascade streams, and rivers to which they are a tributary (Rogue and Umpqua) (fig. 3.9).

In addition to changes in snowpack and streamflow, higher temperatures result in increased human water use. For example, water demand for agriculture increases with higher temperatures and increased evapotranspiration (Blanc et al. 2017). Water supplies have already been stressed in some locations in southwest Oregon. The South Umpqua system has had low summer flows and lacks enough storage capacity to meet demands of water users during most years. In 2015 and 2018, very dry years in southwest Oregon, there was a high rate of regulation for instream water rights and senior irrigators. Many tributaries to the Applegate, Illinois, and Rogue Rivers, and throughout the Umpqua Basin, experienced regulation for senior priority dates (but irrigators who had primary or supplemental water available from storage projects were able to continue irrigating)[2]. Similar shortages may increase in frequency with higher temperatures, higher evapotranspiration, and lower summer streamflows in a changing climate.

Dams and stream diversions affect local hydrology and availability of water for different uses. For example, aging and inefficient stream diversion infrastructure can increase loss of water for human uses (Clifton et al. 2017). However, dams also store water that can be released to alleviate low streamflows. Dams on the North Umpqua are primarily designed for hydropower and have limited capacity for flood

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[2] Jake Johnstone. 2018. Personal communication. Southwest regional manager, Oregon Water Resources Department, 10 South Oakdale Avenue, Medford, OR 97501.

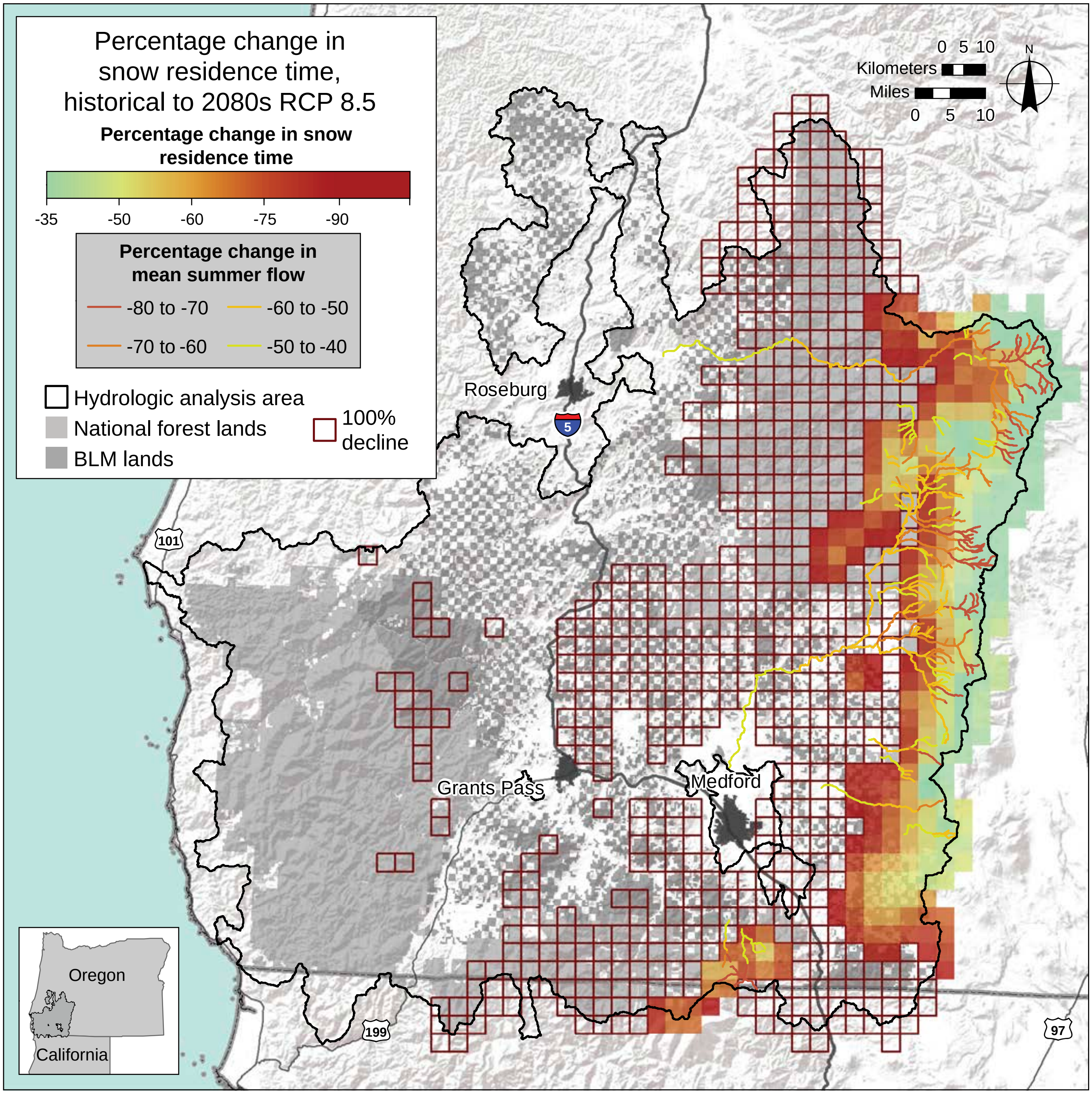

Figure 3.9—Projected percentage decrease in mean summer flow (cfs) (under the A1B greenhouse gas emission scenario, a moderate scenario similar to RCP 4.5) and snow residence time in 2080. Streamflow projections are based on Variable Infiltration Capacity model output for surface water input changes filtered by geologically based unit hydrograph. Snow residence time is based on a 3 °C increase in December–March average temperature at Natural Resources Conservation Service Snow Telemetry stations in the Southwest Oregon Adaptation Partnership assessment area (from Luce et al. 2014).

control or water release during summer low flow. Dams on the South Umpqua River system (Berry Creek Dam and Galesville Dam), however, were designed for water storage and release during summer low flow.

Backup water systems are also an important factor affecting the vulnerability of water supplies for human uses; those systems with redundant supplies will generally be less vulnerable (Clifton et al. 2017). Some water providers in Douglas County have emergency tie-ins with adjacent districts to provide water in case of emergency. Other systems do not. For example, Oakland, Oregon, has only one water source (surface water on Calapooya Creek).

Climate change may also affect water quality in southwest Oregon. Water temperatures are expected to increase (Luce et al. 2014b), and shifts in precipitation and runoff affect the transport of pollutants into water bodies (Georgakakos et al. 2014). Algal blooms could increase in frequency because of longer periods of warm water temperatures (Chapra et al. 2017). Increased frequency of insect outbreaks and fire may also affect water quality. All of these changes may affect water treatment costs and are a risk to water supplies (Lall et al. 2018).

Road Infrastructure and Access

Roads, trails, bridges, and other transportation infrastructure in the SWOAP assessment area connect people to National Forest System (NFS) and BLM lands for recreation, extracting resources, managing resources, commuting, and responding to emergencies. Access to public lands promotes use, stewardship, and appreciation, contributing to quality of life (Louter 2006). Access management balances these benefits with ecosystem services. This and the following section describe current road conditions and infrastructure management and maintenance constraints to provide context for identifying key climate change vulnerabilities and adaptation options.

In the SWOAP assessment area, there are 28 056 km of roads, only 8256 km (29 percent) of which are suitable for passenger vehicles (table 3.4). Most of the passenger vehicle roads are on BLM lands, 47 percent on the BLM Medford District, and 23 percent on the BLM Roseburg District. Umpqua National Forest has 10 percent of passenger roads in the assessment area, and Rogue River-Siskiyou National Forest has 20 percent. Many of the roads (and trails) cross streams and rivers; there are 4,591 road-water crossings in the assessment area (fig. 3.10), 449 of which are bridges (table 3.5), and most are culverts. Approximately 3148 km (11 percent) of roads in the assessment area are within 90 m of a stream (table 3.6), suggesting they may be vulnerable to increased peak flows with climate change (table 3.7).

Table 3.4—Length of road by maintenance level on national forests and grasslands in the Southwest Oregon Adaptation Partnership (SWOAP) assessment area

Operation maintenance level		Rogue River-Siskiyou National Forest	Umpqua National Forest	BLM Medford District	BLM Roseburg District	Oregon Caves National Monument and Preserve	Total in SWOAP assessment area
Code	Description						
		Kilometers					
ML 1	Basic custodial care (closed)	1144	1423	289	418	7	3281
ML 2	High clearance cars/ trucks	5628	5309	2933	1945	48	15 862
ML 3	Suitable for passenger cars	1293	560	3321	1318	8	6500
ML 4	Passenger car (moderate comfort)	295	200	504	447		1446
ML 5	Passenger car (high comfort)	28	66	62	154		310
	Unknown			365	290		656
Total		8388	7559	7474	4572	62	28 056

BLM = Bureau of Land Management.

Table 3.5—Count of bridges administered by Rogue River-Siskiyou and Umpqua National Forests based on projected percentage of change in peak streamflow at bridge crossings

National forest	Time period	Percent change in peak streamflow				
		<0	0 to 10	10 to 20	20 to 30	>30
		Percent				
Rogue River-Siskiyou	Mid century (2040s)	4	81	25	20	2
	Late century (2080s)	16	70	24	9	6
Umpqua	Mid century (2040s)	2	60	25	7	2
	Late century (2080s)	13	46	25	4	8

Source: Data are from the Forest Service INFRA database.

Table 3.6—Length of roads within 90 m of streams and rivers by administrative unit

	Rogue River-Siskiyou National Forest	Umpqua National Forest	BLM Medford District	BLM Roseburg District	Oregon Caves National Monument and Preserve
	Kilometers				
Length of roads within 90 m of streams	778	682	714	386	2

BLM = Bureau of Land Management.

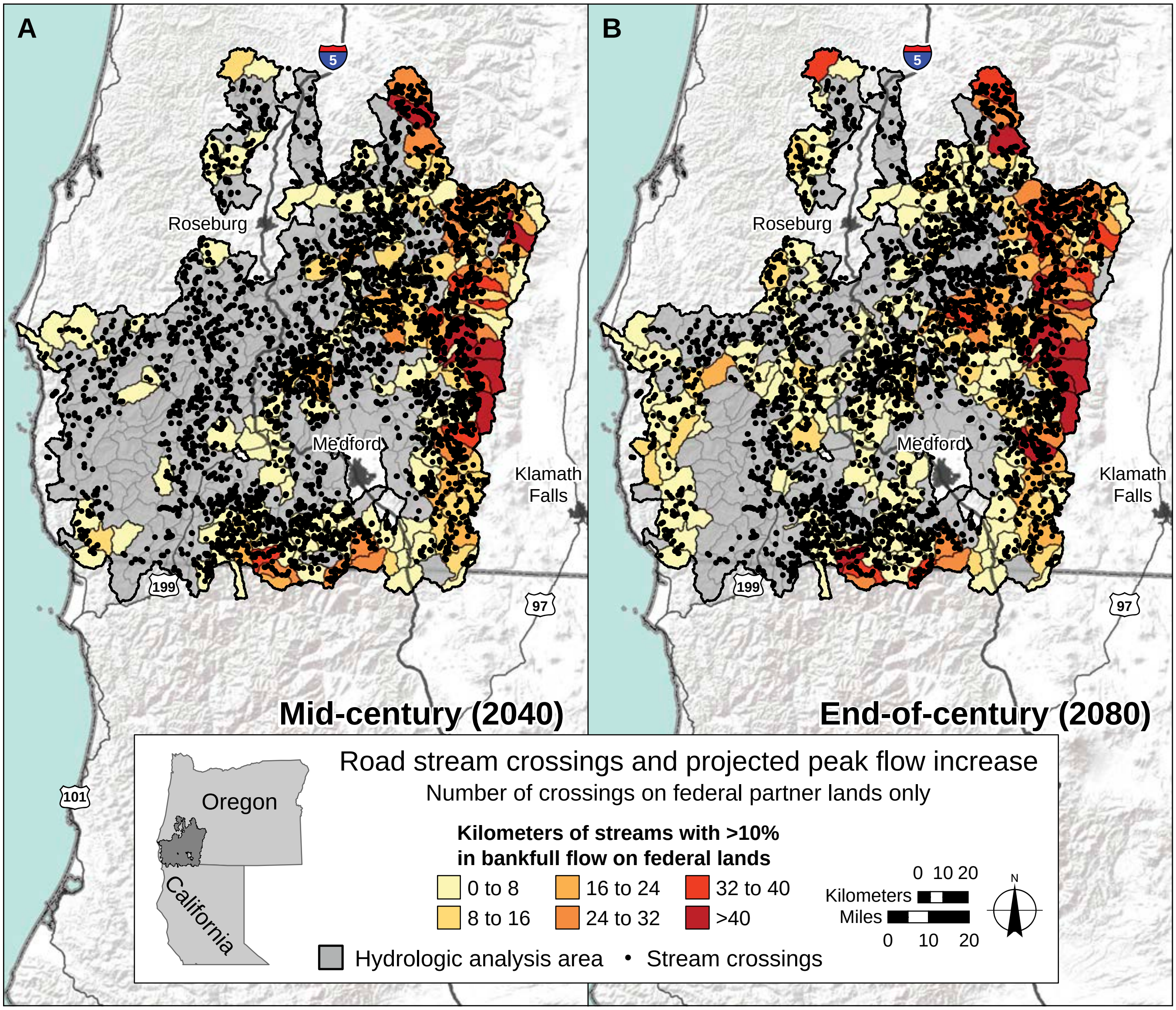

Figure 3.10—Road stream crossings on federal partner lands with projected peak flow increases in 2040 (left) and 2080 (right). Streamflow projections are based on Variable Infiltration Capacity model output (under the A1B emission scenario, a moderate scenario similar to RCP 4.5) for surface water input changes filtered by geologically based unit hydrograph.

Roads can have negative effects on aquatic ecosystems. Roads intercept precipitation, surface runoff, and shallow groundwater; reduce the infiltration capacity of the land; concentrate and accelerate runoff; redirect overland and subsurface flow; and increase rates of erosion and the potential for sediment delivery to streams (Forman et al. 1997, Furniss et al. 1991, Luce and Black 1999). Within the stream network, these processes tend to increase peak flows (Jones and Grant 1996). Roads closer to rivers and streams (table 3.7) generally have a greater direct impact on the fluvial system (Luce and Black 1999). However, roads in the uplands

Table 3.7—Hydrologically sensitive transportation infrastructure under the jurisdiction of Southwest Oregon Adaptation Partnership administrative units

Unit[a]	Subbasin	Subbasin area in unit[b]	Number of stream crossings	Total	Length of roads within 90 m of streams: With projected increases in peak flow of >10% (2040)[c]	With projected increases in peak flow of >20% (2040)	With projected increases in peak flow of >30% (2040)	With projected increases in peak flow of >10% (2080)	With projected increases in peak flow of >20% (2080)	With projected increases in peak flow of >30% (2080)
		Square kilometers	*- - - Number - - -*		*- - - - - - - - - - - - Kilometers - - - - - - - - - - - -*					
RRS	Illinois	1803	245	150	12	0	0	3	0	0
	Upper Rogue	1707	575	311	138	49	17	144	60	31
	Chetco	1012	65	50	1	0	0	3	0	0
	Applegate	788	234	209	77	14	0	75	18	7
	Lower Rogue	719	90	53	0	0	0	2	0	0
	Sixes	274	24	36	0	0	0	0	0	0
	Coquille	265	61	65	1	0	0	0	0	0
	Others	340	20	15	0	0	0	0	0	0
	Total	6908	1,314	889	229	63	17	227	78	38
UMP	North Umpqua	2317	802	366	116	34	7	154	56	28
	South Umpqua	1299	416	265	35	0	0	54	0	0
	Coast Fork Will	352	146	84	40	0	0	32	0	0
	Others	24	9	5	0	0	0	0	0	0
	Total	3992	1,373	720	191	34	7	240	56	28
MED	Lower Rogue	849	255	192	27	0	0	30	4	0
	Upper Rogue	658	268	189	12	0	0	45	2	1
	Applegate	600	268	146	1	0	0	5	0	0
	Middle Rogue	538	226	184	50	0	0	32	0	0
	South Umpqua	330	140	138	0	0	0	8	0	0
	Upper Klamath	295	70	34	16	2	0	19	6	0
	Illinois	254	143	79	1	0	0	1	0	0
	Total	3524	1,370	962	107	2	0	140	12	1
ROSE	South Umpqua	711	224	240	7	2	0	20	0	0
	Umpqua	494	140	198	24	0	0	40	0	0
	North Umpqua	353	128	101	2	1	0	18	1	0
	Coquille	76	35	30	0	0	0	7	0	0
	Total	1634	527	569	33	3	0	85	1	0
OR CAVE	Illinois	18	7	5	0	0	0	0	0	0

[a] RRS = Rogue River-Siskiyou National Forest; UMP = Umpqua National Forest; MED = Medford District of the Bureau of Land Management; ROSE = Roseburg District of the Bureau of Land Management; and OR CAVE = Oregon Caves National Monument and Preserve.

[b] Area of a subbasin (4th field watershed) within the administrative unit.

[c] For streams within 90 m of roads; based on streamflow projections from the Variable Infiltration Capacity hydrologic model under the A1B emission scenario (moderate scenario similar to RCP 4.5).

also affect these processes and can play a role in slope instability (Trombulak and Frissell 2000).

Historically, the primary purpose of the road system on national forests was timber hauling. Reduced harvesting during the past 30 years has decreased the need for roads for timber purposes. However, local population growth has increased demand for access for recreational activities (see chapter 7).

Recreational use in Umpqua National Forest is concentrated along river corridors, especially along the North Umpqua River and at Diamond Lake. Oregon Highway 138, built along the North Umpqua and past Diamond Lake, is a major travel corridor. Campgrounds and trailheads are concentrated along the North Umpqua River, Diamond Lake, and Lemolo Lake. Recreation visitation is highest in summer, but winter steelhead (*Oncorhyncus mykiss* Walbaum) fishing draws a number of visitors to the North Umpqua Ranger District, and winter sports are popular in the Diamond Lake Ranger District.[3]

In Rogue River-Siskiyou National Forest, arterials (maintenance level 4 and 5 roads) are used to reach almost every recreation river and backcountry destination on the forest. Use typically peaks around the July 4th holiday and drops off after Labor Day. Another peak in use occurs during bow and rifle hunting seasons, which often coincide with the first early winter snows at high and midelevations. High-use areas are typically centered along river corridors, such as the Chetco, Illinois, and Rogue Rivers. Secondary focal points for recreational use include access points and trailheads for Sky Lakes and Red Buttes wilderness areas, as well as major campgrounds. Use in areas distant from urban population centers is typically moderate to low.[4]

Most mid- to high-elevation roads (above 750 m) in the SWOAP assessment area are snow covered and inaccessible to wheeled motor vehicles from late November through at least April each year, depending on snowpack. Higher elevation roads (above 1200 m) remain snow covered for most of the winter. More than 60 percent of trips to national forests last 6 hours or less, and short visits concentrate human impacts on areas that are easily accessible (USDA FS 2010). In the future, demand is expected to continue to increase for trail use by mountain bikes, motorized vehicles, and off-highway vehicles, as well as for winter recreation (Oregon Parks and Recreation Department 2013).

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[3] Joe Blanchard. 2018. Personal communication. Watershed program manager, Willamette National Forest (formerly a hydrologist, Umpqua National Forest), 46375 Highway 58, Westfir, OR 97492.

[4] Chris Park. 2018. Personal communication. Hydrologist, Rogue River-Siskiyou National Forest, 3040 Biddle Road, Medford, OR 97504.

Road Management and Maintenance

Road designs and conditions vary widely across the SWOAP assessment area. Many roads on U.S. Forest Service lands have not been maintained on a regular basis, whereas roads in other jurisdictions may undergo more frequent maintenance to support timber harvest. Although some roads are paved and designed to provide a high degree of comfort to the public traveling in passenger cars, much of the road system, particularly in national forests (table 3.4), was designed with lower standards to facilitate timber extraction, mining, and recreational access for four-wheel-drive vehicles. Most roads are suitable for high-clearance vehicles.

Forest Service road construction began in the late 1930s, with construction peaking in the 1960s and 1970s. By 1980, 90 percent of the total road system had been constructed. The construction techniques used during that time period do not meet the standards required for building stable roads today or current best management practices. When timber harvest practices changed in the 1990s from clearcutting large trees to thinning previously logged stands, the reduction in timber revenues left inadequate funds to upgrade or maintain the existing road system. Today, funding for road maintenance covers only 10 to 15 percent of the existing road system. Much of the existing road infrastructure, including bridges and culverts, has exceeded its design life and is deteriorating.

National forests develop annual road maintenance plans based on road operational maintenance level and category (table 3.4). 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.

Appropriated funding is typically used to maintain level 3, 4, and 5 roads. Level 2 road systems used for log hauling are maintained as part of timber sale contracts. Timber revenue covers maintenance costs for roads that would otherwise go unmaintained because of a lack of funding. However, timber stand age and thinning needs determine timber sale locations, not road system needs. Roads within watersheds that have been identified as high priority for restoration are also targeted for road maintenance to reduce sediment input to streams and improve fish passage. In addition, road systems at risk for postfire damage from flooding and debris flows are high priorities for maintenance through the Burned Area Emergency Response program.

Planning for transportation and access on national forests is included in forest land management plans. The 2001 Road Management Rule (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 provides benefits in terms of increasing 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 transportation system with more financial sustainability and flexibility.

A forestwide travel analysis was completed for Umpqua National Forest in 2015. Part of this analysis included ranking road segments according to their importance for public and administrative use, as well as their environmental risks (see fig. 3.11 in box 3.1). Impacts to aquatic resources were weighted heavily in determining environmental risk, although climate change was not considered. The climate change information in this report can supplement information currently used in travel analysis.

Box 3.1

Travel Analysis and Climate Change in the Lower Fish Creek Project

A forestwide travel analysis was completed for Umpqua National Forest in 2015 (USDA FS 2015). Part of this analysis included ranking road segments according to their importance for public and administrative use, as well as for environmental risks. Effects on aquatic resources were weighted heavily in determining environmental risk; modeled sediment yield from road prisms and sediment delivery to streams, roads occupying riparian reserves, and stream crossings were all taken into consideration.

This forest-scale assessment of roads was paired with the modeled hydrologic effects of climate change, including the percentage decrease in mean summer flow and percentage increase in peak bankfull flow in 2040. The purpose of this exercise was to demonstrate a potential use of a scaled-down climate vulnerability assessment. The results from climate change models can be useful at multiple scales, from ecoregional assessments to subwatershed restoration projects.

Figure 3.11 in this scaled-down example (see below) shows the Lower Fish Creek watershed, which is a subwatershed within the Fish Creek 5th-field watershed and a tributary to the North Umpqua River. An interdisciplinary team gathered data on existing conditions within the Fish Creek Project area to determine opportunities for restoration, including forest thinning, fuel breaks, road improvement and decommissioning, and stream restoration. The existing conditions of the road network in the project area, including benefit for future use and potential risk to aquatic resources, can be compared to future changes in streamflow caused by climate change.

Continued on next page

In the Fish Creek watershed, peak flow is expected to increase, summer low flow is expected to decrease, and snowpack is expected to shift from seasonal to intermittent. The location and density of the roads in the watershed can be evaluated in relation to these changes; a dense road network can intercept groundwater and exacerbate summer low-flow conditions, and stream crossings can have an increased risk of failure with increased peak flows. Opportunities for road decommissioning exist where roads have lower benefit for public and administrative use and high risk now (based on results of travel analysis) or in the future (based on modeling). Alternatively, roads can be improved to limit the risk of current or projected impacts from peak flows if the roads are determined to be important for future use.

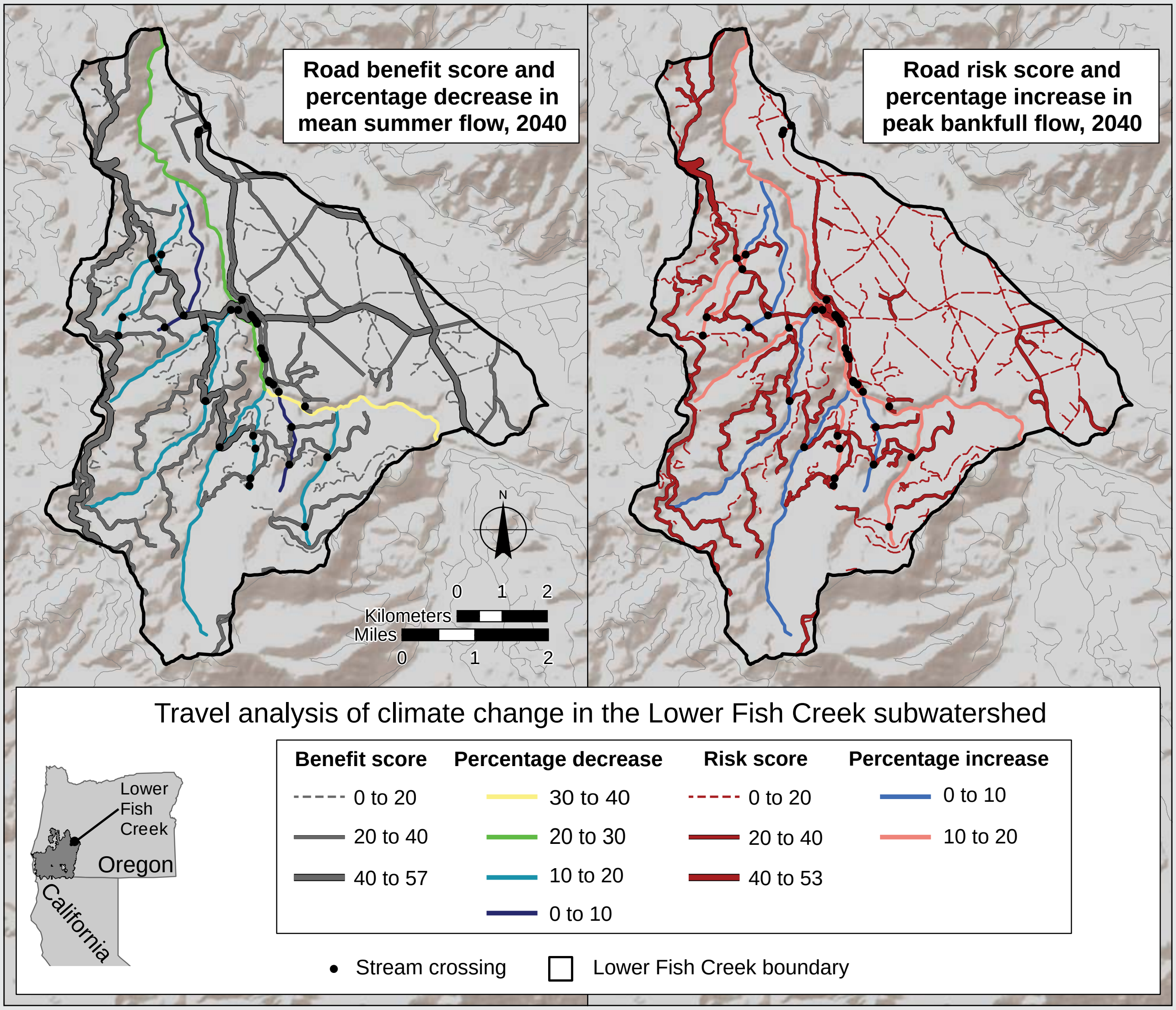

Figure 3.11—Vulnerable roads within the Southwest Oregon Adaptation Partnership assessment area, and percentage change in bankfull flow between historical data (1970–1999) and 2050 projections under the A1B greenhouse gas emissions scenario. Streamflow projections are based on Variable Infiltration Capacity model output for surface water input changes filtered by geologically based unit hydrograph.

Climate Change Effects on Transportation Systems

As discussed previously in this chapter, climate change will lead to shifts in the hydrologic regime in southwest Oregon. Altered magnitude and timing of runoff will affect the transportation system and drive changes in management. Higher peak flows will increase flood risk in winter and early spring in some streams, and elevated soil moisture in the winter will increase landslide risk (Strauch et al. 2014). These changes have both direct and indirect effects on infrastructure and access.

Direct effects of climate change on transportation systems are those that physically alter the operation or integrity of transportation facilities. These include effects related to floods, snow, landslides, extreme temperatures, and wind. Hydrologic extremes, such as flooding, may exceed the historical range of intensity and frequency, as well as the current design standards for infrastructure. Roads throughout the region use river valleys as access routes. Roads along streams and rivers affected by large changes in snowpack are at greatest risk of flooding (fig. 3.12). High-elevation areas (in the eastern and southeastern portion of the assessment area) have subwatersheds with high projected increases in peak flows (fig. 3.11) or peak flow sensitivity (fig. 3.13), and a notable number of potentially flood-vulnerable roads (within 90 m of streams).

Indirect effects of climate change on transportation systems include secondary influences on access that can change visitor-use patterns and increase threats to public safety. A large portion of the SWOAP assessment area will lose almost all snowpack by the end of the century, which will change seasonal access to federal lands (fig. 3.14). Less snow increases early- and late-season (spring and autumn) access to roads that are not currently built to handle wet-weather use. Many roads in the eastern portion of the assessment area have historically been closed by deep snowpacks, and some of these roads are likely to have reduced snowpack in the future. Increased access to these roads has two main effects: one is increased erosion potential related to traffic on roads that have not been prepared for wet-season traffic; and the second is increased safety concerns. Increased road use from fire prevention or suppression, thinning, and hazard-tree removal after droughts may all additionally damage roads. Recreationists may have access to federal lands during the time of year when landslides and flood events are most likely to occur (Strauch et al. 2014).

Changes in the location of rain-on-snow events could affect erosion and stream processes in the Cascade and Siskiyou Mountains. Rain-on-snow events can trigger landslides and debris flows (Harr 1986), which deliver large amounts of sediment and wood to streams (Swanson et al. 1990). If the risk of landslide

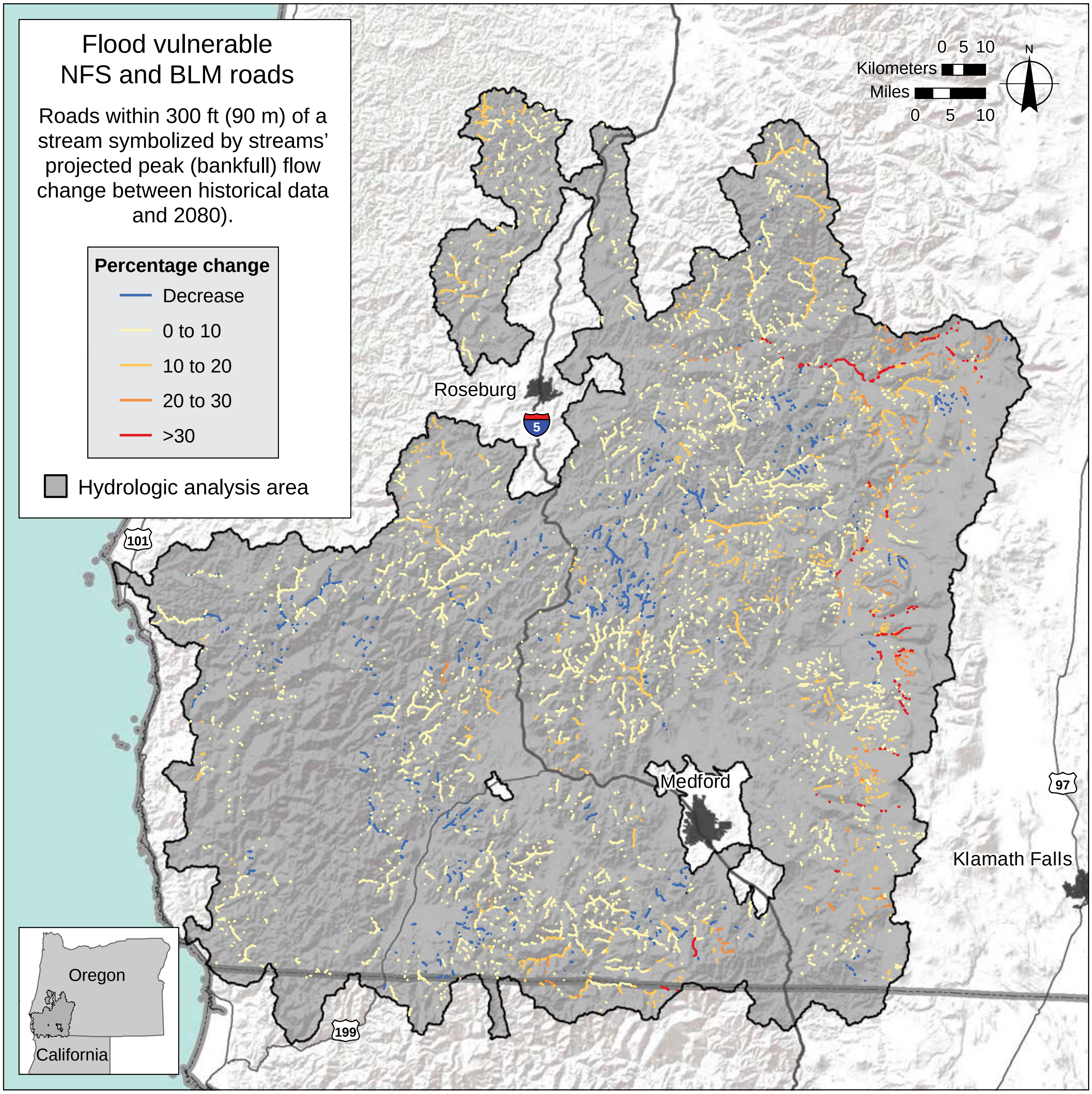

Figure 3.12—Vulnerable roads within the Southwest Oregon Adaptation Partnership assessment area, and percentage change in bankfull flow between historical data (1970–1999) and 2050 projections under the A1B greenhouse gas emission scenario (yellow to red colors indicate projected increases in bankfull flow). Streamflow projections are based on Variable Infiltration Capacity model output for surface water input changes filtered by geologically based unit hydrograph.

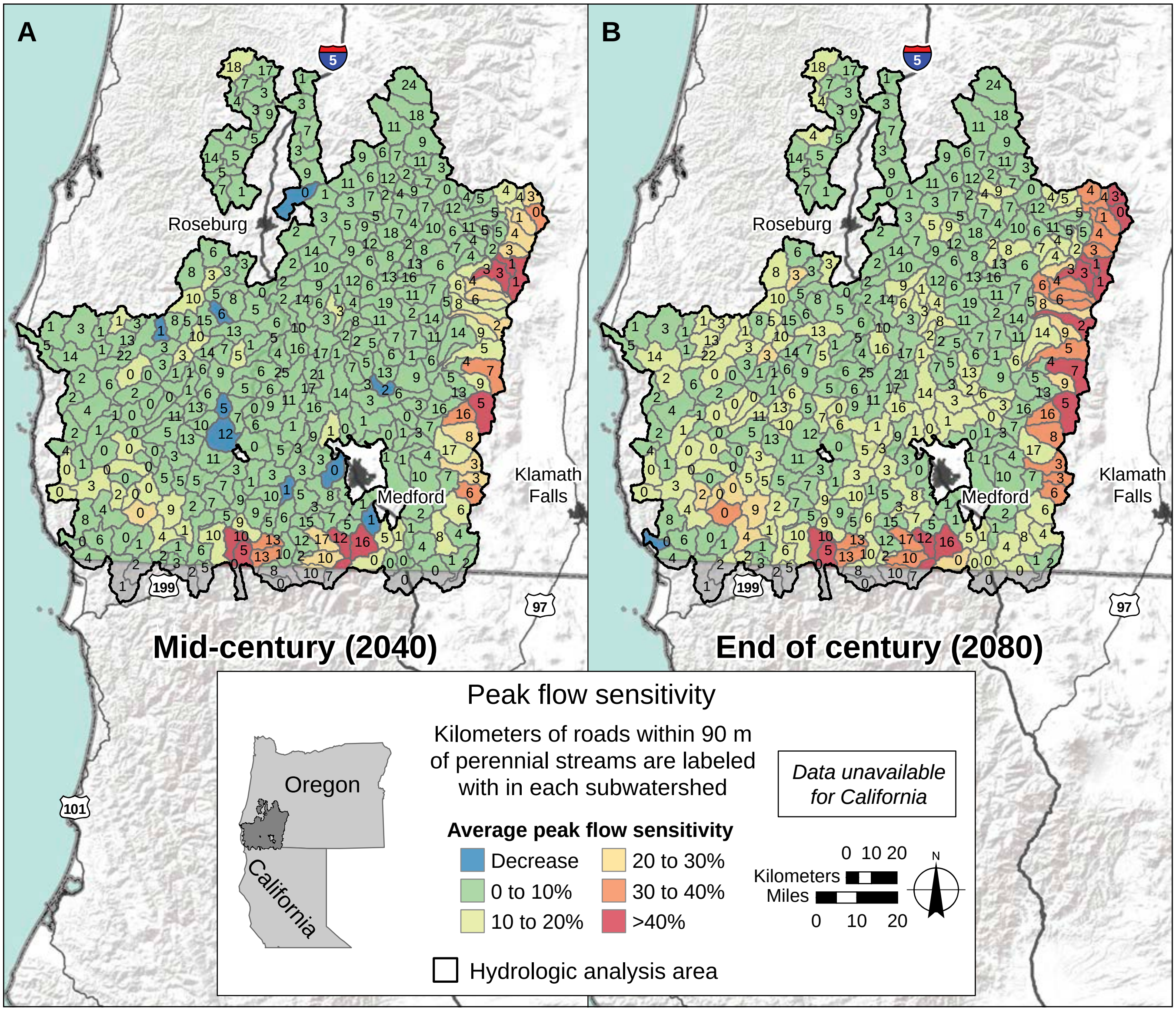

Figure 3.13—Kilometers of roads within 90 m of streams, and projected change in peak flow sensitivity in 2040 (left) and 2080 (right). Peak flow sensitivity is based on Safeeq et al. (2015). NFS = National Forest System, BLM = Bureau of Land Management.

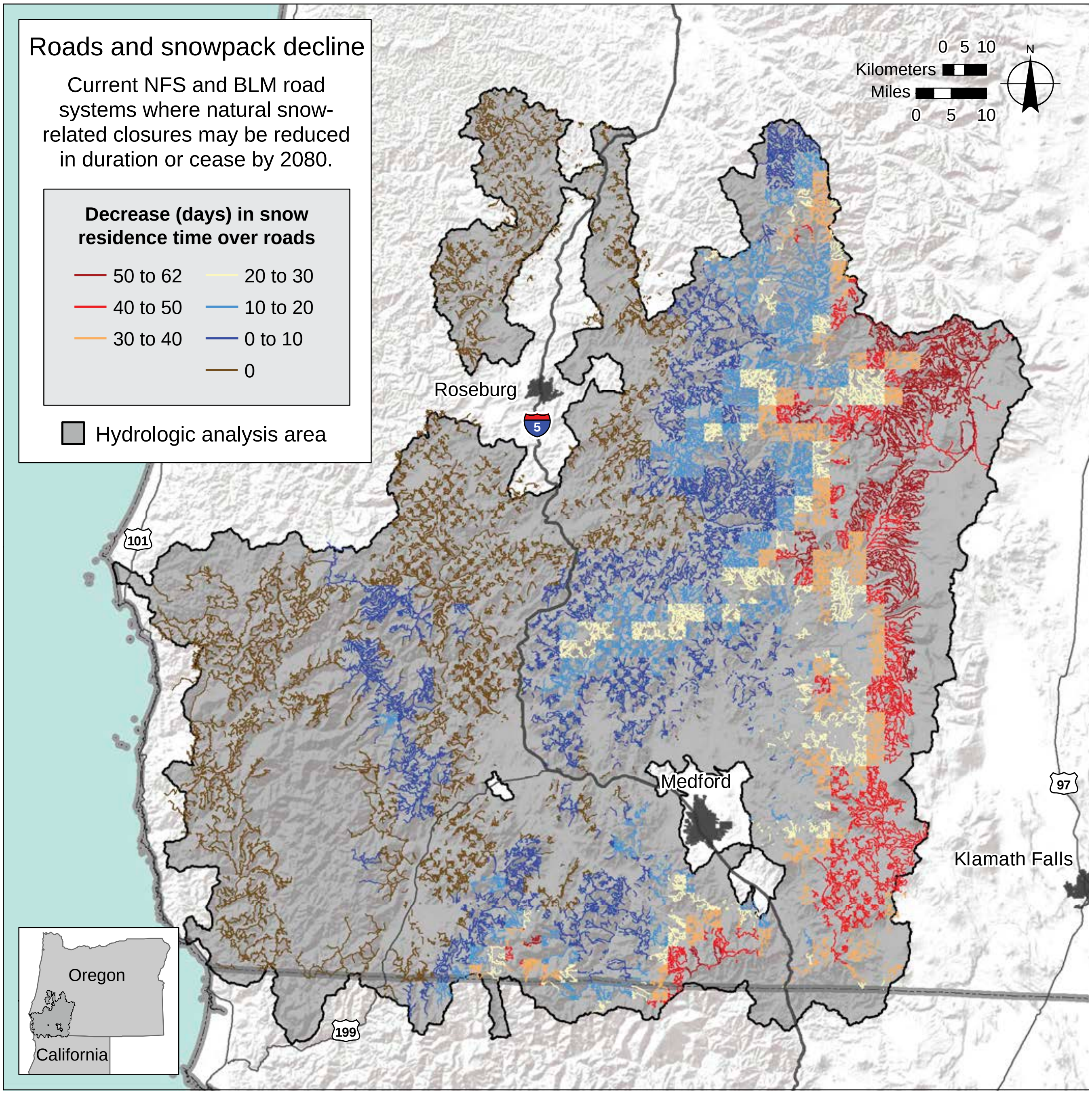

Figure 3.14—Percentage change in snow residence time over roads by 2080. Snow residence time is based on a 3 °C increase in December–March average temperature at Natural Resources Conservation Service Snow Telemetry stations in the Southwest Oregon Adaptation Partnership assessment area (from Luce et al. 2014). NFS = National Forest System, BLM = Bureau of Land Management.

and debris-flow events moves up in elevation following the projected shift in the rain-on-snow zone, subsequent changes to stream flooding regimes and function could occur.

Roads and trails built decades ago have increased sensitivity because of age and declining condition. 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. Higher severity storms, aging infrastructure, and outdated design standards can lead to increased incidents of road failure. The age, foundation, and water channel near bridges must be considered when evaluating the stability of the bridges to withstand high flow and debris (fig. 3.15). Much of the travel network in the SWOAP assessment area, when originally constructed, did not have the advanced design, materials, alignment, drainage, and subgrade required by today’s standards. Problems stemming from poor road designs, outdated standards, and lack of maintenance are likely to worsen, given changes in hydrologic regimes anticipated under changing future climates.

New or replaced infrastructure is likely to have improved resilience to climate change. New culverts and bridges are typically wider than the original structures to meet agency regulations and current design standards. In Umpqua National Forest, most of the bridges are old and have had retrofits to allow continued use. However, many of these bridges are weight-restricted owing to age, even with retrofits. The bridges are being replaced as funding becomes available.

The management of roads and trails (planning, funding, maintenance, and response) will partly determine the degree of sensitivity the current and future transportation system will have to the effects of climate change. Highways in southwest Oregon that are built to a higher design standard and regularly maintained, while not immune to these potential effects, will be less sensitive to climate change than unpaved roads built to a lower design standard. The current lack of funding limits options for responding to the need for infrastructure repair and improvement, thus contributing to the vulnerability of roads and trails.

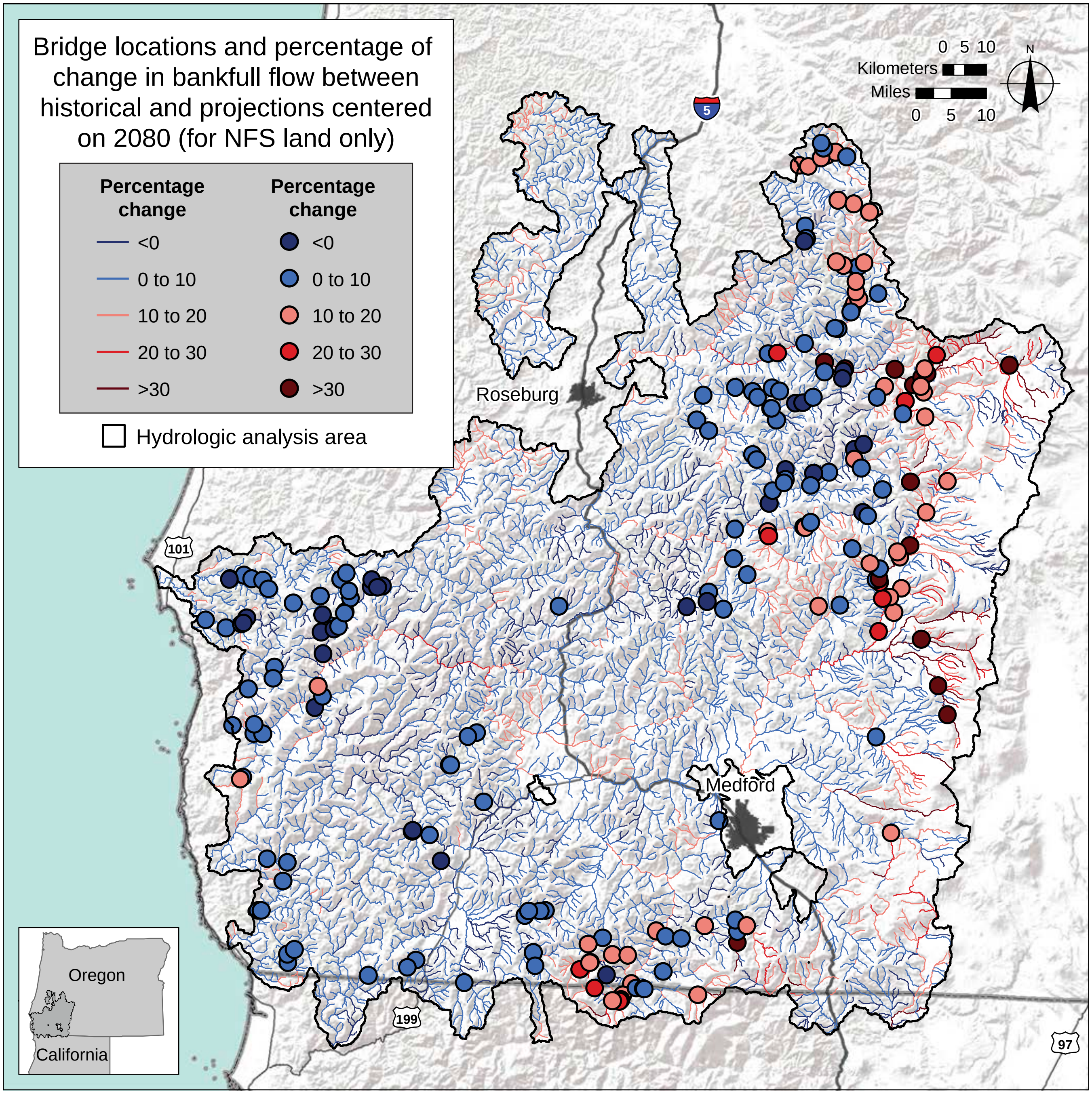

Figure 3.15—Bridge locations and percentage change in bankfull flow between historical data (1970–1999) and 2080 projections under the A1B greenhouse gas emission scenario (moderate scenario similar to RCP 4.5). Streamflow projections are based on Variable Infiltration Capacity model output for surface water input changes filtered by geologically based unit hydrograph. Light blue to red colors indicate projected increases in bankfull flow. NFS = National Forest System.

Current and Short-Term Climate Change Effects

Assessing the vulnerability of the transportation network in the SWOAP assessment area to climate change requires evaluating potential changes in hydrologic processes. Ongoing changes in climate and hydrologic response in 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 increase the risk of flooding and impacts to structures, roads, and trails. In the short term, flooding of roads will likely increase, threatening the structural stability of stream-crossing infrastructure and subgrade material. Roads near perennial and other major streams are especially vulnerable (figs. 3.12 and 3.13), and many of these roads are used for recreation access. Many transportation professionals consider flooding and inundation to be the greatest threat to infrastructure and operations because of the damage that standing and flowing water cause to transportation structures (MacArthur et al. 2012, Walker et al. 2011). Floods transport logs and sediment that block culverts, or are deposited on bridge abutments, and they accelerate scour. During floods, roads and trails can become preferential paths for overland flow, reducing operational function and potentially damaging infrastructure not designed to withstand inundation. If extreme peak flows become more common, they will have a major effect on roads and infrastructure.

Landslides also contribute to flooding by diverting water, blocking drainage, and filling channels with debris (Chatwin et al. 1994, Crozier 1986, Schuster and Highland 2003). Increased sedimentation from landslides causes aggradation within a stream, thus elevating flood risk. Culverts filled with landslide 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 (Swanson and Dyrness 1975; Swanston 1971, 1976), especially if they are built on steep slopes. Chatwin et al. (1994) and Montgomery (1994) found that the number of landslides is directly correlated with total kilometers of roads in an area. Consequently, areas with high road or trail density and projected increases in soil moisture that already experience frequent landslides may be most vulnerable to increased landslide risks.

Short-term exposures to changes in climate may affect safety and access in the SWOAP assessment area. Damaged or closed roads 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 5) could reduce safe operation of some roads and require additional emergency response to protect recreationists and communities (Strauch et al. 2014). Furthermore, damaged and closed roads can reduce agency capacity to respond to wildfires.

Emerging and Intensifying Climate Change Exposure in the Medium and Long Term

Many of the observed exposures to climate change in the short term are likely to increase in the medium (10 to 30 years) and long term (greater 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 in the High Cascades, but 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. 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. Even as crossing structures are replaced with wider and taller structures, shifting channel dynamics caused by changes in flow and sediment may affect lower elevation segments adjacent to crossings, such as bridge approaches. See box 3.2 for a description of a past flood event on infrastructure on the Siskiyou side of the Rogue River-Siskiyou National Forest.

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

Box 3.2

Effects of a Flood Event on Infrastructure in Rogue River-Siskiyou National Forest

The December 1996/January 1997 storm and flood in southern Oregon—estimated to be a 25- to 50-year hydrologic event—provides an opportunity to evaluate susceptibilities of the road system to episodic erosional events, identify downstream effects, and recommend actions that will reduce the frequency and magnitude of future road failures (SNF 1998). Most of the road damage in this storm event was associated with culverts and stream crossings. Culvert plugging was more than twice as common as the second leading cause of road failure, accounting for 43 percent of all road failures. Other causes included fill failure by stream undercutting (21 percent), culvert plugging by debris torrents (12 percent), fill failures not at stream crossings (11 percent), cutbank failures (9 percent), and hydraulic exceedance of culvert capacity (4 percent) (SNF 1998).

Stream diversions at road-stream crossings were identified as the cause of the most damaging storm-related erosional process in the analysis. A stream diversion is where a culvert at a road-stream crossing plugs, causing the water to divert down the road ditch, and resulting in accelerated surface erosion. Diversion potential existed at many mid and upper hillslope road-stream crossings, greatly increasing the downstream effects of road failure sites. Stream diversions resulted in two to three times more sediment delivery than fill overtopping and complete stream crossing washout (SNF 1998). In-sloped roads often carried ditch runoff and diverted streamflow long distances across the hillside, sometimes more than 0.8 km.

Culvert exceedance and plugging, in turn, caused ponding, overtopping, crossing failure (washout), or stream diversion. Stream diversions led to gullying, landsliding, and other cascading effects where small failures high in the watershed produced or contributed to increasingly large failures farther down the hillside. For example, stream diversions frequently caused plugging of multiple ditch-relief culverts, ditch scour, hillslope landslides, and gullies. All of these processes greatly increased sediment delivery.

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 cold-water fish populations, although some streams may be buffered by inputs from snowmelt or ground water in the medium term.

Over the long term, higher winter soil moisture may increase the risk of landslides in autumn and winter. Landslide risk may increase more in areas with tree mortality from fire and insect outbreaks, where tree mortality reduces soil root cohesion and decreases interception and evaporation, further increasing soil moisture (Martin 2006, Montgomery et al. 2000, Neary et al. 2005, Schmidt et al. 2001). Landslides may also occur in new areas (e.g., those areas which 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.

Warmer temperatures and earlier snowmelt may encourage use of trails and roads before they are cleared. Relatively rapid warming at the end of the 20th century coincided with greater variability in cool-season precipitation and increased flooding (Hamlet and Lettenmaier 2007). If this pattern continues, early-season visitors may be exposed to more extreme weather than they have encountered historically, creating potential risks to visitors. Warmer winters may shift river recreation to times of the year when risks of extreme weather and flooding are higher. These activities may also increase use of unpaved roads in the wet season, which can increase damage and associated maintenance costs.

Climate change may also benefit access and transportation operations in the SWOAP assessment area 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 mid- and high-elevation areas will be accessible earlier. Earlier access to roads and trails could create opportunities for earlier seasonal maintenance and recreation. A longer snow-free season and warmer temperatures may allow for a longer construction season at higher elevations. Less snow may increase access for summer recreation, but it may reduce opportunities for winter recreation, particularly at moderate elevations (Joyce et al. 2001, Morris and Walls 2009). The highest elevations of the SWOAP assessment area may retain relatively more snow than other areas, which may create higher local demand for winter recreation and for river rafting in summer over the next several decades.

Adapting Water Use and Infrastructure Management to Climate Change

Based on the vulnerability assessment information presented in this chapter, and on documented adaptation principles (e.g., Millar et al. 2007, Peterson et al. 2011, Swanston et al. 2016), adaptation options for southwest Oregon were identified by participants in a workshop that took place in Grants Pass, Oregon, in April 2018. Participants in the hydrology, water use, and infrastructure group included hydrologists and engineers from Rogue River-Siskiyou and Umpqua National Forests and other local partners. Participants identified strategies, or general approaches, for adapting water use and infrastructure management to climate change. Participants also identified more specific on-the-ground tactics, or actions, associated with each adaptation strategy and considered the implementation of those tactics, specifically, locations or situations in which those tactics can be applied. These strategies and tactics, intended to guide both short- and long-term planning and management, were required to be feasible with respect to budget and level of effort, and to be acceptable within current policies. Adaptation options were focused on addressing key climate change sensitivities for water in southwest Oregon, including increased peak flows and associated increases in infrastructure damage and sediment delivery to streams; earlier snowmelt and lower summer baseflows; and increased risk of landslides with higher winter soil saturation. These adaptation options are summarized below and in table 3.8.

Higher peak streamflows and increased vegetation disturbances (e.g., wildfires and drought) with climate change are likely to lead to increased sediment delivery to streams, in some cases, negatively affecting aquatic habitat (Goode et al. 2012, Peterson and Halofsky 2018). Higher peak streamflows are likely to increase damage at road-stream crossings, further contributing to increases to sediment delivery to streams (Halofsky et al. 2011).

To reduce sediment delivery to streams from roads, managers suggested disconnecting ditch lines from streams during watershed restoration projects, timber projects, vegetation management projects, stewardship activities, and road management activities, particularly where peak flows are projected to increase by more than 10 percent by mid-century (table 3.8). Safeguards such as drain dips at stream crossings could help prevent diversions. Construction of sediment retention structures and out-sloping of road segments would also minimize sediment input to streams (Halofsky et al. 2019). Road decommissioning would have local benefits to aquatic habitats in terms of reducing fine sediment inputs (Goode et al. 2012). These actions may be particularly effective in areas where rain-on-snow events are expected in the future (i.e., in watersheds shifting from snow dominated to mixed rain and snow).

Table 3.8—Water use and infrastructure adaptation options for southwest Oregon

Sensitivity to climate change	Adaptation strategy	Adaptation tactic
High peak flows will lead to increased road damage at stream crossings, causing increased sediment delivery to streams and damage to infrastructure.	Reduce stream network extension from constructed features.	Disconnect ditch lines from streams. Construct sediment retention structures. Out-slope road segments.
	Use climate change projections from the vulnerability assessment in project decisionmaking.	Choose appropriate structures and sizing at stream crossings. Take into account future projected increases in peak flows. Use streamflow projections to inform project-level travel management decisions. Apply streamflow projections to the watershed condition framework when choosing watersheds for restoration.
Climate change will lead to earlier snowmelt and lower summer baseflows.	Design, create, and promote upslope features that will increase water storage.	Design vegetation treatments that capture and retain snow on the ground. Thin young to mid-age plantations at a large scale. Restore compacted surfaces, such as landing, skid trials, and old roads.
	Design, create, and promote instream features that will increase water storage.	Conduct instream restoration with large woody debris. Reconnect floodplains and side channels.[a] Conduct meadow restoration and promote beaver dams. Design culverts that accommodate beaver activity.
Increased winter soil saturation leads to higher risk of landslides, affecting road systems, access, water quality, human safety, and maintenance costs.	Increase resilience of existing infrastructure within landslide-prone zones.	Stabilize slopes with vegetation or by mechanical means. Map landslide-prone areas with light detection and ranging, and use mapping to apply mitigation measures. Locate/relocate roads in areas less vulnerable to landslides.[a] Close and decommission roads in areas of high landslide risk.[a] Install early warning systems to notify visitors of danger.

[a] Indicates adaptation strategies and tactics from the Climate Change Adaptation Library for the Western United States (http://adaptationpartners.org/library.php) identified as relevant to southwest Oregon by workshop participants.

To minimize damage to infrastructure from increased peak flows, managers can use streamflow projections that consider climate change to help in making management decisions. For example, managers may want to consider streamflow projections in decisions on structure type and sizing at stream crossings (Halofsky et al. 2011). Similarly, project-level travel management and restoration decisions could be informed by streamflow projections (table 3.8). Areas where damage is most likely can be identified by evaluating where roads are currently damaged by floods, current infrastructure condition, and projected changes in peak flows (Strauch et al. 2015).

Conditions that trigger landslides may occur more frequently in winter with more precipitation falling as rain rather than snow, higher soil moisture, and more intense winter storms (Strauch et al. 2015). To decrease landslide risk, managers suggested stabilizing slopes (with vegetation, drainage, walls, buttresses, or other mechanical means), mapping landslide-prone areas to identify locations for mitigation measures, locating or relocating roads in areas that are less vulnerable to landslides, and decommissioning roads in areas vulnerable to landslides (table 3.8). Landslides may also increase with tree mortality caused by fire and insect outbreaks (Strauch et al. 2015). Identifying landslide hazard areas and susceptible roads prior to the disturbance events can help in identifying areas where treatments may be useful to decrease hazards (Peterson and Halofsky 2018).

Climate change will likely lead to lower snowpack, earlier runoff, and lower summer streamflows in southwest Oregon. Vegetation treatments may help to increase water storage in uplands and thus help to maintain summer baseflows. For example, manipulating forest openings may help increase snow capture and retention (where snow persists) (Troendle 1983), but there is still uncertainty around how to make these types of treatments effective (e.g., how much area would need to be treated to significantly increase snow retention). Roads and other compacted surfaces can be decommissioned or re-engineered to help increase upland water storage (Kolka and Smidt 2004), particularly in locations where summer streamflows are expected to decrease most.

Instream restoration can also increase hydrologic function and water storage. For example, stream restoration techniques that improve floodplain 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 (Halofsky et al. 2019). Reintroducing or supporting populations of American beaver (*Castor canadensis* Kuhl) may also help to slow water movement and increase water storage in some locations (Pollock et al. 2014, 2015).

Conclusions

The greatest changes in water resources and infrastructure in southwest Oregon are likely to occur in areas near the Cascade and Siskiyou crests. Fortunately, many of these areas also have porous bedrocks, offering some dampening of the effects of these changes on low flows and peak flows. The Rogue River and North Fork of the Umpqua River will see effects from these high-elevation changes propagate down much of their length.

A primary change for southwest Oregon will be the loss of snowpack, both in terms of its volume and how long it lasts. Most of this change will be in the currently snow-covered Cascade and northeastern Siskiyou Mountains. The decreased storage of water by snow in the Cascades will lead to lower summer low flows and higher winter peak flows. Changes to low flows will affect water supplies and aquatic habitat. Higher peak flows in currently snow-dominated watersheds may put transportation and recreation facilities at seasonal risk.

Loss of snowpack from roads will affect access and potentially road condition. Many roads are effectively closed by deep snowpacks in the eastern half of the region, and these are likely to see more time open during the wet season. One effect is increased erosion potential related to traffic on roads that have not been prepared for wet-season traffic. Another effect is increased safety concerns because recreationists will have access to federal lands during the time of year when landslides and floods are most likely.

Summer water supplies and water needs for terrestrial and aquatic ecosystem will be more severely strained. Adaptive capacity for water supply exists in terms of reservoir storage, but financial and ecological costs of reservoir construction and operation may impose constraints. Transportation facilities may be substantially challenged by flooding and increased wet weather traffic, requiring decisions about closure or storm damage risk reduction. Stream crossings will need to be considered to see if the infrastructure in place (culverts, dams) will withstand projected increases in peak flow.

Interpreting climate change effects for the rugged western half of the region requires thinking about processes at a fine spatial scale. The canyons and ridges span elevation ranges that are great enough to go from nearly no snowpack near the base to relatively consistent seasonal snow at the top, and the changes in snow frame some of the more obvious effects of climate change. Local loss of snow will likely lead to more small streams drying earlier or being subject to rain-on-snow flooding, with consequences for sediment yields, fisheries, and water quality. At the same time, reduced summer precipitation will likely make more of the region subject to wildfire and other disturbances, while further reducing low flows. Such disturbances would add to water quality declines in these smaller streams.

The fractured and diverse geology of this portion of the assessment area also leads to fine-scale changes in geologic storage of water that will have important consequences for understanding effects on some of the region’s unique biota. This region will require thought and observation by local professionals to understand the full scope of what is likely to happen.

Adaptation actions may help to reduce the negative effects of a changing hydrologic regime on water use, infrastructure, and aquatic ecosystems. Sediment delivery to streams from roads can be reduced by disconnecting ditch lines from streams during watershed restoration, timber projects, vegetation management, and road management. Landslide risk will be reduced by stabilizing slopes, mapping landslide risk, locating or relocating roads in areas that are less vulnerable to landslides, and decommissioning roads in vulnerable locations. Streamflow projections that consider climate change can inform decisions on structure type and sizing at stream crossings, as well as decisions about travel management and restoration. Instream restoration techniques will improve floodplain connectivity and increase water storage capacity (e.g., adding wood to streams). Reintroducing or supporting populations of American beaver may also help to slow water movement and increase water storage.

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Chapter 4: Climate Change Effects on Fish Species in Southwest Oregon

Daniel J. Isaak, Brett B. Roper, Gordon H. Reeves, and Dona Horan[1]

Introduction

The Southwest Oregon Adaptation Partnership (SWOAP) assessment area hosts important coldwater fish species and several regional endemics that have declined in response to invasive species, habitat fragmentation and degradation, overharvest, and water development (Hessburg and Agee 2003, Nehlsen et al. 1991, Sanderson et al. 2009). Environmental trends related to climate change may further alter aquatic habitats and pose additional risks to native populations. In part, that is because fish species are ectothermic, thus thermal conditions dictate their metabolic rates and most aspects of their life cycles—how fast they grow and mature, whether and when they migrate, when and how often they reproduce, and when they die (Brannon et al. 2004, Magnuson et al. 1979, Neuheimer and Taggart 2007). However, aquatic species are equally attuned to hydrologic variability (Barnett et al. 2008, Jonsson and Jonsson 2009, Poff et al. 2010) and disturbance regimes that shape their life history, phenology, dispersal capacity, and persistence in dynamic environments (Reeves et al. 1995, Rieman and Dunham 2000).

Human-caused climate change effects on freshwater ecosystems have long raised concerns because of their potential to directly and pervasively affect aquatic environments (Keleher and Rahel 1996, Meisner 1990). Numerous studies have emerged in recent years that document long-term climate-related trends in aquatic environmental conditions that affect aquatic regimes, both regionally (Arismendi et al. 2013, Barnett et al. 2008, Hamlet and Lettenmaier 2007, Isaak et al. 2012a, Luce and Holden 2009, Mote et al. 2005) and in or near southwest Oregon (Asarian and Walker 2016, Bartholow 2005, Safeeq et al. 2013). Biological evidence also exists for fish population responses to environmental trends associated with climate change in the form of shifting distributions (Al-Chokhachy et al. 2016, Comte and Grenouillet 2013, Eby et al. 2014), adjustments in phenology (Crozier et al. 2011, Martins et al. 2012), and evolutionary change (Kovach et al. 2012, Manhard et al. 2017). Moreover, coldwater salmon and trout populations that are often of management and conservation concern show evidence of heat-related stress in some rivers

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during warm summers, including migration delays, mortality events, or population declines that may lead to fishing season closures (Bowerman et al. 2016, Cooke et al. 2004, Keefer et al. 2009, Lynch and Risley 2003), all of which are expected to increase in the future (Isaak et al. 2018). Climate change during the 21st century (chapter 2) is likely to have important implications for the distribution, abundance, and persistence of some populations of fish species and will complicate conservation and management efforts on their behalf.

A key challenge with respect to climate change is human adaptation strategies, which ultimately require detailed information about local climatic conditions and natural resources to guide tactical decisionmaking. Rather than reviewing the large and growing literature that describes interactions among climate change and aquatic environments (e.g., Comte et al. 2013; Hauer et al. 1997; Hotaling et al. 2017; Isaak et al. 2012a, 2012b; ISAB 2007; Kovach et al. 2016; Lynch et al. 2016; Mantua et al. 2010; Mote et al. 2003; Rieman and Isaak 2010; Whitney et al. 2016), we summarize information specific to the SWOAP assessment area.

First, we provide a historical perspective of the aquatic habitats in the landscape and past activities that affect their current status and ability to support aquatic species. Second, we describe the spatial extent of the stream and river habitats in the analysis area using geospatial datasets, then describe climate-related historical and future trends in hydrologic and thermal regimes using high-resolution scenarios. Third, we describe the status and potential climate vulnerabilities for fish species of concern in the assessment area, which were identified from discussions with U.S. Department of Agriculture, Forest Service (U.S. Forest Service) land managers and regional staff, and biologists from several other agencies. Species were chosen based on their perceived vulnerability to climate change or because of their societal prominence as Endangered Species Act (ESA) listed species and include Chinook salmon (*Oncorhynchus tshawytscha* Walbaum in Artedi) (spring and fall runs); coho salmon (*O. kisutch* Walbaum), the anadromous form of rainbow trout commonly referred to as steelhead (*O. mykiss* Walbaum) (summer and winter runs); coastal cutthroat trout (*O. clarkii clarkii* Richardson); Pacific lamprey (*Entosphenus tridentatus* Richardson); and Umpqua chub (*Oregonichthys kalawatseti* Markle, Pearsons and Bills) (table 4.1). Finally, we conclude with a general discussion of climate adaptation options that may be useful for partially mitigating future effects and tracking or understanding ecosystem responses in the 21st century.

Table 4.1—Summary of fish species of concern and climate vulnerability in the Southwest Oregon Adaptation Partnership assessment area

Species or run	Range extent	Population status/ trend	Climate vulnerability	Comment
Coho salmon	Alaska through California	Depressed/stable	Moderate	ESA listed as threatened[a]
Chinook salmon:				
Spring run	Alaska through California	Depressed/stable	High	
Fall run	Alaska through California	Healthy/stable	Low	
Steelhead:				
Summer run	Alaska through California	Depressed/stable	High	
Winter run	Alaska through California	Healthy/stable	Moderate	
Coastal cutthroat trout	Alaska through California	Depressed/stable	Moderate	
Pacific lamprey	Alaska through California	Depressed/stable	Moderate	
Umpqua chub	Endemic within Umpqua basin	Depressed/declining	Low to moderate[b]	

ESA = Endangered Species Act.

[a] Populations in the Umpqua River and Rogue River basins are part of two distinct evolutionary significant units (Oregon Coast and Southern Oregon–Northern California Coast).

[b] Direct effects of climate change on this species are low, but secondary effects may be high via predation by a smallmouth bass population that is expanding as stream temperatures increase.

Aquatic Landscape Conditions

The aquatic landscape in the SWOAP assessment area consists of a 13 000-km network of streams and rivers that drain topographically steep, forested, relatively low-elevation basins with mixed private and federal ownership. The main rivers are the Rogue River and its two southern tributaries, the Applegate and Illinois Rivers, and the two forks of the Umpqua River upstream of their confluence (fig. 4.1). Minor river drainages with fish species of concern include the Chetco, Coquille, and Elk Rivers. Dams on Lost Creek, Applegate River, Elk Creek, and the upper Rogue River block access to areas historically occupied by anadromous fish. Reservoirs behind the two largest dams on the Applegate and Rogue Rivers thermally stratify, and downstream water releases are approximately 2 °C cooler than ambient conditions during the summer and 2 °C warmer during the winter (Angilletta et al. 2008).

Stream habitats throughout the SWOAP assessment area have been degraded since the mid-19th century Euro-American settlement. Initial entries into basins were often made in pursuit of precious metals (Scott 1917), and later dredge mining activities removed significant amounts of alluvium from riverbeds and have contributed to current conditions wherein some streams are scoured to bedrock (O'Connor et al. 2014). The local economy and human population size grew from the late 19th

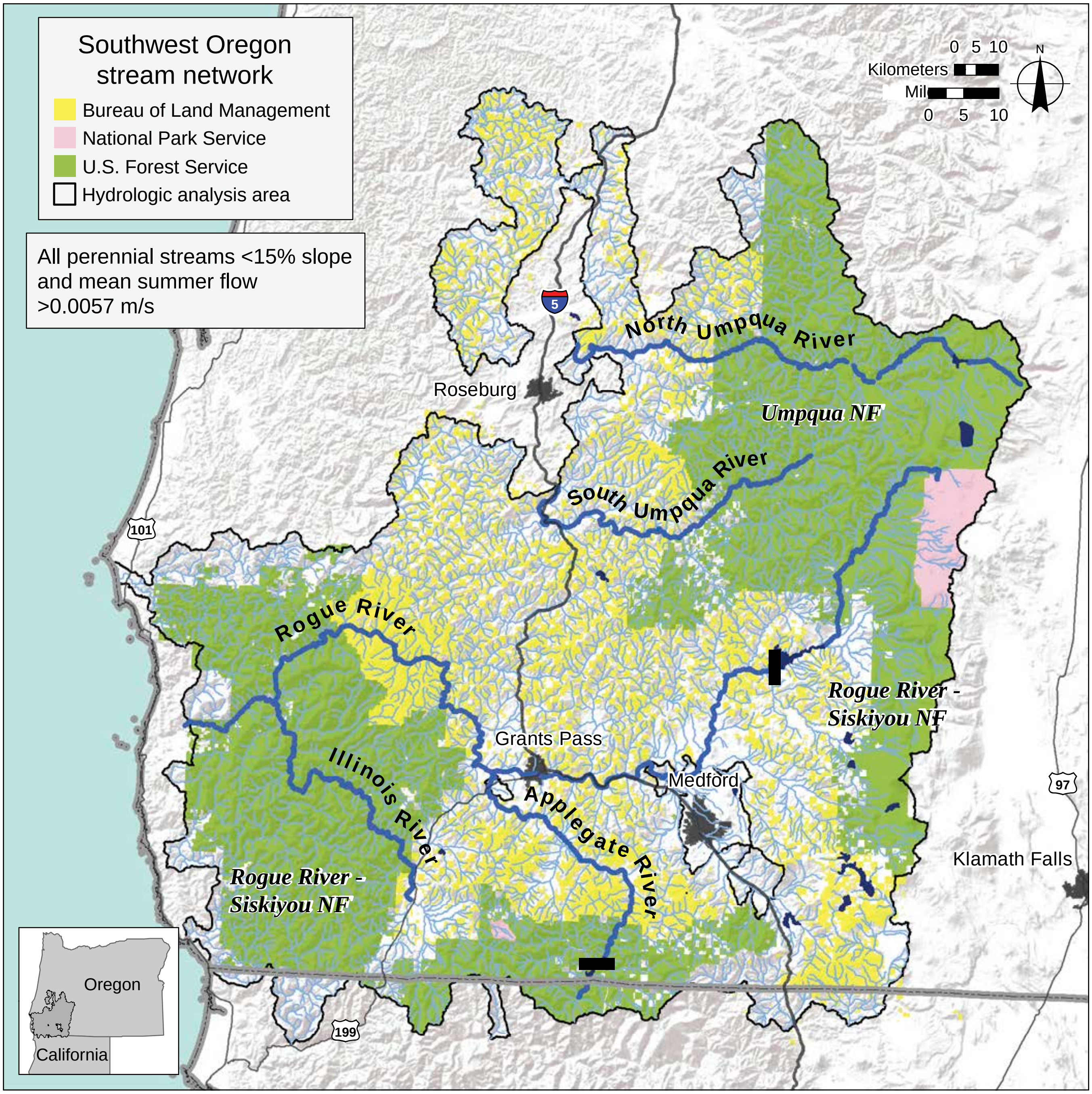

Figure 4.1—Stream network in the Southwest Oregon Adaptation Partnership assessment area. Two of the large dams that affect downstream temperature regimes are shown with black boxes.

until the middle 20th century, spurred by commercial industries focused on harvesting abundant salmon runs and logging the region's timber (Taylor 1999).

Timber extraction was accompanied by development of an extensive road network that contributed fine sediments into streams, increased the incidence of hillslope failures, and sometimes restricted fish movements where road culverts provided inadequate stream passage (Steel et al. 2004, Trombulak and Frissell 2000). Moving timber downstream to sawmills was sometimes accomplished by development and purposeful destruction of splash dams. Subsequent log passage along stream courses was expedited by removal of large woody debris and other roughness elements that are now recognized as important contributors to fish habitat diversity (Miller 2010, Sedell and Froggatt 1984, Wing and Skaugset 2002).

Road construction and timber harvest adjacent to streams opened riparian canopies and probably contributed to alteration of stream thermal regimes (Johnson and Jones 2000, Moore and Wondzell 2005). Intense timber harvest and dense accompanying road networks in some basins altered hydrologic regimes and increased peak flows compared to unharvested basins (Jones and Grant 1996, Moore and Wondzell 2005). Repeat surveys spanning the 50-year period of 1937 to 1987 showed that channels in managed watersheds were significantly wider than those in protected watersheds in the South Umpqua basin (Dose and Roper 1994), a result that is attributed to increased sediment loads, altered hydrology, and poor streambank conditions associated with timber harvest and road construction (Beschta 1978). Growth in municipal and agricultural development during the 19th and 20th centuries also led to increased water needs and diversion of water from stream and river courses (Hayes and Herring 1960). These trends are likely to continue with the growth of urban areas this century, and as the proportion of paved surfaces increases, it could contribute to flashier hydrographs and thermal spikes in some basins (Walsh et al. 2005).

Alteration of stream and river habitats, exacerbated by commercial and recreational overfishing, led to steep declines in many salmon and steelhead populations by the mid 20th century (FCO 1946). Populations currently remain at depressed levels for most species and are estimated to be 5 to 15 percent of their presettlement abundance (Meengs and Lackey 2005). Hatcheries have been developed in the Rogue River (Cole River Hatchery) and North Fork Umpqua (Rock Creek Hatchery) basins to subsidize populations of spring and fall Chinook salmon, coho salmon, summer and winter steelhead, and rainbow trout. Several nonnative fish species have been introduced to southwest Oregon and support popular fisheries, including brown trout (*Salmo trutta* Linnaeus), brook trout (*Salvelinus fontinalis* Mitchill), striped bass (*Morone saxatilis* Walbaum), and smallmouth bass

(*Micropterus dolomieu* Lacepède) (Baigun 2003, Dambacher 1991). These species often compete with, or prey on, native fishes. Smallmouth bass, in particular, has expanded throughout the main stem of the Umpqua River and is thought to be a primary agent causing declines of Umpqua chub populations (O'Malley et al. 2013, Simon and Markle 1999).

The generally poor status of anadromous fish species in southwest Oregon and elsewhere along the west coast of North America has motivated prominent regional conservation efforts, development of the Northwest Forest Plan (Reeves et al. 2018), and subsequent enactment of the Aquatic and Riparian Effectiveness Monitoring Plan (AREMP) to monitor stream conditions on Forest Service and Bureau of Land Management (BLM) lands throughout the region (Reeves et al. 2003). Trend monitoring datasets collected since 1994 with the inception of the AREMP program suggest that stream conditions in watersheds with a majority of public ownership have generally been stable or improving—changes may be attributable to better management practices, reductions in timber harvest, and decommissioning of some roads (Lanigan et al. 2012). Significant stream recovery, however, is expected to take decades given the extent of historical modifications, and fish habitats are likely to remain less diverse and productive than presettlement conditions for the foreseeable future.

Stream Climate Trends

To describe stream climate trends and the extent of habitat available to the species of concern, we delineated a SWOAP assessment area stream network using the 1:100,000-scale National Hydrography Dataset (NHD)-Plus Version 2, which was downloaded from the Horizons Systems website (http://www.horizon-systems.com/NHDPlus/index.php) (McKay et al. 2012). Summer flow values projected by the Variable Infiltration Capacity (VIC) hydrologic model (Wenger et al. 2010) were obtained from the Western U.S. Flow Metrics website (http://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml) and linked to NHD-Plus stream reaches. The network was filtered to exclude reaches with summer flows less than 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. [2013b]) because fish occurrences are rare in these areas (Isaak et al. 2017c). The network was further filtered to exclude reaches with greater than 15 percent slope where fish occurrences are also rare (Isaak et al. 2017c). Especially steep headwater reaches often have geological barriers that are either insurmountable to fish or are prone to frequent disturbances (e.g., postwildfire debris torrents) that may cause local extirpations of fish populations (May and Gresswell 2004, Miller et al. 2003). Application of the reach slope and summer flow criteria created the final 13 000-km network that served as the basis for subsequent analyses and summaries. Forty-three percent of the network flowed through Forest Service lands, 25 percent through BLM lands, and 32 percent through private lands.

Scenarios representing mean August stream temperature were downloaded from the NorWeST website (www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html) (Isaak et al. 2016a) and linked to reaches in the analysis network. NorWeST scenarios have a 1 km resolution and were developed by applying spatial stream network models (Ver Hoef et al. 2006) to temperature records that were collected by resource agencies within the SWOAP assessment area at 989 unique stream sites (Isaak et al. 2017b), and are viewable using a dynamic mapping tool at the NorWeST website. The predictive accuracy of the NorWeST model (cross-validated r^2 = 0.91; cross-validated root mean square prediction error = 1.0 °C), combined with substantial empirical support, provided a consistent and spatially balanced rendering of temperature patterns and thermal habitat for all streams. To depict temperatures during a baseline period, we used the S1 scenario that represented average conditions for 1993–2011 (hereafter 2000s). The mean August stream temperature during this period was 14.7 °C in the SWOAP network and ranged from 5.1 to 23.7 °C among reaches; temperatures were usually cooler in streams flowing through national forest lands at higher elevations (table 4.2, fig. 4.2a).

Future stream temperature scenarios were also downloaded from the NorWeST website and chosen for the same climate periods (2030–2059, hereafter 2040s; 2070–2099, hereafter 2080s) and emission scenario (A1B) as those used for the VIC streamflow analysis in chapter 3. The future NorWeST scenarios used were

Table 4.2—Lengths of streams in the Southwest Oregon Adaptation Partnership assessment area categorized by mean August stream temperatures during a baseline period and two future periods associated with the A1B emission trajectory scenario

	<8 °C	8 to 11 °C	11 to 14 °C	14 to 17 °C	17 to 20 °C	>20 °C
			Kilometers			
All lands:						
2000s (1993–2011)	121	998	3645	5740	1944	548
2040s (2030–2059)	21	611	2006	5609	3629	1097
2080s (2070–2099)	5	333	1361	4643	4807	1798
Forest Service lands:						
2000s (1993–2011)	76	880	2096	1934	384	161
2040s (2030–2059)	15	508	1456	2345	931	276
2080s (2070–2099)	2	257	1106	2237	1510	418

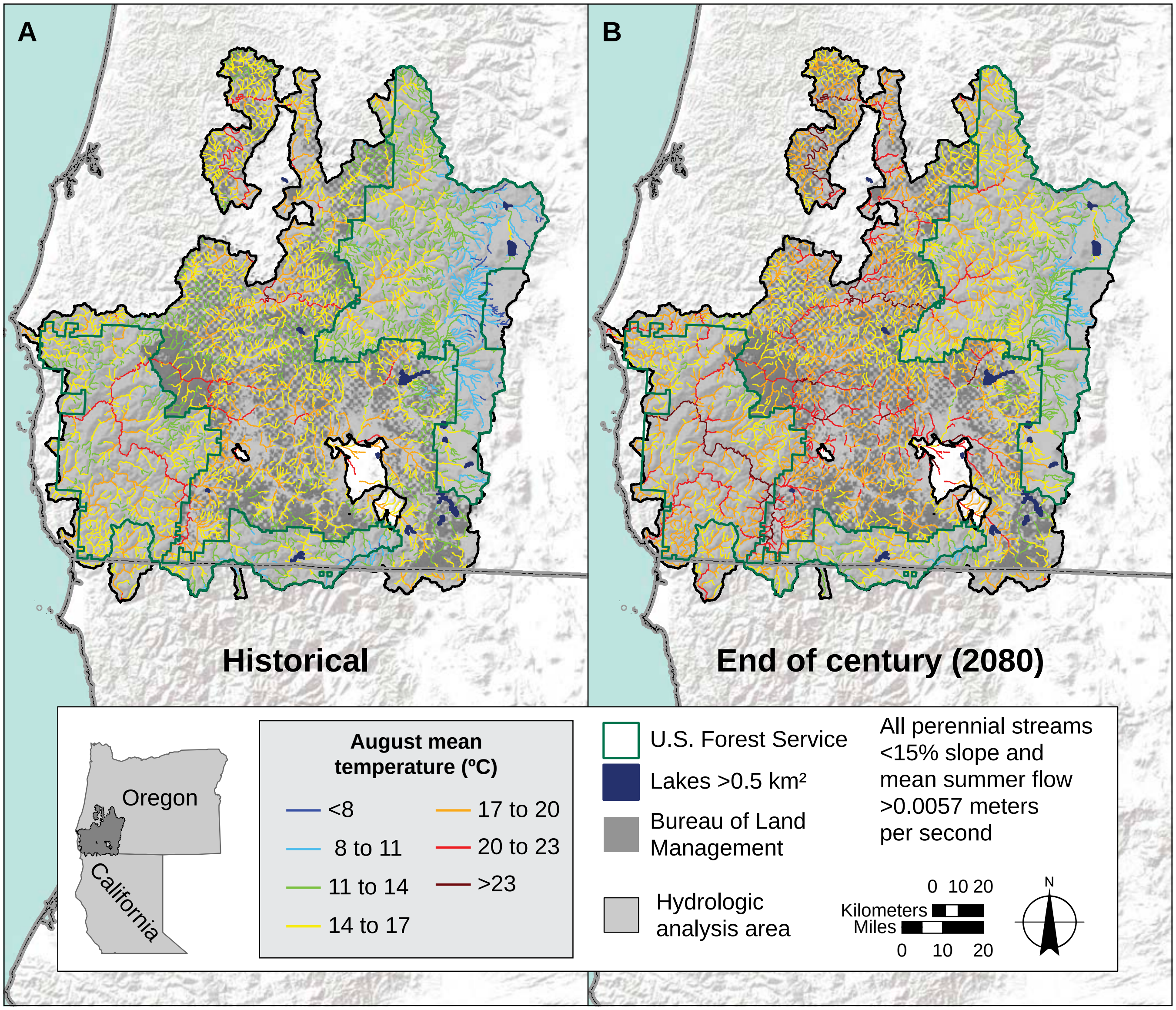

Figure 4.2—Scenarios depicting mean August stream temperatures across the 13 000 km of streams in the assessment area during a baseline period (A: 2000s) and late 21st century (B: 2080s). Panels C and D show future temperature increases relative to the baseline period (future increases are summarized in appendix 4.1 by 6th code hydrologic unit code boundaries that are shown as small black polygons). The Rogue and Applegate Rivers are projected to show minor temperature increases because of dams that release cold water from deep reservoirs during warm summer months. High-resolution images of these maps and ArcGIS shapefiles with reach-scale predictions are available at the NorWeST website (http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html).

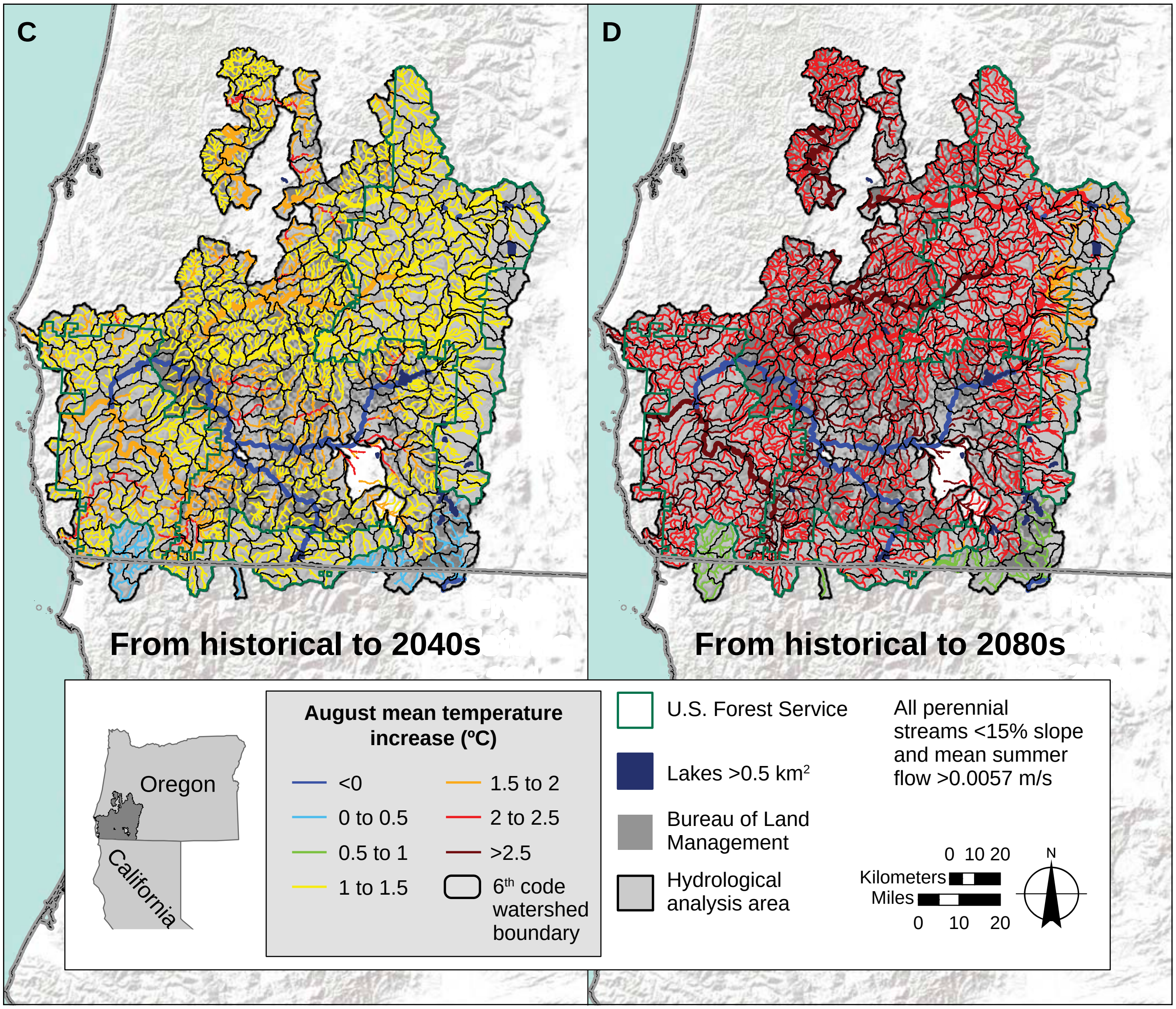

Figure 4.2 (continued)—Scenarios depicting mean August stream temperatures across the 13 000 km of streams in the assessment area during a baseline period (A: 2000s) and late 21st century (B: 2080s). Panels C and D show future temperature increases relative to the baseline period (future increases are summarized in appendix 4.1 by 6th code hydrologic unit code boundaries that are shown as small black polygons). The Rogue and Applegate Rivers are projected to show minor temperature increases because of dams that release cold water from deep reservoirs during warm summer months. High-resolution images of these maps and ArcGIS shapefiles with reach-scale predictions are available at the NorWeST website (http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html).

S30 (2040s) and S32 (2080s) (Isaak et al. 2016b), which account for differential sensitivity and slower warming rates of the coldest streams that are often buffered by groundwater (Isaak et al. 2017b, Luce et al. 2014). Future August stream temperature increases relative to the baseline period of 2000 were projected to average 1.29 °C by the 2040s and 2.23 °C by the 2080s, which implies a warming rate of approximately 0.30 °C/decade (table 4.1, fig. 4.2). That rate is similar to the observed historical warming rate during 1976–2015 of 0.28 °C per decade for mean August temperatures at a small number of unregulated river sites with long-term records in the SWOAP assessment area (fig. 4.3A). A regional analysis of long-term monitoring records at 391 river sites (Isaak et al. 2018) indicates those warming trends are concordant with a broader regional pattern, but also that historical warming trends were common to most summer and early fall months (figs. 4.3 and 4.4).

Spatial variation in patterns of warming were also apparent. River reaches on the Rogue and Applegate Rivers that were downstream of large dams and reservoirs showed little evidence of warming trends during summer months in comparison to free-flowing reaches (figs. 4.2 to 4.4). Releases of cold water from upstream reservoirs account for the lack of warming and represent an adaptation option that water managers may already be exercising to ameliorate thermally stressful conditions for some species. Although these reaches constitute a relatively small portion of the network length within the project area (approximately 2 percent), they are important migratory habitats for some anadromous fish populations. Throughout the broader network outside of the regulated reaches, temperature increases were relatively uniform except for smaller increases in streams at the highest elevations along the eastern and southern portions of the SWOAP assessment area (figs. 4.2C and 4.2D).

Potential changes in streamflow characteristics are described in detail in chapter 3. The SWOAP assessment area has relatively low elevations, so hydrographs of most streams are typical of rainfall runoff patterns, and their form is not anticipated to change appreciably with future warming. For example, projected alterations in runoff timing and mean annual flow are minor (chapter 3). However, important spatial variation exists with regard to projected changes in two ecologically important metrics—the frequency of high-flow events during winter and summer flows (figs. 4.5 and 4.6). The frequency of high winter flows is projected to increase significantly along the Cascade crest in the eastern portion of the SWOAP assessment area (figs. 4.5C and 4.5D).

Summer flows are projected to decline on average throughout the SWOAP assessment area by 21 to 23 percent in the 2040s and 31 to 35 percent in the 2080s (fig. 4.6), which implies similar rates of future change as those observed during

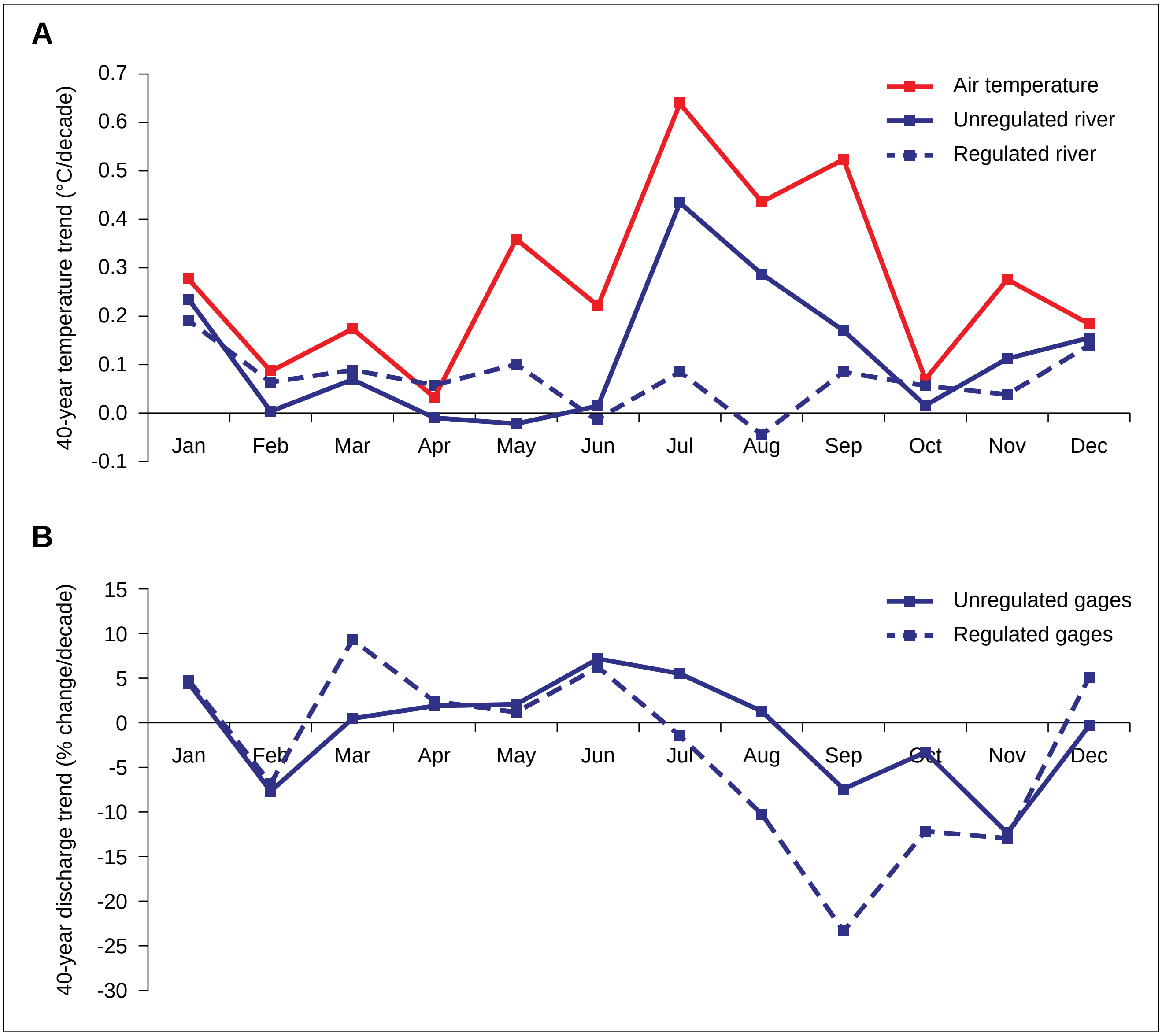

Figure 4.3—Trends in (A) monthly mean air temperatures and river temperatures and (B) discharge at long-term monitoring sites in the Southwest Oregon Adaptation Partnership assessment area for the 40-year period of 1976–2015. Note the differences in summer trends between regulated and unregulated river sites.

past decades at unregulated river sites in the SWOAP assessment area (Asarian and Walker 2016, Isaak et al. 2018). Summer flow declines are anticipated to be particularly large (>30 percent) in streams at the highest elevations along the Cascade crest where snowpacks are at risk (figs. 4.6C and 4.6D, chapter 3). For additional spatial resolution, appendix 4.1 provides a tabular summary of conditions during the historical and future climate periods by 6th code hydrologic units for flow characteristics as well as August stream temperatures.

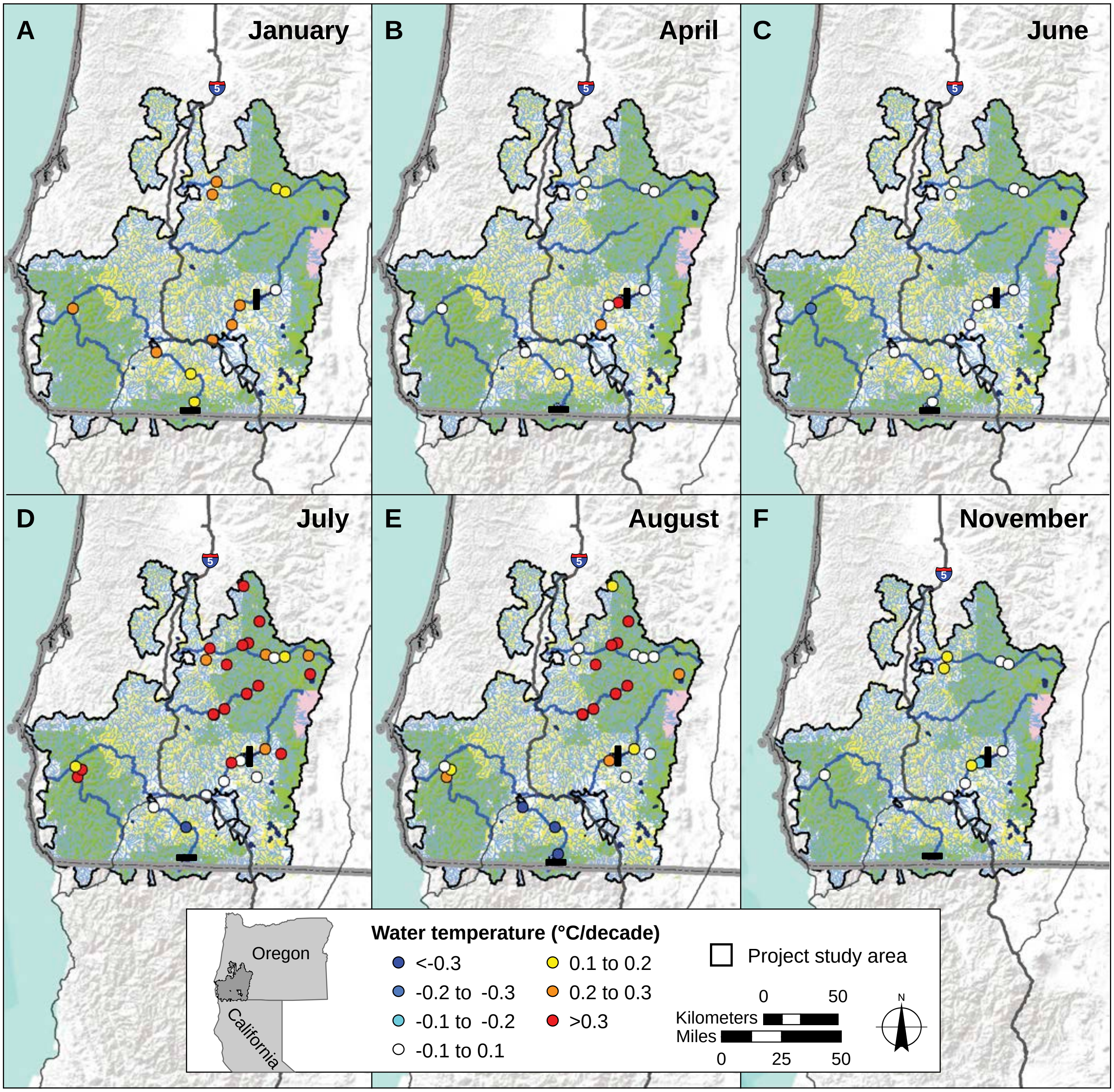

Figure 4.4—Decadal river temperature trends estimated from long-term monitoring records in the Southwest Oregon Adaptation Partnership assessment area for the 40-year period of 1976–2015. Cooling trends in the Rogue and Applegate Rivers during summer months are due to releases of cold water from deep reservoirs. Trend estimates are a subset of those reported for a regional river temperature trend analysis in Isaak et al. (2018). Dams are shown with black boxes.

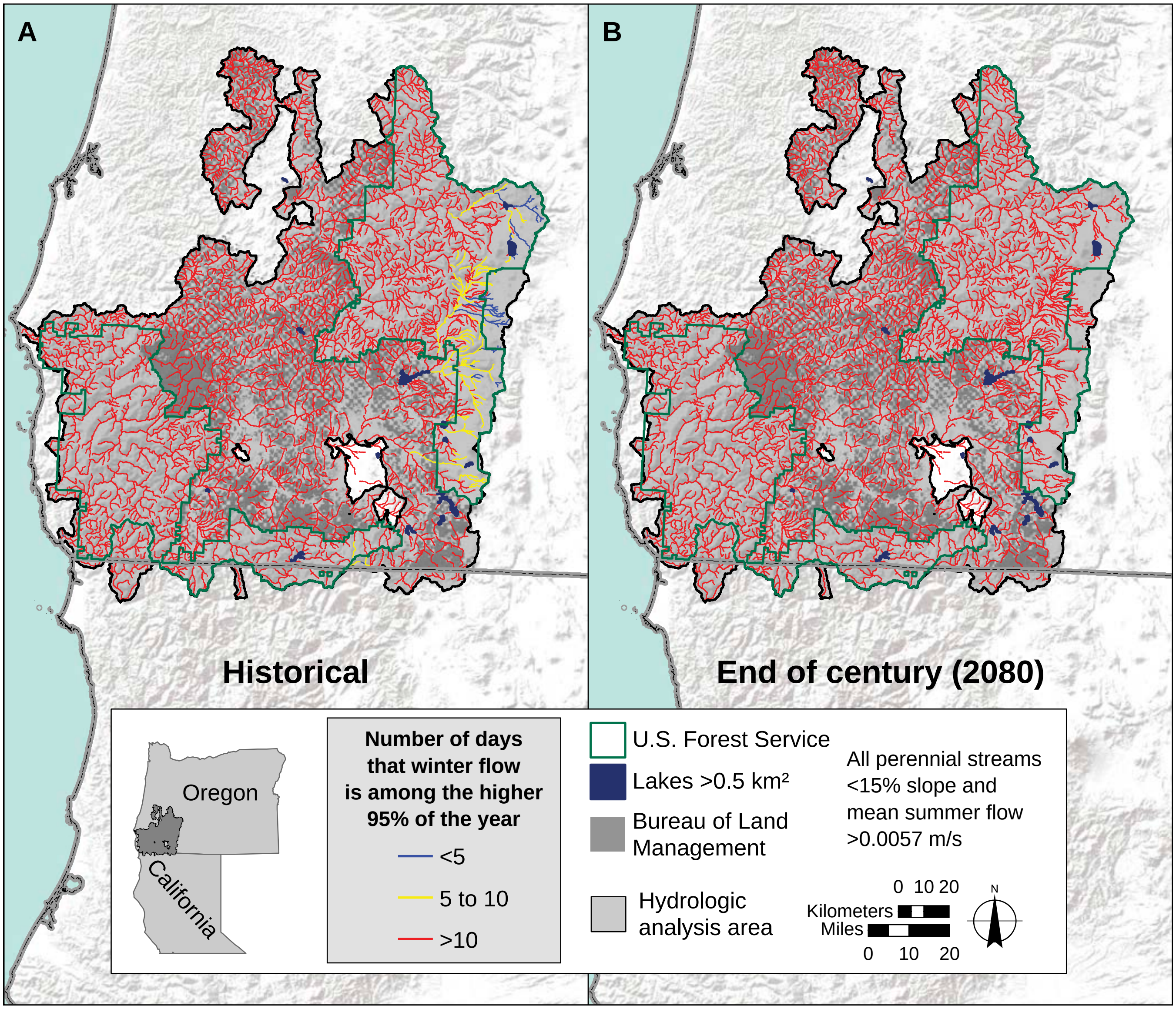

Figure 4.5—Scenarios depicting the number of days with high flows during the winter across the 13 000 km of streams in the assessment area during a baseline period (A: 2000s) and late 21st century period (B: 2080s). Panels C and D show future flow changes relative to the baseline period (future increases are summarized in appendix 4.1 by 6th-code hydrologic unit code boundaries that are shown as small black polygons). ArcGIS shapefiles with reach-scale projections of this flow information are available at the Western U.S. Stream Flow Metrics website (https://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml).

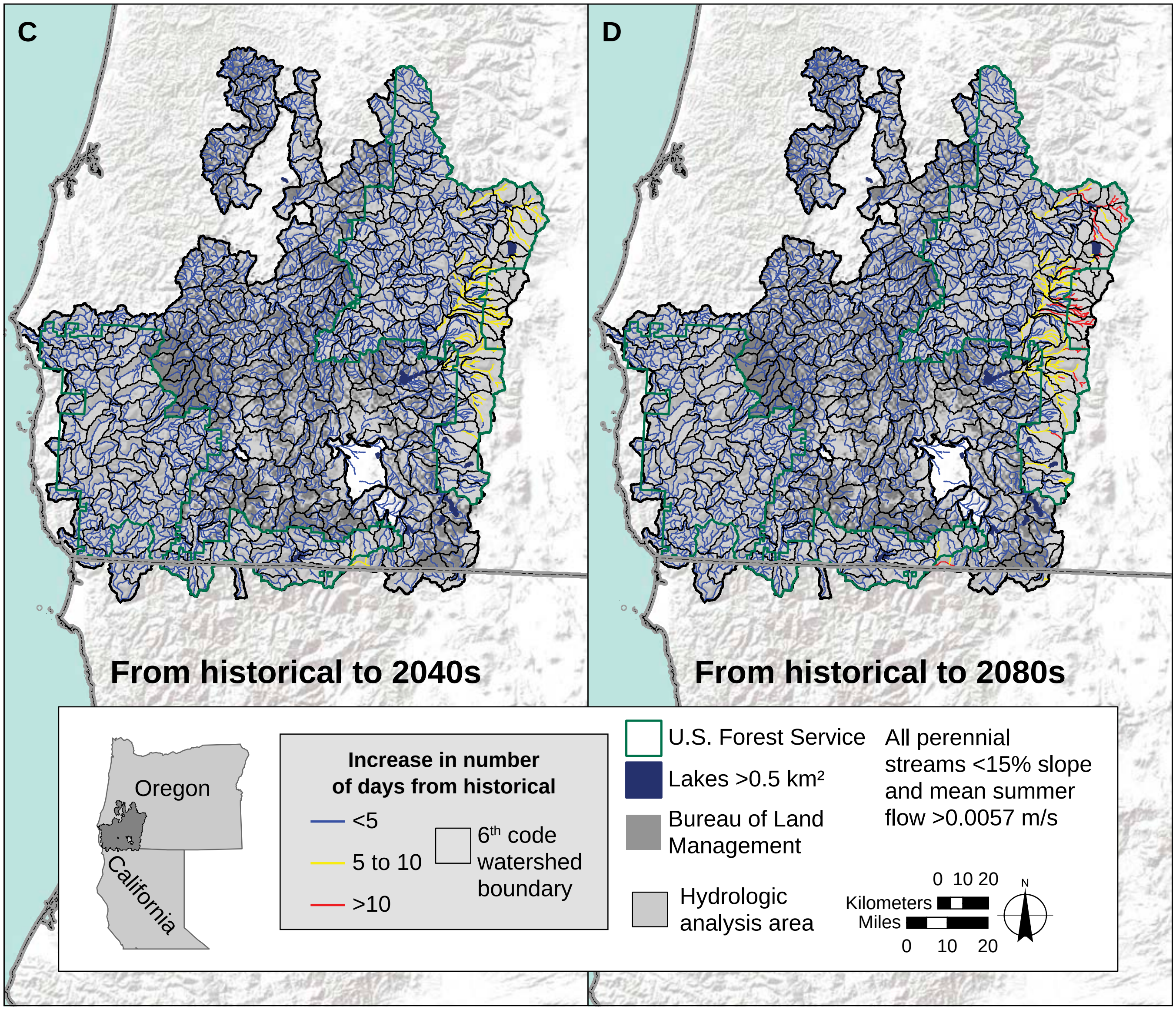

Figure 4.5 (continued)—Scenarios depicting the number of days with high flows during the winter across the 13 000 km of streams in the assessment area during a baseline period (A: 2000s) and late 21st century period (B: 2080s). Panels C and D show future flow changes relative to the baseline period (future increases are summarized in appendix 4.1 by 6th-code hydrologic unit code boundaries that are shown as small black polygons). ArcGIS shapefiles with reach-scale projections of this flow information are available at the Western U.S. Stream Flow Metrics website (https://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml).

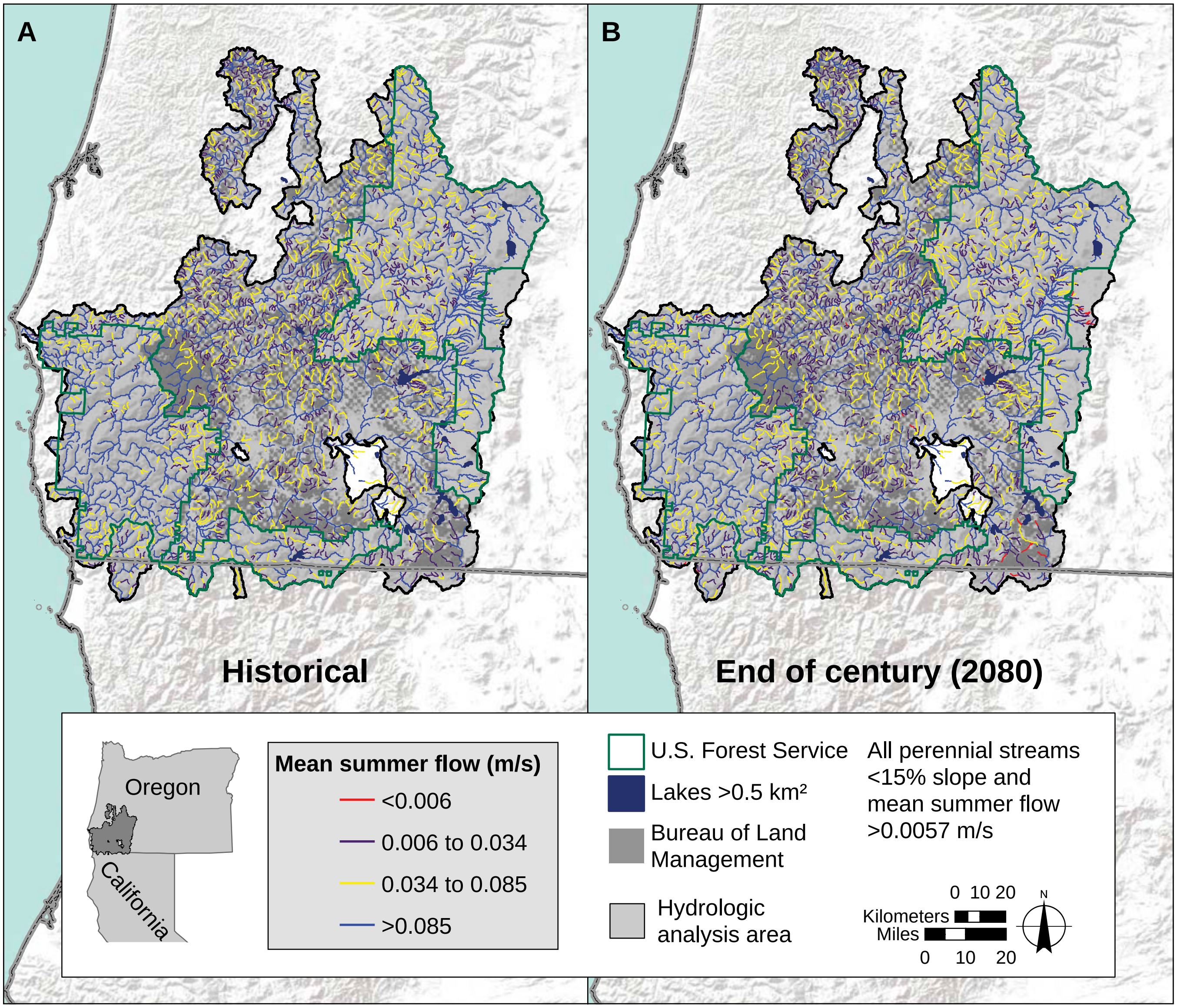

Figure 4.6—Scenarios depicting mean summer flows across the 13 000 km of streams in the assessment area during a historical baseline period (A: 2000s) and late 21st century period (B: 2080s). Panels C and D show future flow changes as percentages relative to the baseline period (future increases are summarized in appendix 4.1 by 6th code hydrologic unit code boundaries that are shown as small black polygons). ArcGIS shapefiles with reach-scale projectons of this flow information are available at the Western U.S. Stream Flow Metrics website (https://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml).

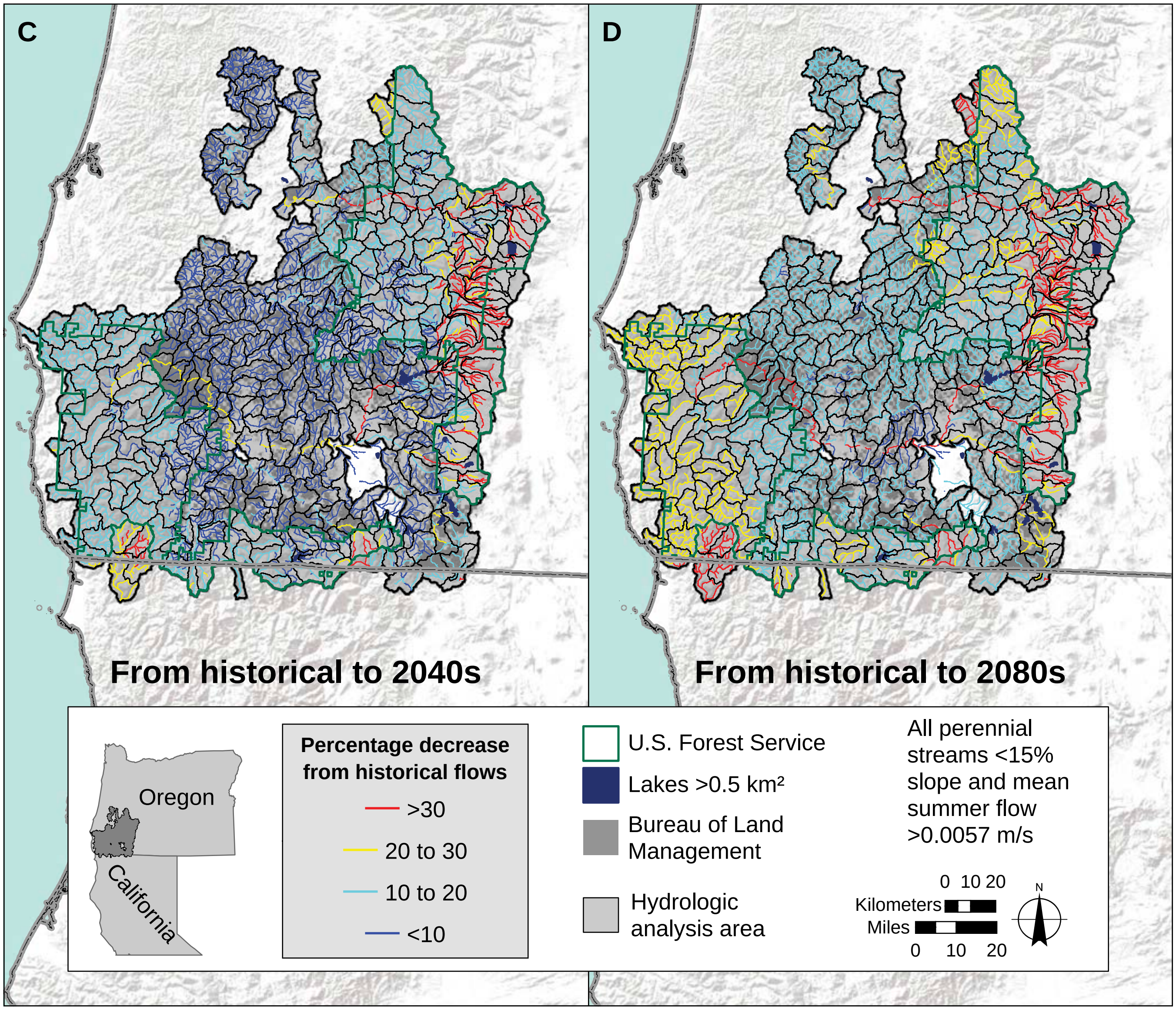

Figure 4.6 (continued)—Scenarios depicting mean summer flows across the 13 000 km of streams in the analysis area during a historical baseline period (A: 2000s) and late 21st century period (B: 2080s). Panels C and D show future flow changes as percentages relative to the baseline period (future increases are summarized in appendix 4.1 by 6th code hydrologic unit code boundaries that are shown as small black polygons). ArcGIS shapefiles with reach-scale projectons of this flow information are available at the Western U.S. Stream Flow Metrics website (https://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml).

Ocean Cycles and Climate Extremes

The abundance of anadromous fish that return to coastal Oregon streams and rivers cycles with changes in ocean productivity, which is an important determinant of fish growth and survival (Hare et al. 1999, Mantua et al. 1997). Ocean productivity varies in response to changes in sea surface temperatures and the strength of coastal upwelling that is tied to regional climate cycles such as the El Niño Southern Oscillation, Pacific Decadal Oscillation (PDO), and the North Pacific Gyre Oscillation (NPGO) (Kilduff et al. 2015). Cooler phases in these cycles alternate with warm phases at 2- to 20-year intervals and are associated with more coastal upwelling and larger returning fish populations (Mantua et al. 1997, Mote et al. 2003).

Recent research has documented a linkage between greenhouse forcing and increasing variance in the North Pacific Oscillation (NPO) (Di Lorenzo and Mantua 2016), which is the primary driver of the NPGO and PDO that explain much of the variation in Chinook salmon and coho salmon recruitment along the west coast of North America (Kilduff et al. 2015, Mantua 2015). Consistent with that linkage, recent winters have shown NPO activity at record highs and the warmest sea surface temperature anomalies ever recorded in the northeast Pacific (i.e., "the blob"), suggesting that extremes in physical conditions linked to salmon survival rates may become more frequent in future decades (Bond et al. 2015, Di Lorenzo and Mantua 2016).

Although these cycles most strongly affect anadromous fishes during their oceanic life stages, inland effects on temperature, precipitation, and hydrologic regimes are also likely to translate to greater variability in the quality and quantity of freshwater habitats (Kiffney et al. 2002, Mote et al. 2003, Sawaske and Freyburg 2014). Increasing temperatures accompanied by more extreme droughts and projected growth of summer water balance deficits create a recipe for more frequent and larger wildfires such as those that have occurred in the SWOAP assessment area in recent decades (chapter 5) (Reilly et al. 2018). More extensive wildfires are likely to result in more debris flows and channel disturbances in steep headwater streams (Miller et al. 2003, Sedell et al. 2015), while also increasing the sediment load being transported through the network (Goode et al. 2012).

Focal Species Status and Vulnerability

Interactions between the climate change trends described in the previous section and the status, ecology, habitat preferences, and climatic sensitivity of individual species determine their vulnerability. Those vulnerabilities are discussed and contextualized in this section using species-specific potential habitat maps. Because the SWOAP assessment area encompasses an area of mixed land ownership, geospatial representations of fish distributions provided by the U.S. Forest Service Pacific Northwest Region, Oregon Department of Fish and Wildlife, and BLM were merged to create the habitat distribution maps.

Coho Salmon

Coho salmon use 1760 km of streams and rivers distributed throughout the assessment area (tables 4.3 and 4.4) and are ESA-listed as threatened (Ford et al. 2011). Populations are part of two evolutionarily significant units (ESUs) that are geographically split along the watershed divide separating the Umpqua and Rogue River basins (Weitkamp et al. 1995). The Oregon coast ESU lies to the north of the divide, and the southern Oregon-northern California coast ESU is to the south.

Table 4.3—Streamflow and temperature characteristics for the Oregon Coast evolutionary significant unit coho salmon habitats shown in figure 4.7 based on changes associated with the A1B emission scenario[a]

Stream metric	Period	Number of high-flow days[b]		
		<5	5 to 10	>10
Number of winter high-flow days	1980s	0	0	619 (100%)
	2040s	0	0	619 (100%)
	2080s	0	0	619 (100%)

		Discharge categories (m^3/s)		
		<0.034	0.034 to 0.085	>0.085
Mean summer flow	1980s	42 (6.7%)	37 (6.0%)	541 (87.3%)
	2040s	45 (7.3%)	37 (6.0%)	537 (86.7%)
	2080s	45 (7.3%)	49 (7.9%)	525 (84.8%)

		Temperature categories (°C)						
		<8	8 to 11	11 to 14	14 to 17	17 to 20	20 to 23	>23
Mean August temperature	2000s	0	0	48 (7.7%)	297 (47.9%)	204 (32.9%)	60 (9.7%)	11 (1.8%)
	2040s	0	0	0	188 (30.3%)	286 (46.2%)	111 (18.0%)	34 (5.5%)
	2080s	0	0	0	107 (17.3%)	282 (45.4%)	161 (25.9%)	70(11.3%)

[a] Values are stream kilometers, and those in parentheses are percentages of the total during a scenario period.

[b] A high-flow day is a day in which the mean flow exceeded the top 5 percent of annual flows during the winter period of December to March as described in Wenger et al. (2010).

Ocean productivity cycles strongly affect growth and survival of coho salmon and the number of adults that annually return to spawn, as is the case for all the anadromous species considered here (Beamish and Mahnken 2001, Hare et al. 1999). Coho adults leave the ocean after 1 to 3 years and migrate upstream from October through January, with variation in timing occurring among populations and individuals within populations. Migration distances to spawning areas are short and can be completed in a few days or weeks.

Coho salmon usually spawn within 1 or 2 weeks of reaching the spawning grounds (Willis 1954). Spawning streams consist of small, unconfined, low-gradient tributaries to larger rivers (Burnett et al. 2007), and females deposit eggs in redds that are excavated from the substrate before dying. The eggs hatch after 6 to 7 weeks from late winter to early spring, and alevins remain in the substrate for another 6 to 7 weeks while the yolk sac is absorbed. After emerging from redd substrates, young coho salmon spend 1 to 2 years growing in their natal streams and exhibit a general preference for pools, alcoves, and beaver ponds rather than habitats with higher flow velocities such as glides and riffles (Gonzalez et al. 2017,

Table 4.4—Streamflow and temperature characteristics for the Southern Oregon-Northern California Coast evolutionary significant unit coho salmon habitats shown in figure 4.7 based on changes associated with the A1B emission scenario[a]

		Number of high-flow days[b]						
Stream metric	**Period**	**<5**	**5 to 10**	**>10**				
Number of winter high-flow days	1980s	0	15 (1.3%)	1,129 (98.7%)				
	2040s	0	0	1,144 (100%)				
	2080s	0	0	1,144 (100%)				
		Discharge categories (m³/s)						
		<0.034	**0.034 to 0.085**	**>0.085**				
Mean summer flow	1980s	10 (0.9%)	38 (3.3%)	1096 (95.8%)				
	2040s	10 (0.9%)	54 (4.7%)	1080 (94.4%)				
	2080s	10 (0.9%)	60 (5.3%)	1073 (93.8%)				
		Temperature categories (°C)						
		<8	**8 to 11**	**11 to 14**	**14 to 17**	**17 to 20**	**20 to 23**	**>23**
Mean August temperature	2000s	0	0	32 (2.8%)	375 (32.8%)	456 (39.9%)	280 (24.5%)	0
	2040s	0	0	18 (1.6%)	219 (19.2%)	451 (39.5%)	358 (31.3%)	97 (8.5%)
	2080s	0	0	11 (1.0%)	137 (12.0%)	416 (36.4%)	415 (36.3%)	164 (14.4%)

[a] Values are stream kilometers, and those in parentheses are percentages of the total during a scenario period.

[b] A high-flow day is a day in which the mean flow exceeded the top 5 percent of annual flows during the winter period of December to March as described in Wenger et al. (2010).

Nickelson et al. 1992). Once juvenile fish reach lengths of 100 to 150 mm, they transform into smolts and migrate to the ocean from late March through June.

The sensitivity of coho salmon to climate change depends on the portion of the life cycle considered (Wainwright and Weitkamp 2013). Low sensitivities are expected during the freshwater migrations of adults and smolts because these movements occur during months with relatively cool temperatures and high flows. However, resident juvenile life stages are likely to be adversely affected by continuation of long-term summer flow declines and temperature increases. Declines in average summer flows of 20 to 30 percent, if realized later this century, would equate to losing a similar amount of habitat and reduce potential population sizes by intensifying competition for food and space. Moreover, as mean summer flows decrease, the probability of extreme low-flow years and drought increases (Luce and Holden 2009), as was the case in 2015 when record low flows and warm temperatures occurred along much of the Washington, Oregon, and California coasts, prompting broad concerns about fish mortality and unprecedented closures of freshwater fishing seasons throughout the region (ODFW 2015).

Because of the low elevations at which most coho salmon streams occur (fig. 4.7), warming trends may be higher than average trends throughout the SWOAP assessment area. Warming trends during the summer may create chronic stresses for juvenile coho salmon in stream reaches that occur near the species' maximum thermal tolerances and could force gradual upstream distribution shifts and range contractions. Temperature increases, by accelerating growth or egg incubation rates, also have the potential to desynchronize the developmental phenology of juveniles from the temporal availability of subsequent habitats (Holtby 1988, Wainwright and Weitkamp 2013).

Increased channel disturbance may negatively affect coho salmon populations during incubation and rearing life stages. If climate change-enhanced variability of ocean cycles (Bond et al. 2015, Di Lorenzo and Mantua 2016) results in higher or more intense precipitation, larger peak flows could scour redds or cause mortality of newly emerged and weakly swimming alevins. Locations where scour could occur, however, are strongly context dependent at local and network scales (Goode et al. 2013, McKean and Tonina 2013, Shellberg et al. 2010), with steeper channels in confined valleys where structural habitat complexity is low, showing higher probabilities of disturbance (Sloat et al. 2017). If wildfires become more common, juvenile life stages could also be negatively affected in the short term by fine-sediment deposition and debris flows into the channel network. Over the longer term, however, those events could have beneficial effects by adding spawning gravels and large woody debris that may increase habitat diversity (Bisson et al. 2003, Dunham et al. 2003).

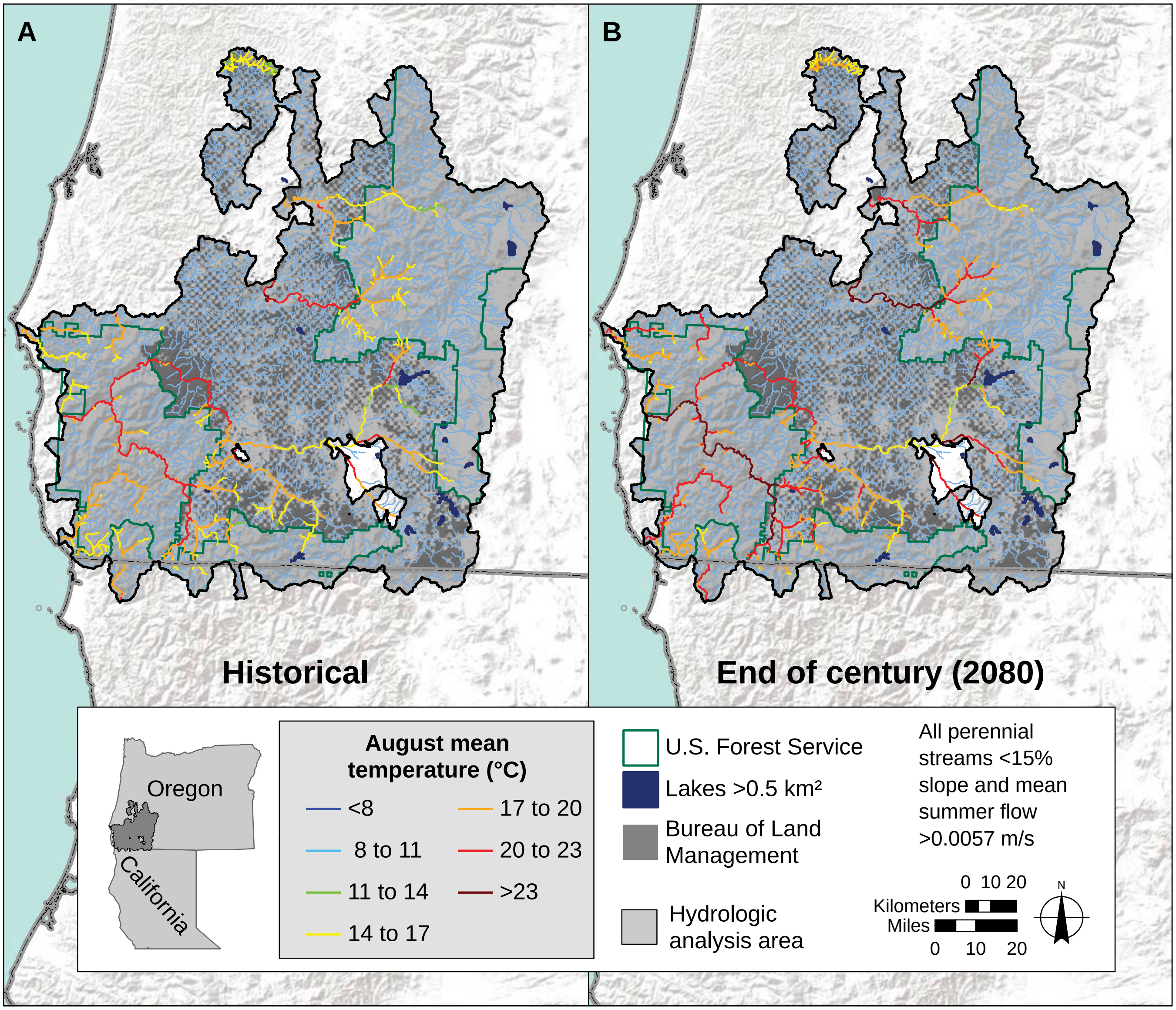

Figure 4.7—Summer stream temperatures in coho salmon habitats during (A) the historical baseline period of the 2000s and (B) a future projection for the 2080s based on NorWeST scenarios and the A1B emission scenario. Future temperature projections in the Rogue and Applegate Rivers were maintained at historical temperatures to reflect water management practices.

Although coho salmon populations may not be acutely vulnerable at any one life stage to the effects of climate change, the pervasive nature of climate change means that cumulative effects over the course of the full life cycle may lead to negative synergies (Crozier et al. 2008, Wainwright and Weitkamp 2013). For example, exacerbation of multiyear or decadal cycles of poor ocean conditions could depress numbers of returning adults, which then reproduce poorly in freshwater habitats subject to extreme drought, warm temperatures, and channel disturbances. Coho salmon populations, like those of most anadromous fishes, are buffered by density-dependent responses, diverse life histories, and multiple age classes (i.e., the portfolio effect) (Schindler et al. 2010) that provide considerable resilience and enable the species to adapt to changing environmental conditions (Bennett et al. 2015, Jones et al. 2014). However, more extreme environmental conditions, if synchronized over larger spatial scales and longer time periods, may begin to pose novel challenges that exceed the species' innate adaptive capacity.

Chinook Salmon (Spring and Fall Runs)

Chinook salmon populations within the SWOAP assessment area belong to the same ESU groupings as coho salmon, which are the Oregon coast ESU and the southern Oregon–northern california coast ESU. These Chinook salmon populations consist of two variants: a spring run of fish that migrates upriver from May through July, and a fall run of fish that migrates later in the year from September through December. Both variants are large bodied (10 to 20 kg), use habitats associated with larger streams and rivers in the analysis area (approximately 3150 km), and support important regional fisheries (tables 4.5 and 4.6, figs. 4.8 and 4.9) (Ford et al. 2011).

Table 4.5—Streamflow and temperature characteristics for spring Chinook salmon habitats shown in figure 4.8 based on changes associated with the A1B emission scenario[a]

		Number of high-flow days[b]						
Stream metric	**Period**	**<5**	**5 to 10**	**>10**				
Number of winter high-flow days	1980s	0	4 (0.4%)	1,000 (99.6%)				
	2040s	0	0	1,004 (100%)				
	2080s	0	0	1,004 (100%)				
		Discharge categories (m^3/s)						
		<0.034	**0.034 to 0.085**	**>0.085**				
Mean summer flow	1980s	19 (1.9%)	7 (0.7%)	978 (97.4%)				
	2040s	23 (2.3%)	4 (0.4%)	978 (97.4%)				
	2080s	23 (2.3%)	4 (0.4%)	978 (97.4%)				
		Temperature categories (°C)						
		<8	**8 to 11**	**11 to 14**	**14 to 17**	**17 to 20**	**20 to 23**	**>23**
Mean August temperature	2000s	0	0	46 (4.6%)	298 (29.7%)	347 (34.6%)	297 (29.6%)	16 (1.6%)
	2040s	0	0	21 (2.0%)	196 (19.5%)	346 (34.4%)	354 (35.3%)	88 (8.8%)
	2080s	0	0	10 (1.0%)	165 (16.4%)	298 (29.7%)	324 (32.3%)	207 (20.6%)

[a] Values are stream kilometers, and those in parentheses are percentages of the total during a scenario period.

[b] A high-flow day is a day in which the mean flow exceeded the top 5 percent of annual flows during the winter period of December to March as described in Wenger et al. (2010).

Although the spring-run fish migrate earlier in the year, they use spawning areas farther upstream and often hold in deep pools near spawning sites for extended periods prior to initiating redd construction in August and September (Ratner et al. 1997). Fall Chinook salmon spawn lower in most rivers and shortly after reaching the spawning grounds (Healey 1991). Eggs incubate over winter, juvenile fish rear for several months, and then most smolt emigrate to the ocean from May to July of their first year. Juveniles of both spring and fall runs exhibit this “ocean type” behavior in the SWOAP assessment area, which is rare for spring Chinook salmon that usually rear for more than 1 year in other portions of the species range (Roper and Scarnecchia 1999). Smolts outmigrating in the Umpqua River are preyed upon by a large population of nonnative smallmouth bass (Simon and Markle 1999), which probably becomes a larger source of mortality during later parts of each year’s migration as river temperatures warm and bass become more active (Rieman et al. 1991, Shultz et al. 2017). Once in the ocean, Chinook salmon range widely and grow for 1 to 4 years before returning to their natal rivers to spawn (Healey 1991). In some years, prespawn mortality of wild fall Chinook salmon has been documented and linked to outbreaks of the bacterial pathogen *Edwardsiella tarda* (Amandi et al. 1982, Ewing et al. 1965).

Table 4.6—Streamflow and temperature characteristics for fall Chinook salmon habitats shown in figure 4.9 based on changes associated with the A1B emission scenario[a]

		Number of high-flow days[b]						
Stream metric	**Period**	**<5**	**5 to 10**	**>10**				
Number of winter high-flow days	1980s	0	13 (0.6%)	2,129 (99.4%)				
	2040s	0	0	2,142 (100%)				
	2080s	0	0	2,142 (100%)				
		Discharge categories (m^3/s)						
		<0.034	**0.034 to 0.085**	**>0.085**				
Mean summer flow	1980s	44 (2.1%)	70 (3.3%)	2028 (94.7%)				
	2040s	50 (2.4%)	85 (4.0%)	2007 (93.7%)				
	2080s	51 (2.4%)	96 (4.5%)	1995 (93.1%)				
		Temperature categories (°C)						
		<8	**8 to 11**	**11 to 14**	**14 to 17**	**17 to 20**	**20 to 23**	**>23**
Mean August temperature	2000s	0	0	70 (3.3%)	712 (33.2%)	815 (38.0%)	530 (24.8%)	16 (0.8%)
	2040s	0	0	25 (1.2%)	384 (17.9%)	840 (39.2%)	704 (32.8%)	190 (8.9%)
	2080s	0	0	16 (0.8%)	230 (10.7%)	778 (36.3%)	712 (33.2%)	406 (19.0%)

[a] Values are stream kilometers, and those in parentheses are percentages of the total during a scenario period.

[b] A high-flow day is a day in which the mean flow exceeded the top 5 percent of annual flows during the winter period of December to March as described in Wenger et al. (2010).

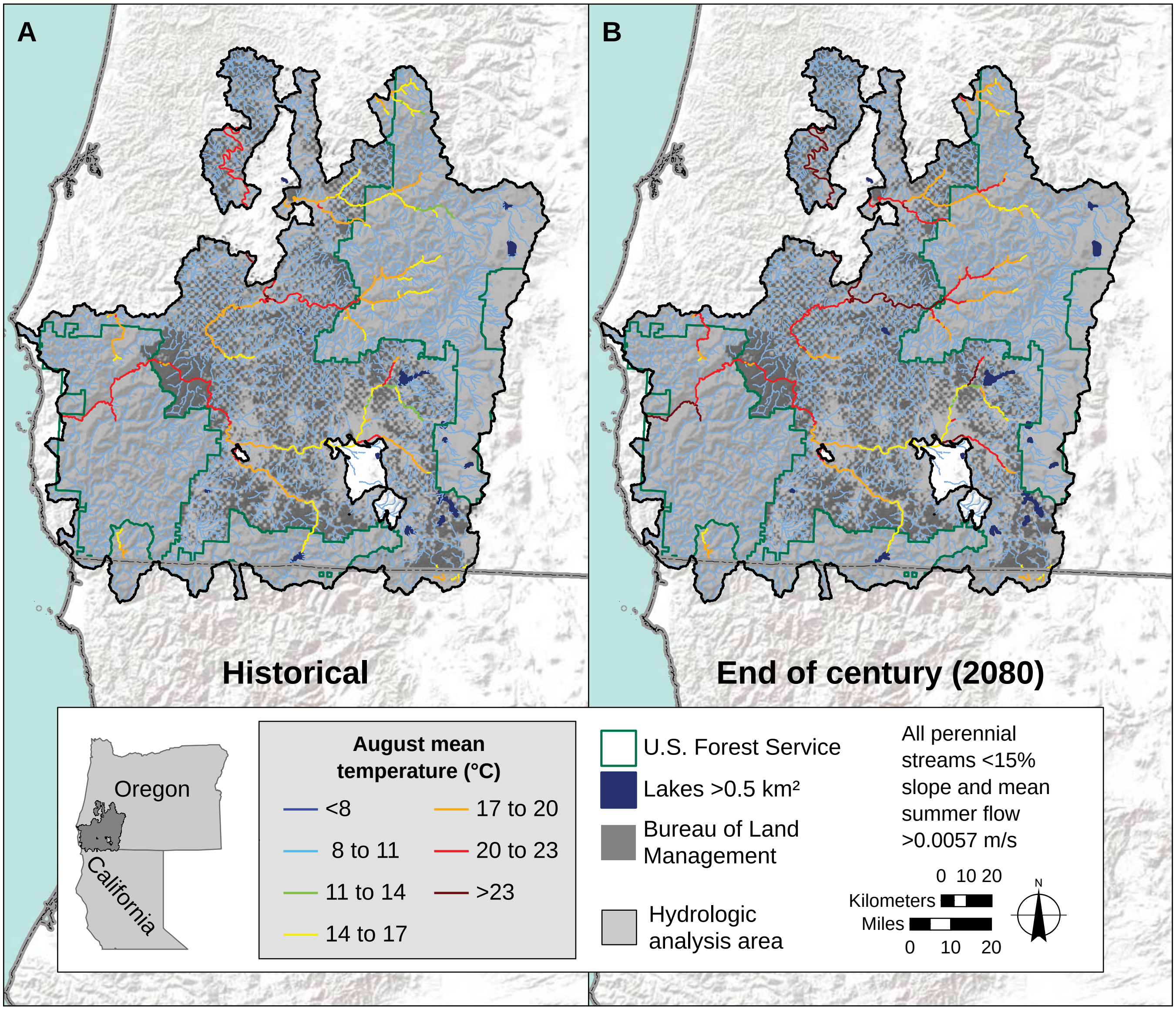

Figure 4.8—Summer stream temperatures in spring Chinook salmon habitats during (A) the historical baseline period of the 2000s and (B) a future projection for the 2080s based on NorWeST scenarios and the A1B emission scenario. Future temperature projections in the Rogue and Applegate Rivers were maintained at historical temperatures to reflect water management practices.

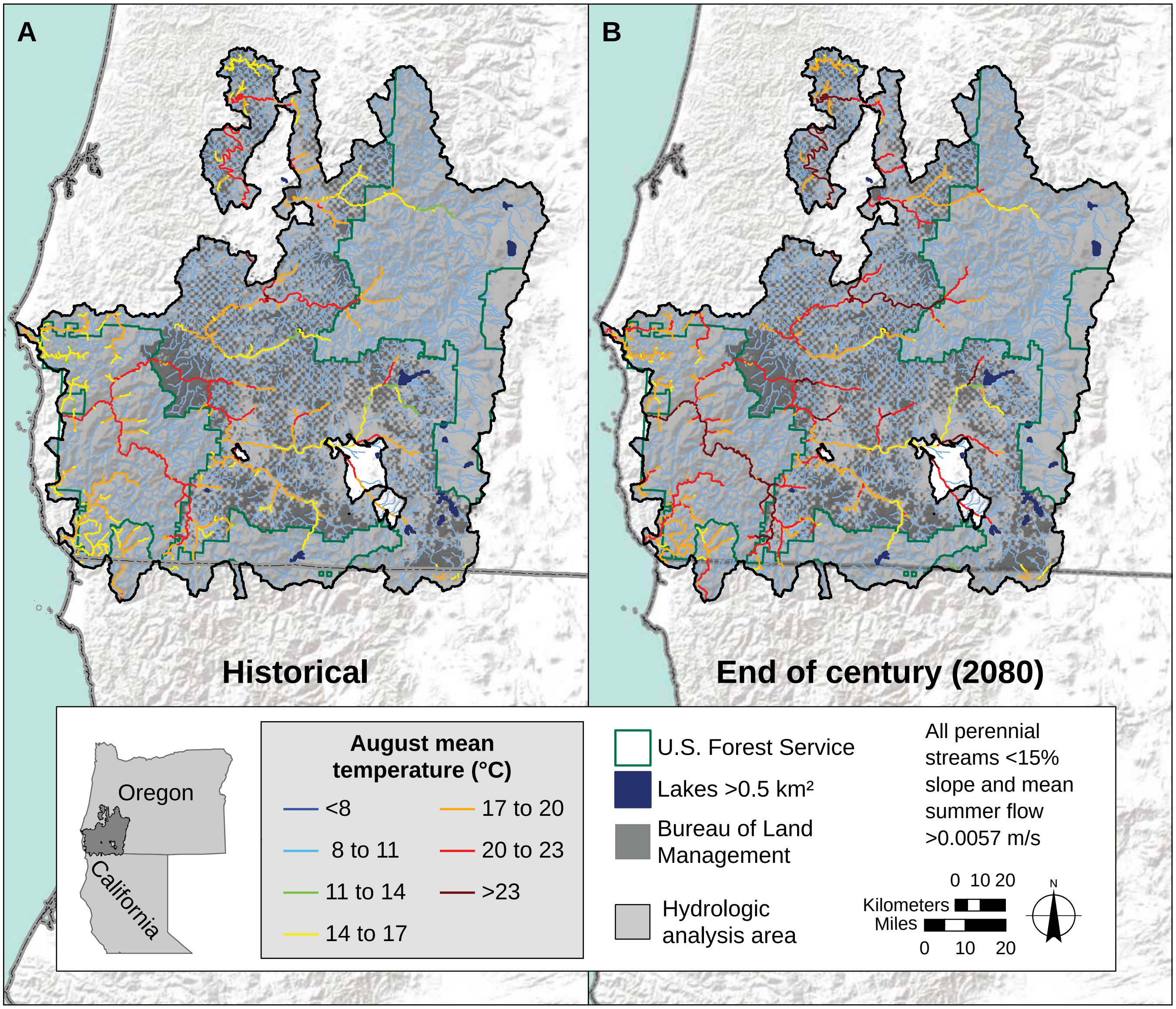

Figure 4.9—Summer stream temperatures in fall Chinook salmon habitats during (A) the historical baseline period of the 2000s and (B) a future projection for the 2080s based on NorWeST scenarios and the A1B emission scenario. Future temperature projections in the Rogue and Applegate Rivers were maintained at historical temperatures to reflect water management practices.

The potential vulnerabilities of Chinook salmon to climate change are similar to those of coho salmon. Chinook salmon habitats consist of large, relatively low-elevation streams and rivers, which are not expected to show dramatic hydrologic changes other than decreasing summer flows (tables 4.5 and 4.6, figs. 4.5 and 4.6). Also, changes in ocean conditions will exert broad effects across all populations on growth, survival, and numbers of returning adults (Beamish and Mahnken 2001, Hare et al. 1999). However, spring-run Chinook salmon adults migrate upriver during warm summer months and often experience thermally stressful conditions, which may alter migration timing or stop migrations temporarily during peak temperatures when fish are forced to seek cold microrefugia (Keefer et al. 2009, Torgersen et al. 1999). Because spring-run fish stage for long periods prior to spawning, thermal stress may accumulate and could adversely affect the viability of eggs or increase prespawn mortality rates in adults (Bowerman et al. 2016).

During especially warm summers in the 1990s, it was noted that spring Chinook salmon returning to the South Umpqua River experienced short-term peak temperatures near lethal limits of 26 °C (Ratner et al. 1997). The summer temperature scenario in figure 4.8 shows that the South Fork Umpqua River and mainstem Umpqua River currently have the warmest temperatures within the SWOAP assessment area, with many reaches averaging 20 to 23 °C. Future projections suggest those reaches will warm by another 1 to 3 °C this century. Coupled with enhanced predation by smallmouth bass and potential for increased disease outbreaks in warmer waters (Kovenen et al. 2010, Marcogliese 2008), higher stream temperatures could threaten the persistence of the South Fork Umpqua River populations. Elsewhere in the assessment area, summer temperatures are less of a concern during adult migrations. The North Fork Umpqua River has cooler temperatures than the South Fork, as do rivers in much of the Rogue River system where cold-water releases from dams reduce thermal maxima.

Risks to Chinook salmon redds and incubating eggs from channel scour may be relatively low because this species usually spawns in larger rivers where valleys are less confined, and peak flow energy is dissipated across floodplains (McKean and Tonina 2013, Sloat et al. 2017). Vulnerability of juvenile life stages is also expected to be low because little time is spent in freshwater prior to ocean outmigration.

Steelhead (Summer and Winter Runs)

Steelhead is the anadromous form of rainbow trout, and populations within the SWOAP assessment area are considered to be part of the Oregon coast distinct population segment and a species of concern by the National Marine Fisheries Service, but are not ESA listed (Ford et al. 2011, Wainwright et al. 1996). Populations consist of two variants—summer-run steelhead that migrate into freshwaters from May to October and use approximately 2500 km of streams and rivers (table 4.7, fig. 4.10), and winter-run fish that migrate from November to March and are more extensively

Table 4.7—Streamflow and temperature characteristics for summer steelhead habitats shown in figure 4.10 based on changes associated with the A1B emission scenario[a]

		Number of high-flow days[b]		
Stream metric	**Period**	**<5**	**5 to 10**	**>10**
Number of winter high-flow days	1980s	2,494 (98.1%)	1 (0.1%)	45 (1.8%)
	2040s	0	0	2,540 (100%)
	2080s	0	0	2,540 (100%)

		Discharge categories (m^3/s)		
		<0.034	**0.034 to 0.085**	**>0.085**
Mean summer flow	1980s	184 (7.2%)	398 (15.7%)	1958 (77.1%)
	2040s	207 (8.1%)	420 (16.6%)	1913 (75.3%)
	2080s	236 (9.3%)	443 (17.4%)	1861 (73.3%)

		Temperature categories (°C)						
		<8	**8 to 11**	**11 to 14**	**14 to 17**	**17 to 20**	**20 to 23**	**>23**
Mean August temperature	2000s	0	14 (0.5%)	281 (11.1%)	1136 (44.7%)	734 (28.9%)	375 (14.8%)	0
	2040s	0	4 (0.2%)	91 (3.6%)	806 (31.7%)	1059 (41.7%)	455 (17.9%)	126 (5.0%)
	2080s	0	3 (0.1%)	49 (1.9%)	517 (20.4%)	1136 (44.7%)	579 (22.8%)	257 (10.1%)

[a] Values are stream kilometers, and those in parentheses are percentages of the total during a scenario period.

[b] A high-flow day is a day in which the mean flow exceeded the top 5 percent of annual flows during the winter period of December to March as described in Wenger et al. (2010).

distributed throughout 6700 km of streams (table 4.8, fig. 4.11). Spawning occurs from January through March (Quinn 2005), so early migrating summer steelhead adults from the previous year reside in deep pools for extended periods while waiting to spawn (Baigun 2003). Females usually excavate redds in steeper streams with more confined valleys than those used by salmon (Burnett et al. 2007, Reeves et al. 1998). After hatching, the juveniles rear for 1 to 3 years near the natal areas before smolting and migrating to the ocean during spring and summer. Most steelhead use the ocean for 2 to 3 years before again returning to freshwater for spawning (Quinn 2005). An exception to those life history strategies are the "half-pounder" steelhead that return to freshwater after only 2 to 4 months at sea, overwinter in freshwater, and then return to the ocean the following spring (Kesner and Barnhart 1972). Also different from other steelhead life history forms, these fish actively feed while in freshwater and rarely spawn (Kesner and Barnhart 1972). This amphidromous migration is relatively rare throughout the range of steelhead but common within several river basins in northern California and southern Oregon (Hodges et al. 2014).

Steelhead populations within the SWOAP assessment area are broadly distributed, considered to be stable, and support robust fisheries within both the smaller coastal rivers and larger systems such as the Umpqua and Rogue Rivers (Wainwright et al. 1996). Both hatchery and wild fish are well represented in these fisheries. Juvenile steelhead

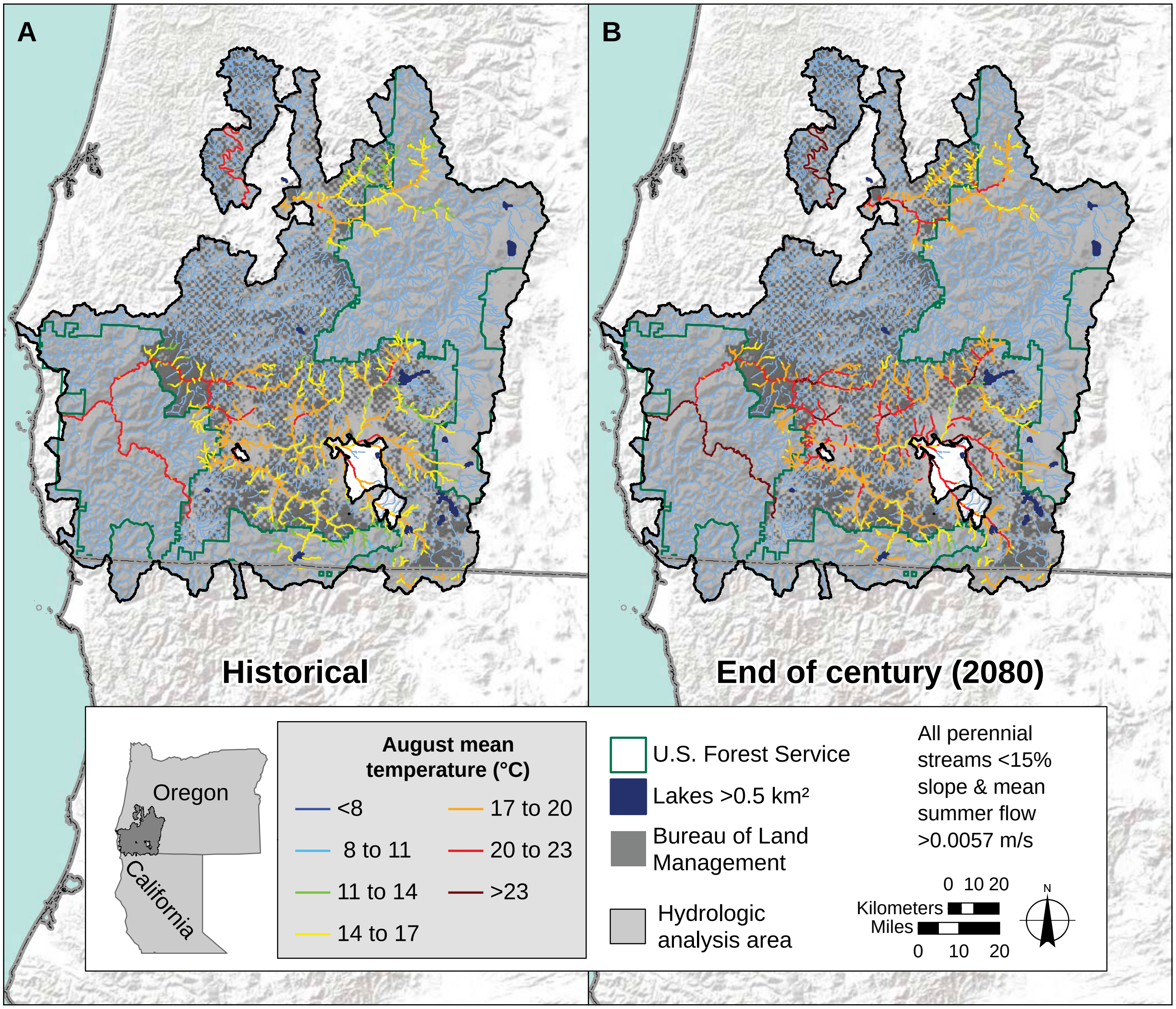

Figure 4.10—Summer stream temperatures in summer steelhead habitats during (A) the historical baseline period of the 2000s and (B) a future projection for the 2080s based on NorWeST scenarios and the A1B emission scenario. Future temperature projections in the Rogue and Applegate Rivers were maintained at historical temperatures to reflect water management practices.

Table 4.8—Streamflow and temperature characteristics for winter steelhead habitats shown in figure 4.11 based on changes associated with the A1B emission scenario[a]

		Number of high-flow days[b]						
Stream metric	**Period**	**<5**	**5 to 10**	**>10**				
Number of winter high-flow days	1980s	1 (0.1%)	45 (0.7%)	6,653 (99.2%)				
	2040s	0	0	6,699 (100%)				
	2080s	0	0	6,699 (100%)				
		Discharge categories (m3/s)						
		<0.034	**0.034 to 0.085**	**>0.085**				
Mean summer flow	1980s	838 (12.5%)	1320 (19.7%)	4542 (67.8%)				
	2040s	949 (14.2%)	1363 (20.3%)	4388 (65.5%)				
	2080s	1064 (15.9%)	1403 (20.9%)	4233 (63.2%)				
		Temperature categories (°C)						
		<8	**8 to 11**	**11 to 14**	**14 to 17**	**17 to 20**	**20 to 23**	**>23**
Mean August temperature	2000s	0	21 (0.3%)	863 (12.9%)	3599 (53.7%)	1672 (25.0%)	528 (7.9%)	16 (0.2%)
	2040s	0	5 (0.1%)	203 (3.0%)	2679 (40.0%)	2749 (41.0%)	872 (13.0%)	190 (2.8%)
	2080s	0	3 (0.1%)	80 (1.2%)	1606 (24.0%)	3362 (50.2%)	1245 (18.6%)	404 (6.0%)

[a] Values are stream kilometers, and those in parentheses are percentages of the total during a scenario period.

[b] A high-flow day is a day in which the mean flow exceeded the top 5 percent of annual flows during the winter period of December to March as described in Wenger et al. (2010).

also occur broadly throughout the analysis area and occur in most stream segments where upstream migration is not blocked (Dose and Roper 1994). Nonetheless, steelhead may be vulnerable to climate change during several portions of their life cycle.

Summer-run adults may encounter thermally stressful temperatures during upstream migrations, which may force them to seek cold microrefugia and delay migrations (Keefer et al. 2009). Access to upstream spawning areas could be limited by ongoing declines in summer flows if passage barriers occur at road culverts or intermittent flows occur in some reaches. Because summer steelhead hold for extended periods in tributaries prior to spawning, flow declines and increasing temperatures place additional stresses on these fish that could increase prespawn mortality rates or adversely affect their spawning ability and the viability of eggs and embryos. Juveniles of both winter- and summer-run fish rear for 1 or more years in relatively steep channels where they may be vulnerable to more frequent or larger disturbances associated with wildfires and debris flows or floods and scour (Goode et al. 2012, Sloat et al. 2017). Juveniles outmigrating through the Umpqua River during the spring and summer are preyed upon by smallmouth bass. Interactions among climate stressors, acting on multiple life stages, could create negative synergies that amplify effects beyond individual life stages (Crozier et al. 2008).

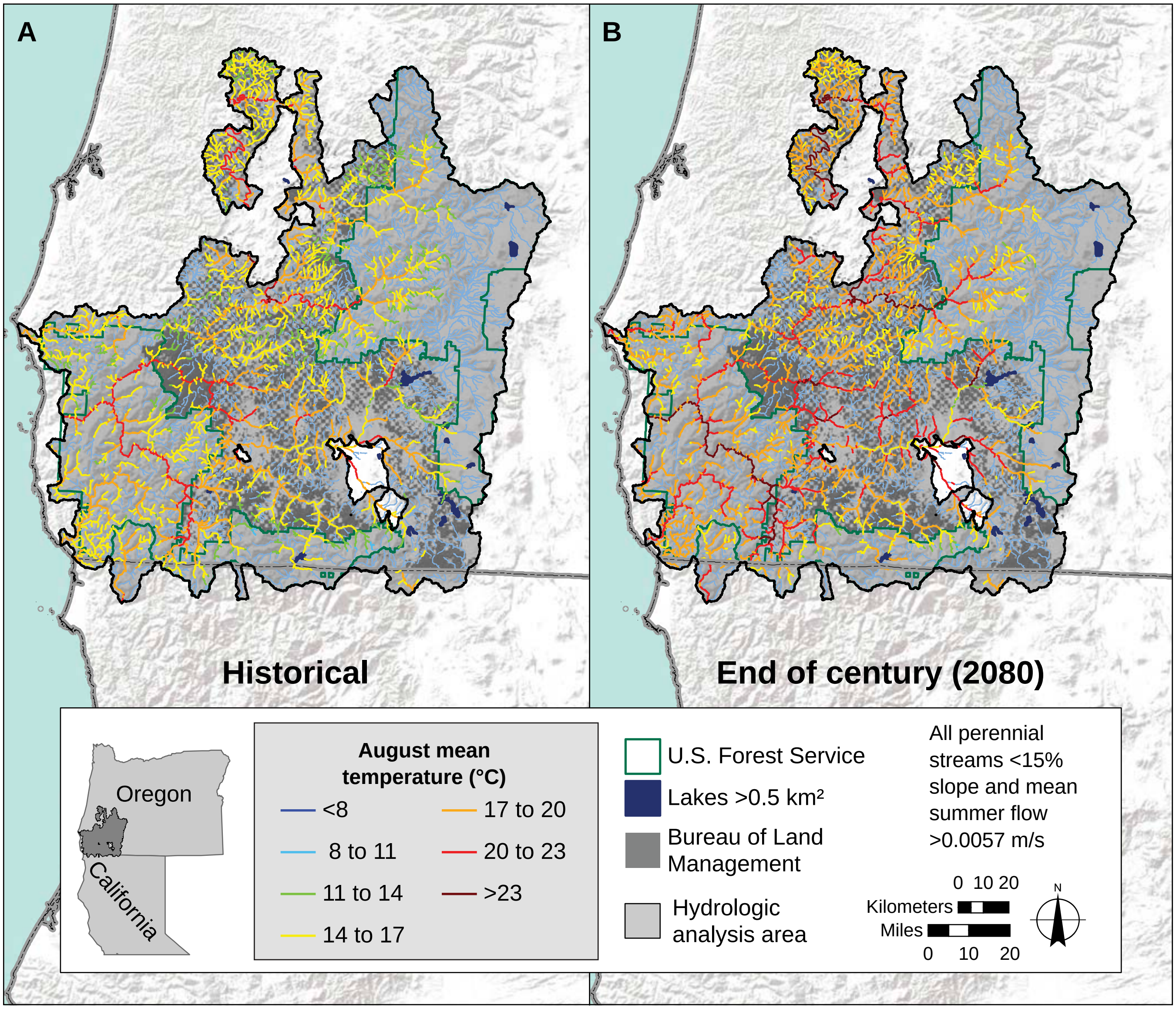

Figure 4.11—Summer stream temperatures in winter steelhead habitats during (A) the historical baseline period of the 2000s and (B) a future projection for the 2080s based on NorWeST scenarios and the A1B emission scenario. Future temperature projections in the Rogue and Applegate Rivers were maintained at historical temperatures to reflect water management practices.

Coastal Cutthroat Trout

Coastal cutthroat trout use approximately 4360 km of streams and rivers throughout the SWOAP assessment area (table 4.9, fig. 4.12). These cutthroat populations are parts of the Oregon coast ESU and southern Oregon–northern California coasts ESU but are not ESA listed (Johnson et al. 1999). This species exhibits considerable life history diversity, possessing anadromous, potamodromous, fluvial, adfluvial, and headwater resident forms (Trotter 1989, Trotter et al. 2018). Populations of the sea-going forms have decreased considerably in recent decades, whereas populations of the other forms appear relatively stable and widely distributed (Johnson et al. 1999), often constituting the most abundant salmonid populations in the coldest headwater streams (Guy et al. 2008).

Coastal cutthroat trout spawn in small tributaries from late winter through spring, with peak activity usually in February. Eggs hatch 6 to 7 weeks after spawning, and juveniles emerge as fry between March and June, with peak emergence in mid April (Sumner 1972). Juveniles rear in streams for at least 2 years before either becoming sexually mature (freshwater forms) or smolting and migrating to the

Table 4.9—Streamflow and temperature characteristics for cutthroat trout shown in figure 4.12 based on changes associated with the A1B emission scenario[a]

		Number of high-flow days[b]						
Stream metric	**Period**	**<5**	**5 to 10**	**>10**				
Number of winter high-flow days	1980s	183 (4.2%)	517 (11.9%)	3,662 (84.0%)				
	2040s	0	63 (1.4%)	4,299 (98.6%)				
	2080s	0	0	4,362 (100%)				
		Discharge categories (m^3/s)						
		<0.034	**0.034 to 0.085**	**>0.085**				
Mean summer flow	1980s	184 (4.2%)	558 (12.8%)	3620 (83.0%)				
	2040s	273 (6.3%)	707 (16.2%)	3381 (77.5%)				
	2080s	328 (7.5%)	781 (17.9%)	3253 (74.6%)				
		Temperature categories (°C)						
		<8	**8 to 11**	**11 to 14**	**14 to 17**	**17 to 20**	**20 to 23**	**>23**
Mean August temperature	2000s	120 (2.8%)	885 (20.3%)	800 (18.3%)	1531 (35.1%)	735 (16.9%)	292 (6.7%)	0
	2040s	20 (0.5%)	597 (13.7%)	780 (17.9%)	1355 (31.1%)	1105 (25.3%)	409 (9.4%)	96 (2.2%)
	2080s	5 (0.1%)	340 (7.8%)	869 (19.9%)	1020 (23.4%)	1379 (31.6%)	571 (13.1%)	178 (4.1%)

[a] Values are stream kilometers, and those in parentheses are percentages of the total during a scenario period.

[b] A high-flow day is a day in which the mean flow exceeded the top 5 percent of annual flows during the winter period of December to March as described in Wenger et al. (2010).

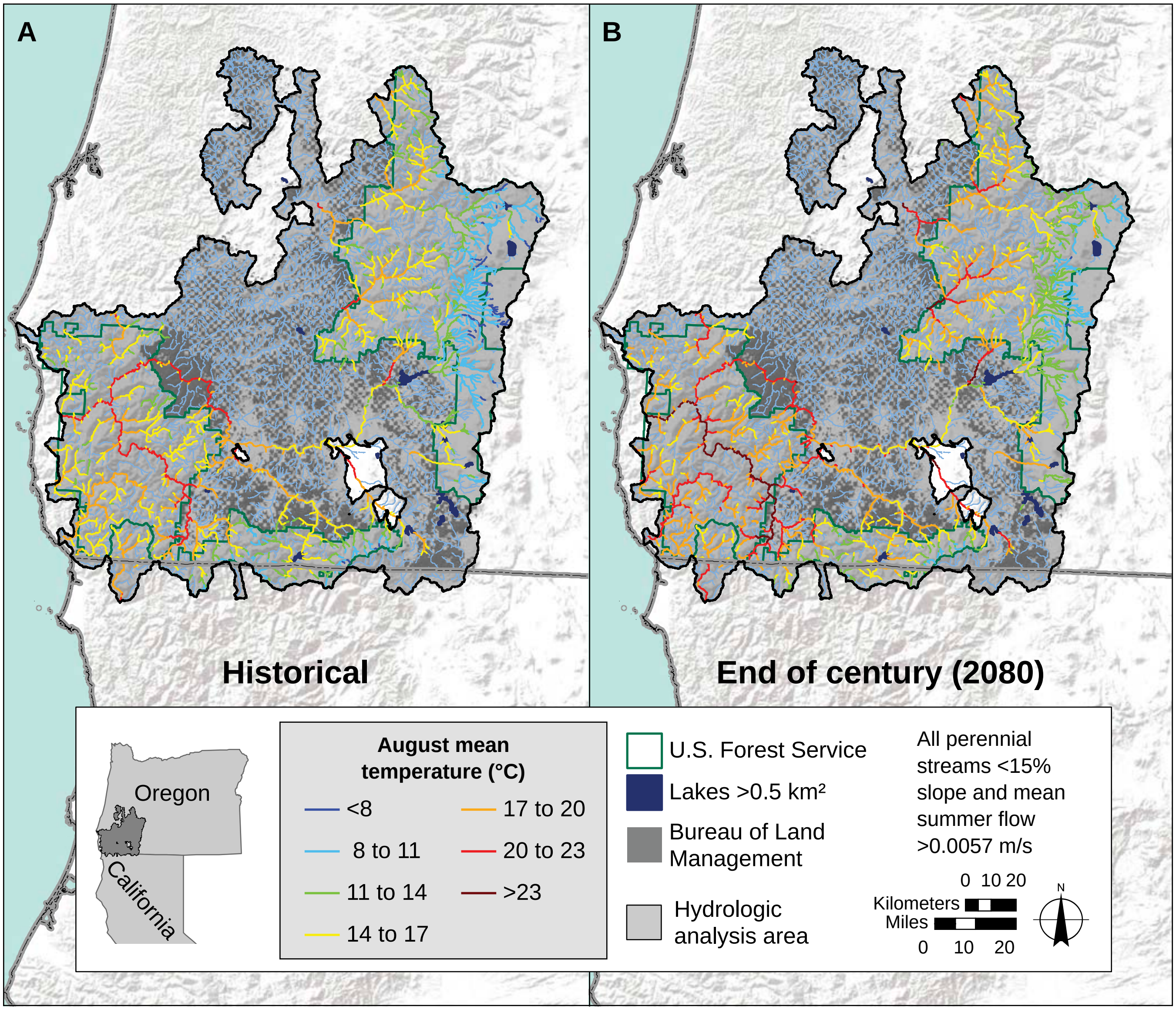

Figure 4.12—Summer stream temperatures in coastal cutthroat trout habitats during (A) the historical baseline period of the 2000s and (B) a future projection for the 2080s based on NorWeST scenarios and the A1B emission scenario. Future temperature projections in the Rogue and Applegate Rivers were maintained at historical temperatures to reflect water management practices.

ocean during the spring and early summer months (Northcote 1997). Unlike steelhead and Pacific salmon, however, anadromous coastal cutthroat trout do not make lengthy ocean migrations and usually remain in or near estuarine waters within 10 to 15 km of the mouths of natal streams (Northcote 1997, Sumner 1972).

The diversity of life histories expressed by coastal cutthroat trout means that all of the climate vulnerabilities previously discussed for salmon and steelhead are relevant to one or more cutthroat trout forms. However, cutthroat trout have a thermal niche that is colder than most other species and may be more sensitive to temperature increases throughout many of the low-elevation streams within the SWOAP assessment area, especially during adult upriver migrations or at thermally mediated boundaries of juvenile distributions (Isaak et al. 2017c). That sensitivity is offset to some degree in headwater populations where temperature increases are projected to be smaller than in lowland streams (fig. 4.2). In these same steep headwater habitats, local populations may be more susceptible to future wildfires and associated debris flows (Goode et al. 2012, Sedell et al. 2015), as well as large summer flow reductions (fig. 4.6). Resident populations of coastal cutthroat trout can persist in very small stream networks (e.g., 2 to 10 km) for extended periods of time (i.e., hundreds to thousands of years) (Peterson et al. 2013a, Whiteley et al. 2010), so identifying streams where disturbances are likely to be rare and flows sufficiently high could reveal long-term climate refugia (Isaak et al. 2015). Anadromous and potamodromous forms of coastal cutthroat trout are affected by ocean productivity cycles, but their more restricted use of environments near natal streams and estuaries compared to salmon and steelhead may result in different responses to the long-term effects of climate change on the ocean (Di Lorenzo and Mantua 2016).

Pacific Lamprey

Pacific lamprey populations in the SWOAP assessment area use 1644 km of streams and rivers for migration, spawning, and juvenile rearing (table 4.10, fig. 4.13). Adult lamprey spend 1 to 3 years in the ocean, reach lengths of 80 cm, and return to freshwater during the spring before beginning their upstream migration in the summer. The adults reside in freshwater until the following spring when they become sexually mature, excavate redds in small gravel substrates, spawn, and die (Clemens et al. 2013). Spawning usually occurs in habitats similar to those used by Pacific salmon and in reaches with low gradients (less than 2 percent slope) and temperatures of 14 to 19 °C in the summer. After hatching, the juveniles begin a lengthy larval phase that lasts 3 to 7 years during which time they live in burrows in soft substrates (Clemens et al. 2013, Dawson et al. 2015). The larvae eventually undergo metamorphosis, take on the adult body morphology, and migrate seaward during high flows in winter and spring months (Dawson et al. 2015, Goodman et al. 2015). Adults have a jawless, sucker-like mouth and are parasitic on other fish during their oceanic phase. Conditions in the marine environment exert a strong influence on Pacific lamprey abundance (Murauskas et al. 2013, Wade and Beamish 2016), although information about their marine ecology is relatively limited (Clemens et al. 2010, Wang and Schaller 2015).

Table 4.10—Streamflow and temperature characteristics for Pacific lamprey habitats shown in figure 4.13 based on changes associated with the A1B emission scenario[a]

		Number of high-flow days[b]						
Stream metric	**Period**	**<5**	**5 to 10**	**>10**				
Number of winter high-flow days	1980s	0	0	1,644 (100%)				
	2040s	0	0	1,644 (100%)				
	2080s	0	0	1,644 (100%)				
		Discharge categories (m^3/s)						
		<0.034	**0.034 to 0.085**	**>0.085**				
Mean summer flow	1980s	16 (1.0%)	23 (1.4%)	1605 (97.6%)				
	2040s	19 (1.2%)	26 (1.6%)	1599 (97.2%)				
	2080s	20 (1.2%)	31 (1.9%)	1593 (96.9%)				
		Temperature categories (°C)						
		<8	**8 to 11**	**11 to 14**	**14 to 17**	**17 to 20**	**20 to 23**	**>23**
Mean August temperature	2000s	0	0	54 (3.3%)	538 (32.7%)	539 (32.8%)	496 (30.2%)	16 (1.0%)
	2040s	0	0	15 (0.9%)	293 (17.8%)	593 (36.1%)	553 (33.6%)	190 (11.6%)
	2080s	0	0	11 (0.7%)	180 (11.0%)	551 (33.5%)	519 (31.6%)	382 (23.2%)

[a] Values are stream kilometers, and those in parentheses are percentages of the total during a scenario period.

[b] A high-flow day is a day in which the mean flow exceeded the top 5 percent of annual flows during the winter period of December to March as described in Wenger et al. (2010).

Trend monitoring datasets for Pacific lamprey, usually from dam passage counts, suggest broad regional declines have occurred in recent decades (Clemens et al. 2017). Most data, however, are from large inland dams with fish-counting facilities associated with fish ladders. Trend information specific to the SWOAP assessment area is lacking, and the lack of information is exacerbated at times by low detection when sampling rearing environments where juveniles reside in the substrate (Dawson et al. 2015, Dunham et al. 2013). An environmental DNA (eDNA) marker for Pacific lamprey has recently been developed (Carim et al. 2017) and is being used for more precise distributional assessments, but these are in early stages.

Several aspects of Pacific lamprey ecology make them vulnerable to climate change. Temperatures greater than 20 °C are physiologically stressful (Clemens et al. 2016), so juveniles in rearing areas and adults migrating upstream through already warm rivers will experience increasing thermal stress as temperatures rise in the future. Adult lamprey are relatively weak swimmers, so dams, road culverts, and other fish passage obstacles that are navigable by salmonids may act as barriers (Chelgren and Dunham 2015, Keefer et al. 2013, Moser et al. 2015), and passage issues could be exacerbated by ongoing declines in summer flows. The long

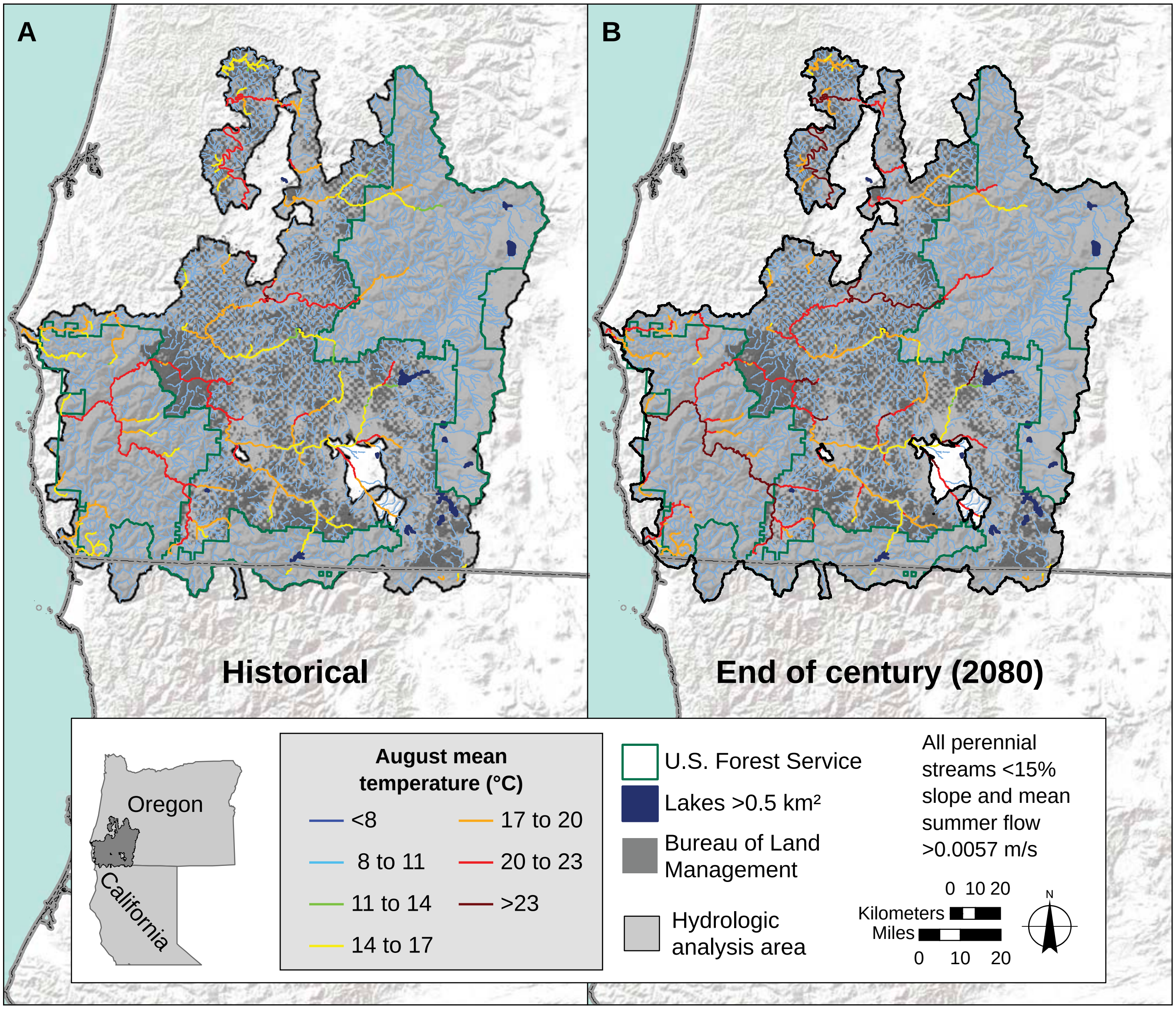

Figure 4.13—Summer stream temperatures in Pacific lamprey habitats during (A) the historical baseline period of the 2000s and (B) a future projection for the 2080s based on NorWeST scenarios and the A1B emission scenario. Future temperature projections in the Rogue and Applegate Rivers were maintained at historical temperatures to reflect water management practices.

residence time of the relatively immobile juveniles in stream substrates also creates risks from increased peak flows and scour, or wildfires that trigger debris flow disturbances and yield large inputs of fine sediments that smother burrows (Goode et al. 2012, 2013). Lamprey juveniles can be preyed upon by smallmouth bass (Schultz et al. 2017), which become more active predators in warmer temperatures (Rieman et al. 1991). Finally, if climate change is affecting ocean conditions in ways that lead to long-term declines in salmon, steelhead, and other species that provide Pacific lamprey with hosts, it could lead to concomitant population declines.

Umpqua Chub

The Umpqua chub is a small-bodied minnow species endemic to the Umpqua River basin and is considered a “sensitive–critical species” by the Oregon Department of Fish and Wildlife. The species occupies habitats that include sluggish backwaters of sloughs and sand- and gravel-bottomed runs and pools of small streams and rivers (Markle et al. 1991). Like most minnow species, Umpqua chub have a warm thermal niche and may be locally abundant, but its restricted geographic range heightens risks for the species (Angermeier 1995, Mims et al. 2018). Within the SWOAP assessment area, potential habitats consist of approximately 140 stream kilometers in Cow Creek and the South Fork of the Umpqua River (table 4.11, fig. 4.14). Predation by smallmouth bass has reduced or eliminated chub populations in much of the Umpqua River such that remaining chub populations persist in isolated enclaves upstream of the bass invasion front (O’Malley et al. 2013, Simon and Markle 1999).

Smallmouth bass have expanded more than 150 km upstream since their inadvertent introduction to the lower Umpqua River in 1964 (Simon and Markle 1999). That expansion, however, occurred through relatively warm riverine environments

Table 4.11—Streamflow and temperature characteristics for Umpqua chub habitats shown in figure 4.14 based on changes associated with the A1B emission scenario[a]

		Number of high-flow days[b]		
Stream metric	**Period**	**<5**	**5 to 10**	**>10**
Number of winter high-flow days	1980s	0	0	140 (100%)
	2040s	0	0	140 (100%)
	2080s	0	0	140 (100%)

		Discharge categories (m^{3}/s)		
		<0.034	**0.034 to 0.085**	**>0.085**
Mean summer flow	1980s	0	0	140 (100%)
	2040s	0	0	140 (100%)
	2080s	0	0	140 (100%)

		Temperature categories (°C)						
		<8	**8 to 11**	**11 to 14**	**14 to 17**	**17 to 20**	**20 to 23**	**>23**
Mean August temperature	2000s	0	0	0	10 (6.8%)	74 (52.9%)	56 (40.3%)	0
	2040s	0	0	0	0	29 (20.9%)	103 (73.6%)	8 (5.6%)
	2080s	0	0	0	0	13 (9.3%)	81 (57.9%)	46 (32.9%)

[a] Values are stream kilometers, and those in parentheses are percentages of the total during a scenario period.

[b] A high-flow day is a day in which the mean flow exceeded the top 5 percent of annual flows during the winter period of December to March as described in Wenger et al. (2010).

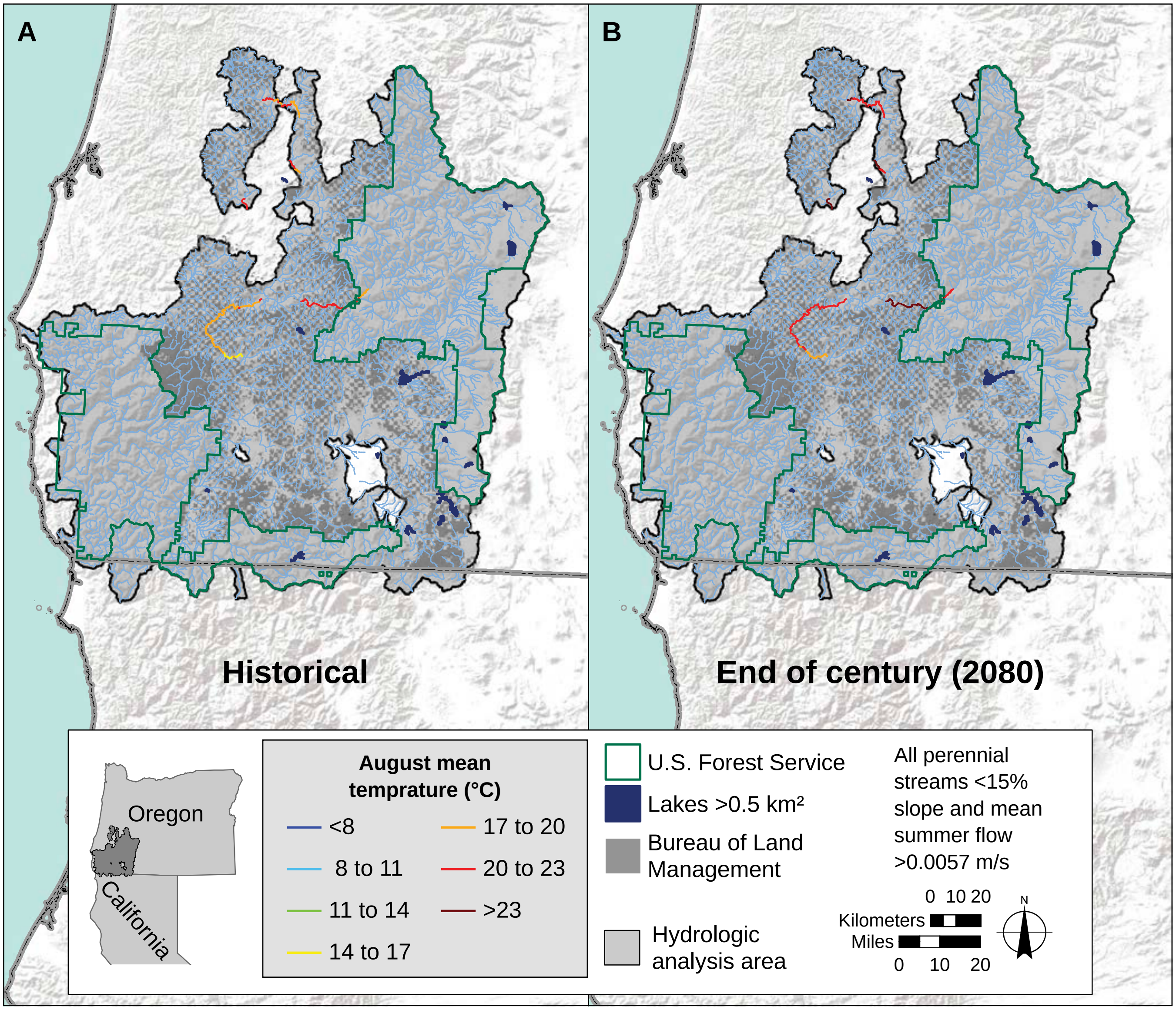

Figure 4.14—Summer stream temperatures in Umpqua chub habitats during (A) the historical baseline period of the 2000s and (B) a future projection for the 2080s based on NorWeST scenarios and the A1B emission scenario.

where mean summer temperatures exceed 20 °C and suit the smallmouth bass thermal niche (Zweifel et al. 1999). Climatic restrictions where summer temperatures are cooler than 17 to 19 °C appear to limit smallmouth bass reproduction and population establishment (Lawrence et al. 2012, Rubenson and Olden 2019), which will slow the upstream invasion at some point along the network. It may be possible, therefore, for Umpqua chub populations to persist in the cooler locations upstream of the bass invasion front, but chub populations may also be limited by the same climatic or habitat factors that constrain bass populations.

More information is needed about the chub's thermal niche, reproductive ecology, and rates at which smallmouth bass are currently expanding upstream before predictions can be made about the likelihood of Umpqua chub persistence with climate change. Given the rate at which Umpqua chub populations appear to have declined in recent decades, a detailed monitoring program is needed to track the status of these populations. Active management interventions that involve assisted migration or predator removal may be considered to bolster population resilience and maintain future options.

Species Adaptive Capacity

The concept of niche conservatism suggests there is little capacity for rapid evolutionary or physiological adaptations to warmer water temperatures or desiccation within the aquatic species considered here (McCullough et al. 2009, Wiens et al. 2010). However, trout and salmon species are noteworthy for their phenotypic plasticity, vagility, and resilience (Northcote 1992, Quinn 2005), evidence of which is provided by their continued persistence in many SWOAP assessment area basins and streams. Where barriers do not impede movements, many species may adapt by shifting their distributions in space or time to track suitable habitats or to recolonize previously disturbed habitats from nearby refugia if a diversity of landscape conditions exists (Reeves et al. 1995, Sedell et al. 1990). Many of the species considered here also have diverse life histories, which may change based on how climate change affects metabolic rates, water temperature, stream productivity, and connectivity. Development of disease resistance or adaptive responses associated with phenology may also bolster population resilience in ways that allow species to persist in dynamic environments subject to long-term climate trends (Crozier et al. 2008, Knapp et al. 2016, Kovach et al. 2012).

Widespread losses of populations or species declines attributable to climate change have not yet been documented despite the prevalence of relatively rapid climate trends in the Pacific Northwest (Arismendi et al. 2013, Isaak et al. 2018, Luce and Holden 2009, Luce et al. 2013). Recently improved freshwater habitat conditions in southwest Oregon streams (Lanigan et al. 2012) may be playing a role in ameliorating potentially negative climate effects. It may also be that negative bioclimatic effects are occurring but have been masked by cycles in ocean conditions and variability in regional abundance of many anadromous species (Kilduff et al. 2015), or that existing monitoring programs and available datasets are inadequate for detecting subtle biological responses related to climate change (Crozier et al. 2011, Eby et al. 2014). As thermal and hydrologic changes attributable to climate change continue to increase later this century, however, biological responses may become more apparent.

Adapting Fisheries and Fish Habitat Management to Climate Change in Southwest Oregon

Exploring and applying an array of conservation strategies will be important for addressing climate change effects on aquatic environments within the SWOAP assessment area. Where habitat conditions are currently productive, maintaining those conditions and avoiding significant new impairments may be all that is necessary to ensure the persistence of native fish populations. Where habitats are degraded, however, strategic investments that involve restoring habitat, manipulating fish populations, or both will be useful to enhance population resilience. Many habitats are situated in landscapes that have multiple resource values and administrative agencies, so balancing competing interests and management goals will be important (Reeves et al. 2018, Roper et al. 2018).

Land and fisheries managers have at their disposal a variety of actions to adapt to climate change and improve the resilience of aquatic species in southwest Oregon. These actions have been summarized in a number of reviews (Beechie et al. 2013, ISAB 2007, Luce et al. 2012, Rieman and Isaak 2010) and previous adaptation partnership efforts throughout the Western United States (Isaak et al. 2017a, Young et al. 2018b; Climate Change Adaptation Library for the Western United States [http://adaptationpartners.org/library.php]). Participants in the SWOAP workshop fisheries group identified several actions that were particularly relevant to local conditions (table 4.12), which can be categorized as follows: (1) maintain and diversify monitoring programs; (2) strategically prioritize and restore natural regimes of flow, sediment, wood, and temperature; (3) manage fluvial connectivity; and (4) remove or suppress nonnative species.

Maintain and Diversify Monitoring Programs

The AREMP monitoring in southwest Oregon provides information about the status and trends of stream conditions and traditional fish habitat metrics. However, more annual monitoring data are needed for streamflow and temperature across a range of stream sizes (Isaak et al. 2018, Kovach et al. 2019) (table 4.12), which may be obtained using inexpensive, reliable temperature and flow sensors (Dunham et al. 2005, Stamp et al. 2014). The fish species distribution maps used in this assessment were relatively coarse because they were compiled from agencies that relied on different data standards and levels of expert opinion, which sometimes created compatibility issues. Therefore, a biological inventory and monitoring program (hundreds to thousands of sample locations) would contribute to more precise distribution models and maps, provide status and trend assessments, and improve understanding of biological responses to climate change, natural variation, and land management.

Table 4.12—Fisheries and aquatic habitat adaptation options for southwest Oregon

Sensitivity to climate change	Adaptation strategy	Adaptation tactic
Increased temperatures and lower snowpack will result in reduced summer streamflows	Increase the quantity of, and access to, summer rearing habitat	• Increase connectivity: • Identify stream crossings that impede fish movements and prioritize culvert replacement. • Use stream simulation design (e.g., bottomless arches, bridges), adjusting designs to provide low flow thalweg. • Rebuild stream bottoms by increasing floodplain connectivity, riparian vegetation, and water tables; decrease road connectivity. • Restore beaver habitat and beaver colonies. • Maintain minimum streamflows (buy and lease water rights, install modern flow structures, monitor water use). • Increase instream flow: • Increase efficiency of irrigation techniques. • Reduce summer withdrawals on federal lands. • Consider alternative water supplies for federal lands to retain instream flows. • Coordinate with downstream partners on water conservation education. • Restore beaver habitat and colonies. • Investigate and quantify connectivity between groundwater and streamflows. • Increase water retention: • Restore fluvial processes. • Promote and reintroduce beavers. • Protect springs. • Thin forests to reduce evapotranspiration. • Manage the road network to reduce negative impacts on streams. • Improve grazing management. • Improve efficiencies in regulated water use; conserve water. • Identify where reservoir management can improve species conservation.

Costs associated with biological monitoring have decreased greatly in recent years with the advent of reliable eDNA techniques accompanied by field-tested protocols for aquatic organisms (Carim et al. 2016, McKelvey et al. 2016). Dozens of sites can be sampled by a single person during the course of a day, and each eDNA sample contains the DNA of multiple species upstream of the site, which makes geographically and taxonomically broad inventories possible. Once biological baselines are established, future trend assessments will be more powerful and easily conducted by resampling subsets of the original baseline sites. Moreover, thousands of eDNA samples are now being collected annually across the Western United States by many agencies (Young et al. 2018a) through partnerships with the National Genomics Center for Wildlife and Fish Conservation (http://www.fs.fed.us/research/genomics-center). Results from those samples are publicly accessible through the eDNAtlas website (https://www.fs.fed.us/rm/boise/AWAE/projects/aquatic-eDNAtlas.html) to make data sharing and interagency collaborations more feasible.

Table 4.12—Fisheries and aquatic habitat adaptation options for southwest Oregon (continued)

Sensitivity to climate change	Adaptation strategy	Adaptation tactic
Stream temperatures will increase	Increase habitat resilience	• Restore structure and function of streams: • Increase habitat and refugia in side channels. • Protect wetland-fed streams that maintain higher summer flows. • Restore structure and heterogeneity of stream channels. • Reconnect floodplains to improve hyporheic and baseflow conditions. • Remove dikes and levees. • Restore and protect riparian vegetation. • Manage livestock grazing to restore ecological function of riparian vegetation and maintain streambank conditions. • Reduce high road densities that are intercepting subsurface streamflows. • Increase the abundance of deep, structurally complex pools that act as thermal refugia. • Enhance and protect hyporheic zones: • Restore stream and floodplain complexity. • Rebuild stream bottoms by increasing floodplain connectivity, riparian vegetation, and water tables; decrease road connectivity. • Increase sinuosity in channels. • Eliminate human disturbances affecting stream width-to-depth ratio. • Avoid activities and structures that disrupt flows (e.g., roads). • Identify locations of hyporheic flows. • Reconnect floodplains and side channels to improve hyporheic and baseflow conditions. • Restore and maintain riparian vegetation: • Plant trees. • Maintain or enhance shade over streams. • Increase sinuosity in channels. • Eliminate human disturbances affecting stream width-to-depth ratio.

Strategically Prioritize Restoration of Natural Thermal, Hydrologic, and Wood Regimes

The resilience of native fish species to climate change can be enhanced using a variety of techniques that help restore hydrologic function and landscape conditions associated with high-quality fish habitat (Beechie et al. 2013, Williams et al. 2015) (table 4.12). Future stream temperature increases are likely to be particularly stressful to coldwater fishes, so prioritizing enhancement of riparian areas in some places to maximize shade and decrease direct solar radiation will be important (Justice et al. 2017, Wondzell et al. 2019). In smaller streams and rivers where riparian conditions are significantly degraded, fully functional riparian vegetation communities could offset most future stream temperature increases (Johnson and Wilby 2015, Nusslé et al. 2015), although the effectiveness of this tactic decreases in larger rivers (Cristea and Burges 2010). More shade could be achieved by decommissioning or

Table 4.12—Fisheries and aquatic habitat adaptation options for southwest Oregon (continued)

Sensitivity to climate change	Adaptation strategy	Adaptation tactic

Warmer stream temperatures may favor nonnative species.	Increase resilience of native fish species through management of nonnative species.	• Monitor nonnative population distribution and abundance:
		  • Evaluate nonnative species that might expand, and plan ahead for management.
		  • Survey and map nonnative species.
		  • Combine nonnative mapping with information on migration barriers.
		  • Consider information from surveys of warmer basins farther south as indicators of vulnerability.
		  • Use environmental DNA (eDNA) monitoring for early detection of nonnative species invasions.
		  • Reduce or suppress brook trout populations.
		  • Use monitoring and boat inspection programs to detect invasive mussels and aquatic plants species in lakes before populations are established.
		• Suppress, eliminate, or control invasive species populations:
		  • Tailor restoration actions to benefit native species.
		  • Remove or control nonnative fish species.
		  • Construct barriers that prevent access/invasion to conservation populations in headwaters.
		• Develop outreach and education at sensitive sites:
		  • Increase public education on nonnative species (e.g., with brochures, flyers, websites, signs).
		  • Conduct education during the initial stages of invasion.

Climate change will alter the distribution of native species and realign communities.	Conduct biodiversity surveys to describe current baseline conditions and manage distribution shifts.	• Protect refugia habitat and restore degraded habitat:
		  • Increase off-channel habitat and protect refugia in side channels and channels fed by wetlands.
		  • Increase habitat and refugia in side channels.
		  • Restore structure and heterogeneity of stream channels.
		• Conduct monitoring and population surveys:
		  • Monitor changes in stream temperature and fish distributions.
		  • Identify and inventory cold water refugia, springs, and groundwater input to springs.
		  • Identify seasonal refugia (winter and summer).
		  • Use (eDNA monitoring for early detection of nonnative species invasions.
		  • Formalize, expand, and standardized biological monitoring programs (e.g., management indicator species).
		  • Use modern, low-cost technologies such as eDNA, DNA barcoding, and digital photopoints.
		  • Use digital technology in data collection and database uploads.
		  • Streamline and integrate field crew data collection protocols.
		  • Fully utilize existing corporate databases and legacy datasets.
		  • Utilize best available technology to monitor, record, and disseminate information regarding the distribution of a broad array of aquatic species (e.g., eDNA, national databases).
		• Use climate niche modeling for future distribution scenarios.

relocating roads away from streams (Al-Chokhachy et al. 2016). Reducing grazing or excluding livestock can promote stronger banks and root masses that help narrow unnaturally wide channels over time (Dose and Roper 1994, Naiman et al. 2010).

As riparian areas recover, they will provide large woody debris that help diversify channel habitats and increase channel roughness. This could force more instream water exchange with cooler hyporheic flows and create microrefugia (Arrigoni et al. 2008). To facilitate this process, engineered logjams can be used to create deep, complex pools (Nichols and Ketcheson 2013). Enhancements of habitat and thermal diversity might also be achieved by reconnecting rivers to floodplains (Beechie et al. 2013) or restoring populations of American beaver (*Castor canadensis* Kuhl) (Bouwes et al. 2016, Pollock et al. 2014). Minimizing flow diversions, especially during the thermally stressful summer period, can have a cooling effect (Elmore et al. 2015) while simultaneously increasing habitat volume (Null et al. 2017). In most cases, insufficient resources will be available to pursue these restoration tactics, so strategic prioritization will be important to ensure work is done in the most important places (Peterson et al. 2013b).

Manage Connectivity

Obstacles to fish migrations may be removed in hopes of enhancing the success of migratory life-history forms (table 4.12), allowing fish species to track shifting habitats and permitting native species to reoccupy former habitat or supplement existing populations (Chelgren and Dunham 2015, Quinn et al. 2017). In some instances, accessible waters may also be invaded by nonnative species, so context-specific assessments are needed (Fausch et al. 2009). Conversely, barriers may be installed to prevent invasions by nonnative species (Rahel 2013). Native populations above barriers may be secure if they can adopt resident life histories but could be susceptible to catastrophic events in small habitats, requiring human intervention for refounding or supplementation.

Another form of managing connectivity, often referred to as assisted migration (or managed relocation), involves moving species from one location to another in efforts to found new populations. Assisted migration might be useful in southwest Oregon for resident species or life histories such as Umpqua chub or coastal cutthroat trout if streams and suitable habitats of sufficient size, upstream of barriers such as waterfalls, can be identified. Those areas could serve as refugia from expanding smallmouth bass populations in the case of chub, or constitute high-quality climate refugia for cutthroat trout where temperatures are projected to remain sufficiently cool (Isaak et al. 2015). Moving native fish to such areas is feasible but may be controversial if it places other native taxa at risk owing to novel predation or competition pressures (Pilliod et al. 2010). Reintroductions of native species to previously occupied habitats (Dunham et al. 2011, 2016) may also be performed when natural refounding is not an option (i.e., if populations in an area are isolated and periodically fail or suffer population bottlenecks). Management at this level will require an understanding of genetic principles and broodstock establishment to be successful in the long run.

Detection and Removal of Nonnative Species

Removal or suppression of nonnative species may also be important for maintaining or restoring some populations (Buktenica et al. 2018) (table 4.12). These efforts are done through chemical treatments or by physical capture and removal but are feasible only in smaller habitats (Shepard et al. 2002). Both chemical and physical treatments are costly, in part because they need to be conducted on multiple occasions to be effective (Buktenica et al. 2013, Peterson et al. 2008). The former is controversial because of effects on water quality and nontarget species. These methods are successful only if the source of nonnative species is removed, often by installation of a migration barrier. Unauthorized introductions are also common and can undermine conservation efforts. Finally, control measures to manage the abundance of nonnative species rather than remove them have been applied in some areas (e.g., removal of lake trout to promote bull trout persistence, or electrofishing to depress brook trout and favor cutthroat trout). Such activities are likely to be successful only if conducted at regular intervals for the foreseeable future (Peterson et al. 2008), which assumes funding and willingness for such ventures will be available indefinitely.

Responding to the environmental trends associated with climate change will require a diverse portfolio comprising many of the actions described above. Equally important will be adapting our mindsets—and our administrative processes—to dynamic disequilibrium in the 21st century. Under this paradigm, stream habitats will become more variable, undergo gradual shifts through time, and sometimes decline. Many populations are resilient enough to persist in or track suitable habitats, but others could be overwhelmed by future changes. It is unlikely that we will be able to preserve all populations of aquatic species as they currently exist. But as better information continues to be developed in the future, managers will have more tools at their disposal to know when and where resource commitments are best made to enhance the resilience of existing populations or to benefit other species for which management was previously not a priority.

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Appendix 4.1

Changes in mean August stream temperature, summer flow, and winter high-flow events by 6th code hydrologic unit codes (HUCs) within the Southwest Oregon Adaptation Partnership assessment area

		Number of days with high winter flows					Mean summer flow					Mean August stream temperature				
HUC number	Stream length	1980s	2040s	2080s	Days changed from 1980 to 2040	Days changed from 1980 to 2080	1980s	2040s	2080s	Change from 1980 to 2040	Change from 1980 to 2080	2000s	2040s	2080s	°C change from 2000 to 2040	°C change from 2000 to 2080
	Kilometers						*Cubic meters per second*			- - - *Percent* - - -					- - - - °C - - - -	
170900020201	101.06	13.48	13.49	13.59	0.01	0.11	0.303	0.258	0.231	-15.0	-24.0	13.66	14.98	15.93	1.32	2.27
170900020202	63.24	13.47	13.65	13.76	0.19	0.29	0.618	0.516	0.461	-16.5	-25.4	13.62	14.94	15.90	1.32	2.27
170900020203	81.81	13.92	13.87	14.01	-0.05	0.09	0.364	0.288	0.251	-20.8	-30.9	14.76	16.12	17.11	1.36	2.35
171003010101	1.79	3.09	12.53	16.47	9.45	13.38	2.803	1.295	0.775	-53.8	-72.3	13.33	14.64	15.58	1.31	2.25
171003010102	4.00	8.62	14.55	16.24	5.93	7.62	0.681	0.378	0.308	-44.4	-54.8	11.89	13.14	14.04	1.25	2.15
171003010103	3.90	5.95	13.23	15.44	7.28	9.48	1.78	0.87	0.59	-51.4	-66.8	11.27	12.50	13.38	1.23	2.11
171003010201	19.69	1.48	7.96	14.32	6.48	12.85	1.07	0.57	0.29	-47.0	-73.2	8.30	9.41	10.22	1.11	1.91
171003010202	8.60	1.22	6.79	13.94	5.56	12.72	1.37	0.75	0.38	-45.0	-72.0	8.60	9.72	10.53	1.12	1.93
171003010203	10.15	6.38	13.11	15.05	6.72	8.67	0.86	0.41	0.29	-52.2	-66.3	9.03	10.17	10.99	1.14	1.96
171003010204	38.29	5.21	12.73	15.32	7.51	10.10	2.89	1.43	0.99	-50.5	-65.7	11.14	12.36	13.24	1.22	2.11
171003010205	10.75	6.92	11.71	14.85	4.79	7.93	3.61	1.93	1.03	-46.3	-71.5	9.41	10.57	11.40	1.16	1.99
171003010301	4.73	13.71	15.37	15.64	1.66	1.93	0.27	0.23	0.20	-17.2	-25.2	8.50	9.62	10.42	1.12	1.93
171003010302	13.96	12.48	14.45	15.17	1.97	2.69	0.67	0.48	0.42	-28.0	-36.5	8.36	9.48	10.28	1.11	1.92
171003010303	21.32	14.50	14.98	15.19	0.48	0.68	0.55	0.46	0.41	-17.0	-24.8	9.36	10.51	11.34	1.15	1.99
171003010304	45.60	14.44	14.73	14.89	0.29	0.46	0.51	0.42	0.39	-16.1	-23.8	11.08	12.30	13.18	1.22	2.10
171003010401	29.10	11.38	14.59	15.52	3.21	4.14	0.27	0.16	0.13	-39.7	-51.4	9.50	10.66	11.49	1.16	2.00
171003010402	15.08	11.91	14.51	15.18	2.61	3.28	0.36	0.25	0.22	-29.8	-38.1	10.85	12.06	12.93	1.21	2.09
171003010403	29.06	12.34	14.57	15.16	2.23	2.82	0.47	0.31	0.26	-34.5	-44.8	10.93	12.15	13.02	1.22	2.09
171003010404	47.09	13.46	14.06	14.40	0.60	0.95	1.01	0.73	0.64	-27.9	-37.0	13.05	14.34	15.28	1.30	2.23
171003010501	19.18	5.74	12.83	14.82	7.10	9.08	6.62	3.42	2.19	-48.4	-66.8	9.00	10.14	10.96	1.14	1.96
171003010502	30.51	13.35	14.74	15.02	1.39	1.67	1.54	0.86	0.61	-44.2	-60.7	10.25	11.44	12.29	1.19	2.04
171003010503	16.35	7.59	13.64	15.23	6.05	7.64	13.13	6.85	4.48	-47.8	-65.9	11.11	12.33	13.21	1.22	2.10
171003010504	19.42	11.86	14.45	14.87	2.59	3.02	2.55	1.42	1.00	-44.3	-60.9	11.14	12.36	13.24	1.22	2.11
171003010505	27.26	11.67	14.06	14.58	2.40	2.91	8.53	4.91	3.53	-42.5	-58.6	12.26	13.53	14.44	1.27	2.18
171003010601	38.60	14.11	14.07	14.18	-0.05	0.06	0.12	0.10	0.09	-12.4	-20.7	13.23	14.54	15.48	1.30	2.25

Changes in mean August stream temperature, summer flow, and winter high-flow events by 6th code hydrologic unit codes (HUCs) within the Southwest Oregon Adaptation Partnership assessment area (continued)

		Number of days with high winter flows					Mean summer flow					Mean August stream temperature				
HUC number	Stream length	1980s	2040s	2080s	Days changed from 1980 to 2040	Days changed from 1980 to 2080	1980s	2040s	2080s	Change from 1980 to 2040	Change from 1980 to 2080	2000s	2040s	2080s	°C change from 2000 to 2040	°C change from 2000 to 2080
	Kilometers						*Cubic meters per second*			- - - *Percent* - - -					- - - - °C - - - -	
171003010602	29.84	14.15	14.09	14.27	-0.06	0.13	0.12	0.11	0.10	-13.5	-22.1	13.53	14.85	15.80	1.32	2.27
171003010603	36.49	13.90	13.92	14.04	0.02	0.14	0.65	0.57	0.52	-12.2	-20.2	15.07	16.44	17.44	1.38	2.37
171003010701	84.81	14.01	14.07	14.19	0.06	0.18	0.18	0.16	0.14	-11.8	-19.6	13.64	14.96	15.91	1.32	2.27
171003010702	38.09	13.43	13.47	13.48	0.04	0.05	0.51	0.46	0.42	-11.3	-18.9	14.85	16.22	17.20	1.37	2.36
171003010703	38.14	13.98	14.11	14.39	0.13	0.41	0.25	0.22	0.20	-13.0	-20.8	12.13	13.39	14.31	1.26	2.17
171003010704	20.58	13.49	13.59	13.70	0.09	0.21	1.37	1.22	1.11	-11.4	-18.9	15.88	17.29	18.30	1.41	2.42
171003010705	21.39	13.29	13.42	13.52	0.13	0.23	0.11	0.10	0.09	-10.2	-17.3	13.84	15.17	16.13	1.33	2.29
171003010706	28.37	13.64	13.65	13.69	0.01	0.05	1.77	1.57	1.44	-11.2	-18.7	15.70	17.10	18.11	1.40	2.41
171003010801	35.09	13.66	14.04	14.18	0.38	0.52	0.20	0.17	0.15	-16.9	-25.2	13.62	14.94	15.89	1.32	2.27
171003010802	45.62	13.39	13.58	13.68	0.19	0.28	0.24	0.21	0.19	-11.7	-19.3	13.79	15.11	16.07	1.33	2.28
171003010803	36.42	12.48	13.68	14.06	1.20	1.58	11.36	7.01	5.34	-38.3	-53.0	14.03	15.37	16.34	1.34	2.30
171003010804	18.97	13.70	13.79	13.91	0.09	0.22	0.21	0.19	0.17	-10.8	-18.3	13.78	15.11	16.06	1.33	2.28
171003010805	28.31	13.66	13.55	13.75	-0.11	0.09	0.11	0.10	0.09	-9.9	-17.1	14.65	16.01	17.00	1.36	2.34
171003010806	15.20	12.11	13.97	14.75	1.87	2.64	25.51	16.09	12.44	-36.9	-51.2	14.38	15.73	16.70	1.35	2.32
171003010807	21.05	13.47	13.84	14.05	0.37	0.58	13.35	9.07	7.32	-32.1	-45.1	14.90	16.27	17.26	1.37	2.36
171003010808	27.13	13.70	14.00	14.23	0.30	0.53	14.41	9.84	7.97	-31.8	-44.7	14.52	15.88	16.85	1.35	2.33
171003010809	35.55	13.59	13.90	14.16	0.31	0.57	12.98	8.93	7.27	-31.2	-44.0	14.95	16.32	17.31	1.37	2.36
171003010901	50.95	14.14	14.16	14.28	0.02	0.14	0.26	0.23	0.21	-13.8	-22.3	13.17	14.47	15.41	1.30	2.24
171003010902	27.27	14.12	14.06	14.13	-0.06	0.01	0.23	0.20	0.18	-12.2	-20.1	13.82	15.14	16.10	1.33	2.29
171003010903	48.39	14.36	14.38	14.44	0.02	0.08	0.78	0.69	0.62	-12.5	-20.4	14.80	16.16	17.15	1.36	2.35
171003011001	45.47	13.89	13.91	14.10	0.02	0.21	0.14	0.12	0.11	-11.4	-19.2	13.05	14.34	15.28	1.30	2.23
171003011002	25.86	13.78	13.94	14.11	0.16	0.33	0.10	0.09	0.08	-11.2	-18.9	13.14	14.44	15.38	1.30	2.24
171003011003	30.38	13.33	13.53	13.64	0.20	0.30	0.53	0.47	0.42	-11.6	-19.5	14.32	15.67	16.64	1.35	2.32
171003011004	14.47	13.58	13.61	13.71	0.03	0.13	0.16	0.14	0.13	-11.3	-19.0	12.76	14.04	14.97	1.28	2.21
171003011005	39.75	13.04	13.12	13.25	0.08	0.21	0.90	0.80	0.73	-11.4	-19.2	15.03	16.41	17.40	1.37	2.37
171003011006	40.07	13.68	13.78	13.92	0.09	0.23	0.10	0.08	0.08	-12.7	-21.3	12.34	13.61	14.53	1.27	2.19

Changes in mean August stream temperature, summer flow, and winter high-flow events by 6th code hydrologic unit codes (HUCs) within the Southwest Oregon Adaptation Partnership assessment area (continued)

		Number of days with high winter flows					Mean summer flow					Mean August stream temperature				
HUC number	Stream length	1980s	2040s	2080s	Days changed from 1980 to 2040	Days changed from 1980 to 2080	1980s	2040s	2080s	Change from 1980 to 2040	Change from 1980 to 2080	2000s	2040s	2080s	°C change from 2000 to 2040	°C change from 2000 to 2080
	Kilometers						*Cubic meters per second*			*- - - Percent - - -*					- - - - °C - - - -	
171003011007	64.90	13.03	13.07	13.24	0.03	0.21	0.58	0.51	0.46	-12.0	-20.2	14.91	16.28	17.27	1.37	2.36
171003011008	35.11	13.07	13.08	13.30	0.01	0.24	1.35	1.19	1.09	-11.3	-19.2	15.79	17.19	18.20	1.40	2.42
171003011101	35.60	13.64	14.02	14.30	0.37	0.65	21.82	15.59	12.94	-28.6	-40.7	17.08	18.53	19.58	1.45	2.51
171003011103	47.48	13.16	13.40	13.64	0.24	0.48	17.73	12.93	10.86	-27.0	-38.8	17.60	19.08	20.14	1.48	2.54
171003020101	55.49	13.60	14.40	14.84	0.80	1.24	0.28	0.22	0.19	-22.2	-31.4	12.78	14.07	15.00	1.29	2.22
171003020102	49.24	13.02	14.07	14.33	1.05	1.31	0.19	0.15	0.14	-18.5	-26.3	13.08	14.38	15.31	1.30	2.24
171003020103	25.27	12.96	13.56	13.89	0.60	0.93	0.16	0.14	0.12	-15.4	-23.1	13.61	14.93	15.89	1.32	2.27
171003020104	45.87	13.00	13.26	13.57	0.26	0.57	0.09	0.08	0.08	-10.1	-17.7	13.76	15.09	16.04	1.32	2.28
171003020105	33.78	13.24	13.55	13.78	0.32	0.54	1.30	1.07	0.97	-17.5	-25.6	15.51	16.90	17.91	1.39	2.40
171003020201	38.59	12.99	14.18	14.77	1.19	1.78	0.17	0.13	0.12	-21.3	-29.8	12.58	13.86	14.79	1.28	2.20
171003020202	38.77	12.99	13.27	13.62	0.29	0.63	0.49	0.41	0.37	-16.2	-24.3	15.11	16.48	17.48	1.38	2.37
171003020203	26.43	12.76	13.20	13.43	0.44	0.67	0.24	0.21	0.19	-10.8	-18.7	12.04	13.30	14.21	1.26	2.17
171003020204	48.00	12.73	12.89	13.16	0.16	0.43	0.13	0.12	0.11	-9.5	-16.8	13.90	15.23	16.19	1.33	2.29
171003020205	56.76	12.88	13.09	13.34	0.21	0.45	1.03	0.90	0.83	-12.3	-19.9	15.42	16.81	17.81	1.39	2.39
171003020301	54.51	13.43	13.49	13.81	0.06	0.38	0.15	0.13	0.12	-10.8	-18.1	14.94	16.31	17.30	1.37	2.36
171003020302	51.00	13.42	13.53	13.75	0.11	0.33	0.25	0.22	0.20	-12.2	-19.9	13.88	15.21	16.17	1.33	2.29
171003020303	42.91	13.00	13.17	13.45	0.17	0.45	1.16	0.99	0.90	-14.8	-22.6	15.90	17.31	18.33	1.41	2.43
171003020304	22.25	12.97	13.17	13.54	0.20	0.57	2.90	2.51	2.29	-13.5	-21.1	16.64	18.08	19.12	1.44	2.47
171003020305	46.65	12.99	13.06	13.19	0.07	0.20	0.11	0.10	0.09	-11.0	-19.0	13.60	14.92	15.87	1.32	2.27
171003020306	22.16	12.85	12.98	13.29	0.13	0.44	4.19	3.66	3.35	-12.6	-20.2	16.88	18.33	19.37	1.45	2.49
171003020401	46.96	13.73	13.82	13.93	0.10	0.20	0.07	0.06	0.06	-9.1	-16.1	14.12	15.45	16.42	1.34	2.31
171003020402	34.07	13.30	13.39	13.51	0.09	0.21	0.20	0.19	0.17	-8.8	-15.6	14.87	16.24	17.23	1.37	2.36
171003020403	24.17	13.43	13.47	13.50	0.04	0.07	0.19	0.17	0.16	-8.5	-15.2	14.47	15.82	16.80	1.35	2.33
171003020404	36.75	13.10	13.21	13.32	0.11	0.22	0.29	0.26	0.25	-8.5	-15.1	15.42	16.81	17.81	1.39	2.39
171003020501	31.95	12.46	12.55	12.70	0.10	0.25	0.09	0.08	0.07	-10.1	-17.4	14.33	15.68	16.65	1.35	2.32
171003020502	42.50	12.87	12.88	13.17	0.01	0.30	3.49	3.08	2.82	-11.9	-19.3	17.00	18.45	19.50	1.45	2.50

Changes in mean August stream temperature, summer flow, and winter high-flow events by 6th code hydrologic unit codes (HUCs) within the Southwest Oregon Adaptation Partnership assessment area (continued)

		Number of days with high winter flows					Mean summer flow					Mean August stream temperature				
HUC number	Stream length	1980s	2040s	2080s	Days changed from 1980 to 2040	Days changed from 1980 to 2080	1980s	2040s	2080s	Change from 1980 to 2040	Change from 1980 to 2080	2000s	2040s	2080s	°C change from 2000 to 2040	°C change from 2000 to 2080
	Kilometers						*Cubic meters per second*			- - - *Percent* - - -					- - - - °C - - - -	
171003020503	34.62	13.18	13.24	13.39	0.05	0.21	0.07	0.06	0.06	-7.9	-14.5	15.24	16.63	17.63	1.38	2.38
171003020504	40.95	12.80	12.77	13.06	-0.03	0.26	2.51	2.22	2.03	-11.7	-19.0	16.18	17.60	18.62	1.42	2.45
171003020505	51.53	12.33	12.43	12.63	0.11	0.30	0.15	0.14	0.13	-9.6	-16.7	15.66	17.06	18.07	1.40	2.41
171003020506	47.35	13.21	13.25	13.50	0.03	0.29	2.75	2.44	2.24	-11.5	-18.8	16.00	17.41	18.43	1.41	2.43
171003020507	59.58	13.21	13.29	13.50	0.08	0.29	0.14	0.13	0.12	-6.5	-11.9	15.02	16.40	17.39	1.37	2.37
171003020508	69.31	13.24	13.25	13.49	0.00	0.25	4.16	3.69	3.39	-11.2	-18.4	18.02	19.51	20.59	1.49	2.57
171003020601	27.32	14.17	14.21	14.33	0.03	0.16	0.09	0.08	0.07	-9.0	-16.2	12.65	13.93	14.85	1.28	2.21
171003020602	62.69	14.11	14.14	14.26	0.03	0.16	0.13	0.12	0.11	-9.4	-17.0	13.93	15.26	16.22	1.33	2.29
171003020603	48.40	14.04	14.09	14.27	0.05	0.23	0.37	0.34	0.31	-9.3	-16.9	13.75	15.08	16.03	1.32	2.28
171003020701	53.28	-203.8	-203.8	-203.6	0.03	0.27	0.35	0.32	0.30	-9.0	-16.2	13.57	14.89	15.84	1.32	2.27
171003020702	43.65	13.95	13.97	14.22	0.02	0.27	0.47	0.43	0.40	-8.6	-15.8	14.62	15.98	16.96	1.36	2.34
171003020703	28.84	14.12	14.06	14.28	-0.06	0.16	0.98	0.90	0.83	-8.3	-15.1	15.21	16.59	17.59	1.38	2.38
171003020704	40.22	14.13	14.13	14.36	0.00	0.23	0.09	0.08	0.08	-6.3	-11.9	14.54	15.89	16.87	1.35	2.33
171003020705	33.54	14.75	14.70	14.95	-0.06	0.20	0.93	0.86	0.80	-7.8	-14.4	15.62	17.01	18.02	1.40	2.41
171003020706	41.33	14.65	14.59	14.81	-0.06	0.16	0.90	0.83	0.77	-7.6	-14.0	15.03	16.40	17.39	1.38	2.37
171003020707	39.54	14.39	14.35	14.55	-0.04	0.16	0.68	0.63	0.58	-7.4	-13.8	15.01	16.38	17.37	1.37	2.36
171003020801	27.61	15.24	15.23	15.34	0.00	0.10	0.13	0.11	0.10	-10.1	-18.1	12.97	14.26	15.19	1.29	2.23
171003020802	41.90	14.50	14.57	14.78	0.07	0.28	0.19	0.17	0.16	-9.5	-17.0	13.41	14.72	15.66	1.31	2.26
171003020803	37.55	14.37	14.34	14.53	-0.03	0.15	0.31	0.29	0.26	-8.7	-15.8	14.35	15.70	16.67	1.35	2.32
171003020804	33.58	14.22	14.24	14.34	0.02	0.12	0.47	0.43	0.40	-8.5	-15.5	15.52	16.92	17.92	1.39	2.40
171003020901	63.39	13.81	13.82	14.04	0.01	0.23	0.14	0.13	0.12	-6.8	-12.5	15.28	16.66	17.66	1.38	2.38
171003020902	45.79	14.36	14.34	14.56	-0.02	0.20	1.73	1.60	1.49	-7.6	-14.0	15.27	16.66	17.65	1.38	2.38
171003020903	23.22	14.41	14.35	14.56	-0.06	0.15	2.54	2.35	2.18	-7.6	-14.0	16.11	17.53	18.55	1.42	2.44
171003020904	59.12	14.06	14.14	14.32	0.08	0.26	1.80	1.66	1.55	-7.5	-13.9	15.68	17.08	18.09	1.40	2.41
171003020905	61.59	13.44	13.44	13.72	0.00	0.28	1.55	1.43	1.34	-7.4	-13.7	16.48	17.91	18.95	1.43	2.46
171003021001	76.88	12.44	12.50	12.76	0.06	0.31	0.16	0.14	0.13	-10.7	-18.3	14.81	16.18	17.16	1.37	2.35

Changes in mean August stream temperature, summer flow, and winter high-flow events by 6th code hydrologic unit codes (HUCs) within the Southwest Oregon Adaptation Partnership assessment area (continued)

		Number of days with high winter flows					Mean summer flow					Mean August stream temperature				
HUC number	Stream length	1980s	2040s	2080s	Days changed from 1980 to 2040	Days changed from 1980 to 2080	1980s	2040s	2080s	Change from 1980 to 2040	Change from 1980 to 2080	2000s	2040s	2080s	°C change from 2000 to 2040	°C change from 2000 to 2080
	Kilometers						*Cubic meters per second*			- - - *Percent* - - -					- - - - °C - - - -	
171003021002	26.21	12.41	12.59	12.75	0.17	0.34	0.60	0.54	0.50	-9.8	-16.9	17.92	19.41	20.48	1.49	2.56
171003021003	51.23	12.50	12.54	12.76	0.04	0.26	0.11	0.09	0.09	-10.5	-18.0	15.26	16.64	17.64	1.38	2.38
171003021004	41.67	12.70	12.77	13.03	0.07	0.33	0.31	0.28	0.26	-9.3	-16.1	17.23	18.69	19.75	1.46	2.52
171003021101	27.82	13.47	13.60	13.80	0.13	0.32	11.86	10.70	9.90	-9.8	-16.6	19.94	21.51	22.64	1.57	2.70
171003021103	32.48	13.97	13.99	14.22	0.02	0.24	5.90	5.33	4.93	-9.6	-16.3	17.73	19.21	20.27	1.48	2.55
171003021201	46.08	14.24	14.21	14.35	-0.02	0.11	0.07	0.07	0.06	-7.3	-13.6	14.33	15.68	16.65	1.35	2.32
171003021202	31.75	14.21	14.22	14.38	0.02	0.18	0.17	0.16	0.15	-6.8	-12.8	14.86	16.23	17.21	1.37	2.36
171003021203	42.81	14.13	14.09	14.29	-0.04	0.16	0.30	0.28	0.26	-6.9	-13.0	16.05	17.47	18.49	1.42	2.44
171003021204	50.59	14.83	14.64	14.72	-0.19	-0.11	0.17	0.16	0.15	-7.6	-13.5	16.79	18.23	19.28	1.44	2.49
171003021302	62.08	12.60	12.72	12.86	0.12	0.26	0.13	0.12	0.11	-8.5	-14.7	17.30	18.76	19.82	1.46	2.52
171003030103	50.02	13.78	13.91	14.03	0.12	0.25	0.95	0.84	0.77	-11.6	-19.3	17.34	18.80	19.86	1.47	2.52
171003030104	23.81	13.41	13.45	13.60	0.05	0.19	0.32	0.29	0.27	-10.0	-17.3	18.78	20.30	21.40	1.52	2.62
171003030201	56.53	13.81	13.76	13.96	-0.05	0.15	31.94	25.81	22.79	-19.2	-28.6	19.15	20.68	21.79	1.54	2.64
171003030202	39.49	14.53	14.53	14.64	0.00	0.11	0.14	0.13	0.12	-8.4	-14.6	14.79	16.16	17.14	1.37	2.35
171003030203	47.22	13.94	14.03	14.23	0.08	0.29	28.03	22.79	20.18	-18.7	-28.0	17.22	18.68	19.73	1.46	2.51
171003030204	67.06	14.49	14.46	14.59	-0.03	0.10	0.12	0.11	0.10	-6.6	-11.7	15.34	16.72	17.72	1.39	2.39
171003030205	47.15	13.89	13.95	14.15	0.05	0.26	38.04	30.98	27.46	-18.6	-27.8	18.02	19.51	20.59	1.49	2.57
171003030206	29.02	14.31	14.36	14.33	0.05	0.02	0.13	0.12	0.11	-8.3	-14.5	15.32	16.70	17.70	1.39	2.39
171003030207	46.34	14.00	14.05	14.21	0.06	0.22	40.75	33.24	29.49	-18.4	-27.6	17.90	19.39	20.46	1.49	2.56
171003030301	37.09	13.61	13.62	13.55	0.02	-0.05	0.23	0.21	0.19	-10.5	-18.0	16.22	17.64	18.67	1.42	2.45
171003030302	61.75	13.62	13.60	13.61	-0.02	-0.01	0.39	0.35	0.32	-9.8	-16.9	17.34	18.81	19.87	1.47	2.52
171003030304	33.59	13.23	13.22	13.22	0.00	0.00	0.12	0.11	0.10	-8.7	-14.9	16.52	17.96	18.99	1.43	2.47
171003030306	44.94	14.19	14.16	14.09	-0.03	-0.10	0.08	0.07	0.07	-8.2	-14.5	15.74	17.15	18.16	1.40	2.42
171003030307	65.29	13.92	13.83	13.81	-0.09	-0.11	1.34	1.22	1.13	-8.7	-15.3	17.62	19.09	20.16	1.48	2.54
171003030308	32.30	14.28	14.18	14.18	-0.10	-0.10	0.31	0.29	0.27	-8.4	-14.6	16.02	17.44	18.46	1.41	2.43
171003030309	38.22	14.22	14.01	14.02	-0.21	-0.21	0.09	0.09	0.08	-8.2	-14.2	15.12	16.50	17.49	1.38	2.37

Changes in mean August stream temperature, summer flow, and winter high-flow events by 6th code hydrologic unit codes (HUCs) within the Southwest Oregon Adaptation Partnership assessment area (continued)

		Number of days with high winter flows					Mean summer flow					Mean August stream temperature				
HUC number	Stream length	1980s	2040s	2080s	Days changed from 1980 to 2040	Days changed from 1980 to 2080	1980s	2040s	2080s	Change from 1980 to 2040	Change from 1980 to 2080	2000s	2040s	2080s	°C change from 2000 to 2040	°C change from 2000 to 2080
	Kilometers						*Cubic meters per second*			*- - - Percent - - -*					- - - - °C - - - -	
171003030310	40.29	14.11	14.04	14.02	-0.07	-0.08	2.41	2.20	2.05	-8.5	-14.9	18.40	19.91	20.99	1.51	2.59
171003030601	82.75	13.93	13.93	13.89	0.00	-0.04	0.09	0.08	0.08	-7.9	-13.4	14.41	15.76	16.73	1.35	2.33
171003030602	96.24	14.21	14.13	14.15	-0.08	-0.06	0.33	0.30	0.28	-8.3	-14.0	14.62	15.98	16.96	1.36	2.34
171003050101	91.49	14.24	14.18	14.31	-0.05	0.07	0.17	0.16	0.15	-7.1	-12.7	15.10	16.48	17.47	1.38	2.37
171003050102	56.40	14.40	14.47	14.65	0.08	0.26	0.10	0.09	0.08	-8.5	-15.3	14.28	15.62	16.59	1.35	2.32
171003050201	85.39	15.54	15.52	15.67	-0.02	0.12	0.35	0.31	0.28	-11.7	-20.5	13.18	14.48	15.42	1.30	2.24
171003050202	24.58	15.58	15.53	15.73	-0.05	0.15	0.20	0.17	0.16	-12.0	-21.5	13.45	14.76	15.71	1.31	2.26
171003050203	28.99	15.32	15.33	15.46	0.01	0.15	2.23	1.97	1.77	-11.5	-20.5	16.90	18.35	19.39	1.45	2.49
171003050204	17.53	14.36	14.61	14.76	0.25	0.40	0.13	0.11	0.10	-13.4	-22.1	12.34	13.61	14.52	1.27	2.18
171003050205	40.03	14.67	14.69	14.98	0.02	0.31	0.80	0.68	0.62	-14.6	-22.3	16.50	17.94	18.97	1.43	2.47
171003050206	41.07	15.49	15.43	15.55	-0.05	0.07	0.15	0.13	0.12	-13.6	-21.6	15.63	17.03	18.03	1.40	2.41
171003060201	91.98	15.84	15.81	15.99	-0.03	0.15	0.29	0.25	0.23	-13.0	-22.0	15.80	17.21	18.23	1.41	2.42
171003060202	61.44	15.93	15.89	16.11	-0.04	0.18	0.71	0.61	0.54	-14.1	-23.9	15.50	16.90	17.90	1.39	2.40
171003060301	90.89	15.73	15.71	15.90	-0.02	0.17	0.61	0.53	0.46	-13.6	-24.2	14.31	15.66	16.63	1.35	2.32
171003060302	65.50	15.85	15.84	15.99	-0.01	0.14	1.46	1.22	1.07	-16.3	-26.6	15.44	16.83	17.83	1.39	2.39
171003070101	31.28	6.87	14.00	16.17	7.13	9.31	1.00	0.50	0.38	-50.4	-62.1	9.45	10.61	11.44	1.16	1.99
171003070102	36.93	9.31	14.45	15.69	5.15	6.38	0.52	0.29	0.22	-45.0	-57.3	9.21	10.36	11.19	1.15	1.97
171003070103	42.75	9.35	14.51	15.96	5.16	6.61	0.98	0.54	0.43	-44.9	-56.8	8.80	9.93	10.75	1.13	1.95
171003070104	39.06	8.70	13.78	15.65	5.08	6.94	0.57	0.29	0.19	-48.5	-66.4	9.09	10.23	11.06	1.14	1.97
171003070105	66.12	7.43	13.13	15.48	5.69	8.04	1.15	0.62	0.45	-46.3	-61.0	9.65	10.81	11.65	1.16	2.00
171003070106	79.72	8.21	13.15	15.40	4.94	7.19	1.79	0.99	0.73	-44.7	-59.4	9.61	10.77	11.61	1.16	2.00
171003070107	26.04	12.63	14.02	14.68	1.39	2.06	1.88	1.11	0.84	-41.0	-55.4	13.29	14.60	15.54	1.31	2.25
171003070108	42.95	10.66	14.94	15.70	4.28	5.04	0.67	0.38	0.30	-43.0	-55.4	8.21	9.32	10.12	1.11	1.91
171003070109	47.66	4.32	11.92	15.76	7.60	11.44	2.62	1.32	0.90	-49.5	-65.8	9.27	10.42	11.25	1.15	1.98
171003070110	52.83	12.73	13.12	13.38	0.39	0.65	0.15	0.14	0.12	-10.3	-18.2	13.57	14.89	15.84	1.32	2.27
171003070111	54.80	11.88	13.16	13.74	1.29	1.86	4.39	2.58	1.94	-41.3	-55.8	12.60	13.88	14.81	1.28	2.20

Changes in mean August stream temperature, summer flow, and winter high-flow events by 6th code hydrologic unit codes (HUCs) within the Southwest Oregon Adaptation Partnership assessment area (continued)

		Number of days with high winter flows					Mean summer flow					Mean August stream temperature				
HUC number	Stream length	1980s	2040s	2080s	Days changed from 1980 to 2040	Days changed from 1980 to 2080	1980s	2040s	2080s	Change from 1980 to 2040	Change from 1980 to 2080	2000s	2040s	2080s	°C change from 2000 to 2040	°C change from 2000 to 2080
	Kilometers						*Cubic meters per second*			*- - - Percent - - -*					- - - - °C - - - -	
171003070112	92.85	10.55	13.41	14.16	2.86	3.61	0.79	0.53	0.43	-33.1	-45.3	10.25	11.44	12.30	1.19	2.05
171003070113	48.78	11.79	13.04	13.69	1.25	1.90	5.73	3.51	2.71	-38.7	-52.6	12.62	13.90	14.82	1.28	2.21
171003070201	31.59	7.71	13.30	15.48	5.58	7.77	0.74	0.37	0.29	-49.6	-60.5	9.42	10.57	11.40	1.15	1.99
171003070202	23.31	6.51	11.22	13.78	4.71	7.27	0.38	0.24	0.17	-38.0	-55.7	9.69	10.85	11.70	1.17	2.01
171003070203	41.84	6.20	12.37	14.86	6.17	8.66	1.19	0.62	0.39	-47.9	-67.2	9.71	10.88	11.72	1.17	2.01
171003070204	52.31	6.35	11.97	14.68	5.61	8.33	1.93	1.04	0.62	-46.3	-67.8	11.78	13.03	13.93	1.25	2.15
171003070205	22.75	8.12	12.06	13.88	3.95	5.77	2.04	1.15	0.76	-43.8	-62.9	10.84	12.05	12.92	1.21	2.08
171003070206	41.33	12.03	12.35	12.56	0.32	0.52	0.20	0.18	0.16	-9.1	-16.9	12.78	14.07	15.00	1.29	2.22
171003070207	40.78	9.48	12.56	13.88	3.08	4.41	3.53	2.10	1.59	-40.4	-54.8	10.96	12.18	13.06	1.21	2.09
171003070300	64.06	12.80	13.18	13.46	0.37	0.66	2.09	1.33	1.04	-36.3	-50.5	13.78	15.04	15.95	1.26	2.16
171003070401	52.99	10.82	12.45	13.09	1.63	2.28	0.15	0.13	0.11	-16.4	-24.9	10.94	12.15	13.03	1.21	2.09
171003070402	38.96	8.50	11.98	13.85	3.49	5.36	0.56	0.35	0.27	-37.2	-51.6	13.18	14.48	15.42	1.30	2.24
171003070403	56.09	10.82	11.99	12.79	1.17	1.97	0.24	0.19	0.17	-21.0	-31.0	13.81	15.14	16.10	1.33	2.29
171003070404	31.30	11.31	12.10	12.73	0.79	1.42	1.23	0.94	0.80	-23.6	-34.6	13.56	14.88	15.83	1.32	2.27
171003070405	52.80	12.00	12.53	12.85	0.54	0.85	0.19	0.17	0.16	-9.2	-16.9	13.91	15.24	16.20	1.33	2.29
171003070406	25.35	11.90	12.65	13.04	0.75	1.14	2.26	1.80	1.57	-20.5	-30.7	13.47	14.79	15.74	1.31	2.26
171003070407	22.12	12.64	12.95	13.23	0.31	0.59	0.17	0.15	0.14	-6.9	-13.3	16.18	17.59	18.62	1.42	2.44
171003070408	38.64	12.47	12.92	13.26	0.44	0.79	1.11	0.91	0.80	-18.0	-27.6	13.35	14.66	15.60	1.31	2.25
171003070501	56.94	13.10	13.41	13.58	0.31	0.48	0.12	0.10	0.09	-10.9	-18.7	13.75	15.08	16.04	1.33	2.28
171003070502	33.25	13.35	13.44	13.79	0.09	0.44	0.25	0.23	0.21	-9.9	-17.3	15.25	16.63	17.63	1.38	2.38
171003070503	52.73	12.75	13.07	13.25	0.32	0.51	0.12	0.10	0.10	-10.3	-17.8	14.72	16.08	17.06	1.36	2.35
171003070504	37.67	13.59	13.66	13.82	0.08	0.23	0.41	0.37	0.34	-9.7	-16.9	17.03	18.49	19.54	1.45	2.50
171003070505	43.39	13.77	13.81	13.98	0.04	0.22	0.49	0.45	0.41	-9.5	-16.5	16.34	17.77	18.79	1.43	2.46
171003070601	29.86	13.94	14.04	14.18	0.09	0.23	0.10	0.09	0.09	-8.3	-14.7	14.14	15.48	16.44	1.34	2.31
171003070602	29.87	13.91	13.96	14.02	0.05	0.10	0.11	0.10	0.09	-7.5	-13.3	15.62	17.02	18.02	1.40	2.41
171003070603	4.53	13.83	13.98	14.05	0.16	0.22	0.77	0.72	0.67	-7.4	-13.2	18.21	19.71	20.79	1.50	2.58

Changes in mean August stream temperature, summer flow, and winter high-flow events by 6th code hydrologic unit codes (HUCs) within the Southwest Oregon Adaptation Partnership assessment area (continued)

		Number of days with high winter flows					Mean summer flow					Mean August stream temperature				
HUC number	Stream length	1980s	2040s	2080s	Days changed from 1980 to 2040	Days changed from 1980 to 2080	1980s	2040s	2080s	Change from 1980 to 2040	Change from 1980 to 2080	2000s	2040s	2080s	°C change from 2000 to 2040	°C change from 2000 to 2080
	Kilometers						*Cubic meters per second*			- - - *Percent* - - -					- - - - °C - - - -	
171003070701	12.96	11.44	13.29	14.15	1.85	2.71	36.07	23.80	18.89	-34.0	-47.6	14.88	15.16	15.36	0.28	0.49
171003070702	10.15	11.49	13.34	14.28	1.85	2.78	46.39	31.20	25.06	-32.7	-46.0	14.04	14.04	14.04	0.00	0.00
171003070703	43.42	12.49	13.40	13.91	0.91	1.42	19.79	13.51	10.95	-31.7	-44.7	16.71	17.60	18.24	0.89	1.53
171003070801	12.77	7.32	11.46	13.30	4.15	5.99	1.44	0.92	0.65	-36.0	-55.1	15.52	16.91	17.92	1.39	2.40
171003070802	18.02	9.75	11.60	12.74	1.84	2.98	1.11	0.78	0.59	-30.0	-46.5	14.97	16.34	17.33	1.37	2.36
171003070803	26.39	9.26	13.01	14.08	3.75	4.82	0.27	0.18	0.15	-33.9	-43.5	10.49	11.69	12.56	1.20	2.06
171003070804	28.04	10.49	12.32	12.76	1.82	2.27	0.20	0.16	0.14	-18.3	-27.1	12.53	13.81	14.73	1.28	2.20
171003070805	37.20	12.62	13.34	13.77	0.72	1.14	0.54	0.44	0.39	-18.9	-27.9	14.05	15.39	16.35	1.34	2.30
171003070806	62.37	11.49	12.12	12.53	0.63	1.04	0.60	0.51	0.46	-15.7	-24.2	14.79	16.16	17.15	1.37	2.35
171003070807	28.86	11.12	11.83	12.20	0.71	1.08	1.00	0.80	0.70	-19.5	-30.4	16.54	17.97	19.00	1.43	2.47
171003070808	24.06	11.13	11.60	12.09	0.47	0.97	0.12	0.11	0.10	-9.0	-16.5	14.37	15.72	16.70	1.35	2.32
171003070809	20.48	11.99	12.50	12.90	0.51	0.91	1.56	1.28	1.11	-18.4	-28.9	17.07	18.52	19.57	1.46	2.50
171003070810	66.09	11.79	12.11	12.47	0.32	0.68	0.21	0.19	0.18	-8.6	-16.1	15.78	17.19	18.20	1.40	2.42
171003070812	31.35	11.95	12.61	12.99	0.66	1.04	3.50	2.92	2.57	-16.6	-26.4	19.70	21.25	22.38	1.56	2.68
171003080101	53.63	14.03	14.28	14.56	0.25	0.54	0.06	0.05	0.05	-8.6	-15.3	15.22	16.60	17.60	1.38	2.38
171003080102	28.35	12.74	13.07	13.55	0.34	0.82	0.21	0.20	0.18	-8.2	-14.7	15.76	17.17	18.18	1.40	2.42
171003080103	52.38	11.98	12.29	12.67	0.31	0.69	0.16	0.14	0.13	-8.8	-16.1	14.81	16.17	17.16	1.37	2.35
171003080104	33.38	13.62	13.88	14.15	0.27	0.54	0.27	0.25	0.23	-7.8	-14.0	14.80	16.17	17.15	1.37	2.35
171003080106	48.09	13.45	13.70	14.12	0.25	0.67	0.44	0.40	0.37	-9.6	-16.3	14.70	16.06	17.05	1.36	2.34
171003080108	30.86	12.35	12.61	13.04	0.26	0.68	0.39	0.36	0.34	-8.4	-14.7	14.67	16.03	17.01	1.36	2.34
171003080109	54.62	12.48	12.77	13.09	0.29	0.61	0.32	0.29	0.27	-7.9	-14.0	16.08	17.49	18.51	1.42	2.44
171003080111	27.53	13.04	13.47	13.80	0.43	0.76	1.58	1.46	1.37	-7.6	-13.4	17.39	18.86	19.91	1.47	2.53
171003080112	40.47	13.39	13.67	13.89	0.28	0.50	4.03	3.03	2.59	-24.9	-35.8	17.57	18.96	19.97	1.39	2.40
171003080201	28.28	13.17	13.58	13.91	0.41	0.74	10.77	7.60	6.27	-29.4	-41.8	17.85	19.06	19.94	1.21	2.09
171003080203	45.76	13.45	13.84	14.16	0.39	0.71	9.17	6.64	5.56	-27.6	-39.4	17.46	18.71	19.62	1.26	2.16
171003080204	34.56	13.51	13.99	14.28	0.48	0.77	10.78	7.81	6.54	-27.6	-39.4	16.65	17.84	18.69	1.19	2.04

Changes in mean August stream temperature, summer flow, and winter high-flow events by 6th code hydrologic unit codes (HUCs) within the Southwest Oregon Adaptation Partnership assessment area (continued)

		Number of days with high winter flows					Mean summer flow					Mean August stream temperature				
HUC number	Stream length	1980s	2040s	2080s	Days changed from 1980 to 2040	Days changed from 1980 to 2080	1980s	2040s	2080s	Change from 1980 to 2040	Change from 1980 to 2080	2000s	2040s	2080s	°C change from 2000 to 2040	°C change from 2000 to 2080
	Kilometers						*Cubic meters per second*			- - - *Percent* - - -					- - - - °C - - - -	
171003080205	26.32	13.22	13.74	14.15	0.52	0.93	16.10	11.70	9.81	-27.3	-39.1	16.86	17.93	18.70	1.07	1.84
171003080206	28.43	13.86	14.05	14.10	0.19	0.24	0.07	0.07	0.07	-5.8	-10.1	16.25	17.67	18.70	1.42	2.45
171003080207	32.87	13.80	14.01	14.17	0.21	0.37	4.33	3.16	2.66	-26.9	-38.5	16.27	17.60	18.55	1.33	2.28
171003080301	50.94	14.04	14.06	14.22	0.02	0.18	0.18	0.17	0.16	-7.3	-13.4	14.92	16.29	17.28	1.37	2.36
171003080302	47.88	14.63	14.52	14.77	-0.10	0.15	0.11	0.10	0.09	-9.3	-17.2	14.98	16.35	17.34	1.37	2.36
171003080303	62.37	14.48	14.48	14.60	0.00	0.13	0.16	0.14	0.13	-9.0	-16.7	15.41	16.80	17.80	1.39	2.39
171003080304	57.96	13.86	14.06	14.19	0.19	0.33	0.54	0.50	0.47	-7.4	-13.8	17.72	19.20	20.27	1.48	2.55
171003080305	44.60	14.19	14.27	14.37	0.08	0.18	0.14	0.13	0.12	-7.4	-13.8	16.67	18.11	19.15	1.44	2.48
171003080306	25.11	14.02	14.07	14.22	0.05	0.20	0.94	0.87	0.81	-7.2	-13.4	17.98	19.47	20.54	1.49	2.57
171003080401	25.30	13.77	14.22	14.48	0.45	0.70	17.08	12.61	10.67	-26.2	-37.5	16.60	17.66	18.42	1.06	1.82
171003080402	31.35	13.97	14.16	14.42	0.19	0.45	11.80	8.74	7.41	-25.9	-37.3	18.12	19.35	20.24	1.23	2.12
171003090101	18.87	16.50	16.57	16.67	0.08	0.17	0.11	0.09	0.09	-10.7	-15.6	12.26	13.53	14.44	1.27	2.18
171003090102	23.41	14.00	15.13	15.66	1.12	1.65	0.14	0.11	0.10	-19.4	-28.1	10.18	11.36	12.22	1.18	2.04
171003090103	21.79	14.08	14.77	15.18	0.68	1.09	0.50	0.42	0.38	-15.8	-23.0	14.11	15.45	16.41	1.34	2.30
171003090104	36.71	15.70	15.78	15.93	0.08	0.23	0.23	0.20	0.19	-9.9	-15.9	12.67	13.95	14.87	1.28	2.21
171003090105	17.78	14.54	14.68	14.87	0.13	0.33	0.22	0.19	0.17	-13.6	-21.5	11.77	13.02	13.92	1.25	2.15
171003090106	32.54	15.18	15.19	15.50	0.02	0.32	0.23	0.20	0.18	-13.3	-21.3	12.25	13.51	14.42	1.26	2.18
171003090107	33.02	14.35	14.47	14.72	0.12	0.37	0.48	0.42	0.39	-12.0	-19.5	14.03	15.37	16.33	1.34	2.30
171003090108	31.64	13.48	13.83	14.13	0.35	0.65	0.19	0.17	0.16	-10.8	-17.9	13.55	14.87	15.82	1.32	2.27
171003090109	8.98	14.15	14.24	14.37	0.09	0.22	0.02	0.02	0.02	-6.2	-11.2	14.56	15.92	16.89	1.36	2.33
171003090201	34.78	14.27	14.43	14.58	0.15	0.31	1.13	1.00	0.93	-11.0	-17.6	14.40	15.34	16.01	0.94	1.62
171003090202	38.10	13.33	13.54	13.74	0.21	0.41	0.76	0.69	0.64	-10.3	-16.6	13.92	15.01	15.80	1.09	1.88
171003090203	31.79	14.09	14.24	14.43	0.15	0.34	0.97	0.87	0.81	-10.2	-16.4	14.33	15.39	16.15	1.06	1.82
171003090301	33.20	10.63	13.66	15.09	3.03	4.46	0.26	0.17	0.15	-32.1	-42.7	11.21	12.44	13.32	1.23	2.11
171003090302	14.93	12.47	13.56	14.30	1.09	1.83	0.81	0.61	0.54	-24.6	-33.8	14.69	16.05	17.03	1.36	2.34
171003090303	28.98	13.37	13.63	14.03	0.26	0.66	0.10	0.09	0.08	-10.8	-17.8	13.26	14.57	15.51	1.31	2.25

Changes in mean August stream temperature, summer flow, and winter high-flow events by 6th code hydrologic unit codes (HUCs) within the Southwest Oregon Adaptation Partnership assessment area (continued)

		Number of days with high winter flows					Mean summer flow					Mean August stream temperature				
HUC number	Stream length	1980s	2040s	2080s	Days changed from 1980 to 2040	Days changed from 1980 to 2080	1980s	2040s	2080s	Change from 1980 to 2040	Change from 1980 to 2080	2000s	2040s	2080s	°C change from 2000 to 2040	°C change from 2000 to 2080
	Kilometers						*Cubic meters per second*			*- - - Percent - - -*					- - - - °C - - - -	
171003090304	30.06	13.14	13.46	13.94	0.32	0.80	0.58	0.48	0.43	-17.2	-24.8	15.76	17.16	18.18	1.40	2.42
171003090401	10.54	14.30	14.39	14.60	0.08	0.30	2.66	2.34	2.16	-12.2	-18.8	15.26	16.07	16.65	0.81	1.39
171003090402	36.77	13.75	13.95	14.18	0.19	0.42	0.07	0.07	0.07	-5.7	-10.0	14.49	15.84	16.82	1.35	2.33
171003090403	21.42	13.87	14.00	14.14	0.13	0.28	1.55	1.37	1.27	-11.6	-18.0	15.58	16.66	17.45	1.09	1.87
171003090404	37.42	13.88	14.02	14.26	0.14	0.38	0.38	0.34	0.32	-9.9	-15.9	14.94	16.26	17.22	1.32	2.28
171003090405	15.00	14.12	14.14	14.33	0.02	0.21	2.47	2.19	2.04	-11.1	-17.4	16.61	17.58	18.29	0.97	1.68
171003090501	13.63	14.31	14.33	14.48	0.01	0.16	0.13	0.12	0.11	-8.0	-14.4	14.26	15.60	16.57	1.34	2.32
171003090502	39.86	14.67	14.61	14.75	-0.05	0.08	0.17	0.16	0.14	-8.7	-15.7	14.55	15.91	16.89	1.36	2.33
171003090503	27.25	14.54	14.49	14.66	-0.05	0.12	0.37	0.35	0.32	-7.5	-13.9	15.54	16.94	17.94	1.39	2.40
171003090601	50.49	14.33	14.41	14.53	0.08	0.20	2.08	1.87	1.74	-10.3	-16.5	16.70	17.82	18.63	1.12	1.93
171003090602	31.51	14.62	14.69	14.90	0.07	0.28	1.49	1.34	1.25	-10.0	-16.2	16.13	17.33	18.20	1.20	2.07
171003090603	36.75	15.02	15.03	15.18	0.02	0.16	3.12	2.81	2.62	-9.9	-16.0	17.63	18.65	19.38	1.02	1.76
171003090604	77.85	15.30	15.28	15.39	-0.02	0.09	0.30	0.28	0.26	-8.1	-14.0	16.87	18.29	19.32	1.42	2.45
171003100101	32.50	13.76	13.85	13.89	0.09	0.13	0.10	0.09	0.09	-7.0	-12.9	16.86	18.31	19.35	1.45	2.49
171003100102	10.65	13.81	13.89	13.92	0.08	0.11	0.50	0.47	0.44	-6.2	-11.4	20.10	21.67	22.81	1.58	2.71
171003100103	27.81	13.96	14.01	14.01	0.04	0.05	0.14	0.14	0.13	-5.7	-10.6	16.50	17.93	18.96	1.43	2.46
171003100104	31.61	14.63	14.61	14.71	-0.02	0.08	0.40	0.38	0.36	-5.7	-10.9	19.26	20.80	21.91	1.54	2.65
171003100201	69.95	-142.1	-141.8	-141.6	0.27	0.43	22.35	17.17	14.84	-23.2	-33.6	18.03	19.01	19.72	0.98	1.69
171003100202	25.28	14.62	14.77	14.99	0.15	0.38	22.84	17.59	15.22	-23.0	-33.4	17.77	18.81	19.55	1.03	1.78
171003100203	41.87	15.06	15.06	15.07	0.00	0.01	0.11	0.11	0.10	-6.3	-11.9	15.75	17.15	18.17	1.40	2.41
171003100204	29.01	15.12	15.23	15.29	0.11	0.16	0.11	0.10	0.10	-7.2	-13.4	16.12	17.54	18.56	1.42	2.44
171003100205	41.55	14.45	14.73	15.01	0.28	0.56	33.85	26.15	22.67	-22.7	-33.0	18.39	19.24	19.85	0.85	1.46
171003100301	43.06	14.52	14.48	14.75	-0.04	0.23	0.15	0.14	0.12	-9.2	-16.7	14.77	16.13	17.12	1.36	2.35
171003100302	24.86	14.27	14.26	14.45	0.00	0.18	0.37	0.34	0.31	-8.3	-15.3	17.48	18.95	20.02	1.47	2.53
171003100303	26.11	14.59	14.47	14.76	-0.12	0.17	0.62	0.57	0.54	-7.3	-13.6	18.51	20.02	21.11	1.51	2.60
171003100304	56.89	14.58	14.49	14.65	-0.09	0.07	0.18	0.17	0.16	-5.6	-10.9	16.94	18.38	19.43	1.45	2.50

Changes in mean August stream temperature, summer flow, and winter high-flow events by 6th code hydrologic unit codes (HUCs) within the Southwest Oregon Adaptation Partnership assessment area (continued)

		Number of days with high winter flows					Mean summer flow					Mean August stream temperature				
HUC number	Stream length	1980s	2040s	2080s	Days changed from 1980 to 2040	Days changed from 1980 to 2080	1980s	2040s	2080s	Change from 1980 to 2040	Change from 1980 to 2080	2000s	2040s	2080s	°C change from 2000 to 2040	°C change from 2000 to 2080
	Kilometers						*Cubic meters per second*			- - - *Percent* - - -					- - - - °C - - - -	
171003100305	68.26	15.09	15.03	15.20	-0.06	0.11	0.51	0.48	0.45	-6.2	-11.9	17.33	18.79	19.85	1.46	2.52
171003100401	23.22	14.40	14.58	14.72	0.18	0.31	13.28	10.33	8.98	-22.2	-32.3	15.83	16.98	17.82	1.15	1.99
171003100402	26.89	14.74	14.90	15.06	0.17	0.32	20.26	15.77	13.72	-22.1	-32.3	16.73	17.80	18.56	1.06	1.83
171003100403	26.95	14.68	14.72	14.88	0.05	0.21	10.68	8.33	7.26	-22.0	-32.0	16.13	17.35	18.23	1.22	2.10
171003100404	20.74	14.42	14.64	14.78	0.22	0.35	30.10	23.49	20.45	-22.0	-32.1	16.18	17.04	17.66	0.86	1.48
171003100405	24.75	14.32	14.32	14.48	0.00	0.16	0.11	0.10	0.09	-7.8	-14.5	13.55	14.87	15.82	1.32	2.27
171003100406	11.80	13.94	14.33	14.73	0.39	0.79	70.32	54.93	47.86	-21.9	-31.9	19.25	19.51	19.69	0.25	0.44
171003100407	36.74	15.32	15.26	15.41	-0.05	0.09	2.98	2.36	2.06	-21.0	-30.9	14.32	15.62	16.55	1.30	2.23
171003100501	3.97	14.98	14.94	15.17	-0.04	0.19	0.41	0.37	0.33	-10.1	-18.8	16.05	17.47	18.49	1.41	2.44
171003100502	40.39	14.45	14.74	15.02	0.30	0.57	52.44	41.14	35.88	-21.6	-31.6	18.64	19.21	19.62	0.57	0.98
171003100601	27.84	14.25	14.33	14.63	0.07	0.37	0.73	0.65	0.58	-11.5	-20.7	14.49	15.85	16.83	1.35	2.33
171003100602	33.84	14.73	14.85	15.13	0.12	0.40	32.15	25.30	22.09	-21.3	-31.3	17.19	18.08	18.72	0.89	1.53
171003100701	63.43	15.45	15.36	15.57	-0.09	0.12	0.37	0.32	0.28	-13.1	-23.3	14.30	15.65	16.62	1.34	2.32
171003100702	30.28	15.72	15.73	15.90	0.01	0.18	0.98	0.81	0.72	-16.6	-26.2	15.10	16.47	17.47	1.38	2.37
171003100801	37.21	15.19	15.39	15.54	0.20	0.35	77.08	62.72	55.36	-18.6	-28.2	19.09	20.57	21.65	1.49	2.56
171003100802	31.23	15.50	15.48	15.59	-0.02	0.09	17.28	14.10	12.45	-18.4	-28.0	16.16	17.58	18.60	1.42	2.44
171003110100	76.19	15.48	15.43	15.62	-0.05	0.13	0.18	0.17	0.15	-8.5	-15.9	14.34	15.68	16.66	1.35	2.32
171003110201	21.51	14.87	14.87	15.13	0.00	0.26	0.16	0.14	0.13	-11.4	-19.4	13.39	14.70	15.64	1.31	2.25
171003110202	29.48	15.16	15.17	15.42	0.01	0.26	0.47	0.42	0.39	-10.3	-18.2	14.91	16.28	17.27	1.37	2.36
171003110203	15.68	14.44	14.69	14.99	0.24	0.55	0.25	0.22	0.20	-14.1	-22.0	12.13	13.39	14.30	1.26	2.17
171003110204	30.76	14.97	15.13	15.26	0.16	0.29	1.13	1.00	0.92	-10.9	-18.6	16.25	17.67	18.70	1.42	2.45
171003110301	22.05	15.22	15.41	15.61	0.19	0.39	0.09	0.08	0.07	-15.9	-23.1	13.10	14.39	15.33	1.30	2.24
171003110302	22.24	15.49	15.62	15.76	0.12	0.27	0.09	0.08	0.07	-15.1	-22.3	13.37	14.68	15.63	1.31	2.26
171003110303	90.30	15.53	15.55	15.68	0.02	0.15	0.62	0.56	0.51	-10.1	-17.3	16.91	18.36	19.41	1.45	2.49
171003110401	18.12	14.92	15.02	15.20	0.09	0.28	0.14	0.12	0.11	-13.6	-23.4	16.54	17.97	19.00	1.43	2.47
171003110402	59.60	16.11	16.04	16.18	-0.06	0.07	0.09	0.08	0.08	-10.0	-16.7	15.65	17.05	18.06	1.40	2.41

Changes in mean August stream temperature, summer flow, and winter high-flow events by 6th code hydrologic unit codes (HUCs) within the Southwest Oregon Adaptation Partnership assessment area (continued)

		Number of days with high winter flows					Mean summer flow					Mean August stream temperature				
HUC number	Stream length	1980s	2040s	2080s	Days changed from 1980 to 2040	Days changed from 1980 to 2080	1980s	2040s	2080s	Change from 1980 to 2040	Change from 1980 to 2080	2000s	2040s	2080s	°C change from 2000 to 2040	°C change from 2000 to 2080
	Kilometers						*Cubic meters per second*			*- - - Percent - - -*					- - - - °C - - - -	
171003110403	32.06	15.91	15.84	16.08	-0.07	0.17	0.36	0.32	0.29	-10.6	-18.5	18.16	19.66	20.74	1.50	2.58
171003110404	55.65	14.33	14.48	14.65	0.15	0.32	0.39	0.34	0.30	-13.7	-23.5	17.00	18.45	19.50	1.45	2.50
171003110405	30.86	15.37	15.41	15.51	0.04	0.14	1.46	1.29	1.17	-11.2	-19.5	19.47	21.01	22.13	1.55	2.67
171003110501	20.29	14.80	14.83	14.98	0.03	0.18	0.13	0.12	0.11	-9.0	-16.4	15.13	16.50	17.50	1.38	2.37
171003110502	36.92	15.04	15.09	15.24	0.05	0.20	0.34	0.31	0.29	-8.3	-15.3	17.27	18.73	19.78	1.46	2.52
171003110503	32.33	15.37	15.34	15.44	-0.04	0.06	0.19	0.18	0.16	-7.5	-14.2	17.29	18.76	19.81	1.46	2.52
171003110504	56.41	15.84	15.78	15.89	-0.07	0.05	0.40	0.37	0.35	-7.3	-13.7	17.25	18.71	19.77	1.46	2.52
171003110601	29.07	15.32	15.35	15.50	0.03	0.18	3.00	2.70	2.47	-10.1	-17.6	19.22	20.76	21.87	1.54	2.65
171003110602	60.18	14.74	14.84	15.02	0.09	0.28	0.28	0.25	0.23	-10.3	-18.2	17.53	19.00	20.06	1.47	2.54
171003110603	23.70	15.76	15.64	15.76	-0.12	0.01	5.16	4.67	4.29	-9.6	-16.9	18.41	19.92	21.01	1.51	2.60
171003110604	31.84	15.28	15.22	15.33	-0.06	0.04	6.29	5.70	5.24	-9.4	-16.7	18.82	20.34	21.44	1.52	2.62
171003110701	63.86	15.22	15.28	15.33	0.07	0.11	0.09	0.08	0.08	-7.9	-14.5	14.32	15.67	16.64	1.35	2.32
171003110702	51.67	15.74	15.68	15.75	-0.07	0.01	0.35	0.32	0.30	-8.6	-15.6	15.26	16.64	17.64	1.38	2.38
171003110801	12.62	15.20	15.20	15.37	-0.01	0.16	11.41	10.34	9.50	-9.4	-16.7	20.39	21.97	23.11	1.58	2.73
171003110802	17.06	14.54	14.57	14.74	0.04	0.21	0.36	0.32	0.29	-11.9	-21.1	15.91	17.31	18.33	1.41	2.43
171003110803	41.50	15.05	15.07	15.17	0.02	0.12	0.33	0.29	0.26	-12.7	-22.6	14.90	16.27	17.25	1.37	2.36
171003110804	29.83	15.30	15.27	15.48	-0.02	0.18	16.46	14.87	13.63	-9.6	-17.2	21.44	23.06	24.24	1.62	2.80
171003110901	71.97	15.29	15.31	15.50	0.02	0.22	0.24	0.21	0.19	-10.5	-18.9	13.53	14.85	15.80	1.32	2.27
171003110902	30.18	15.11	15.13	15.38	0.02	0.27	0.36	0.32	0.29	-10.0	-18.2	14.20	15.54	16.51	1.34	2.31
171003110903	9.95	15.23	15.26	15.59	0.03	0.35	2.22	1.99	1.81	-10.4	-18.8	17.36	18.83	19.89	1.46	2.52
171003111001	30.43	14.11	14.24	14.53	0.12	0.41	0.41	0.35	0.32	-13.3	-22.8	12.76	14.04	14.97	1.28	2.21
171003111002	28.44	14.84	14.73	15.05	-0.10	0.21	0.33	0.29	0.27	-10.6	-19.1	13.64	14.96	15.91	1.32	2.27
171003111003	26.32	14.87	14.82	15.09	-0.05	0.23	1.21	1.07	0.96	-11.6	-20.7	16.91	18.35	19.40	1.45	2.49
171003111101	36.60	15.01	15.11	15.21	0.10	0.20	0.75	0.64	0.57	-13.8	-24.2	14.52	15.87	16.85	1.35	2.33
171003111102	27.01	15.52	15.51	15.71	-0.02	0.18	12.45	11.19	10.20	-10.1	-18.1	19.06	20.59	21.69	1.53	2.64
171003120101	52.40	13.90	14.04	14.35	0.14	0.45	0.34	0.30	0.26	-13.9	-24.0	15.47	16.86	17.87	1.39	2.40
171003120102	39.86	14.06	14.28	14.53	0.22	0.47	1.17	1.01	0.89	-13.5	-23.4	16.51	17.94	18.98	1.43	2.47

Changes in mean August stream temperature, summer flow, and winter high-flow events by 6th code hydrologic unit codes (HUCs) within the Southwest Oregon Adaptation Partnership assessment area (continued)

		Number of days with high winter flows					Mean summer flow					Mean August stream temperature				
HUC number	Stream length	1980s	2040s	2080s	Days changed from 1980 to 2040	Days changed from 1980 to 2080	1980s	2040s	2080s	Change from 1980 to 2040	Change from 1980 to 2080	2000s	2040s	2080s	°C change from 2000 to 2040	°C change from 2000 to 2080
	Kilometers						*Cubic meters per second*			*- - - Percent - - -*					- - - - °C - - - -	
171003120103	20.47	13.97	14.24	14.42	0.26	0.44	0.37	0.32	0.28	-13.2	-23.2	15.46	16.85	17.85	1.39	2.40
171003120104	26.84	14.57	14.60	14.75	0.03	0.18	0.49	0.43	0.39	-12.3	-21.9	15.45	16.84	17.85	1.39	2.40
171003120105	15.88	14.07	14.39	14.60	0.32	0.53	5.10	4.43	3.93	-13.2	-23.0	19.49	21.04	22.16	1.55	2.67
171003120106	29.47	14.55	14.69	15.01	0.14	0.46	0.38	0.33	0.29	-12.8	-23.0	15.23	16.62	17.61	1.38	2.38
171003120107	51.86	15.29	15.28	15.52	0.00	0.24	2.45	2.14	1.89	-12.9	-22.7	16.65	18.09	19.13	1.44	2.48
171003120108	51.00	14.93	15.04	15.27	0.12	0.34	0.49	0.43	0.38	-13.4	-23.6	16.44	17.86	18.90	1.43	2.46
171003120109	71.04	15.27	15.25	15.57	-0.02	0.30	3.72	3.16	2.82	-15.1	-24.0	17.29	18.75	19.81	1.46	2.52
171003120111	28.41	-385.4	-385.4	-385.1	0.00	0.34	2.83	2.32	2.10	-18.1	-26.0	16.44	17.87	18.90	1.43	2.46
171003120201	67.44	15.49	15.46	15.70	-0.03	0.21	0.18	0.16	0.14	-13.4	-23.9	15.41	16.80	17.81	1.39	2.39
171003120202	58.74	15.75	15.74	16.06	-0.01	0.32	0.58	0.50	0.44	-14.3	-24.3	16.35	17.78	18.81	1.43	2.46
171003120401	25.72	15.25	15.29	15.37	0.04	0.12	0.33	0.28	0.25	-14.3	-25.1	14.20	15.54	16.51	1.34	2.31
171003120402	34.20	15.63	15.59	15.70	-0.04	0.07	1.14	0.98	0.85	-14.2	-25.1	16.19	17.61	18.63	1.42	2.45
171003120403	32.50	15.85	15.88	16.05	0.03	0.19	0.27	0.22	0.20	-16.6	-26.6	15.20	16.59	17.58	1.38	2.38
171003120501	25.88	15.64	15.59	15.76	-0.05	0.12	0.24	0.20	0.18	-17.1	-27.5	15.03	16.40	17.40	1.38	2.37
180101010101	53.54	14.11	14.27	14.47	0.16	0.35	0.17	0.12	0.11	-26.5	-35.8	15.74	16.18	16.54	0.43	0.80
180101010102	40.67	13.74	13.75	13.98	0.02	0.25	0.17	0.12	0.10	-30.5	-40.0	16.13	16.57	16.94	0.44	0.81
180101010103	43.84	14.71	14.73	14.93	0.01	0.22	0.09	0.06	0.05	-29.5	-38.6	15.83	16.27	16.63	0.44	0.80
180101010104	74.58	14.71	14.84	15.03	0.12	0.31	0.74	0.53	0.46	-28.1	-37.6	16.95	17.40	17.78	0.45	0.83
180102060401	23.87	15.22	15.53	15.84	0.31	0.62	0.08	0.07	0.06	-16.6	-22.0	13.11	13.51	13.85	0.40	0.73
180102060404	26.20	14.97	15.14	15.48	0.16	0.51	0.18	0.14	0.13	-18.5	-23.5	13.75	14.16	14.50	0.41	0.75
180102060405	31.14	15.21	15.42	15.76	0.21	0.55	0.05	0.04	0.04	-19.8	-25.5	12.96	13.35	13.69	0.40	0.73
180102060406	31.04	14.75	14.83	15.06	0.08	0.31	0.33	0.27	0.26	-17.7	-22.5	15.36	15.78	16.15	0.43	0.79
180102060501	28.79	15.83	15.58	15.82	-0.24	-0.01	0.02	0.01	0.01	-12.4	-15.2	16.13	16.57	16.94	0.44	0.81
180102060502	11.89	12.15	13.62	14.10	1.47	1.95	5.85	3.27	2.87	-44.1	-51.0	17.05	17.50	17.88	0.45	0.83
180102060601	19.62	15.73	16.03	16.20	0.30	0.47	0.02	0.02	0.02	-10.7	-14.0	13.68	14.08	14.42	0.41	0.75
180102060602	17.25	15.58	15.69	15.83	0.10	0.24	0.03	0.02	0.02	-9.1	-12.1	15.19	15.61	15.97	0.43	0.79

Changes in mean August stream temperature, summer flow, and winter high-flow events by 6th code hydrologic unit codes (HUCs) within the Southwest Oregon Adaptation Partnership assessment area (continued)

		Number of days with high winter flows					Mean summer flow					Mean August stream temperature				
HUC number	Stream length	1980s	2040s	2080s	Days changed from 1980 to 2040	Days changed from 1980 to 2080	1980s	2040s	2080s	Change from 1980 to 2040	Change from 1980 to 2080	2000s	2040s	2080s	°C change from 2000 to 2040	°C change from 2000 to 2080
	Kilometers						*Cubic meters per second*			- - - *Percent* - - -					- - - - °C - - - -	
180102060603	28.04	15.95	16.04	16.16	0.09	0.21	0.07	0.06	0.06	-10.0	-12.7	16.83	17.28	17.65	0.45	0.83
180102060901	39.24	11.60	14.87	16.35	3.28	4.75	0.05	0.03	0.02	-43.9	-50.5	11.06	11.43	11.75	0.37	0.69
180102090103	17.31	16.15	16.06	16.16	-0.09	0.01	0.06	0.05	0.04	-17.0	-23.7	12.06	12.45	12.78	0.39	0.71

Note: Geospatial shapefiles summarizing conditions within the 6th-code HUCs are available on the U.S. Forest Service shared T drive in the SWOAP project folder.

Chapter 5: Climate Change Effects on Vegetation and Disturbance in Southwest Oregon

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Introduction

The Southwest Oregon Adaptation Partnership (SWOAP) assessment area (see chapter 1, fig. 1.1) is characterized by high geologic, topographic, and climatic diversity, which fosters the highest vegetative diversity in the Pacific Northwest (PNW) region. There are 26 conifer species that occur on federal lands in the SWOAP assessment area (Oregon Flora Project 2018). The SWOAP region encompasses a portion of the Klamath-Siskiyou Ecoregion, one of seven International Union for Conservation of Nature areas of global botanical significance in North America (Wagner 1997). Diverse floras from several U.S. floristic provinces are found in the region, which is characterized by complex environmental and geomorphological gradients, including an east-west transition from continental to coastal climates and a north-south transition from temperate to mediterranean climates. These gradients have allowed for persistence of local climatic conditions, or climate refugia, amid broader climatic changes in the past (e.g., glaciations and volcanic events) (Waring 1969, Whittaker 1960). Thus, endemism is high in the region.

Vegetation in the SWOAP assessment area ranges from high-elevation parklands, with patchy or dispersed trees intermixed with grassland, shrubland, and alpine tundra, to low-elevation, dry interior ponderosa pine (*Pinus ponderosa* C. Lawson) forests and oak woodlands. High-elevation forests are dominated by mountain hemlock (*Tsuga mertensiana* (Bong.) Carrière), Shasta red fir (*Abies magnifica* A. Murray), Pacific silver fir (*A. amabilis* Douglas ex J. Forbes), and lodgepole pine (*P. contorta* var. *murrayana* (Balf.) Engelm.). Moist forests dominated by western hemlock (*T. heterophylla* (Raf.)

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Sarg) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) occur at mid-elevations in the Cascade Range and the coastal mountains north of the Wild Rogue Wilderness. Mesic inland forests are dominated by white fir (*A. concolor* (Gordon & Glend.) Lindl. ex Hildebr.) and Douglas-fir, mixed with a variety of other conifers and hardwoods. Ultramafic soils in some locations support open forests and woodlands, frequently dominated by Jeffrey pine (*P. jeffreyi* Balf.), Douglas-fir, and incense cedar (*Calocedrus decurrens* (Torr.) Florin).

Dry mixed conifer–hardwood forests dominated by Douglas-fir and ponderosa pine, with smaller amounts of Pacific madrone (*Arbutus menziesii* Pursh), California black oak (*Quercus kelloggii* Newberry), and canyon live oak (*Q. chrysolepis* Liebm.), grow in hotter, drier microclimates, such as south-facing slopes and in areas affected by rain shadows. Within the mountains closer to the coast, tanoak (*Notholithocarpus densiflorus* (Hook. & Arn.) Rehder), in both shrub and tree varieties, is a major component of the forests, along with Douglas-fir and western hemlock. Although oak species are present throughout much of the lower elevation forests, true oak woodlands of Oregon white oak (*Q. garryana* var. *garryana* Douglas ex Hook) are largely confined to the lowest elevations within and bordering the inland valleys. More detailed vegetation type descriptions can be found in the "Assessment for Vegetation Units" sections below.

Vegetation composition in the various management units of the SWOAP assessment area differs (figs. 5.1 through 5.5). Rogue River-Siskiyou National Forest, located primarily in the southwestern portion of the assessment area, consists of mesic Douglas-fir and white fir forests (approximately 40 percent), moist western hemlock and Douglas-fir forests (approximately 30 percent), dry Douglas-fir forest (approximately 10 percent), and ultramafic plant communities (approximately 10 percent), with a portion of high-elevation mountain hemlock and Shasta red fir forests in the High Cascades Ranger District (eastern portion of the forest) (approximately 6 percent) (fig. 5.1). Rogue River-Siskiyou National Forest also has 13 distinct coast redwood (*Sequoia sempervirens* (Lamb. ex D. Don) Endl.) groves (in the Winchuk River watershed), and small patches (up to 4 ha in size) of interior chaparral, dominated by *Ceanothus* (L.) and manzanita (*Arctostaphylos* Adans.) species.

Umpqua National Forest, in the northeastern portion of the SWOAP assessment area, supports mesic white fir and Douglas-fir forests (approximately 40 percent), moist western hemlock and Douglas-fir forests (approximately 25 percent), and dry Douglas-fir forests (approximately 10 percent) (fig. 5.2). Umpqua National Forest also has high-elevation mountain hemlock, Shasta red fir, Pacific silver fir, and

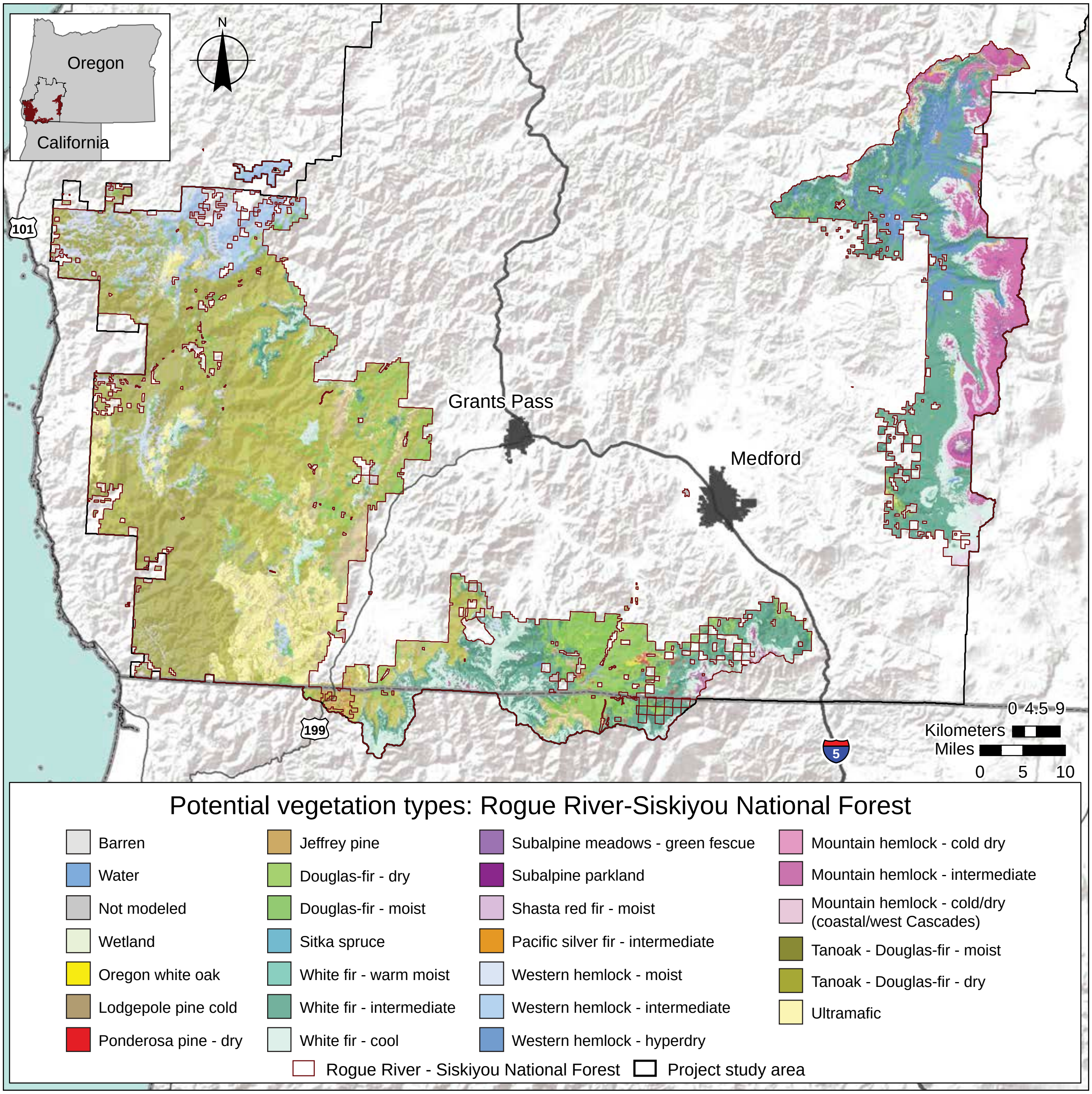

Figure 5.1—Potential vegetation types for Rogue River-Siskiyou National Forest (Halofsky et al. 2014).

lodgepole pine forests in the eastern (High Cascades) portion of the forests; high-elevation forests make up approximately 25 percent of Umpqua National Forest.

The Medford District of the Bureau of Land Management (BLM), in the southeastern portion of the study area, consists largely of dry Douglas-fir-dominated forests (approximately 50 percent), with a mesic white fir and Douglas-fir forest component (approximately 30 percent), and some oak woodlands (approximately 5 percent) (fig. 5.3). The Roseburg BLM district in the northwestern portion of the study region is composed of moist western hemlock and Douglas-fir forest (primarily in the northern portion) (approximately 35 percent), dry Douglas-fir forests (approximately 30 percent), and mesic Douglas-fir and white fir forests (approximately 25 percent) (fig. 5.4). Lands administered by the Medford and Roseburg BLM districts are dominated by a checkerboard pattern, owing to 19th-century railroad development in the region and the Oregon and California Revested Lands Sustained Yield Management Act of 1937. Oregon Caves National Monument and Preserve supports mesic white fir and Douglas-fir forests (approximately 70 percent), moist forest (approximately 10 percent), and high-elevation mountain hemlock forests and parkland in the eastern portion of the park (fig. 5.5).

Southwest Oregon is largely characterized by a mixed-severity fire regime, with historical fire return intervals of 15 to 50 years over much of the region (fig. 5.6). Existing fire history studies in southwest Oregon indicate that fire regimes may have been significantly different from moister forests of western Oregon and Washington (Weisberg and Swanson 2003) and have been disrupted by fire exclusion for around 100 years across old-growth conifer forests (Agee 1991, Colombaroli and Gavin 2010, McNeil and Zobel 1980, Metlen et al. 2018, Sensenig et al. 2013, Taylor and Skinner 1998) and lowland and mixed-conifer riparian forests (Messier et al. 2012). However, the northeastern portion of the SWOAP assessment area (and much of the Umpqua National Forest) is characterized by a mixed-severity fire regime with moderately frequent fire (50- to 200-year fire return intervals). Higher elevation and wetter forests in the eastern (Cascades) portions of the assessment area and wetter western hemlock forests near the coast are characterized by an infrequent, high-severity (stand-replacement) fire regime with greater than 200-year fire return intervals (fig. 5.6).

In this chapter, we assess climate change vulnerabilities for vegetation in the SWOAP assessment area. We use output from models run under future climatic conditions and disturbance regimes, paleoecological studies, and other relevant literature and studies for seven vegetation groups (table 5.1) to assess vulnerabilities. The chapter includes general descriptions of historical and projected changes in vegetation and disturbance, followed by discussion of potential vegetation and disturbance trends for the vegetation groups as well as special habitats (riparian areas, fens, and meadows).

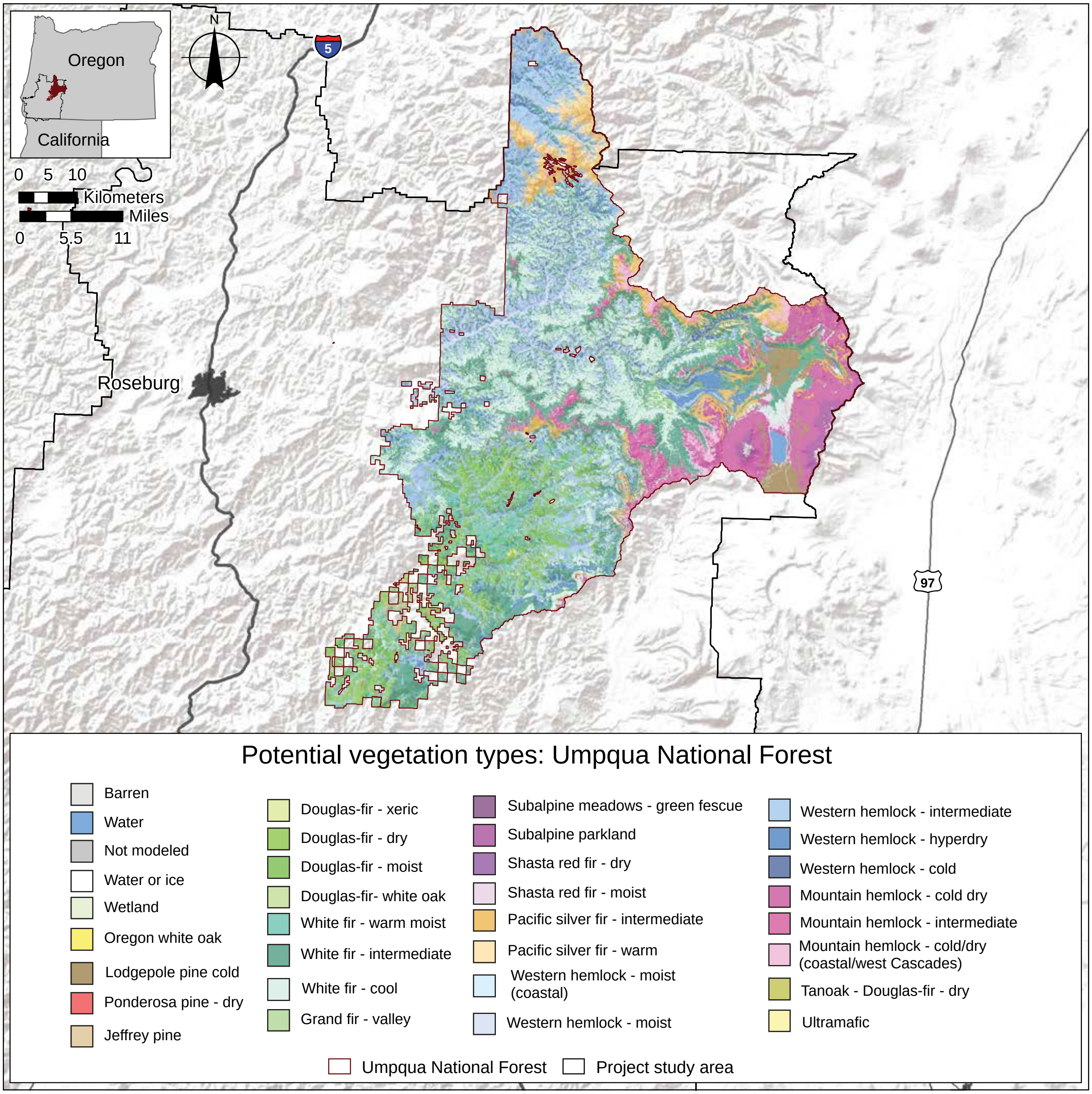

Figure 5.2—Potential vegetation types for Umpqua National Forest (Halofsky et al. 2014).

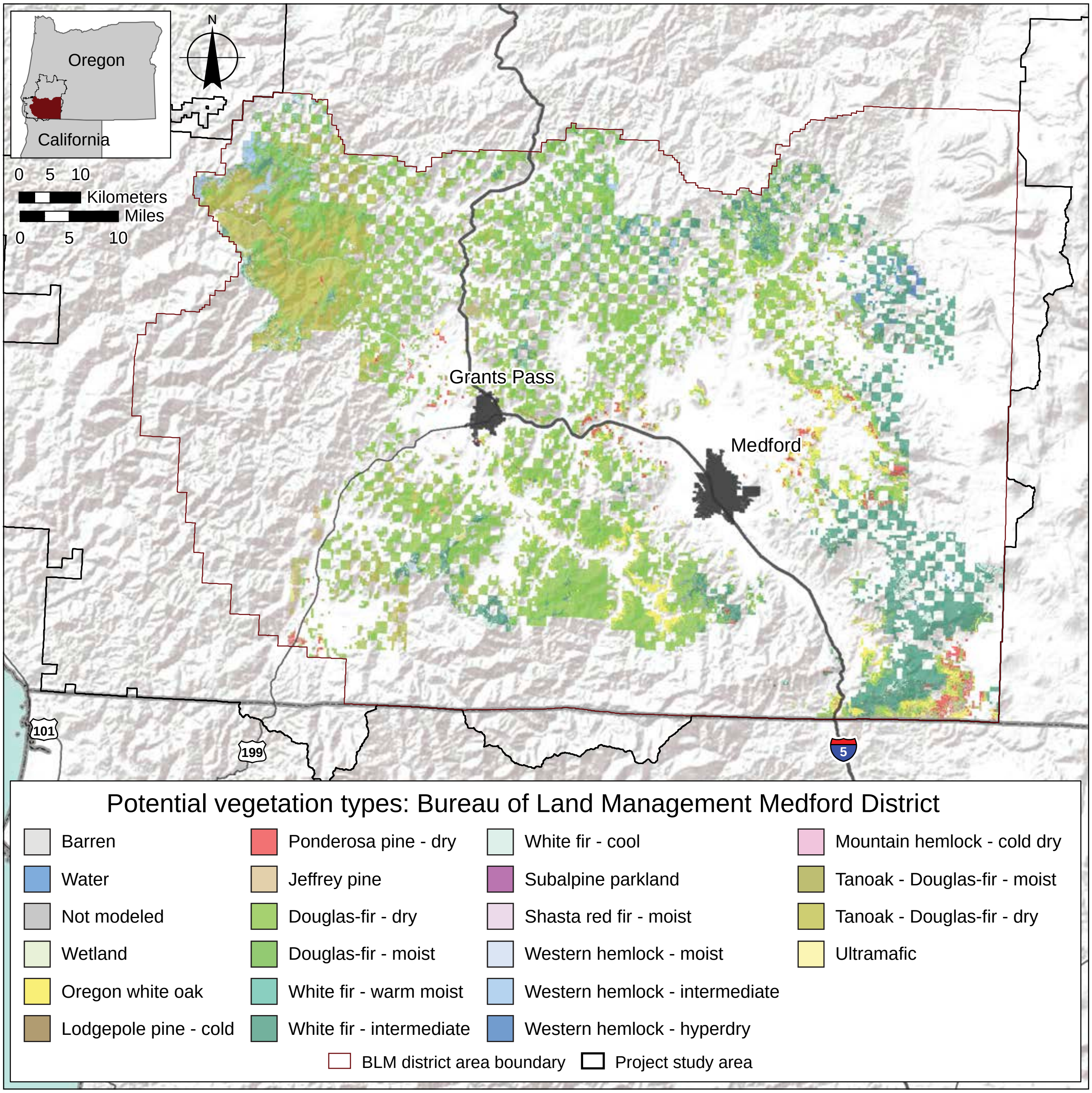

Figure 5.3—Potential vegetation types for the Medford District of the Bureau of Land Management (BLM) (Halofsky et al. 2014).

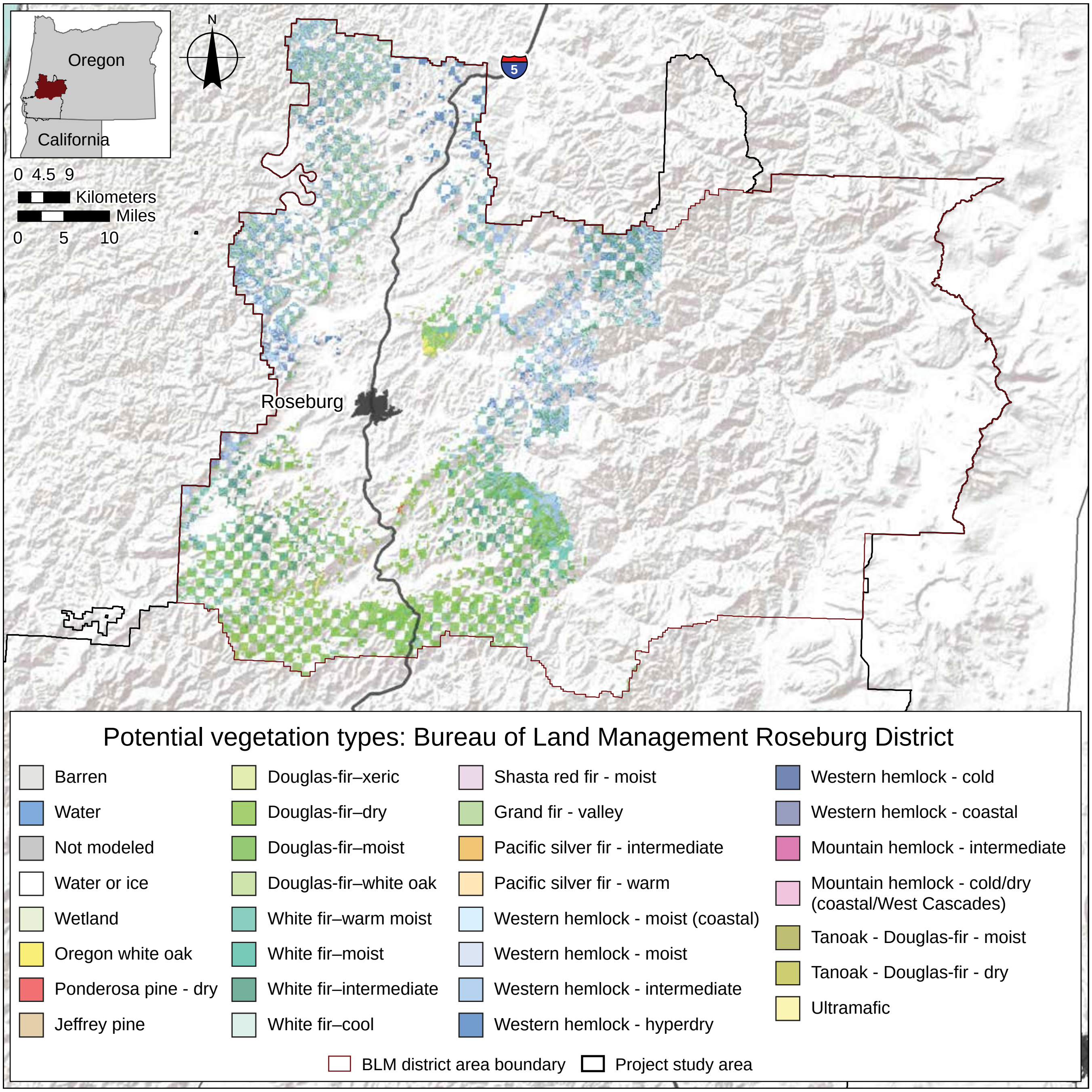

Figure 5.4—Potential vegetation types for the Roseburg District of the Bureau of Land Management (BLM) (Halofsky et al. 2014).

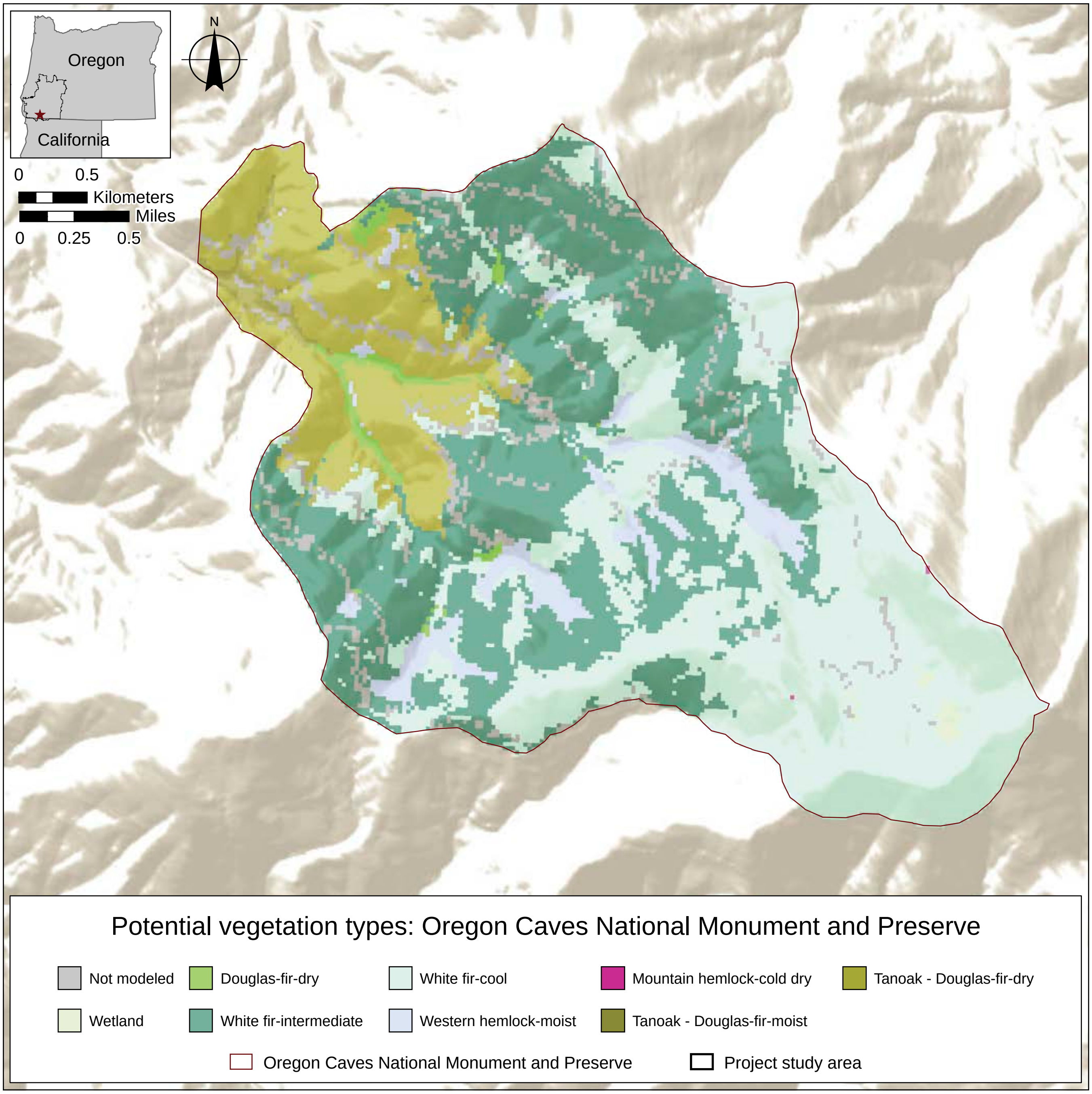

Figure 5.5—Potential vegetation types for the Oregon Caves National Monument and Preserve (Halofsky et al. 2014).

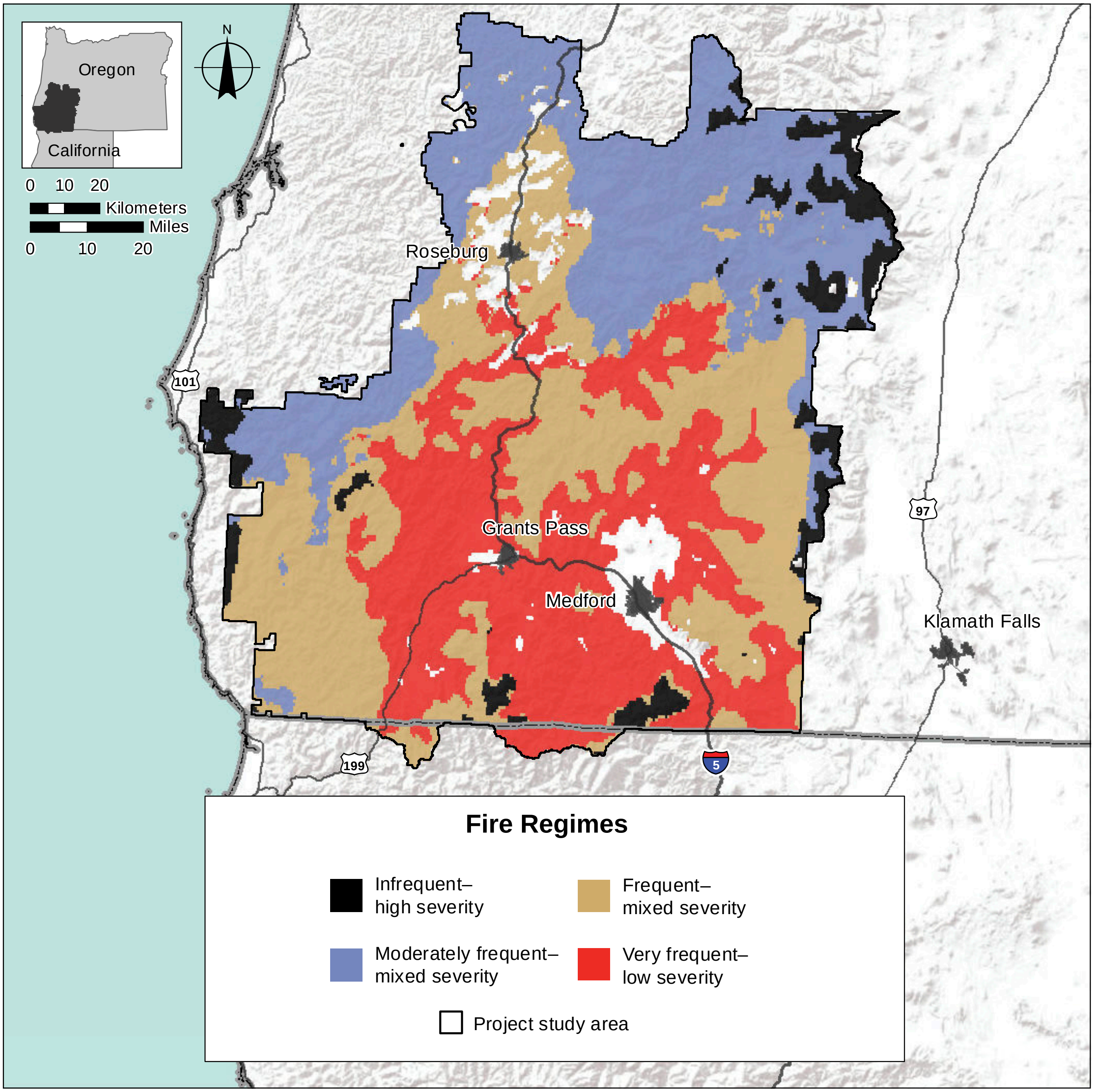

Figure 5.6—Historical fire regimes in the Southwest Oregon Adaptation Partnership assessment area. Infrequent, high severity = >200-year fire return intervals; moderately frequent, mixed severity = 50- to 200-year fire return intervals; frequent, mixed severity = 15- to 50-year fire return intervals; and very frequent, low severity = 5- to 25-year fire return intervals. Data are from Spies et al. (2018).

Potential Climate Change Effects on Vegetation

Climate change will alter ecosystem processes and vegetation structure and composition in future decades (Peterson et al. 2014). Southwest Oregon is projected to permanently depart from its historical (1895 to 2008) climate regime by the 2040s (Kerns et al. 2016). Different species respond in different ways to climate, affecting both the spatial distribution of species and interactions among species. Climate also influences the disturbance processes that shape vegetation structure and composition, and altered disturbance regimes will likely be the most important catalyst for vegetation change in a warming climate (Littell et al. 2010).

Several information sources are useful for assessing potential climate change effects on vegetation composition and structure, including long-term paleoecological records, evidence from observational studies of recent vegetation shifts with changing climate, evaluation of likely changes in disturbance regimes, and simulation model projections for the future. The following sections review these information sources relevant to the SWOAP assessment area.

Paleoecology—Summary of Relevant Research

Plant pollen and charcoal from wildfires deposited in lake sediments provide records of past vegetation composition and abundance and fire at local to regional scales over hundreds to thousands of years. Charcoal records can be used to identify individual fire events and to estimate fire frequency (Itter et al. 2017). Sediment records do not cover all environments because they rely on pooling water to collect and stratify sediments (Minckley et al. 2008). Resolution is typically limited to decades (Whitlock and Bartlein 2004), and detection is biased toward recording high-severity events (Higuera et al. 2005). However, in combination with sediment pollen records, charcoal records help to determine how vegetation and fire regimes shifted with climatic variation in the past. Although the future may not directly mirror any time in the past, paleoecological records can help us test our understanding of the processes that link vegetation and fire regimes, allowing us to determine how both may shift with changing climate (Gavin et al. 2007).

Vegetation composition and fire regimes varied significantly with climate in the past (thousands of years) in southwest Oregon and northern California (Briles 2017; Briles et al. 2005, 2008; Colombaroli and Gavin 2010). Paleoecological studies also indicate that species respond individualistically to climate change, and it is possible that novel communities will develop in response to future climatic changes. However, in southwest Oregon, most of the plant communities of the past have modern analogs, suggesting that even with climatic change, species were able to find nearby niches and persist (Briles 2017, Briles et al. 2011, Daniels et al. 2005).

Paleoecological studies indicate that during wetter and cooler periods in the past, fires were less frequent in southwest Oregon and northern California, and vegetation was dominated by species favored by wetter and cooler conditions, such as western hemlock, mountain hemlock, and true firs (Briles 2017, Briles et al. 2008, Mohr et al. 2000). For example, in the late Holocene (ca. 4,500 BP to present), cool, wet conditions favored closed forests of true fir, Douglas-fir, and hemlock on most soils (Briles et al. 2008). In contrast, during warmer and drier periods in the past, fire frequency was higher in southwest Oregon and northern California, and Douglas-fir, pines, oaks, and chaparral species were more abundant (Briles 2017, Briles et al. 2005, Colombaroli and Gavin 2010, Daniels et al. 2005).

The early Holocene (ca. 10,500 to 4,500 years BP) was the warmest postglacial period in the PNW (Whitlock 1992). During that time, summers were warmer and drier relative to recent historical conditions, with more intense droughts (Briles et al. 2005, Whitlock 1992). In many parts of the PNW, these warmer and drier summer conditions led to higher fire frequency (Walsh et al. 2015, Whitlock 1992).

Sediment charcoal analysis showed high fire activity during the early Holocene in locations across southwest Oregon and northern California (Briles 2017, Briles et al. 2005, Colombaroli and Gavin 2010). For example, between 9,800 and 7,200 years BP, climate dried considerably at Mumbo Lake (Trinity Mountains, northwest California, 1860 m elevation)—allowing for the expansion of oak, incense cedar, lodgepole pine, and Jeffrey pine—and fire increased; peak magnitudes of charcoal particles increased after 8,450 years BP by more than 250 times compared to pre-10,400 BP (Daniels et al. 2005). During this time (early Holocene), oaks, pines, and incense cedar were dominant at Bluff Lake (1921 m elevation) farther south in the Klamath Mountains of northwest California (Mohr et al. 2000). Also during the early Holocene, maritime forest in the Oregon Coast Range shifted to open Douglas-fir forest, with red alder (*Alnus rubra* Bong.) in areas of frequent disturbance and oak on the driest sites; mean fire interval for these coastal forests was relatively short compared to both before and since, and was estimated to be approximately 110 years during that time period (Long et al. 1998) (current fire return interval is greater than 200 years). These findings are consistent with those described in an analysis of fire (from charcoal sediment records) across the Western United States, in which there was a spatially consistent increase in burning during warmer periods across a diversity of forest types (Marlon et al. 2012).

During warmer and drier periods at higher elevations, subalpine parklands were replaced by moist forest species. For example, during the early Holocene, subalpine parklands in the Siskiyou Mountains were replaced by a closed forest of pines (western white pine [*Pinus monticola* Douglas ex D. Don] or sugar pine [*P. lambertiana* Douglas]), species in the Cupressaceae (Cypress) (most likely Port Orford cedar (*Chamaecyparis lawsoniana* (A. Murray) Parl.)), fir, and Douglas-fir (Briles et al. 2008). Vegetation at Twin Lake (1200 m elevation) in the southern Siskiyou Mountains shifted from subalpine forest dominated by mountain hemlock to a forest of pine and cedar, with Douglas-fir and tanoak as minor components (Wanket 2002). Fire activity also increased during this time.

As other species adjusted their ranges along elevation gradients, the diverse biota of the serpentine soils of the Klamath and Siskiyou Mountains have been relatively stable over millennia (Briles 2017). During a cooler and wetter period in the late Holocene, open forests of Jeffrey pine, lodgepole pine, and fir occurred on ultramafic soils when other forest types were shifting to species favored by wetter and cooler conditions (e.g., hemlock and true fir) (Briles 2017). However, vegetation changed on both ultramafic and non-ultramafic soils after 11,500 BP in response to warmer and drier conditions. On ultramafic soils, warmer and drier conditions led to development of open forests of Cupressaceae (Port Orford cedar or incense cedar) and oak, with less abundant Jeffrey pine, lodgepole pine, and fir. The species composition shifted back to more Jeffrey pine and lodgepole pine (and less cedar and oak) during a cooler and wetter period late in the Holocene, and species composition on these sites has changed little since that time. These patterns suggest that climate has had less influence on forest species composition on ultramafic soils (at least those identified in the pollen record), with soils being the primary driver of vegetation (Briles 2017).

Observational Studies of Vegetation Changes in a Warming Climate

Several scientific studies have examined the effects of climatic changes over the past several decades with shifts in vegetation composition and structure in southwest Oregon. For example, scientific studies have documented the effects of warming climate and land management on herbaceous communities at 185 sites in the Siskiyou Mountains (on Rogue River-Siskiyou National Forest) between 1950 and 2008 (Damschen et al. 2010, Harrison et al. 2010). Damschen et al. (2010) tested the sensitivity of vegetation on serpentine and diorite soils to climate change by resampling vegetation in the Siskiyou Mountains of southern Oregon and northern California at sites studied by ecologist Robert Whittaker from 1949 to 1951 (Whittaker 1960). They documented significant decreases in cover of herbs and abundance of endemic species, suggesting that species with a narrow ecological range (i.e., habitat specialists and endemics) may be at risk. Species composition shifted to more closely resemble that of warm, south-facing slopes. Tree species composition did not significantly shift over that time period.

Harrison et al. (2010) evaluated composition changes in herbaceous communities in upper montane primary (never logged) forest (high-elevation forests in table 5.1), lower montane primary forest (mesic and dry forests in table 5.1), and lower montane secondary (previously logged) forest (also on plots studied by Robert Whittaker in southern Oregon and northern California between 1949 and 1951). They found modest changes in herbaceous communities in the higher elevation forests, and significant changes in the lower elevation forests, regardless of management history. Composition changes in lower montane forests, including a reduction in specific leaf area and a reduction in cover of more northerly species, were consistent with a shift to a warmer and drier climate. In general, because of increasing drought stress with recent warming, herbaceous communities in lower montane (water-limited) forests shifted to more closely resemble those on southern aspects. At higher elevations, forest canopy cover increased, possibly because of longer snow-free growing seasons (Harrison et al. 2010).

Monleon and Lintz (2015) examined the presence and absence of 46 tree species on Forest Service Forest Inventory and Analysis plots across Washington, Oregon, and California. They found that the mean temperature of the range of seedlings was significantly different from the mean temperature for the range of mature adults for 20 species. This implies that despite land management practices, fire suppression, and other land uses, many species are shifting toward relatively colder environments. Species with altered distributions include western hemlock, tanoak, western redcedar (*Thuja plicata* Donn ex D. Don), and Oregon white oak, among others. Sugar pine, Jeffrey pine, incense cedar, and white fir appear to be responding in the opposite direction, with seedlings moving toward hotter environments compared to adults. As mentioned above, each species is expected to respond differently to changing climate.

Recent studies in the Klamath and southern Cascade Mountains of northern California have quantified high levels of recent mortality in Shasta red fir (DeSiervo et al. 2018, Mortenson et al. 2015). In the Klamath Mountains, DeSiervo et al. (2018) reported recent (in the past 18 years) mortality in about 20 percent of Shasta red fir. Mortality increased with stand density, and in locations with greater increases in minimum winter temperature over the past several decades (DeSiervo et al. 2018). Mortality was also related to Wien's dwarf mistletoe (*Arceuthobium abietinum* subsp. *wiensii*), and there was a positive correlation between mistletoe infestation and the proportion of trees with fir engraver beetle (*Scolytus ventralis* LeConte). Subalpine fir and lodgepole pine also had relatively high recent mortality (28 and 18 percent, respectively). Similarly, Mortenson et al. (2015) found a high proportion of recently dead Shasta red fir trees in the Klamath and southern Cascade Mountains. Dwarf mistletoe and drought stress were significant predictors of red fir mortality.

Table 5.1—Broad vegetation groups discussed in this chapter and potential vegetation types

Vegetation group	MC2 vegetation type(s)	Potential vegetation type(s)	Dominant species
High-elevation forests and parklands	Subalpine forests	Lodgepole pine–cold Mountain hemlock–cold, dry Mountain hemlock–intermediate Pacific silver fir–intermediate Pacific silver fir–warm Shasta red fir–dry Shasta red fir–moist Subalpine parkland Subalpine meadows–green fescue	Mountain hemlock, Shasta red fir, lodgepole pine, Pacific silver fir, western white pine, Douglas-fir
Moist forest	Moist coniferous forest, and maritime coniferous forest	Tanoak-Douglas-fir–moist Western hemlock–coastal Western hemlock–cold Western hemlock–hyperdry Western hemlock–intermediate Western hemlock–moist Western hemlock–moist (coastal) Sitka spruce	Douglas-fir, western hemlock, tanoak, western redcedar, white fir, Pacific silver fir
Mesic forest	Coniferous forest	Grand fir–valley Tanoak-Douglas-fir–dry White fir–cool White fir–intermediate White fir–moist White fir–warm moist	White fir, Douglas-fir, incense cedar, Shasta red fir, sugar pine, western hemlock, tanoak
Ultramafic forests and woodlands	NA	Jeffrey pine Ultramafic	Jeffrey pine, Douglas-fir, incense cedar, western white pine, Port Orford cedar, tanoak
Dry forest	Dry coniferous forest	Douglas-fir–dry Douglas-fir–moist Douglas-fir–white oak Douglas-fir–xeric Ponderosa pine–dry	Douglas-fir, ponderosa pine, incense cedar, sugar pine, Oregon white oak, California black oak
Woodlands	Coniferous woodland cool mixed woodland warm mixed woodland subtropical evergreen broadleaf woodland	Oregon white oak	Oregon white oak, Douglas-fir, ponderosa pine, Pacific madrone, incense cedar
Shrublands	Shrubland subtropical shrubland	NA	Buckbrush, whiteleaf manzanita, greenleaf manzanita

Note: MC2 plant functional types are listed and roughly correspond to the vegetation groups, but MC2 does not model species. NA = not applicable.
Source: Halofsky et al. (2014).

Potential Climate Change Effects on Disturbance

Fire

Historical fire patterns—

Fire has helped to shape the complex vegetation patterns in southwest Oregon, and in turn, the diversity of vegetation and fuel conditions contribute to complex burn patterns. Mixed-severity fires are characterized by mixed patches of vegetation burned at varied levels of severity, at relatively fine scales (tens to a few hundreds of meters) (Halofsky et al. 2011). Mixed-severity fires and irregular fire return intervals in southwest Oregon lead to highly variable patch age. Varied fire effects result in (and result from) fine-scale variation in patch age and vegetation composition, which provides habitat for a variety of species in relatively close proximity, and likely promotes resilience to fire (Halofsky et al. 2011).

Fire-scar studies provide strong evidence that climate was historically (over the past several hundred years) a primary determinant of fire regimes in southwest Oregon and across the PNW. There was widespread fire across western Oregon and Washington during the periods of ca. 1400–1575 and ca. 1800–1925 (Weisberg and Swanson 2003). Years with increased fire frequency and area burned were generally associated with warmer and drier spring and summer conditions in the PNW (Hessl et al. 2004, Heyerdahl et al. 2008, Metlen et al. 2018, Taylor et al. 2008, Wright and Agee 2004). However, summer drought during the year of the fire seems to have the strongest association with major fire years at the site and regional scales (Hessl et al. 2004, Metlen et al. 2018). Summer drought conditions are likely more important in the PNW (compared to other regions, where spring conditions are more strongly related to fire), because the PNW has a winter-dominant precipitation regime, the fire season occurs primarily in the late summer (August-September), and summer drought reduces fuel moisture (Hessl et al. 2004).

Modern climate and fire records indicate that, over the past century in the PNW, warm and dry conditions in any given year (primarily in summer, but also in winter and spring) generally led to larger fires and greater area burned (Abatzoglou and Kolden 2013; Cansler and McKenzie 2014; Dennison et al. 2014; Holden et al. 2018; Kitzberger et al. 2017; Littell et al. 2009, 2010; McKenzie et al. 2004; Miller et al. 2012; Reilly et al. 2017; Stavros et al. 2014; Trouet et al. 2006, 2009; Westerling 2016; Westerling et al. 2006). In the 20th century, area burned in the PNW was positively related to low precipitation and high temperature (Abatzoglou and Kolden 2013, Holden et al. 2018, Littell et al. 2009). In southwest Oregon and northern California, area burned is also positively associated with drought and atmospheric instability that increases potential for wildfire spread and fire risk (Trouet et al. 2009).

Warmer spring and summer conditions lead to relatively early snowmelt, increased evapotranspiration, lower summer soil and fuel moisture, and thus a longer period of time during which fires can potentially burn (Westerling 2016, Westerling et al. 2006). Precipitation during the fire season also exerts a strong control on area burned through wetting effects and feedbacks to vapor pressure deficit (a measure of humidity) (Holden et al. 2018). Between 2000 and 2015, warmer temperatures and higher vapor pressure deficit decreased fuel moisture during the fire season in 75 percent of the forested area in the Western United States and added about 9 days per year of high fire potential (Abatzoglou and Williams 2016). Dry fuels and longer fire seasons are associated with increased area burned (Gedalof et al. 2005).

Annual area burned has increased only slightly between 1985 and 2010 in the PNW, and the proportion of fires that burned at high severity has not increased, across the entire region or for any particular vegetation zone (Reilly et al. 2017). However, as total annual area burned has increased, so has the total area burned at high severity. Several analyses in recent decades have shown a positive correlation between annual area burned and area burned severely (in large patches) in the PNW (Cansler and McKenzie 2014, Dillon et al. 2011, Reilly et al. 2017). Drought years with greater fire extent generally have greater proportions and larger patches of high-severity fire, resulting in more severely burned forest that is far from live tree seed sources (Harvey et al. 2016). But even under extreme conditions, low- and moderate-severity fire make up most of the area burned in the region (Reilly et al. 2017).

Over the past several decades, a number of large mixed-severity fires have occurred in southwest Oregon (fig. 5.7), and relatively short-interval reburns have occurred. The 200 000-ha Biscuit Fire of 2002 was the largest recorded forest fire for the state of Oregon. During the summer of 2017, the 77 000-ha Chetco Bar Fire burned more than 40 000 ha of the Biscuit Fire area, including a portion of the Biscuit Fire area that had burned over part of the 1987 Silver Fire area. The 2018 Klondike Fire (approximately 70 000 ha) also burned over a portion of the Biscuit Fire area. The Umpqua North Complex (17 500 ha), Falcon Complex (1200 ha), and High Cascades Complex (11 000 ha) fires also took place during the summer of 2017 (fig. 5.7). Again in 2018, several large fires (Klondike, Taylor, Miles, and Columbus) burned a total of 112 252 ha in southwest Oregon.

The relatively high productivity and postfire abundance of sprouting evergreen hardwoods in southwest Oregon may allow repeated high-severity fires, even with relatively short fire return intervals (Halofsky et al. 2011, Odion et al. 2010). The shrub and hardwood-dominated vegetation that establishes after fire in this region can maintain dominance for up to 30 years without fire (Odion et al. 2010). For example, 4 years after the Biscuit Fire, sprouting broadleaf vegetation cover ranged from 4 to 63 percent, depending on fire severity and elevation (Donato et al. 2009a). The relative dominance of non-conifers after high-severity fire depends on a number of factors, and repeated fires at

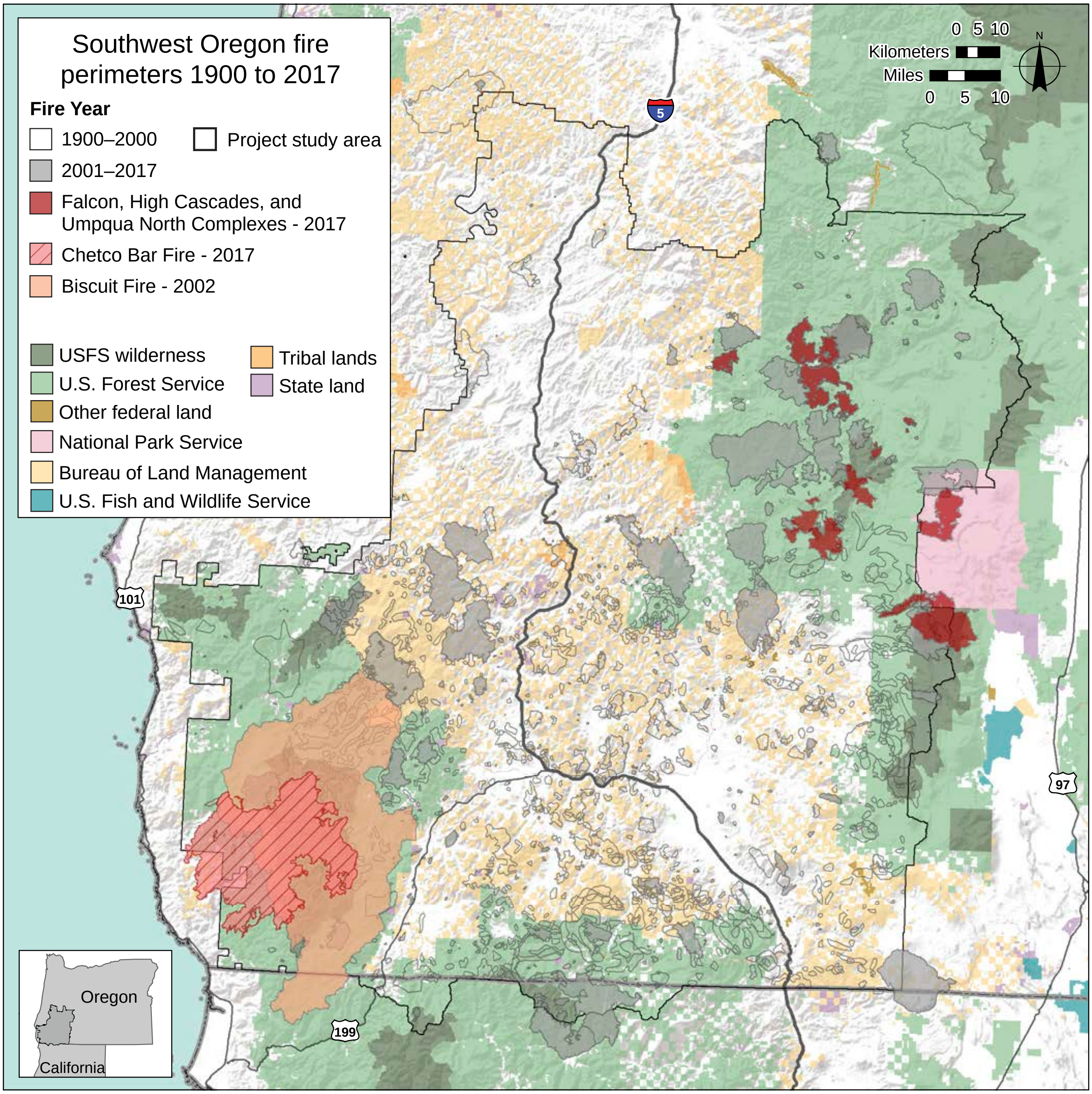

Figure 5.7—Fire history in the Southwest Oregon Adaptation Partnership assessment area from 1900 to 2017. Recent (2017) fires are highlighted as well as the 2002 Biscuit Fire, which is the largest forest fire on record in Oregon. USFS = U.S. Forest Service.

relatively short intervals maintain the persistence of these nonforest states. In the absence of disturbance, conifers, if present, will eventually overtop shrubs. Even conifer-dominated, early-seral states, with an abundance of live and dead fuels close to the surface, are likely to burn at high severity, given a relatively short fire return interval (Odion et al. 2010; Thompson and Spies 2009, 2010).

The topography and vegetation of southwest Oregon are complex, so generalizations about effects of fire exclusion on forests in the region are difficult (Perry et al. 2011). However, fire exclusion has likely increased forest density and favored shade- and fire-intolerant species such as white fir in some locations (Sensenig et al. 2013; Taylor and Skinner 1998, 2003). The effects of fire exclusion and lack of fuel treatments, combined with the effects of extensive timber harvest (mostly 20thcentury clearcutting), created areas of dense, young trees and likely increased the risk of large, high-severity fires (Myer 2013, Perry et al. 2011). Currently, dense forest cover is found across much of the landscape, creating continuous fuels that can carry high-severity crown fire.

Comparing current forest conditions to the historical range of variation for the southwest Oregon region, Haugo et al. (2015) suggested there is a significant need for thinning or low-severity fire treatments to restore forests characterized by low- and mixed-severity fire to historical conditions. Similarly, a recently completed terrestrial condition assessment for national forest lands suggested that fuel loading, and therefore wildfire hazard, is very high in southwest Oregon (Cleland et al. 2017). High wildfire hazard, combined with high road density and exposure to recent climate change (elevated temperatures, particularly winter temperatures, and reduced precipitation), led to condition ratings of poor to very poor in some watersheds in the SWOAP assessment area (fig. 5.8). However, most of the assessment area is classified as being in moderate or good condition.

Future fire projections—

A warming climate in future decades will have profound effects on fire frequency and extent in southwest Oregon. Increased temperatures, decreased snowpack, and declining summer precipitation will probably lead to longer fire seasons, lower fuel moisture, higher likelihood of large fires, and greater area burned by wildfire (Holden et al. 2018; Littell et al. 2010; McKenzie et al. 2004; Stavros et al. 2014; Westerling et al. 2006, 2016). Interactions between fire and other disturbance agents (e.g., drought, insect outbreaks) will likely drive ecosystem changes in a warming climate (McKenzie et al. 2009). Increased moisture stress in trees and interacting effects of drought will likely contribute to increasing area burned (Littell et al. 2016, Reilly et al. 2017, Stavros et al. 2014). Climatic changes and associated stressors will interact with vegetation conditions, as affected by historical land uses such as tree harvest and fire suppression, to affect fire regimes and forest conditions in the future (Keeley and Syphard 2016).

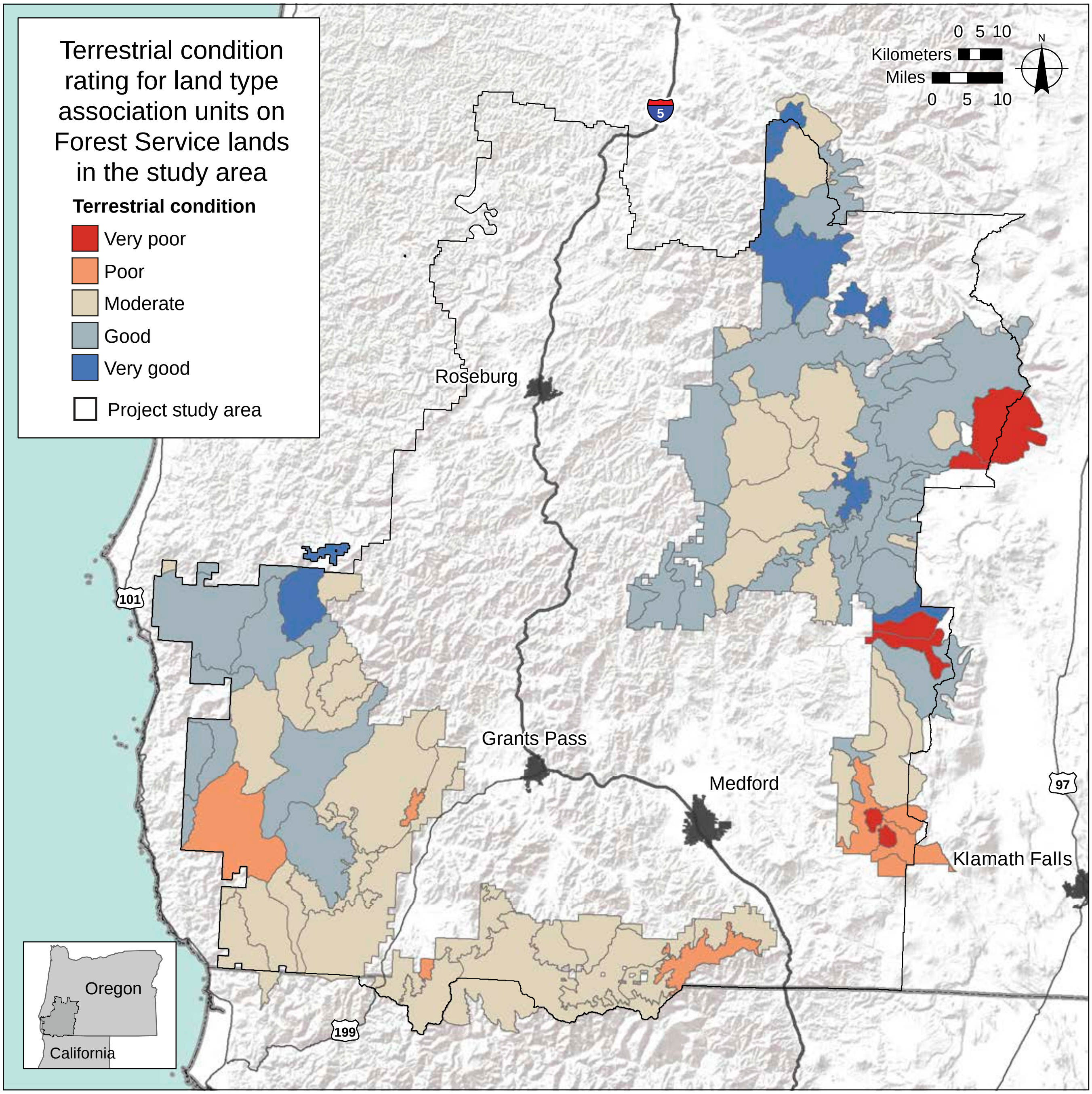

Figure 5.8—Terrestrial condition assessment rating for national forests in the Southwest Oregon Adaptation Partnership assessment area. Data are from Cleland et al. (2017).

Several types of models can help explore potential future fire regimes in a changing climate (McKenzie et al. 2004). We focus here on models for which output is available in the PNW—empirical (statistical) models and mechanistic (process-based) models. Both types of models have limitations as well as strengths, but they are conceptually useful to assess and explore potential changes in fire regimes with climate change. See Peterson et al. (2014) for more information on model attributes, strengths, and weaknesses.

Empirical model projections—Empirical models use the statistical relationship between observed climate and area burned during the historical record (the past 100 years or so). Future area burned in a changing climate is based on projections of future temperature and precipitation, usually from global climate models (GCMs). Numerous studies have developed empirical models to project future area burned or fire potential at both global (Krawchuk et al. 2009, Moritz et al. 2012) and regional scales (e.g., Western United States) (Kitzberger et al. 2017, Littell et al. 2010, McKenzie et al. 2004, Yue et al. 2013). All of these studies, including the global-scale studies, agree that fire potential or area burned will increase in the Western United States in the future with warming climate. McKenzie et al. (2004) projected that area burned by wildfire will increase by a factor of 1.4 to 5 for most Western States, including Oregon, with a mean temperature increase of 2 °C. Similarly, Kitzberger et al. (2017) projected increases in annual area burned of five times the median in 2010–2039 compared to 1961–2004 for the 11 Western United States. Empirical models developed for the PNW suggested that area burned will increase 300 to 500 percent with a 1.2 °C increase in temperature in the SWOAP assessment area (Mote et al. 2014). The temperature increases used in these studies are a fraction of the approximately 5 °C increase projected under representative concentration pathway (RCP) 8.5 in the most recent runs of GCMs (see chapter 2 and below).

Another application of empirical models is to project the future incidence of very large fires, often defined as the largest 5 to 10 percent of fires (greater than 5000 ha) (Barbero et al. 2015). These models suggest that the annual probability of very large fires will increase in the PNW. Barbero et al. (2015) projected that, in a Western United States region encompassing the PNW, the annual probability of very large fires will increase by a factor of four in 2041–2070 compared to 1971–2000 under RCP 8.5. Projections by Davis et al. (2017) suggested that the proportion of forests highly suitable for large wildfire (greater than 40 ha) will increase by more than 20 percent in the next century under RCP 8.5 for nearly all ecoregions in Oregon and Washington, including the ecoregion that covers southwest Oregon (Klamath Mountains) (fig. 5.9). The number of fires that escape initial attack suppression will also likely increase (Fried et al. 2008).

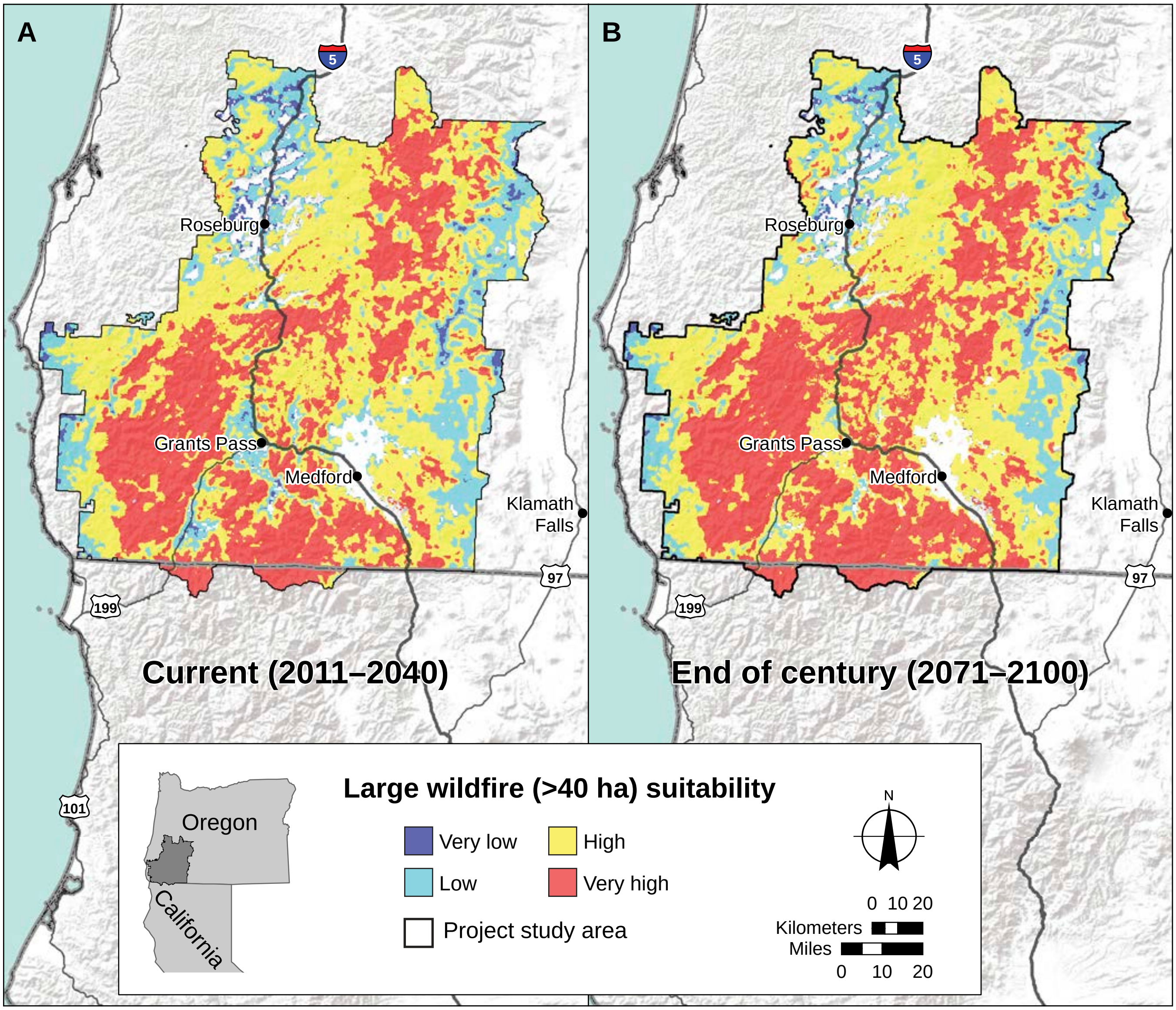

Figure 5.9—Modeled environmental suitability for large forest fires under current climate (2011–2040) and projected future climate at the end of the century (2071–2100), as projected under Representative Concentration Pathway 8.5. Modeling methods follow Davis et al. (2017).

Relatively fewer projections are available for future fire severity. Using empirical models, Parks et al. (2016) suggested that fire severity in a warming climate may not change significantly in the PNW because fuels may limit future fire severity. However, changes in fire severity will depend partly on vegetation composition and structure (fuels), and climate change will alter vegetation composition and structure both directly and indirectly (through disturbance).

Mechanistic model projections—Mechanistic (process-based) models use mathematical relationships to represent understanding of physical and biological processes and the interactions among those processes. These models allow for exploration of the potential interactions between vegetation and fire under changing and potentially novel (i.e., with no past analog or equivalent) climate. Mechanistic models can also account for elevated carbon dioxide (CO^2) concentration on vegetation. Mechanistic models that simulate fire include dynamic GCMs, such as MC1 and MC2 (Bachelet et al. 2001, Conklin et al. 2016), and landscape models such as LANDIS-II (Scheller et al. 2007). Vegetation and fire projections from these models are discussed in later sections.

Mechanistic model simulations for the PNW suggest that both fire frequency and area burned will increase in the future (Rogers et al. 2011, Sheehan et al. 2015). Fire severity may also increase, depending partly on fuels (i.e., forest composition, structure, and productivity) over time. Warmer temperatures in winter and spring, and increased precipitation during the growing season (even early in the growing season), could increase forest productivity. This increase in productivity could result in increases in fuel levels and promote high-severity fires (when drought and ignitions occur). If the size of high-severity fire patches increases, local seed sources to regenerate these patches will be limited. Regeneration will thus require long-distance seed dispersal (or assisted migration) and may be slower in large, high-severity patches (Donato et al. 2009a). However, future increased fire frequency without increased vegetation productivity is likely to eventually result in decreased fire severity.

Under a warming climate, increased frequency and extent of fire will increase the likelihood of reburns, increasing the need to understand how earlier fires affect subsequent overlapping fires and how forests respond to multiple fires. Areas burned in short-interval, stand-replacing fires may be particularly vulnerable to lasting compound disturbance effects; short-interval reburns can produce compound effects on tree regeneration, altering species composition, and in some cases, leading to shifts to nonforest vegetation (Airey Lavaux et al. 2016).

In relatively productive areas such as southwest Oregon, fire severity can be greater in reburns than in comparable single burns once the interval between fires exceeds 10 to 12 years (Thompson et al. 2007). However, in southwest Oregon, short-interval (i.e., 15 years between fires), high-severity (Silver Fire-Biscuit Fire) reburn areas were not qualitatively different than areas that burned once at a longer interval (greater than 100 years between fires). That is, the reburn had no compound effect on regeneration of Douglas-fir, the dominant tree species (Donato et al. 2009b). In contrast, plant species diversity was higher in reburns compared to single-burn areas (Donato et al. 2009b). Whether reburns decrease postfire conifer regeneration seems to depend on legacy trees that survive both fires and provide critical seed sources for postfire regeneration across fire events (Donato et al. 2009b). In locations where legacy trees are rare (i.e., thin-barked species easily killed by fire) or where shrubs can outcompete trees for long durations, reburns are more likely to produce lasting compound effects on forest structure and composition.

Insects

Interactions with climate—

Insects are major components of forest ecosystems, representing much of the biological diversity and affecting virtually all processes (Mattson 1977). Temperature is a major driver of physiological processes in insects, and as such, all insect species will be affected in some way by climate change (Fettig et al. 2013). Population status, host condition, and weather influence insect life history and the potential impact of insects on vegetation. Insects often operate in association with plant pathogens. Forest insect outbreaks and tree diseases combined exceed other sources of disturbance to North American forests (Hicke et al. 2016, Weed et al. 2013) and have significant interactions with climate.

In general, insect species have relatively short life cycles, high reproductive capacity, and a high degree of mobility, and therefore physiological responses to warming temperatures can produce large and rapid effects on species population dynamics (Stange and Ayres 2010). In addition to direct effects on insect population status, climate change can indirectly affect insects and associated forest disturbances. Indirect effects on insects can occur via climate effects on host tree distribution and defense, as well as on interactions among disturbance agents and their own enemies, competitors, and mutualists (Weed et al. 2013). Much of the literature on insect interactions with climate in North America focuses on bark beetles and defoliators within the genera *Dendroctonus* (Coleoptera: Curculionidae: Scolytinae) and *Choristoneura* (Lepidoptera: Tortricidae), respectively, with additional attention to other aggressive bark beetles, defoliators, and stem and phloem sap tappers (Weed et al. 2013).

Temperature affects insect survival nonlinearly and exponentially; insect metabolism is estimated at two times faster per 10 °C increase in temperature (Ayres and Lombardero 2018). Warmer temperatures increase insect consumption, growth, movement, and dispersal, and also affect phenology and species interactions (Ayres and Lombardero 2018). Enhanced winter survival and shortened generation times owing to warming may facilitate larger populations of insects, particularly those with multiple generations per year (Weed et al. 2013). Those species with necessary sequences of life cycle events, such as mountain pine beetle (*Dendroctonus ponderosae* Hopkins) and other bark beetles, have experienced increased population success and recent range expansion owing to warmer climatic conditions lifting life cycle constraints (Fettig et al. 2013).

Alternatively, species with an obligate overwintering diapause, a structured form of dormancy that serves to synchronize populations with their environment, may be inhibited at locations where temperatures no longer reach required minimum thresholds or duration (e.g., larval fir engraver beetles and adult Douglas-fir beetles [*D. pseudotsugae* Hopkins]) (Bentz et al. 2010). Mismatches within a population could occur as thermal conditions move beyond the current limits of a species plasticity (Fettig et al. 2013), resulting either in range shifts or adaptation. Insect life cycles may eventually be disrupted at lower elevations by higher temperatures, with discordant development and lower likelihood of survival entering winter (Bentz et al. 2010, Costello and Schaupp 2011). Higher temperatures may also decrease the likelihood of large epidemics (Preisler et al. 2012).

Temperature and precipitation effects on insect hosts, either plants or other insects, may indirectly affect insect-climate interactions. The relative success of many herbivorous insect species is closely tied to host plant vigor, which can be influenced by altered climatic conditions. Trees under stress are commonly attacked by bark beetles and wood borers and may become more vulnerable to root diseases and other disturbance agents. Wildfire and drought, both influenced in frequency, extent, and severity by temperature, are sources of host tree stress that can facilitate insect population increases and associated impacts. In particular, extreme drought events have induced and been followed by large-scale tree mortality involving insects in western North America where sufficient susceptible hosts exist (Hicke et al. 2016, Millar and Stephenson 2015, Young et al. 2017). Drought effects on host plants may increase their attractiveness to herbivores, such as defoliators, because of the host plant physiological response to drought that increases concentration of nitrogen compounds and sugars in young plant tissue (McDowell et al. 2016). Climate change effects on tree physiology may also increase host stress and thus provide poorer nutrition to insect herbivores (Fettig et al. 2013).

Host distribution, density, and abundance are affected by climate, and all indirectly affect the likelihood of insect outbreaks and associated disturbance (Fettig et al. 2007, Weed et al. 2013). A relatively dense forest with a high proportion of host tree species is a prerequisite for extensive epidemics of many bark beetle species. Climate factors benefitting insect herbivores may also enhance population performance of insect predators and parasitoids, perhaps lengthening the time between host population irruptions or shortening their duration. Two species of essential fungal symbionts of the mountain pine beetle have differing benefits and temperature optima, so shifts in temperature and precipitation could indirectly affect beetle population success through direct effects on these fungal symbionts (Fettig et al. 2013).

Climate change may affect the success of introduced nonnative insects. Some introduced insects and plant pathogens have caused significant ecosystem disturbance in North America, although the majority of introduced species do not survive (Williamson 1999). Many fail because the climate is unsuitable at their points of arrival. An altered climate will lead to a different mix of surviving introduced species. In general, one might expect a larger fraction of survivors when the climate is warmer; introduced species comprise a larger fraction of the biota in the warmer areas of the United States (Simberloff 1997).

Potential future change—

The effects of insects in a warmer climate are difficult to project because of uncertainties related to factors that regulate ecological systems and the resilience fostered by compensatory feedback processes. Many of the complex relationships among herbivores, their hosts, and their associates are poorly understood (Agne et al. 2018, Bale et al. 2002), making projections of climate change effects on insects difficult (Bentz et al. 2010). Climate affects plant defenses to insects and pathogens via the interaction between water and carbon transport, but the specific physiological processes are unclear (Fettig et al. 2013). In addition, many of the vegetation models do not agree on future distributions of tree species, nor is it certain whether southwest Oregon will receive more or less precipitation (chapter 2).

Nevertheless, warmer temperatures will affect insect population dynamics directly through effects on survival, generation time, fecundity, and dispersal. Insect populations limited by cold during the growing seasons are anticipated to benefit from climate change through more rapid life cycle completion and increased survival. Insect mortality may decline with warmer winter temperatures, thereby leading to higher elevation and poleward range expansions (Stange and Ayres 2010). Indeed, an increase in the frequency and severity of insect-mediated disturbances is expected in the Western United States as a result of increased temperatures and more frequent and intense drought stress, although this expectation is derived from a limited number of species in conifer forests (Kolb et al. 2016).

Increased drought severity and frequency are likely to make forests more vulnerable owing to both direct (reduced growth and mortality) and indirect (insect outbreaks, pathogens and wildfire) mechanisms (Dale et al. 2001, Kolb et al. 2016b, Weed et al. 2013). Changes in the timing and type of precipitation will indirectly affect bark beetles and probably some wood borers by influencing the suitability and spatial distribution of host trees (Fettig et al. 2013). If the characteristic summer drought period in southwest Oregon is longer or drier, additional moisture stress and fire effects on host trees would favor opportunistic insects. Secondary insect species, for example some bark beetles in the genera *Ips* and *Scolytus*, may become more significant disturbance agents with an increase in trees stressed by other factors. Extreme drought stress and hotter temperatures have fostered short-term, large increases in Douglas-fir mortality resulting primarily from a wood borer, *Phaenops drummondi* (Kirby), on low-elevation, dry sites in southwest Oregon (see "Dry Forests" section below for additional information), and this is likely to occur in the future with additional hotter droughts.

For some insects, the effects of an increase in extreme events may outweigh the effects of small increases in mean temperature (Bale et al. 2002). For example, recent pulses of bark beetle and wood borer population growth in New Mexico and California are attributed to extreme drought (Millar and Stephenson 2015, Preisler et al. 2017, Young et al. 2017). Both the magnitude of change and higher variability may affect insect-tree interactions in the future (Bale et al. 2002).

Because insects typically migrate much faster than trees, many temperate tree species are likely to encounter nonnative insect herbivores that previously were restricted to subtropical forests (Dale et al. 2001). In addition, increased temperatures under a changing climate may allow northward migration of introduced and native insects from areas south of the SWOAP assessment area, such as California and northern Mexico. Of special concern are ambrosia beetles (Curculionidae: Scolytinae) and their associated fungi, which have large host ranges, are easily transported deep within untreated wood, and can have devastating impacts to native and introduced tree species (Ploetz et al. 2013). The list of potential problem insect species unintentionally introduced into California and western North American continues to grow, as does the list of unwanted nonnative invasive insects established elsewhere on the continent. Unfortunately, the behavior and impact of insects in novel ecosystems may be inconsistent with what is evident in their place of origin.

Native forest insects that currently cause disturbances within the SWOAP assessment area include the fir engraver (*Scolytus ventralis* LeConte) (a bark beetle species) in true firs (*Abies* sp.); western pine beetle (*Dendroctonus brevicomis* LeConte) in ponderosa pine; and mountain pine beetle in sugar pine, lodgepole pine, western white pine, and ponderosa pine. Of these, only the firs and some areas of lodgepole pine occur across a sufficient expanse with a high percentage of host such that widespread bark beetle epidemics will be possible in the future. However, much of the significant mortality in the other pine host species occurs in mixed-conifer forests where isolated, large, old individuals and small groups are attacked. A recent study in the Klamath Mountains found a positive association between dwarf mistletoe infestation and the proportion of Shasta red fir trees with fir engraver beetle, suggesting that Shasta red fir is at high risk for fir engraver infestation owing to damage from dwarf mistletoe (DeSiervo et al. 2018).

Despite the widespread presence of susceptible Douglas-fir in southwest Oregon, the Douglas-fir (bark) beetle is infrequently found killing standing trees other than in the Cascade Range, most often in the northeastern part of the SWOAP assessment area. Overall, Douglas-fir beetle epidemics have been infrequent and need to be induced through prior population increase within damaged hosts, for example, following a large-scale windthrow event. Overall, mortality caused by Douglas-fir beetles is less common than in eastern Oregon. Significant mortality episodes in Douglas-fir occur as a result of the flatheaded fir borer (*Phaenops drummondi* [Kirby]) at lower elevations, primarily in the Klamath-Siskiyou ecoregion (fig. 5.10). For unknown reasons, there are no known instances of significant impacts in southwest Oregon from the two major insect defoliators in western North America, western spruce budworm (*Choristoneura freemani* Clemens) and Douglas-fir tussock moth (*Orgyia pseudotsugata* [McDunnough]), though both are present in the SWOAP assessment area.


Bob Schroeter, U.S. Forest Service

Figure 5.10—Aerial view of flatheaded fir borer mortality in the Applegate Valley of southwestern Oregon in June 2016.

Fungal Pathogens and Other Disease Organisms

Many plant pathogens are strongly influenced by the vigor of the host, which is often related to environmental conditions. Environmental stressors such as drought reduce tree defenses, predisposing trees to attack. The dynamics of host-pathogen interactions are influenced by local climate, and therefore a change in climate will likely affect the behavior and distribution of tree diseases (Kolb et al. 2016). Changes in environmental conditions with climate change will likely shift the distribution of trees and the pathogens that interact with them. Any change in climatic conditions that results in an environment more suitable to a pathogen, or host susceptibility to that pathogen, will result in an increase in the incidence of disease.

Some forest diseases, such as Swiss needle cast (caused by *Phaeocryptopus gaeumannii* (Rohde) Pilát) and white pine blister rust (caused by *Cronartium ribicola* A. Dietr.), require specific environmental conditions for growth, sporulation, and spread. These pathogens are influenced directly by climate and local site conditions and are most likely to be affected by climate change (Sturrock et al. 2011). Diseases such as laminated root rot (caused by *Phellinus sulphurascens* Pilát) and dwarf mistletoe (caused by *Arceuthobium* spp.) appear to be indirectly associated with local climate and are less likely to be affected by climate change. Nonetheless, these biotic disturbance agents interact in complex ways (Agne et al. 2018), and the role of climate is poorly understood for most forest tree diseases. However, climate change is very likely to affect the interactions of pathogenic fungi with trees stressed by drought and other environmental factors. For example, Armillaria root disease (caused by *Armillaria ostoyae* (Romagnesi) Herink) often infects drought-stressed trees (Kolb et al. 2016).

The native forest pathogens that occur in southwest Oregon are integral components of these ecosystems and can influence species richness and abundance, forest succession, and forest structure and composition at different spatial scales, as well as wildlife habitat (Hansen and Goheen 2000). Root diseases, such as laminated root rot and Armillaria root disease, often influence management decisions in mixed-conifer forests. Loss in tree vigor caused by these diseases and others can often predispose individuals to attack by secondary agents such as tree-killing bark beetles. Nonnative diseases such as sudden oak death (caused by the pathogen *Phytophthora ramorum* Werres et al.) and white pine blister rust can also influence species richness and forest succession, often by removing a tree species from a stand or at larger spatial scales. Restoration-focused integrated management strategies, such as prevention, eradication, and resistance breeding, are often required to control epidemics and further spread of these diseases.

Although it is uncertain how specific pathogens will respond to climate change, some general inferences can be drawn (Kliejunas 2011):

- Climate change will affect the epidemiology (spread) of plant diseases. Prediction of disease outbreaks could become difficult with rapid climate change or extreme weather events.
- Many pathogens are limited by winter temperature, and seasonal increases in temperature are expected to be greatest during winter. Accordingly, both overwintering survival of pathogens and disease severity are likely to increase.
- The most substantial effect of climate change on plant diseases may be changes in interactions between biotic diseases and abiotic stressors such as drought.
- Climate change may facilitate establishment by new nonnative pathogens and thus new epidemics.

Temperature and precipitation are important epidemiological factors for many foliar diseases of forest trees in southwest Oregon. Local seed sources are adapted to local climate and pathogen pressures, and seed sources from regions with high foliage disease pressure are most resistant to those foliage diseases (Wilhelmi et al. 2017). Increased probability of losses resulting from foliage diseases are observed when trees produced from seed from dry environments were planted in mild, mesic environments. For example, abundance of Swiss needle cast in coastal Douglas-fir forests is higher in warmer winter temperatures (Lee et al. 2016, Manter et al. 2005, Stone et al. 2008). Foliage and canker diseases of Pacific madrone in southwest Oregon are often associated with moisture stress (Shaw and Bennett 2008). Sudden oak death is strongly influenced by climate, and increased precipitation during spring would favor increased damage where it occurs as well as its expansion into new locations (Davidson et al. 2002, Kliejunas 2011).

Hotter, drier summers projected to occur as a result of climate change are likely to have substantial effects on forests. Damage caused by pathogens that respond to changes in host vigor will be greater in areas where tree vigor is diminished because of hotter, drier summers and associated drought stress (Agne et al. 2018). Armillaria root disease is common in white fir and grand fir (*Abies grandis* (Douglas ex D. Don) Lindl.) and occasionally attacks Douglas-fir in the Cascade Range of southwest Oregon. Climatic conditions that favor these species will also favor the pathogen. High levels of damage have been observed in stands located on compacted soil (Lockman and Kearns 2016). Pines and other less susceptible conifers are at a higher risk of infection on these types of sites.

Port Orford cedar—

Phytophthora lateralis is a nonnative pathogen that causes root disease throughout the range of Port Orford cedar. The relatively cool, wet conditions of the coastal forests of southwest Oregon are ideal for growth and reproduction of this pathogen. The road system in Port Orford cedar habitat is the principal pathway for uphill disease spread. Humans are responsible for long-distance spread, primarily by vehicles during the wet season. Port Orford cedar nearest roads and waterways are at the highest risk for infection (Hansen and Goheen 2000). Flooding and other extreme weather events can exacerbate the spread of this disease. Continued active management, such as permanent and wet-season road closures and resistance breeding, are key to preserving Port Orford cedar in the future.

Whitebark pine—

Little is known about the current population of whitebark pine or the status of white pine blister rust that occurs in high-elevation locations of Rogue River-Siskiyou National Forest (Sky Lakes Wilderness) and Umpqua National Forest. White pine blister rust requires a primary and secondary host (usually *Ribes* spp., but also *Pedicularis* spp. and *Castilleja* spp.) in addition to extended periods of ample moisture to complete its life cycle. Climate-driven disturbances could alter the geographic distribution of these hosts (Kolb et al. 2016). Lower snowpack and earlier melt will likely create more opportunities for infection in the spring, especially where high humidity persists (Agne et al. 2018).

Drought

With higher temperatures in southwest Oregon, evapotranspiration will increase, increasing summer water deficit and drought severity (Littell et al. 2013, 2016) (chapter 2). Water deficit directly contributes to potentially lethal stresses in forest ecosystems by intensifying negative water balances (Littell et al. 2008, Milne et al. 2002, Restaino et al. 2016, Stephenson 1998). Although water deficit is rarely fatal to trees by itself, it is a predisposing factor that can exacerbate the forest stress complex, or combinations of biotic and abiotic stressors that affect forests (Manion 1991, McKenzie et al. 2009). Water deficit also indirectly increases the frequency, extent, and severity of disturbances, especially wildfire and insect outbreaks (Logan and Powell 2009, McKenzie et al. 2004). Fire area burned in southwest Oregon is positively related to drought conditions (Trouet et al. 2009). These indirect disturbances alter forest ecosystem structure and function, at least temporarily, much faster than do chronic effects of water deficit (e.g., Loehman et al. 2017).

Tree growth will likely decline for many species in southwest Oregon with increasing summer drought stress (Restaino et al. 2016). Increased atmospheric

CO_2 concentrations could increase water-use efficiency and drought tolerance by reducing the amount of time stomata must remain open to draw in CO_2, thereby reducing incidence of photorespiration. However, the degree to which increased CO_2 concentrations offset increased temperatures and water stress is not known.

High-density stands (e.g., those resulting from fire exclusion) will be more susceptible to drought stress because of increased competition for water among individual trees. In western and central Oregon, Douglas-fir is more sensitive to drought than ponderosa pine (Kwon et al. 2018, Minore 1979). However, drought stress is more pronounced in young pine than mature pine, because of shallower roots in the young pine.

Drought will also likely affect forest regeneration and development, particularly when drought conditions follow fire events. On southwest Oregon and northwest California sites that burned between 1985 and 2015, low soil water reduced conifer regeneration but apparently increased shrub biomass (Tepley et al. 2017). The lower the soil moisture, the higher the propagule pressure (smaller high-severity patches with more live seed trees) needed to achieve a given level of regeneration. Therefore, at high levels of climatic water deficit, even small high-severity patches are at risk for low regeneration, and areas with high climatic water deficit are projected to increase with warming (Tepley et al. 2017). Successive fires could further limit local seed sources.

Individual drought years are not likely to alter postfire successional pathways, especially if wet years occur between dry years (Tepley et al. 2017). However, long-term drought that coincides with critical postfire regeneration years or repeated fire can lead to altered vegetation states (e.g., where shrub or grass species become dominant for a protracted period, or species that are minor but drought tolerant at the seedling stage become dominant). On some sites, recruitment of conifers following a disturbance can require years to decades in the PNW (Little et al. 1994, Shatford et al. 2007, Tepley et al. 2013). Thus, shrubs may dominate during drought periods, but conifers could establish and overtop shrubs during wetter and cooler periods (Donato et al. 2016, Dugan and Baker 2015).

Potential soil drought stress maps (fig. 5.11) (Ringo et al. 2018) may help managers identify where drought effects will be most severe in the future and where seedling survival and establishment may be more successful. However, the existence of “droughty soils” does not automatically imply vulnerability. Nevertheless, the map may be useful for identifying where seedling survival and establishment will not be deterred by future drought.

Mildrexler et al. (2016) calculated a forest vulnerability index (FVI) using drought and high temperatures across Oregon and Washington from 2003 to 2012.

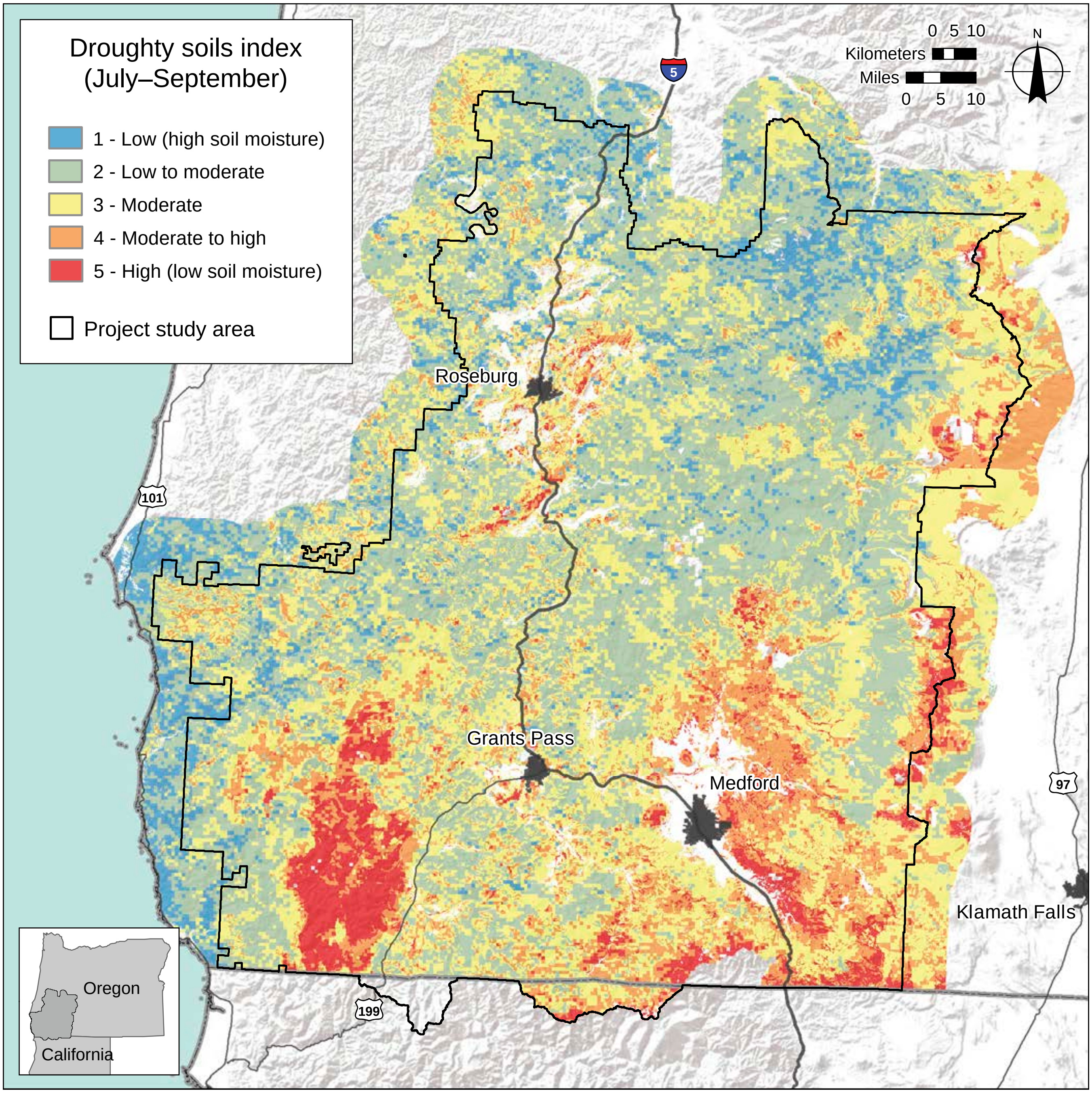

Figure 5.11—Potential soil drought stress in southwest Oregon (July–September). Data are from Ringo et al. (2018).

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 types. For the SWOAP assessment area, substantial portions of the area did not show positive FVI values (higher drought stress) until September (fig. 5.12). Much of the area with positive FVI values occurred in Umpqua National Forest and the BLM Roseburg District. Positive FVI values occurred across forest types. These results indicate where future drought and high temperatures may occur, but response to these stresses will vary geographically and by species.

Invasive Plant Species

Climate change is expected to alter the distribution and spread of invasive plants, and new invasive species will likely establish with changing climatic conditions (Ayres et al. 2014, Hellmann et al. 2008). An invasive species is a nonnative species whose introduction does or is likely to cause economic or environmental harm or harm to human health (NISC 2016). Plant invasions can be influenced by warmer temperatures, drier or wetter conditions, seasonal temperature and precipitation changes such as earlier springs and earlier snowmelt, reduced snowpack, as well as changes in fire regimes, elevated nitrogen deposition, and elevated CO_2 concentrations. Invasive plants tend to have characteristics that differ from native species and allow for rapid expansion with changes in environmental conditions. For example, invasive species are often highly adaptive (Sexton 2002) and have life-history characteristics such as high fecundity and dispersal that facilitate rapid population expansion. However, changes in climate will inevitably translate to “winners” and “losers” among invasive plants.

Studies have been conducted on potential changes in species performance, spread, and distribution for some of the high-priority invasive species in southwest Oregon, such as knapweed species (*Centaurea* L.). Yellow star thistle (*C. solstitialis* L.) productivity increased in response to elevated CO_2 under controlled conditions, although plant responses in field conditions may differ markedly (Dukes 2002, Dukes et al. 2011). Modeling projections suggest that the habitat for knapweed species may change in a warmer climate; Broennimann and Guisan (2008) projected a northern distribution shift and reduced invasion extent for spotted knapweed (*C. stoebe* L.) by 2080 using a hot and dry future climate scenario. However, another study (Bradley et al. 2009) indicated the opposite, and that the habitat for the species was likely to increase by 2100 as it warms in the West. Cumming (2007) found that small increases in temperature and precipitation (in Montana) would expand the suitable habitat for spotted knapweed in the short term, but large increases (+4.5 °C, +10 cm precipitation) would decrease suitable habitat in the long term (over several decades).

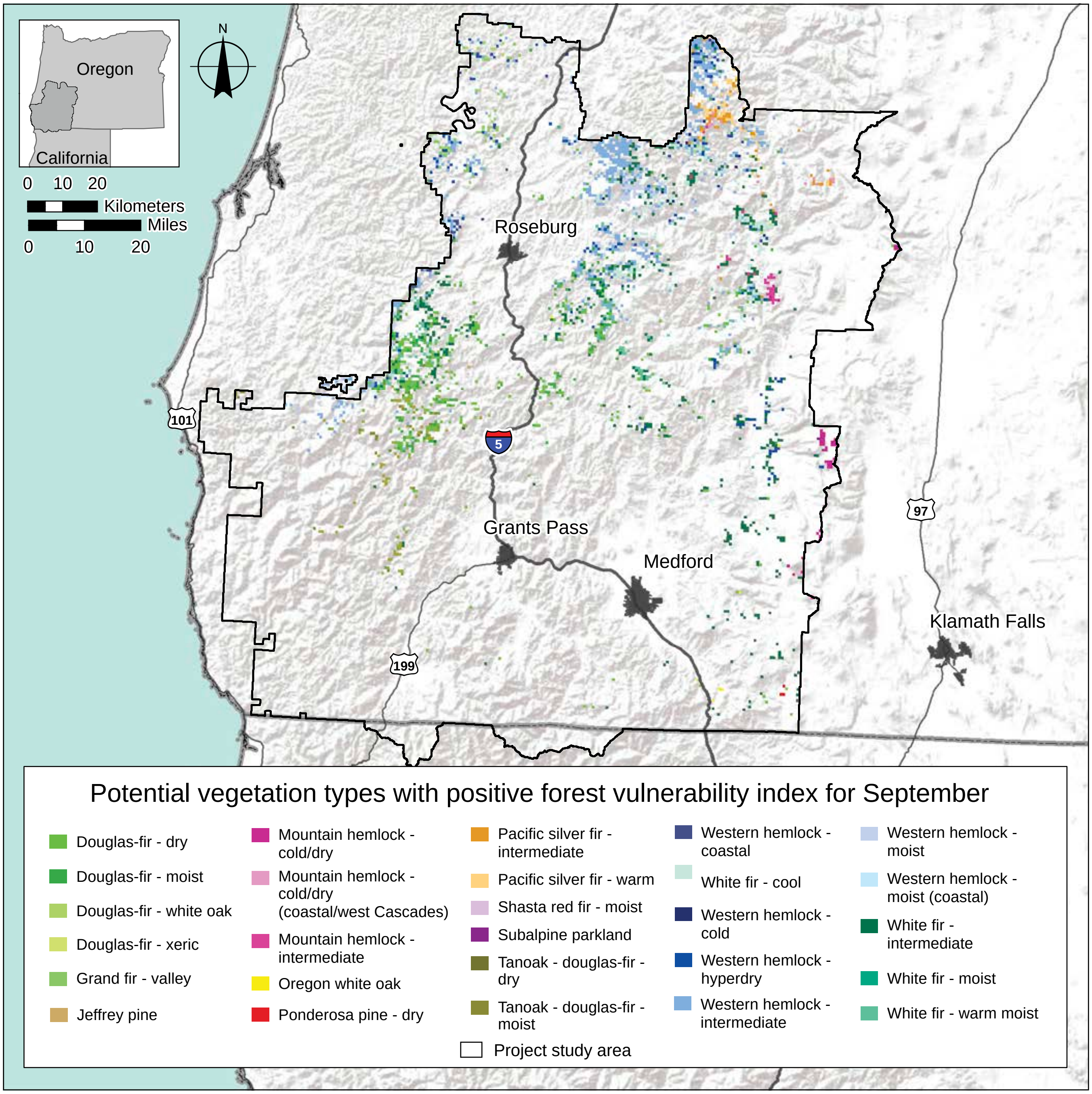

Figure 5.12—Positive forest vulnerability index (FVI) values (p-value <0.05) for September in the Southwest Oregon Adaptation Partnership assessment area by potential vegetation type (Halofsky et al. 2014). Positive FVI values indicate forest areas that have experienced statistically significant trends in rising temperatures and increasing water deficits from 2003 to 2012. These trends lead to expected forest vulnerability, although forest type-specific responses will vary. Only vegetation subzones with more than 5 percent positive FVI values are shown. Data are from Mildrexler et al. (2016).

In forests, invasive plants are most often found in disturbed areas (e.g., along roads, streams, or trails, or in areas disturbed by harvesting, windthrow, landslide, or fire), and some of these disturbances may increase in a warming climate. Invasive species such as meadow knapweed (*C. debeauxii* Gren. & Godr.) can be spread by active management and favored by increased light availability to the forest floor when forest canopies are opened. Climate change may increase the likelihood of invasion of forest lands owing to increased potential for these disturbances. Forest thinning, fuel treatments, and biofuel harvesting may also increase in order to adapt to or mitigate climate change. All of these activities can promote invasion by opening forest canopies, reducing competition, exposing mineral soil, and increasing light and nutrient availability (Bailey and Tappeiner 1998, D'Antonio et al. 1999, Hobbs and Huenneke 1992, Kerns et al. 2006, Nelson et al. 2008, Silveri et al. 2001). Changes in resource availability, coupled with available propagules, can allow invasive species to invade or spread after disturbance (Davis et al. 2000, Halpern 1989, Parks et al. 2005). Successful invaders also commonly have strong dispersal strategies and short generation times, which can allow them to quickly establish on disturbed sites.

Slender false brome (*Brachypodium sylvaticum* P. Beauv.) is a perennial grass that can thrive in both shaded and open forested areas in western Oregon and is a prominent invader in southwest Oregon. Invasion of slender false brome can be accelerated by road and stream networks (Kim 2015). In a study near Estacada, soil and vegetation disturbance led to increased seedling recruitment, especially where conditions of high propagule pressure and deciduous forest canopy existed (Taylor and Cruzan 2017). Another study suggested that slender false brome has the potential to invade native understory communities, but the progress of invasion will depend on the frequency and intensity of perturbations of the accumulated leaf litter (Taylor et al. 2015). Invasion of this grass was not found to increase fire severity (in prescribed burns), but abundance increased in patches of low-severity fire sites (Poulos and Roy 2015).

Madwort (*Alyssum corsicum* Duby) and yellowtuft (*A. murale* Waldst. & Kit.) are prominent invaders that colonized diverse and unique biological areas on serpentine soils in southwest Oregon. Yellowtuft is widespread in its native range (the Mediterranean region and southern Europe), readily colonizing sites with low soil moisture and low fertility (Amsberry et al. 2008). It is tolerant of a broad range of environments, including serpentine soils. Madwort has a more restricted native range (also in the Mediterranean region and southern Europe). Studies regarding the ecology of these species and response to climate change and disturbance are limited. However, breeding of agricultural cultivars of both madwort and yellowtuft has likely increased genetic diversity, which may allow these species to adapt to future climate change.

To assess which invasive species may increase with climate change, and which habitats may be at risk, it is critical to understand the potential responses of the most detrimental invasive plants (current and watch list species) to individual climatic factors, interactions between those factors, and interactions among biological and environmental factors, including disturbance (Ayres et al. 2014). Many invasive species found in the SWOAP assessment area will proliferate following fire and other disturbances. Control activities may need to be increased or modified in response to increased invasive species establishment after disturbance in southwest Oregon. Although there may be limited specific information regarding species of concern, simulation model outputs, such as those presented in this chapter, can be used as “what-if” scenarios. For example, some of the MC2 plant functional types that may be more common in the future (e.g., subtropical mixed forests, warm mixed forests) (see section below) are more common south of the assessment area. These areas, and their invasive species issues, can be used as analogs to develop watch lists for species of interest. Understanding problematic species and their ecology in these areas may provide insight into future invasive species issues and management in southwest Oregon.

Model Projections for the Future

Overview

Different models can be used to assess potential changes in vegetation with climate change (Peterson et al. 2014). Here, we focus on output for southwest Oregon from two process-based models: the MAPSS-CENTURY 2 (MC2) DGVM, and the LANDIS-II model. Both models use mathematical relationships to represent understanding of physical and biological processes (e.g., nutrient cycling, growth, mortality, carbon dioxide fertilization), and the interactions among those processes. Neither model incorporates potential changes in insect outbreaks and pathogens in the future. However, these models were chosen because they have been vetted scientifically, they are widely used to assess vegetation vulnerabilities to climate change, and output was available for the SWOAP assessment area. The models are described briefly below, and modeling methods and results for each model are described in the following sections.

MC2 (Bachelet et al. 2001, Conklin et al. 2016, Daly et al. 2000) simulates plant physiology, biogeography (the geographic distribution of plants), and biogeochemistry, and their interactions with wildfire. MC2 represents the landscape as a grid (spatial resolution varies) and is driven with monthly climate data. MC2 represents vegetation in terms of plant functional types (e.g., tree, shrub, or grass; evergreen or deciduous; broadleaf or needleleaf), grouped into major biomes (forest, savanna, or shrub-steppe). Gridded output data from MC2 include vegetation distribution, fire effects, and ecosystem conditions, including various ecosystem carbon pools and water balance information. Species-level information is not included in MC2 output but can be inferred at coarse scales based on modeled vegetation type and local vegetation information.

The LANDIS-II model (Scheller et al. 2007) is a spatially explicit forest simulation model that has been applied to landscapes adjacent to southwest Oregon, including the Oregon Coast Range (Creutzburg et al. 2017) and the Sierra Nevada (Scheller et al. 2018). The model simulates growth, mortality, and regeneration at the species level by incorporating biophysical (e.g., climate, disturbance) and ecological processes (e.g., species interactions, dispersal) in a grid-based framework, with processes occurring both within and across grid cells. The LANDIS-II model also integrates forest management activities. Vegetation is simulated as tree species binned into age cohorts; each tree species has different successional characteristics (e.g., fire tolerance, seed dispersal distance) and physiology (e.g., optimal temperature for growth).

MC2

Methods—

MC2 was used to simulate potential changes in broadly defined vegetation types in the SWOAP assessment area at 30 arc-second (approximately 800-m) spatial resolution from 1895 to 2100. The historical portion of the simulation (1895–2012) was driven with PRISM climate data (Daly et al. 2008), and an ensemble of future simulations was driven with National Aeronautics and Space Administration (NASA) NEX-DCP30 dataset, as described below. Soils data were synthesized from the best available regional soil surveys and converted to a format required by MC2.

We calibrated MC2 for the Forest Service Pacific Northwest Region (Oregon and Washington) for this assessment. Simulating a spatial extent larger than the limits of the SWOAP assessment area allows the model to be calibrated for a broader range of vegetation types than those extant in the SWOAP assessment area. MC2 was calibrated for the historical period (1895–2012) using a structured approach (Kim et al. 2018). First, we created a calibration sample by sampling every fifth grid cell 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 net primary production data (Zhao and Running 2010). We adjusted thresholds in its biogeography (i.e., vegetation distribution) algorithm by comparing the simulation output for the calibration sample with a map of potential vegetation zones. We adjusted and calibrated the MC2 fire parameters 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, and thus fire occurrence may be overestimated in MC2 simulations. Once calibration was complete, we ran the simulation at full resolution for 1895–2012.

MC2 simulations of future vegetation dynamics were driven with climate data (monthly averages of daily maximum and minimum temperatures, precipitation, and vapor pressure) from the NASA NEX-DCP30 climate dataset (Thrasher et al. 2013). This is the same dataset used to examine future climate for the SWOAP assessment area (chapter 2). The NEX-DCP30 dataset comprises outputs from 31 GCMs published by the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al. 2012), downscaled from each GCM's coarse spatial resolution to 30 arc-second resolution for the conterminous United States. NEX-DCP30 includes climate projections for two future scenarios: RCPs 4.5 and 8.5. RCPs describe scenarios of emissions and land use (van Vuuren et al. 2011). For this study, we selected RCP 8.5, which represents a rapid warming scenario without any effective climate change mitigation activities, leading to approximately 1,370 ppm CO_2 (Riahi et al. 2011) and 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 decisionmaking. The likelihood of a particular RCP being realized is unknown; however, current global emissions are consistent with the RCP 8.5 trajectory.

MC2 simulations were run from 1950 through 2100 with 28 GCMs for which vapor pressure data were available. In other words, we generated 28 projections of future vegetation conditions under one climate change scenario, RCP 8.5. The same soils data as in the historical simulations were used for future simulations.

The 28-member ensemble of simulations is useful for capturing the range of variability and uncertainty arising from GCMs and to obtain the most robust average values. We used the ensemble of simulations to quantify the degree of agreement in their future vegetation projections. To also be able to have concrete pictures of future vegetation conditions, we selected simulations driven by five GCMs and focused on their outputs. The selected GCMs are among the better-performing models for the PNW, as ranked by Rupp et al. (2013). We use the same five illustrative models as in chapter 2 to show a range of MC2 output for specific variables (table 2.2): "mean" CESM1(CAM5) (hereafter CESM1); "hot-wet" CanESM2; "hot" BNU-ESM; "hot-dry" MIROC-ESM-CHEM (hereafter MIROC); and "warm" MRI-CGCM3 (hereafter MRI).

MC2 output—

Vegetation—Across 28 future climate projections, MC2 consistently projected vegetation type changes at the elevation extremes (i.e., the High Cascades and low interior valleys) and along the coast (figs. 5.13A and 5.14A). Agreement was also high for shifts in biomes at the lowest elevations (figs. 5.13B and 5.14B). These include shifts from forest to woodland, and woodland to shrubland. Agreement that vegetation type and biome changes will occur increased between mid-century (fig. 5.13) and the end of the century (fig. 5.14).

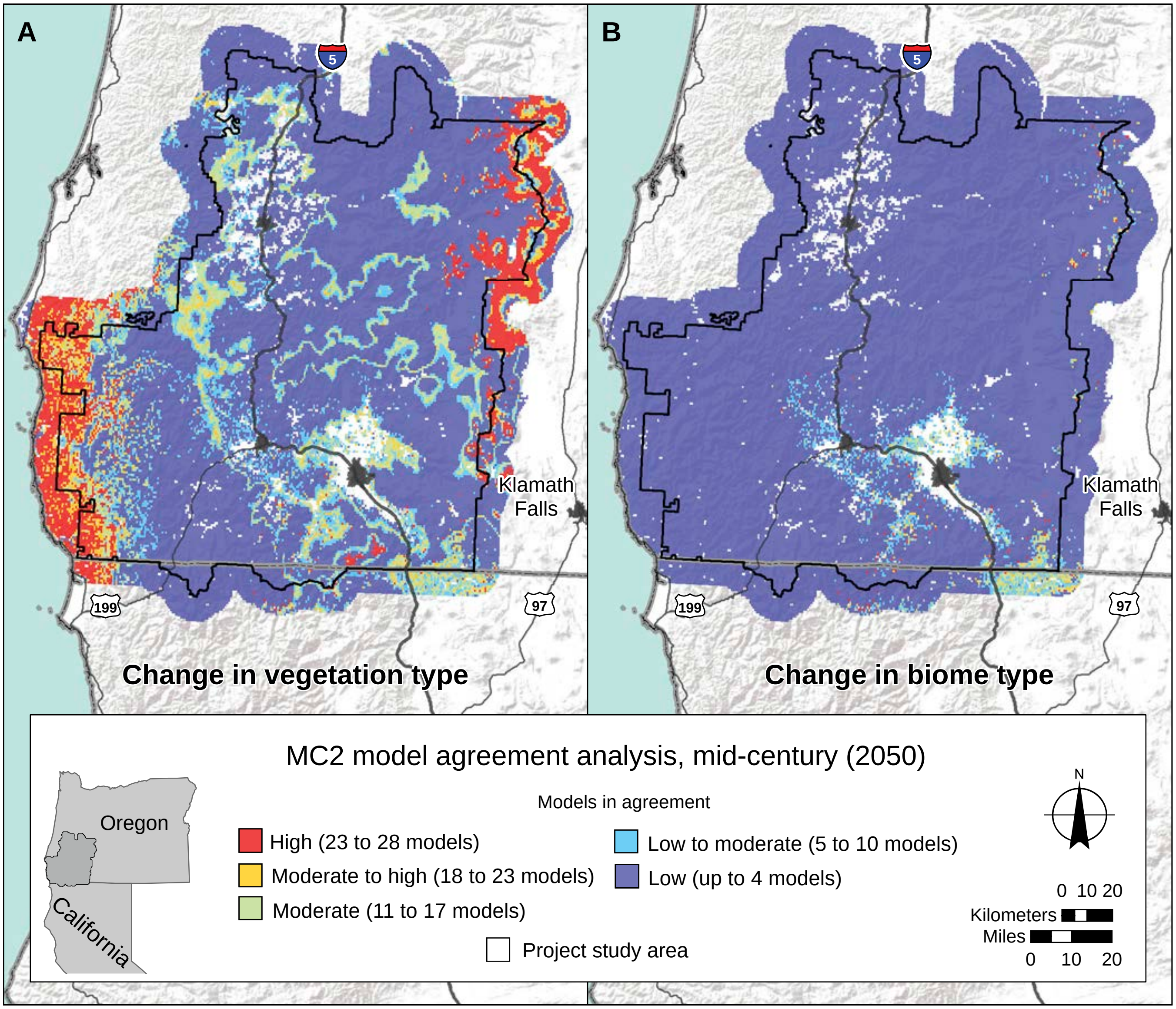

Figure 5.13—MC2 model agreement (among 28 climate scenarios) at mid-century (2050) for (A) simulated change in vegetation type and (B) simulated change in biome (e.g., forest to woodland or shrubland to grassland).

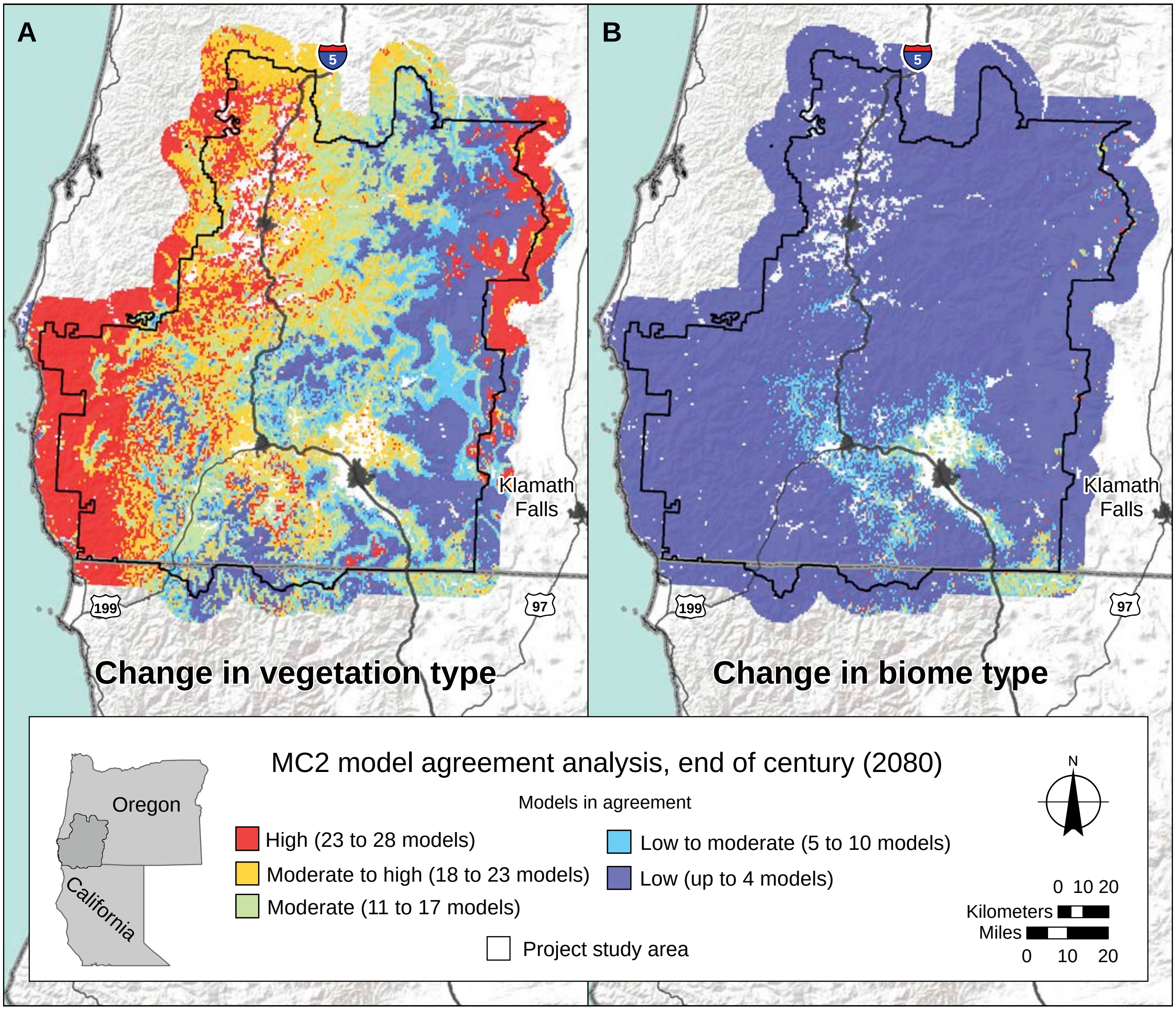

Figure 5.14—MC2 model agreement (among 28 climate scenarios) at the end of the century (2080) for (A) simulated change in vegetation type and (B) simulated change in biome (e.g., forest to woodland or shrubland to grassland).

With the exception of low-elevation areas in the southeastern portion, much of the SWOAP assessment area was projected to have increased productivity by the end of the 21st century (fig. 5.15). The largest increases in productivity were projected for the High Cascades in the eastern portion of the SWOAP assessment area. Cold temperatures, a short growing season, and long-lasting snowpack currently limit productivity at high elevations. Thus, projected increases in productivity are likely driven by warming temperatures and a longer growing season at high elevations. Productivity increased least when the simulation was driven with the hot and dry MIROC climate projection. However, MC2 does not model the potential effects of summer drought well. In the model, although productivity shuts down when

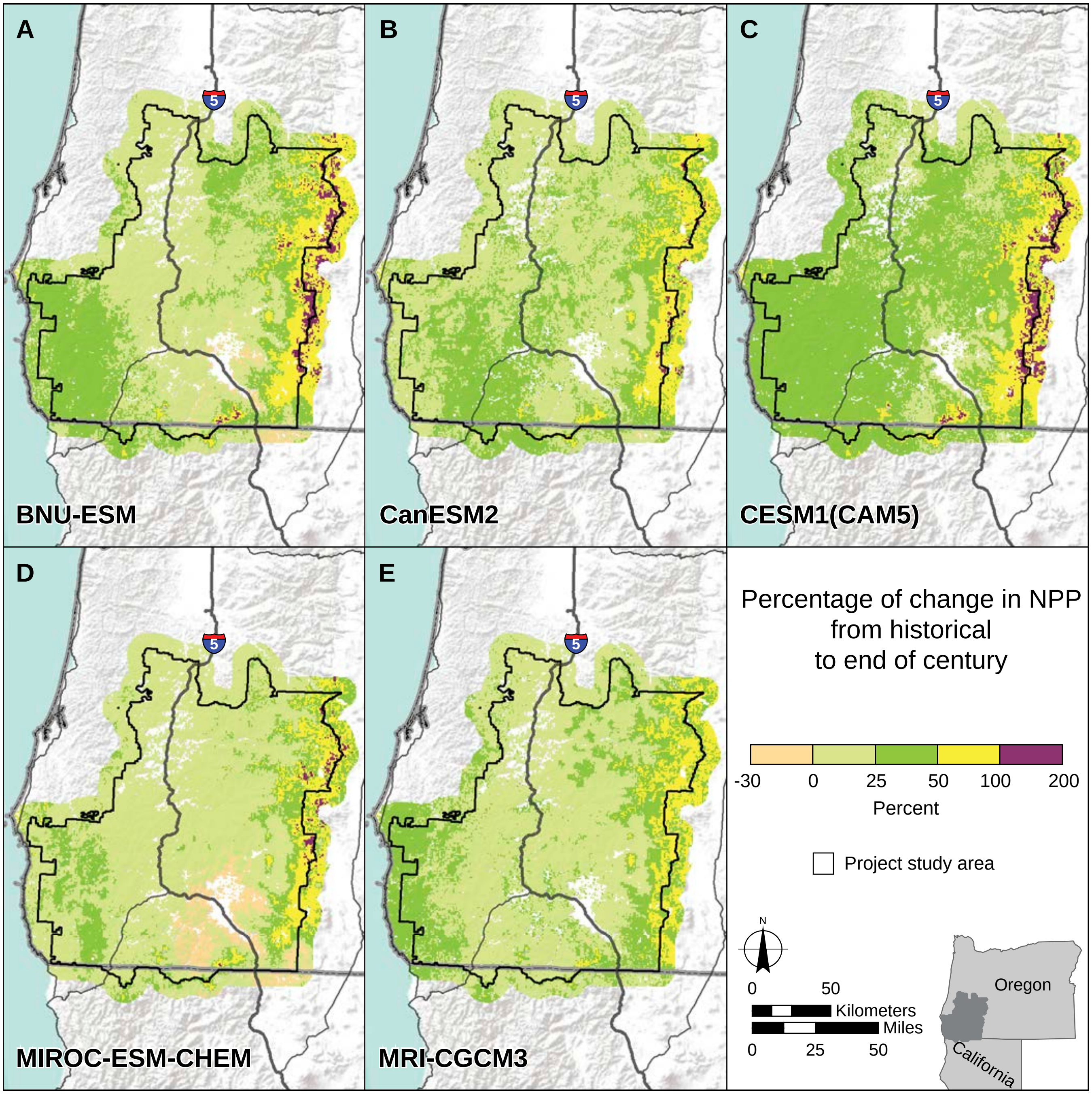

Figure 5.15—Percentage of change in net primary production (NPP), as simulated by MC2 for the end of the century under five future climate scenarios (from five global climate models). The CESM1(CAM5) model is a top performer for the Pacific Northwest, with output similar to the model ensemble mean. CanESM2 represents the "hot-wet" extreme, BNU-ESM "hot," MIROC-EMS-CHEM "hot-dry," and MRI-CGCM3 "warm" (less warming than the hot extremes).

water is limited, complex plant responses (e.g., branch death, biomass loss, mortality) are not modeled. Thus, summer drought and climatic water deficits (chapter 2) may offset projected gains in productivity and exacerbate losses.

Projected modal (most often occurring) vegetation types for the historical period and the middle and end of the 21st century are shown for five different future climate projections in figures 5.16 through 5.20, and proportion of the landscape in different vegetation types for the historical period and end of the century are shown in figure 5.21. See table 5.1 for approximate crosswalks between potential vegetation types (figs. 5.1 through 5.5) and MC2 vegetation types. Changes in MC2 vegetation types in figures 5.16 through 5.20 indicate that the climate will no longer be suitable for many current vegetation types and that changes in species composition and abundance are likely. However, in the absence of disturbance, changes in species composition and abundance will likely be gradual because of the high tolerance of mature trees to climatic variation and the long lifespan of many tree species; disturbances such as fire will likely be the main triggers for major compositional change.

Under all five climate projections, MC2 projected the loss of climatically suitable habitat for high-elevation subalpine forest. Areas of subalpine forest converted to moist coniferous forest under all climate projections. This result suggests that species from lower elevation moist forests will likely become more competitive in high-elevation environments.

MC2 projected an expansion of subtropical mixed forest in the western portion of the SWOAP assessment area under all five future climate projections, with greater eastward expansion between mid-century and the end of the century. Under historical climate, this type was projected to occur in a few locations in a narrow strip along the coast. The range expansion of the subtropical forest type was at the expense of the currently dominant moist coniferous forest. The shift to the subtropical vegetation type is a response to increases in average monthly temperatures and a loss of winter frosts. Thus, the expansion of this type was lowest under the GCM with the least warming, MRI (fig. 5.20), and greatest for the GCMs with the most warming (BNU-ESM [fig. 5.16], CanESM2 [fig. 5.17], and MIROC [fig. 5.19]; see also fig. 5.21). Projections of subtropical mixed forest suggest that broadleaf species may increase in abundance, but many current species characteristic of coastal forests are likely to persist. In the SWOAP assessment area, examples of deciduous broadleaf species include vine maple (*Acer circinatum* Pursh), bigleaf maple (*A. macrophyllum* Pursh), Pacific madrone, and Rocky Mountain maple (*A. glabrum* Torr.).

MC2 also projected expansion of the warm mixed forest type under all five future climate projections. Under historical climate conditions, this type occurred along the coast. The warm mixed-forest type replaced both coniferous and moist

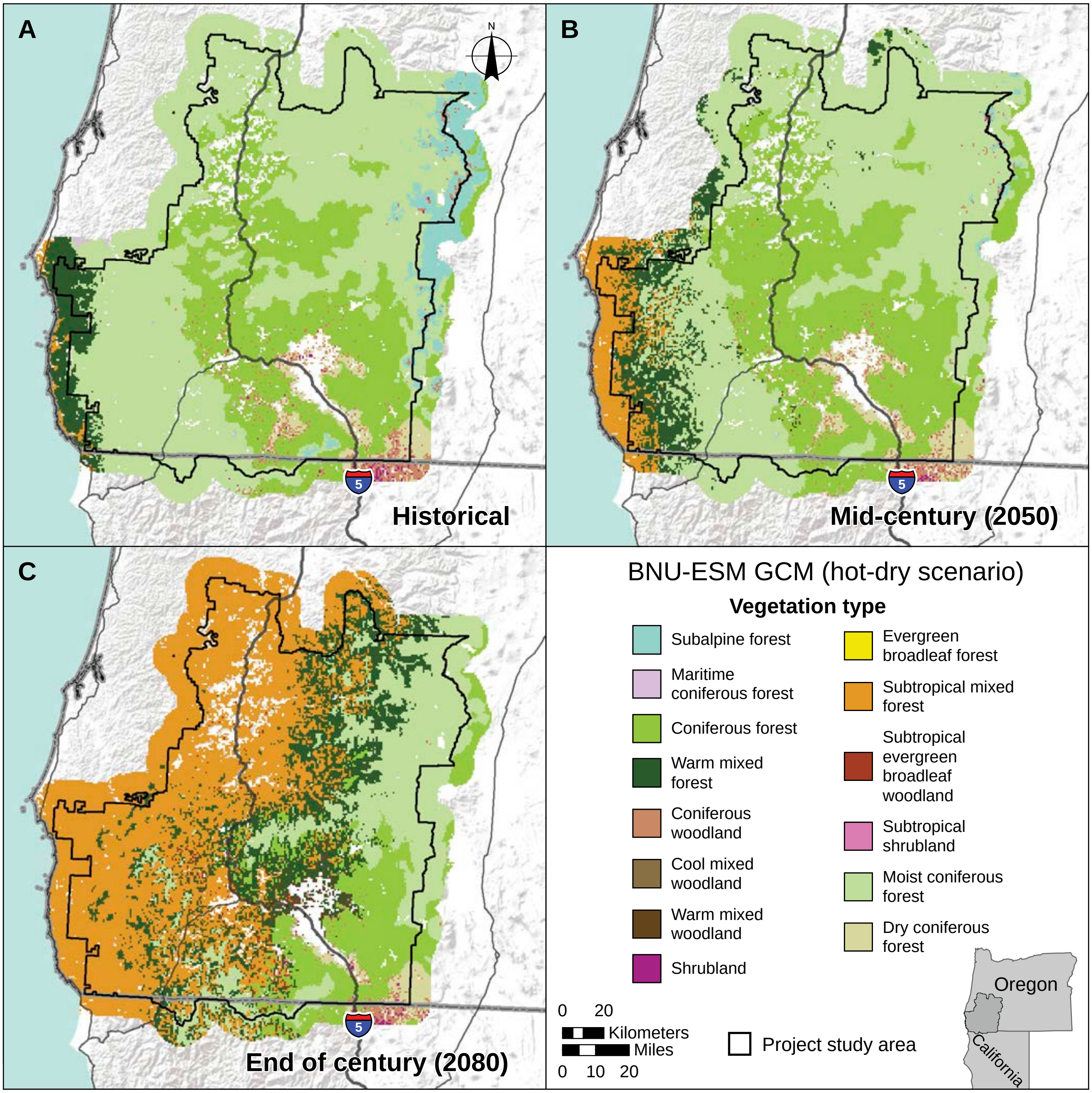

Figure 5.16—Vegetation types for the Southwest Oregon Adaptation Partnership assessment area for the historical, mid-century, and end-of-century periods, as simulated by MC2 under the BNU-ESM global climate model (GCM) scenario for Representative Concentration Pathway 8.5. This model has projected changes in temperature and precipitation that represent the "hot" extreme of higher performing models for the Pacific Northwest (Rupp et al. 2013).

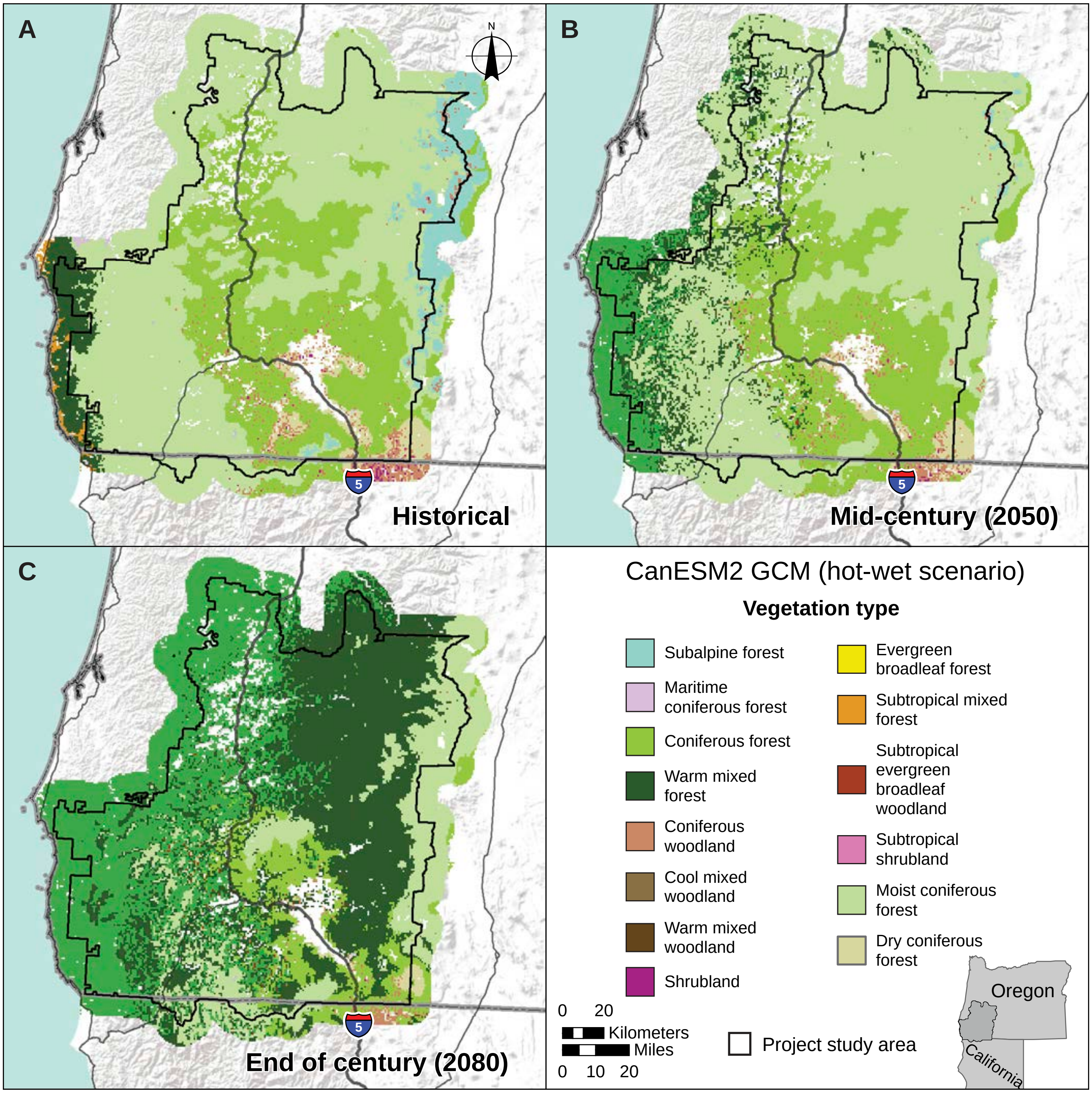

Figure 5.17—Vegetation types for the Southwest Oregon Adaptation Partnership assessment area for the historical, mid-century, and end-of-century periods, as simulated by MC2 under the CanESM2 global climate model (GCM) scenario for Representative Concentration Pathway 8.5. This model has projected changes in temperature and precipitation that represent the "hot-wet" extreme of higher performing models for the Pacific Northwest (Rupp et al. 2013).

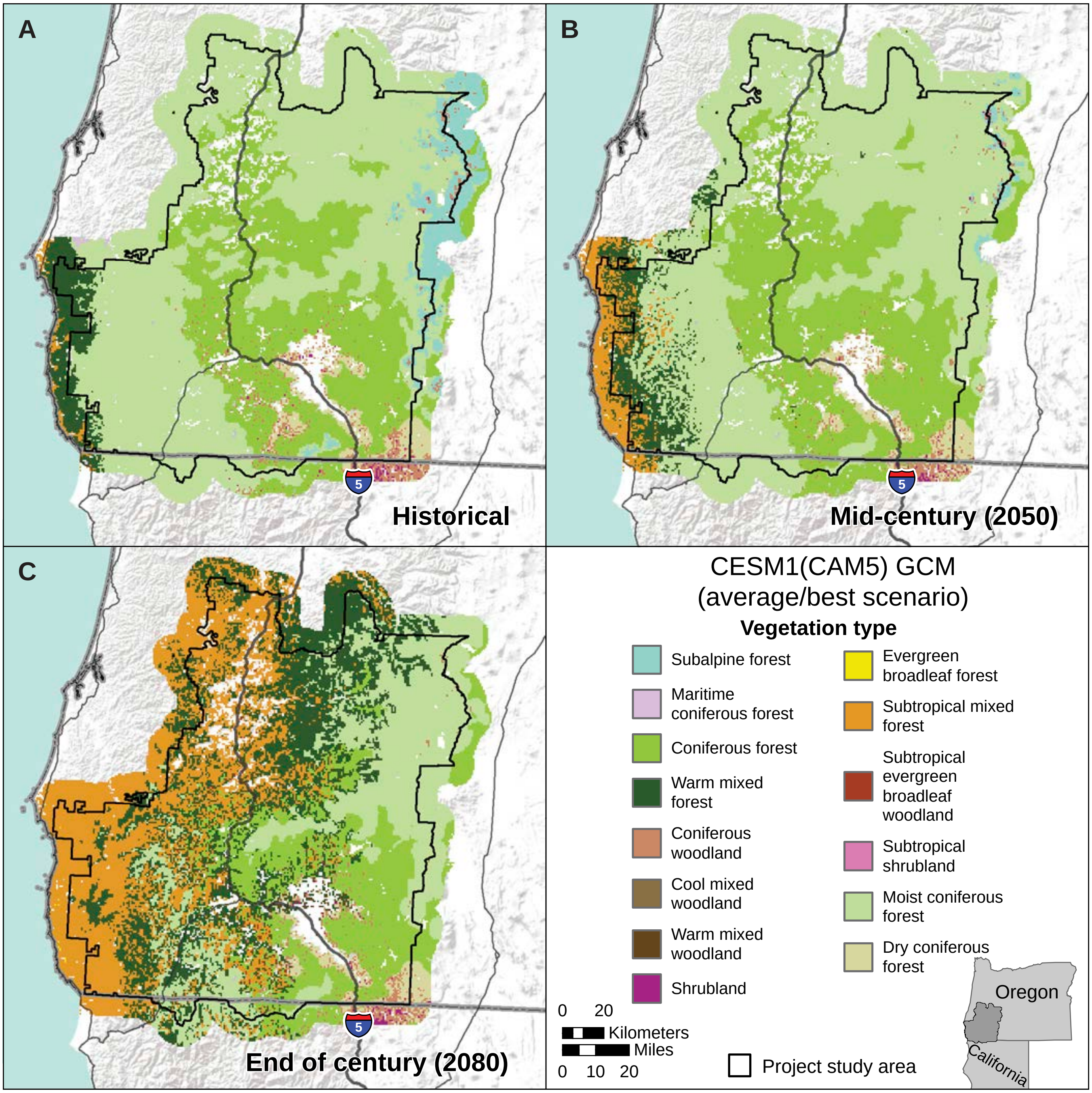

Figure 5.18—Vegetation types for the Southwest Oregon Adaptation Partnership assessment area for the historical period, mid-century, and end-of-century periods, as simulated by MC2 under the CESM1(CAM5) global climate model (GCM) scenario for Representative Concentration Pathway 8.5. This model is a highly ranked model for the Pacific Northwest (Rupp et al. 2013), with projected changes in temperature and precipitation similar to the ensemble mean ("average/best scenario").

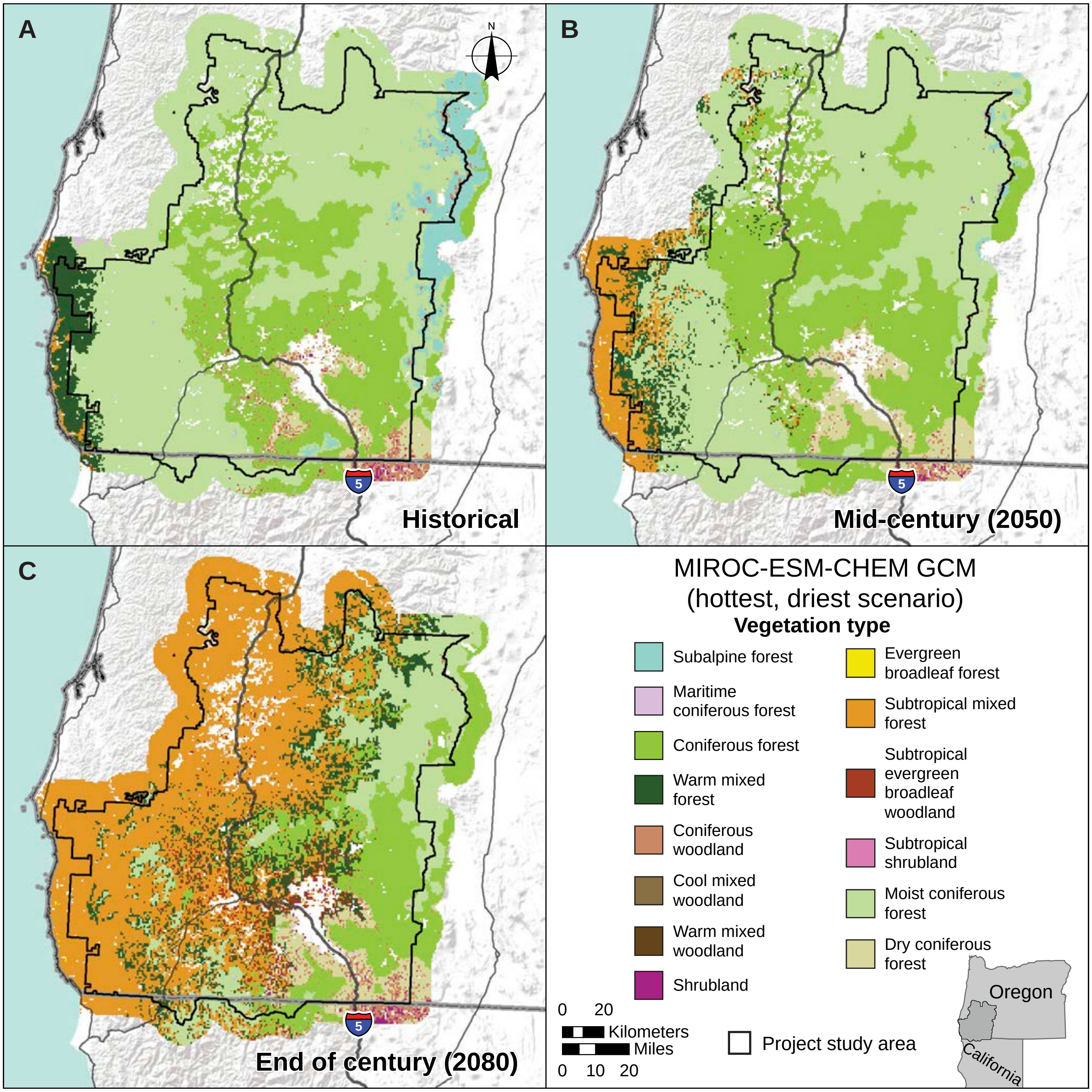

Figure 5.19—Vegetation types for the Southwest Oregon Adaptation Partnership assessment area for the historical, mid century, and end-of-century periods, as simulated by MC2 under the MIROC-EMS-CHEM global climate model (GCM) scenario for Representative Concentration Pathway 8.5. This model has projected changes in temperature and precipitation that represent the "hot-dry" extreme of higher performing models for the Pacific Northwest (Rupp et al. 2013).

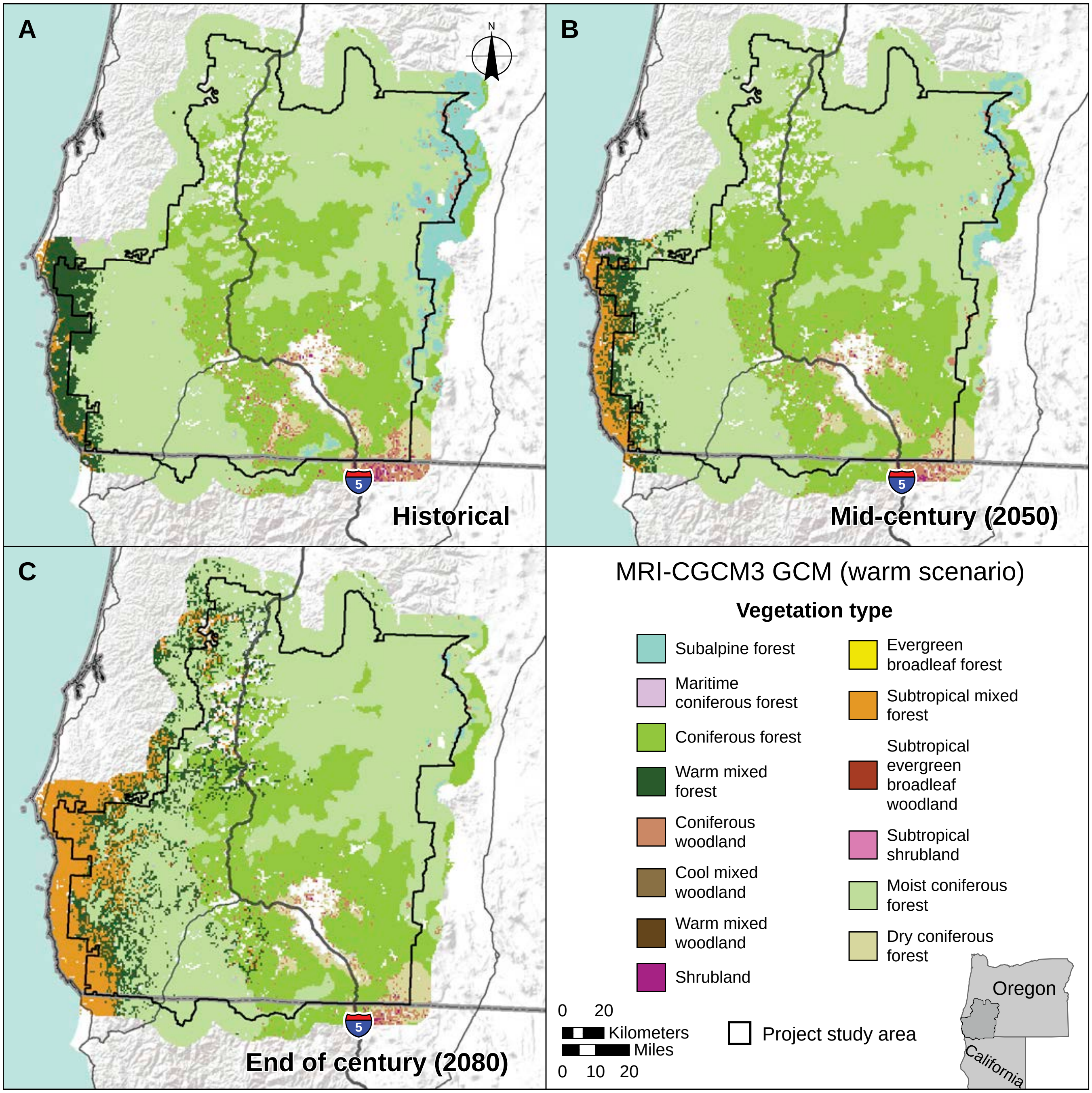

Figure 5.20—Vegetation types for the Southwest Oregon Adaptation Partnership assessment area for the historical, mid century, and end-of-century periods, as simulated by MC2 under the MRI-CGCM3 global climate model (GCM) scenario for Representative Concentration Pathway 8.5. This model has projected 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).

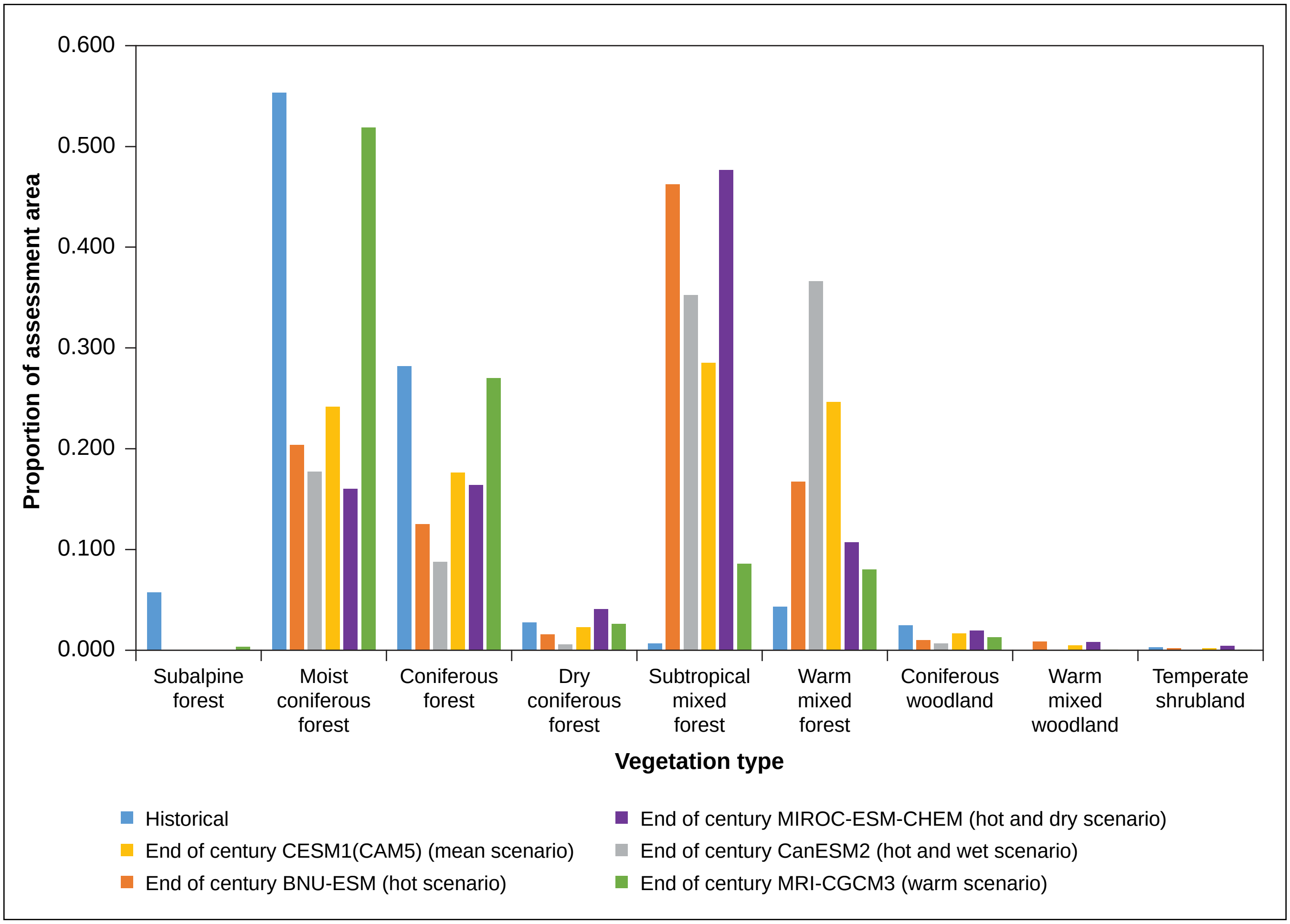

Figure 5.21—Proportion of different vegetation types for the Southwest Oregon Adaptation Partnership assessment area for the historical and end-of-century periods, as simulated by MC2 under five global climate model scenarios for Representative Concentration Pathway 8.5. Differences between the historical period and mid-century periods were minimal and thus are not shown.

coniferous forest. This vegetation change is in response to increased precipitation (particularly in the summer compared to the rest of the year), which allows for range expansion of deciduous broadleaf species. Thus, expansion of this type was greatest under CanESM2, the hot-wet GCM (figs. 5.17 and 5.21), in which summer precipitation increased by 41 percent compared to the 1970–1999 average (chapter 2). With CanESM2, much of the expansion of the warm mixed forest type occurred in the eastern portion of the assessment area and included much of the Umpqua National Forest.

Under all but the hottest and driest future climate projections (MIROC) (fig. 5.19), the area of dry coniferous forest decreased somewhat (fig. 5.21). This type is mostly replaced by more productive coniferous and warm mixed forest types. The change to more mesic forest conditions in the MC2 model is related to increased productivity. With MIROC, the hot and dry GCM, dry coniferous forest expanded somewhat around its current distribution in the southeastern portion of the assessment area. As noted above, increases in water deficit may lead to greater increases in area of dry forest than MC2 projections suggest.

The projected area in woodlands varied with future climate projections. Under the hot and wet GCM (CanESM2) and the warm GCM (MRI), some woodlands convert to more productive forest types (or novel subtropical evergreen broadleaf or warm mixed woodland types). With the mean GCM (CESM1), area of woodlands was mostly maintained, and several novel woodland types expanded, including subtropical evergreen broadleaf woodland and warm mixed woodland. Expansion of these types was largely in response to loss of winter frost and increased precipitation. The simulation driven by BNU-ESM also showed expansion of these novel woodland vegetation types. In the hot and dry case (MIROC), woodland area expanded significantly.

Shrublands remained a minor component of the landscape across climate projections (fig. 5.21). However, precipitation differences among the models seemed to drive whether or not shrublands were projected to increase or decrease; hotter models showed increases in shrublands, whereas wetter models showed decreases in shrublands. Climatically suitable habitat for shrublands largely disappeared in the hot and wet projection (CanESM2). Area of shrublands decreased somewhat under the warm projection (MRI), converting to more productive woodland types. Shrubland area expanded somewhat with the hot GCM (BNU) and hot and dry GCM (MIROC).

Wildfire

Results for fire frequency (mean fire return interval [MFRI]) and fire severity (measured as aboveground biomass killed by fire) are shown in figures 5.22 and 5.23. Note that all data presented in these figures are simulated, and because modeled historical MFRIs may not closely match historical data, figures should be examined in terms of relative changes. Overall, MC2 simulated decreased MFRI for mid-century and the end of the century compared to the historical (1970–1999) time period (fig. 5.22). Thus, fires are expected to become more frequent in the future. The exceptions were with the hot and wet CanESM2 GCM, which is characterized by significant increases in summer precipitation. With CanESM2, MFRI increased for subalpine forests and woodland types. However, MC2 projected that subalpine forests will shrink substantially or disappear by the end of the century, so the small number of remaining pixels at the end of the century indicates that the fire projections may be spurious. Woodland types are also projected to cover little area.

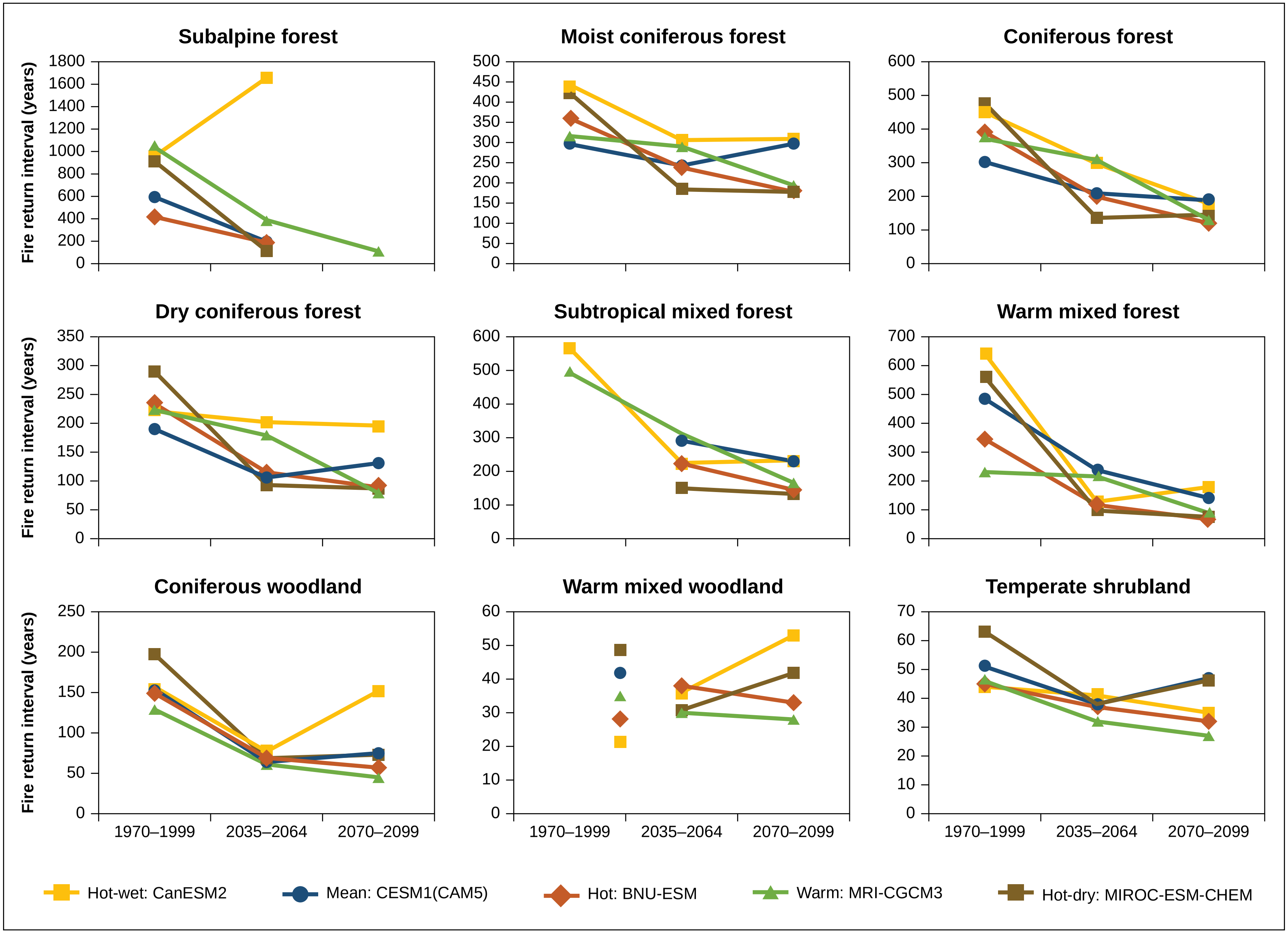

Figure 5.22—Projected mean fire return interval in years for the historical (1970–1999), mid-century (2035–2064), and end-of-century (2070–2099) periods for relevant MC2 vegetation types and global climate model (GCM) scenarios. Note differences in scale for the y-axes. Historical data are unavailable for warm mixed woodlands and for two GCM scenarios for subtropical mixed forest because these types were not present in historical simulations. No warm mixed woodlands occurred in the CESM1 scenario. Data are unavailable for subalpine forest for the end of the century because this type is greatly reduced in area.

For other vegetation types, decreases in MFRI were generally more moderate with CanESM2 than under other future climate projections. Decreases in MFRI were greatest under the hot and dry MIROC and hot BNU-ESM GCMs.

Fire severity, in contrast, was generally projected to increase for mid-century and the end of the century compared to the historical time period (fig. 5.23). With the hot and wet CanESM2 GCM, there were decreases in fire severity for the subalpine forest and woodland types. For other vegetation types, increases in fire severity were more moderate with CanESM2 than other future climate projections. Increases in fire severity were generally greatest under the hot BNU-ESM, hot and dry MIROC, and warm MRI-CGCM3 GCMs.

Changes in MFRI and fire severity projected by MC2 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, and by the model's complex interplay between these factors for each vegetation type and GCM. Fuel moisture (fuels must be dry enough to burn) and a stochastic algorithm drive fire occurrence in the MC2 model. Fire severity is coupled with standing biomass or productivity. The amount of fuel or biomass may increase with higher productivity for some vegetation types in the future (fig. 5.15), which increases fire severity. Given that MC2 does not model the effects of summer drought on productivity, increased fire severity may be less than indicated by MC2.

Interpreting MC2 results—

MC2 plant functional types are broad groups that approximate local vegetation groups (table 5.1), and because species-specific dynamics are not modeled in MC2, users should not make species-specific interpretations. Fine-scale, pixel-by-pixel examination should be avoided, and even individual national forests and national parks are relatively small compared to the resolution of MC2 output. The results in figures 5.13 through 5.21 can be used for each unit as "what-if" scenarios across the range of illustrative GCMs (mean, hot-wet, hot, hot-dry, warm).

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 included. MC2 also does not model the complexities of summer drought and climatic water deficit as noted above, so projected increases in productivity and fire severity may not be realized. As noted above, the historical MFRIs may not align well with observations because they are model simulation outputs.

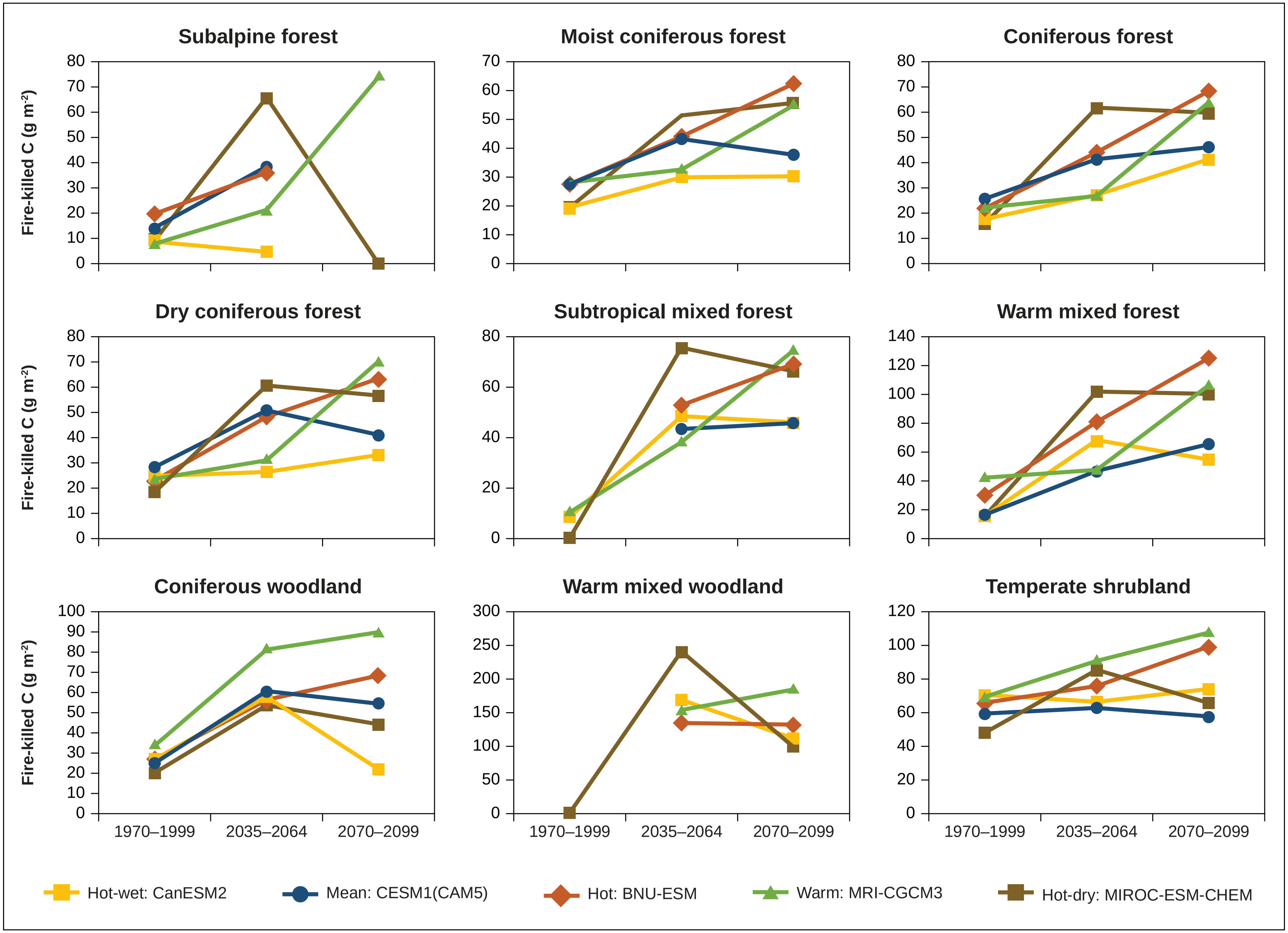

Figure 5.23—Projected fire severity (in fire-killed carbon [C] in g m^{-2}) for the historical (1970–1999), mid-century (2035–2064), and end-of-century (2070–2099) periods for relevant MC2 vegetation types and global climate model (GCM) scenarios. Note differences in scale for the y-axes. Historical data are unavailable for three GCM scenarios for warm mixed woodlands and for two GCM scenarios for subtropical mixed forest. No warm mixed woodlands occurred in the CESM1 scenario. Data are unavailable for subalpine forest for the end of the century because this type is greatly reduced in area.

LANDIS-II

Methods—

We used the process-based model LANDIS-II to examine potential effects of climate change on vegetation and fire in southwest Oregon. However, because we took advantage of another effort to access this information (covering the Klamath-Siskiyou bioregion, extending into California), the output from LANDIS-II is available for only the southern portion of the SWOAP assessment area (west of Interstate 5).

The model was parameterized and calibrated for the Klamath-Siskiyou bioregion for current (2015) conditions and run at a resolution of 270 m (see Serra-Diaz et al. 2018). Inputs to LANDIS-II include soils information, an initial conditions map with tree species assigned to age cohorts, topographic data, and climate data. Soil characteristics were generalized from the STATSGO2 soil database (http://websoilsurvey.nrcs.usda.gov/). Initial forest communities to populate the model for the Klamath-Siskiyou bioregion were derived from gradient nearest neighbor imputation of forest inventory data (Ohmann and Gregory 2002) developed by the Landscape Ecology, Modeling, Mapping, and Analysis Team (http://www.fsl.orst.edu/lemma/splash.php). All climate projections were processed through the U.S. Geological Survey geo data portal (https://cida.usgs.gov/gdp) using the bias-corrected constructed analogs V2 daily climate projections. Thirteen tree species and seven functional groups of shrubs were modeled. Species-level parameters were derived from published literature (Serra-Diaz et al. 2018), and initial growth and biomass conditions were verified against Hudiburg et al. (2009) and Wilson et al. (2013). Fire data from 2000 to 2010 were obtained from Monitoring Trends in Burn Severity (http://www.mtbs.gov) (Eidenshink et al. 2007) to calibrate the fire portion of the model. The 2000–2010 time period was chosen to capture recent fire area and severity.

A business-as-usual management scenario was developed to reflect current-day management practices across the landscape. Management on federal lands reflected the amount of area and timber harvest volume, as reported through the U.S. Forest Service Forest Activity Tracker System database (available from the U.S. Forest Service geodata clearinghouse; https://data.fs.usda.gov/geodata) and through Forest Service staff in the region. Management on private lands was based on the timber volume reported by county-level timber receipts (available from the Oregon Forest Resource Institute; https://www.oregonforests.org/), and further broken down by land use type (industrial and nonindustrial forestry).

After the model was calibrated, verified, and tested, it was run using five CMIP5 climate change scenarios that represented a range of potential future conditions: (1) contemporary climate (Maurer [2002] for 1950–2010), (2) a hotter and drier climate (ACCESS GCM under RCP 8.5), (3) a hotter and wetter climate (CanESM2 GCM under RCP 8.5), (4) a warmer and wetter climate (CNRM GCM under RCP 4.5), and (5) a warmer and drier climate (MIROC5 GCM under RCP 2.6). These four projections indicate an increase of 1 to 3 °C over contemporary climate, and a change of -50 mm to +200 mm in annual precipitation from contemporary climate, on average, across the landscape. The contemporary climate can be used as a reference condition, showing the effects of successional changes (e.g., recovery of forests after logging), but not climatic changes. The simulations were run for 85 years, starting in 2015. To capture some of the stochasticity and uncertainty surrounding fire in this region, the business-as-usual management scenario was run under each climate projection 10 times, resulting in 50 model runs. All model outputs were processed in R (v. 3.4.1) and in ArcGIS (v. 10.4.1).

LANDIS-II output—

Vegetation—The LANDIS-II model produces cover type maps (fig. 5.24), in which the species (or species group) with the most biomass per cell determines how the cell is classified. Under all future climate change projections, the LANDIS-II model projected (1) a decrease in the amount of forested area (table 5.2); (2) a significant decrease in the area dominated by high-elevation mixed-conifer forest; and (3) an increase in the cover of shrubs, chaparral, and hardwoods. By the end of the 21st century, the high-elevation mixed-conifer type, which included white fir, Shasta red fir, and western white pine, was almost completely replaced by the Klamath mixed-conifer type, which included Douglas-fir, sugar pine, ponderosa pine, and incense cedar (fig. 5.24). However, total area of conifer forest was reduced by as much as 14 percent in the hotter scenarios (Access and CanESM) (table 5.2). Conifer forest loss occurred with the expansion of two cover types: the shrub, chaparral, and hardwood cover type (seven shrub groups plus Oregon white oak and California black oak); and the hardwood cover type (Pacific madrone, giant chinquapin [*Chrysolepis chrysophylla* (Douglas ex Hook.) Hjelmq.], and canyon live oak). The expansion of these types was concentrated in the eastern interior portion of the LANDIS-II assessment area. With all future climate projections, the tanoak forest cover type (dominated by tanoak) was projected to decrease in area and shift eastward to primarily the central portion of the LANDIS-II assessment area (fig. 5.24).

Over the course of the simulations, total aboveground biomass (fig. 5.25) substantially increased in the western portion of the assessment area, where precipitation is less limiting. This trend is sufficient to offset the potential forest loss or forest conversion to shrublands. Thus, average biomass across the entire landscape was projected to increase.

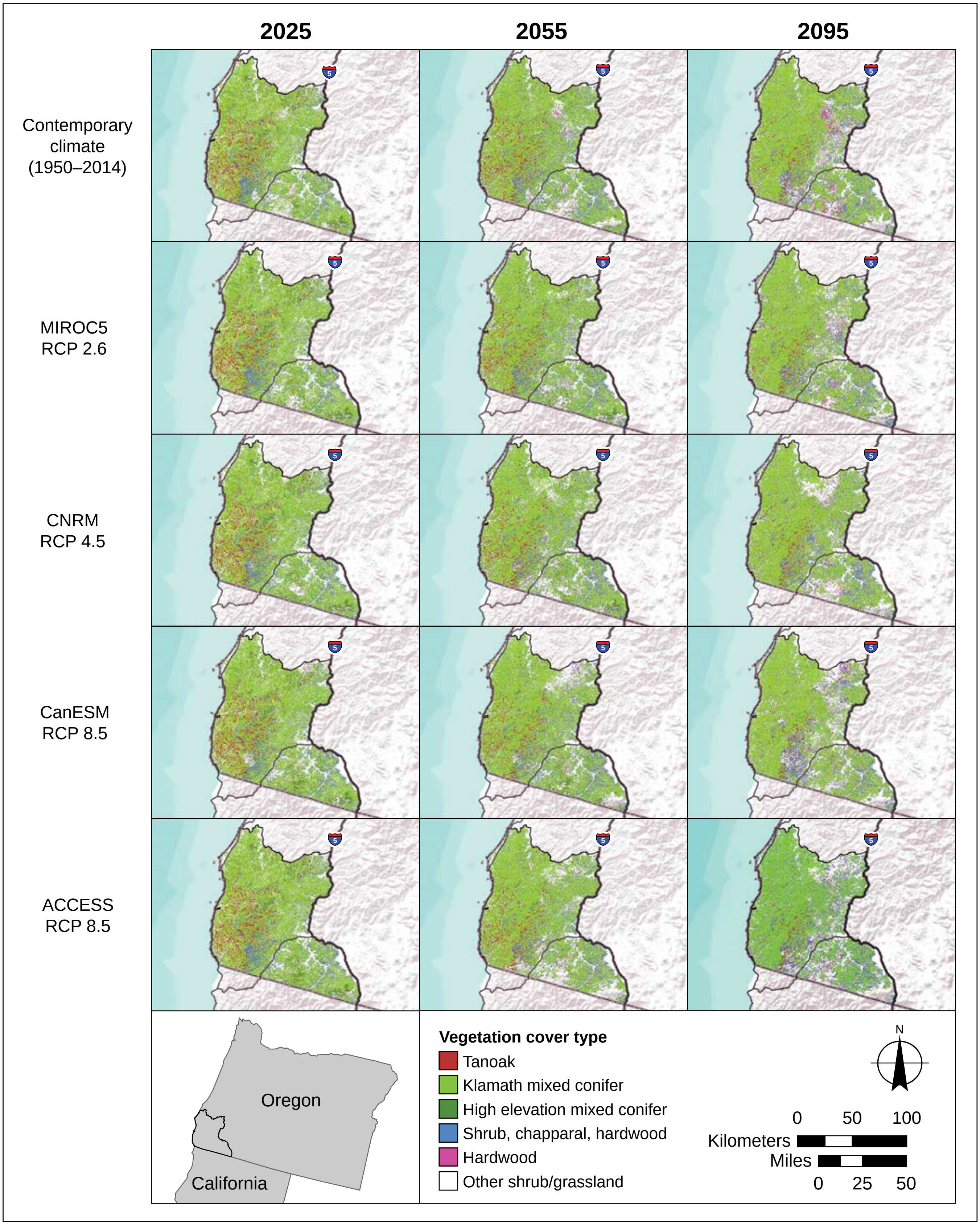

Figure 5.24—Projected cover of different vegetation types for future time periods under contemporary (1950–2014) and four future climate scenarios, as simulated by the LANDIS-II model.

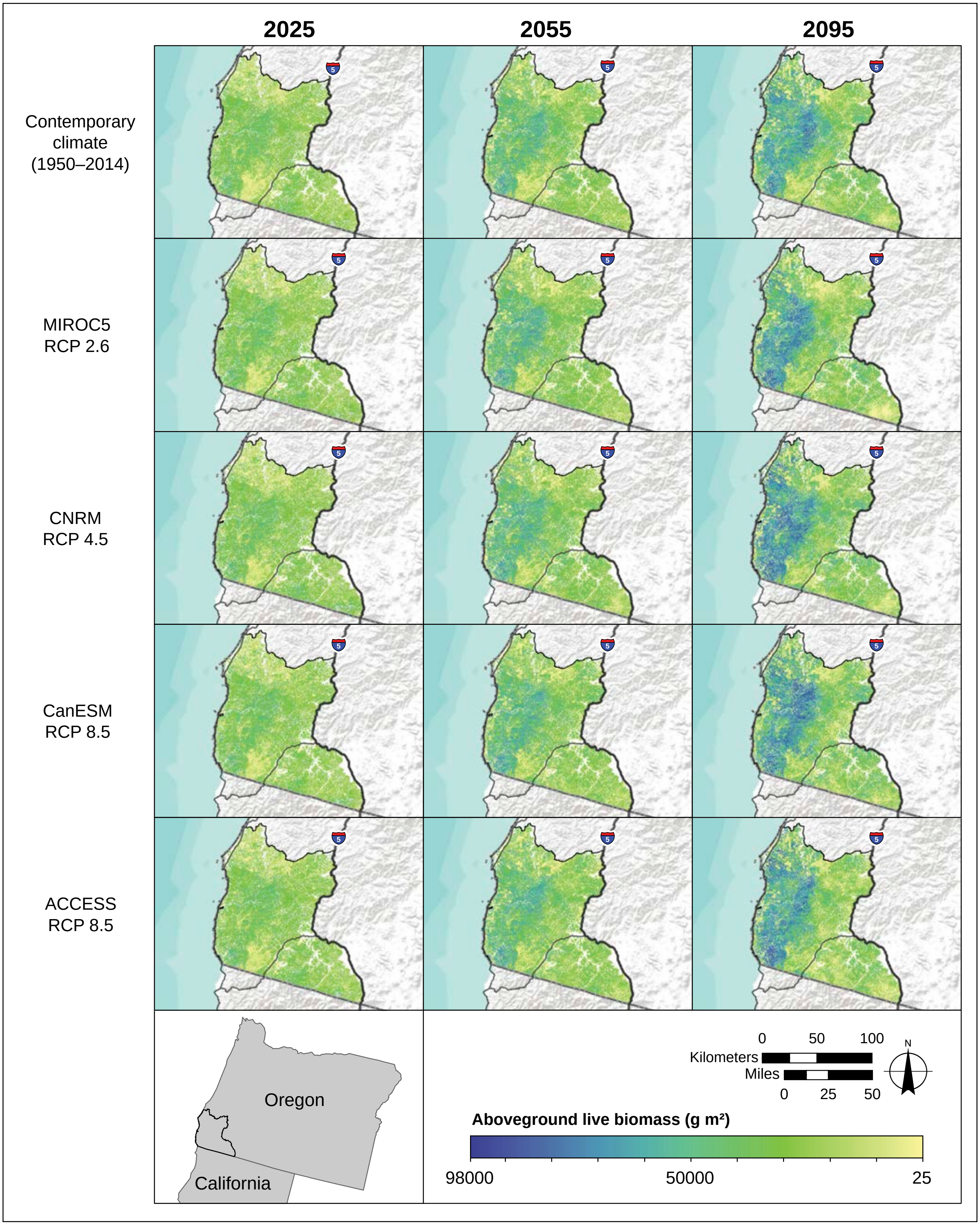

Figure 5.25—Projected total aboveground biomass for future time periods under contemporary (1950–2014) and four future climate scenarios, as simulated by the LANDIS-II model. The darker the blue color, the higher the increase in productivity.

Table 5.2—Percentage change in forested area for three future points in time under contemporary and four future climate scenarios[a]

	Change in forested area		
	2025	2065	2105
		Percent	
Contemporary	0	0	1
MIROC5 (warmer and drier)	-1	-1	-9
CNRM (warmer and wetter)	-1	-2	-5
CanESM2 (hotter and wetter)	-2	-2	-14
ACCESS (hotter and drier)	-2	-3	-14

[a] Trends in temperature and precipitation for each future climate scenario are indicated in parentheses after the scenario title.

Projections for individual species biomass (fig. 5.26) also showed reductions in area of high-elevation species and species associated with wetter forest types (moist and mesic), including Shasta red fir, western white pine, and white fir. Species projected to increase in biomass under the different climate projections include Pacific madrone, incense cedar, chinquapin, tanoak, sugar pine (although one scenario showed a decrease), ponderosa pine, Douglas-fir, canyon live oak, Oregon white oak, and California black oak (fig. 5.26, table 5.3). As noted above, LANDIS-II does not model potential changes in insect outbreaks and pathogens in the future. Increases in biomass may be limited by these disturbance agents for some species (e.g., sudden oak death may limit increases in canyon live oak, California black oak, and tanoak).

Wildfire—In all but the warmer and drier climate projection (MIROC 5 RCP 2.6), fire sizes were projected to increase (Serra-Diaz et al. 2018) and return intervals decrease (fig. 5.27). Fires were more likely to occur in the drier eastern portion of the LANDIS-II assessment area. Precipitation was projected to increase under two of the projections; however, with climate change, especially with the CanESM2 scenario, the length of the precipitation-free period is expected to increase. Moreover, under the CanESM2 projection, increased precipitation during the spring might have produced more growth in the LANDIS-II simulations, resulting in more fuel to burn over the summer, which could explain the increase in fire size and frequency in the hotter and drier scenario (ACCESS RCP 8.5).

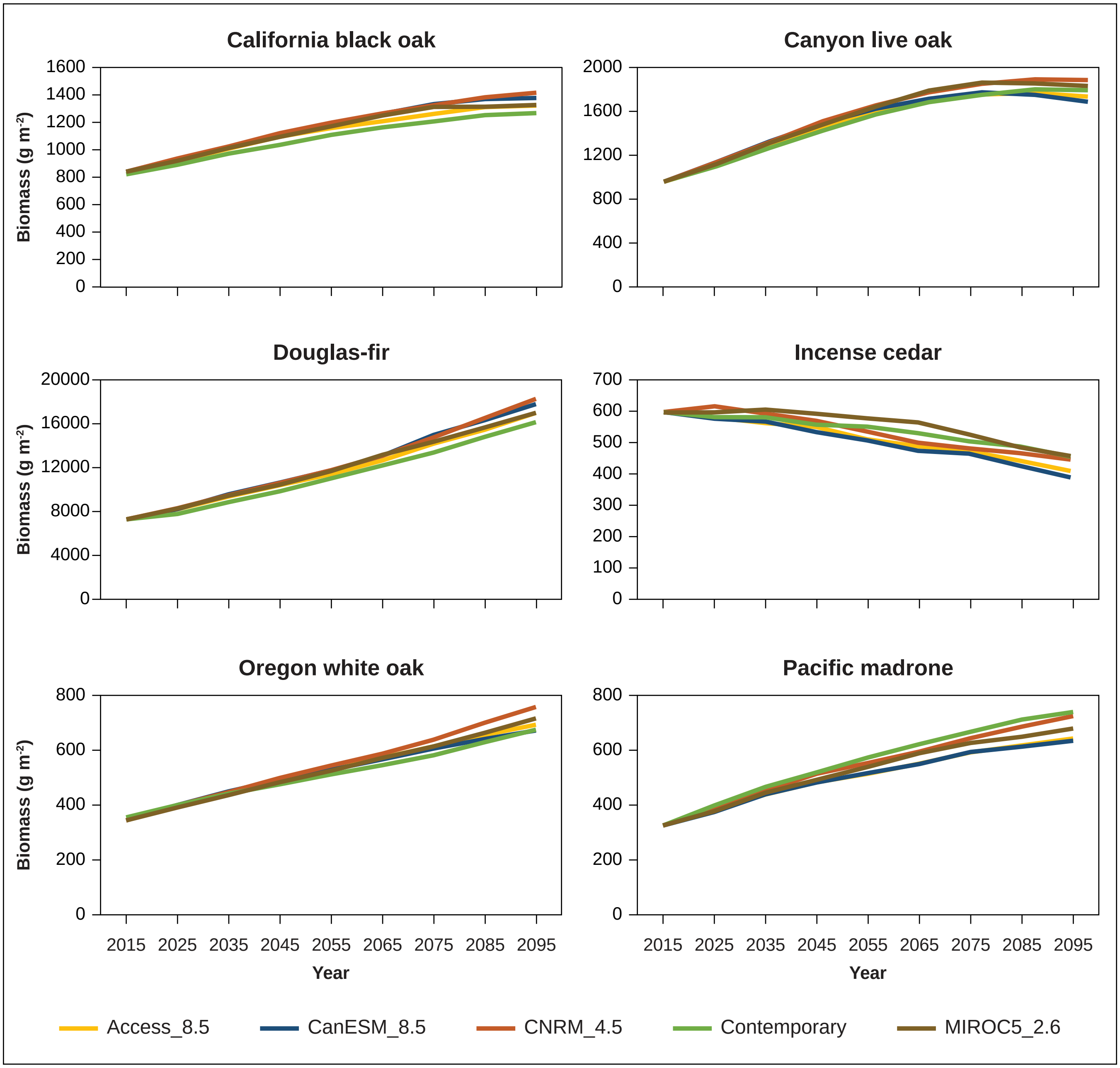

Figure 5.26—Projected species biomass under contemporary climate (1950–2014) and four future climate scenarios over an 85-year period as simulated by the LANDIS-II model.

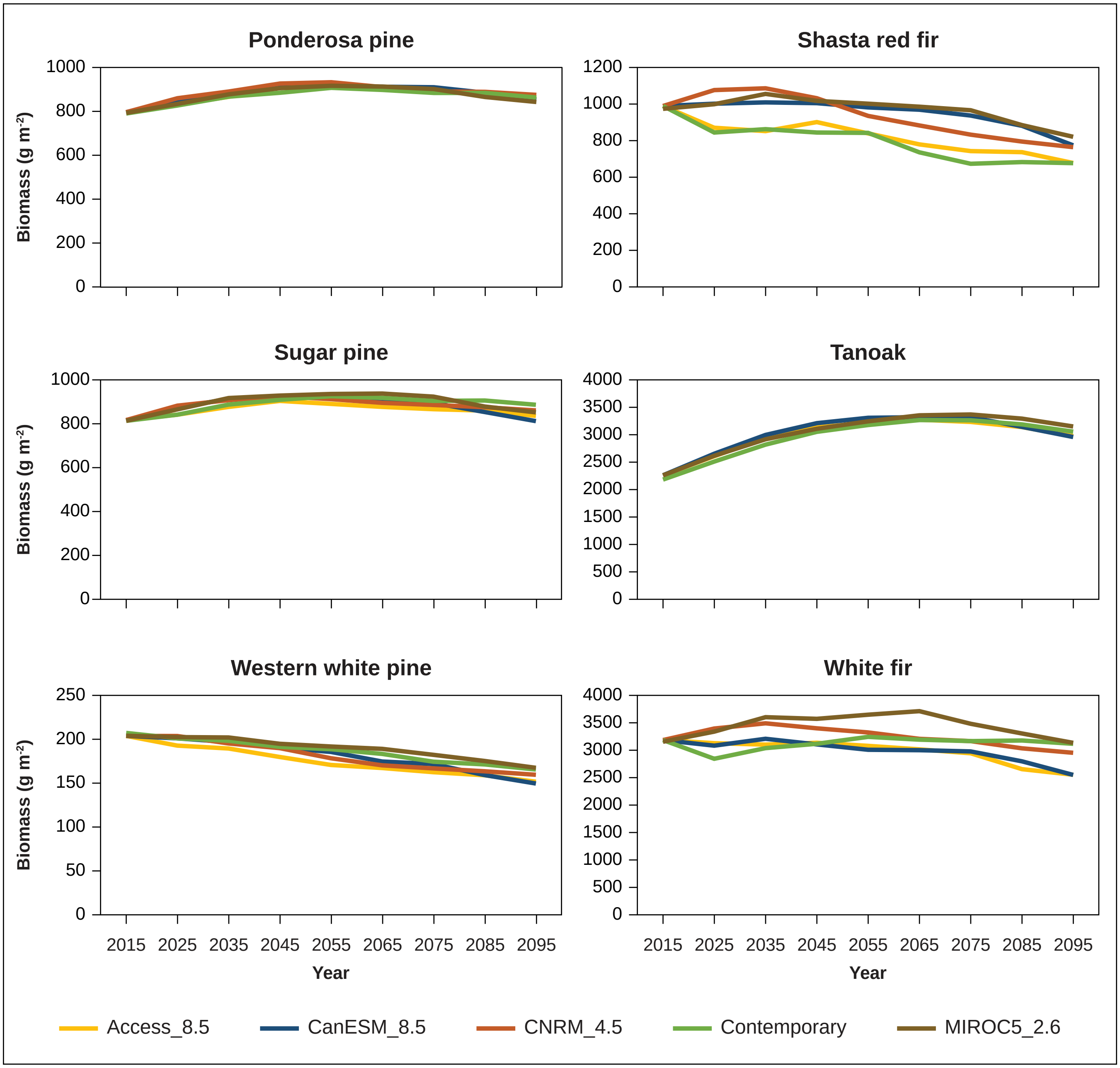

Figure 5.26 continued—Projected species biomass under contemporary climate (1950–2014) and four future climate scenarios over an 85-year period, as simulated by the LANDIS-II model.

Table 5.3—Expected trends for vegetation groups and dominant species within vegetation groups for southwest Oregon[a]

Vegetation group	Current dominant species	LANDIS-II trends	Paleoecological literature	General trends expected
High-elevation forests and parklands	Mountain hemlock	—	↓	Reduction in climatically suitable habitat for high-elevation forests is likely with warming. Conifer tree growth will likely increase, and meadow habitat will decrease as conifers establish and advance from the forest edge. The summer dry period may increase in length, and area burned by high-severity fires may increase.
	Shasta red fir	↓	↓	
	Lodgepole pine	—	↑	
	Pacific silver fir	—	↓	
	Douglas-fir	↑	↑	
	Western white pine	↓	↑	
	White fir	—	↑	
	Western hemlock	—	↓	
Moist forest	Douglas-fir	↑	↑	Species such as Douglas-fir and tanoak will be favored over fire- and drought-intolerant species. Productivity may increase because of increased growing season length, but moisture may become limiting for tree establishment and growth on drier sites.
	Western hemlock	—	↓	
	Tanoak	↑	↑	
	Western redcedar	—	↓	
	White fir	↓	↓	
	Pacific silver fir	—	↓	
Mesic forest	White fir	↓	↓	With higher temperatures, higher area burned, and increasing drought stress, mesic forests may transition to more xeric forest. Tree growth will likely decrease for many species. Hardwoods and large shrub patches will be favored by more frequent fire.
	Douglas-fir	↑	↑	
	Incense cedar	↓	↑	
	Shasta red fir	↓	↓	
	Sugar pine	↑↓	↑	
	Western hemlock	—	↓	
	Tanoak	↑	↑	
Ultramafic forests and woodlands	Jeffrey pine	—	↓	Changes in species composition may be limited on serpentine soils because many species are drought tolerant, and other factors limit species on these sites. Shrubs may have an advantage over conifers with increasing fire frequency.
	Douglas-fir	↑	↑	
	Incense cedar	↓	↑	
	Western white pine	↓	↑	
	Port Orford cedar	—	↑	
	Tanoak	↑	—	
Dry forest	Douglas-fir	↑	↑	Dry forest may shift to woodlands or shrublands in the driest portions of the current range because of drought and increased fire frequency. Tree growth will likely be reduced. Tree mortality may also increase in some locations because of the interacting effects of drought, disturbance, and insects.
	Ponderosa pine	↑	↑	
	Incense cedar	↓	↑	
	Sugar pine	↑↓	↑	
	Oregon white oak	↑	↑	
	California black oak	↑	↑	
Woodlands	Oregon white oak	↑	↑	Expansion of woodland types is likely with hotter and drier conditions and increased fire frequency. However, effects of fire suppression and invasive species may limit the capacity of oak woodlands to adapt to changing climate and disturbance regimes.
	Douglas-fir	↑	↓	
	Ponderosa pine	↑	↑	
	Pacific madrone	↑	—	
	Incense cedar	↓	↑	
Shrublands		↑	↑	Shrublands will likely expand with increased fire and summer water deficit. Shrub species establish well in forests burned at high severity, and repeated fire could perpetuate shrublands because short intervals between severe fires and drought conditions do not allow for forest establishment.

Note: Upward arrows indicate expected increases in abundance, and downward arrows indicate expected decreases in abundance.
— = no change.

[a] Trends were derived from LANDIS-II model output (see fig. 5.25) and paleoecological studies (pollen and charcoal records from lake sediments) for the Pacific Northwest and northern California. General trends are partly derived from MC2 output.

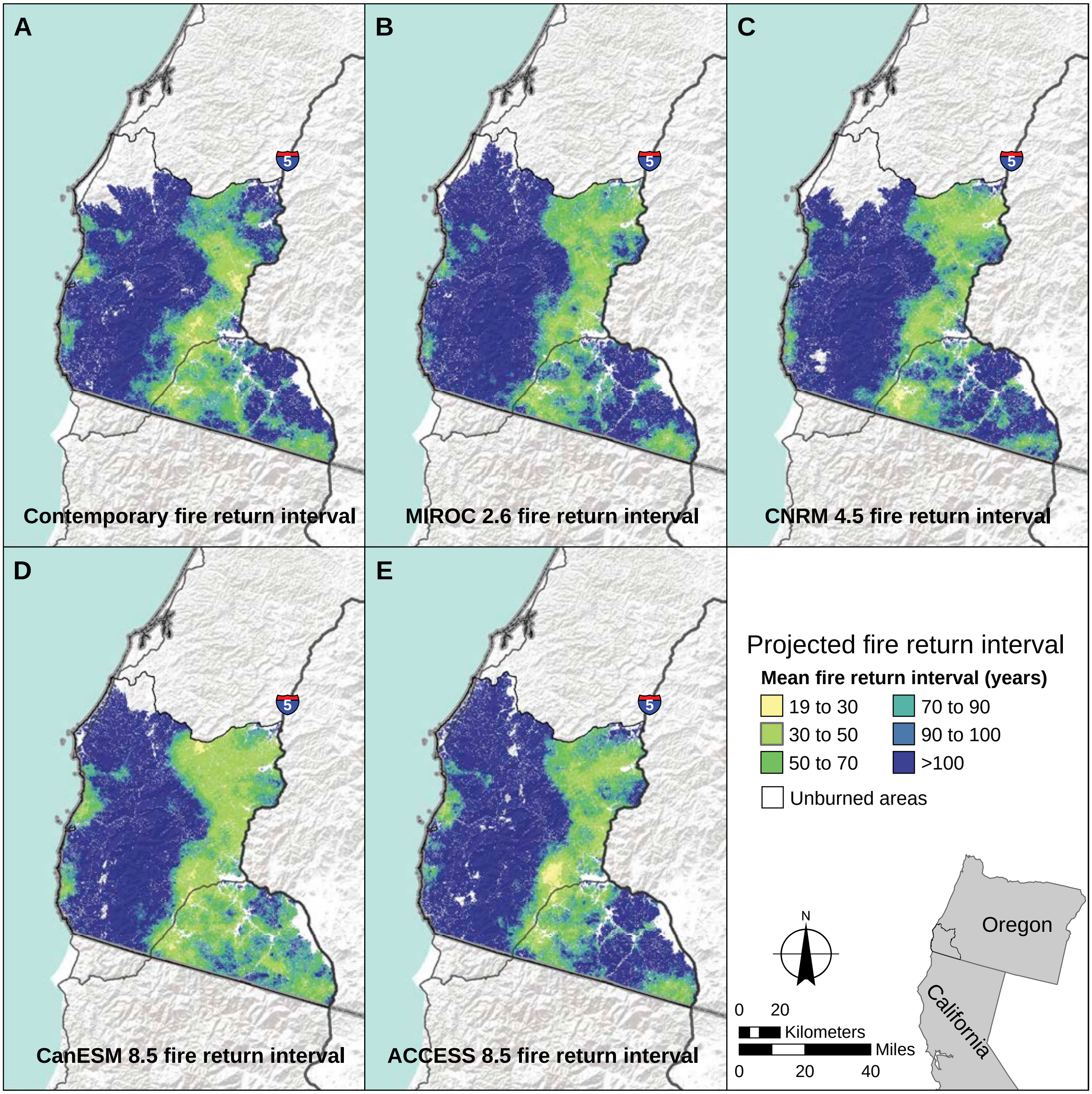

Figure 5.27—Projected fire return interval under contemporary (1950–2014) and four future climate scenarios over an 85-year period as simulated by the LANDIS-II model.

Assessment for Vegetation Units

This section synthesizes available information and uses expert opinion to determine potential effects of climate change on seven broad vegetation groups in the SWOAP assessment area: high-elevation forests and parklands, moist forests, mesic forests, forests and woodlands on ultramafic soils (ultramafic forests and woodlands), dry forests, woodlands, and shrublands (table 5.1). For each vegetation group, summaries cover current vegetation and potential future changes in species composition, structure, and disturbance processes.

High-Elevation Forests and Parklands

Description—

The highest elevations in the SWOAP assessment area are characterized by subalpine parklands, where trees are patchy or dispersed rather than contiguous, often occurring as islands in grassland, shrubland, and alpine tundra. Mountain hemlock is the primary tree species in subalpine parklands of the SWOAP assessment area. Other species that occur in subalpine parklands include lodgepole pine, whitebark pine, and western white pine. The understory of more open stands often consists of huckleberry species (*Vaccinium* spp.), beargrass (*Xerophyllum tenax* (Pursh) Nutt.), and many other species. Subalpine parklands also include meadows, which consist of a broad range of graminoid, herb, and shrub species.

Continuous forests dominated by mountain hemlock occur below subalpine parklands in the SWOAP assessment area, occurring from approximately 1200 to 2100 m in the Cascade Range and from 1600 to 2200 m in the Siskiyou Mountains (Atzet et al. 1996). In the southern Oregon Cascades, mountain hemlock forests occur as a mostly continuous band; in the Siskiyou Mountains, mountain hemlock forests are more fragmented, occurring primarily on northerly aspects of higher peaks and ridges. Mountain hemlock and Shasta red fir are the dominant overstory species in these forests, with western white pine, Douglas-fir, western hemlock, lodgepole pine, and Pacific silver fir also occurring occasionally to frequently, depending on the site. Douglas-fir, white fir, and western hemlock occur more frequently on warmer sites (Atzet et al. 1996). Common understory species include grouse huckleberry (*V. scoparium* Leiberg ex Coville), thinleaf huckleberry (*V. membranaceum* Douglas ex Torr.), common prince's-pine (*Chimaphila umbellata* (L.) W.P.C. Barton), one-sided pyrola (*Orthilia secunda* (L.) House), and Pacific rhododendron (*Rhododendron macrophyllum* D. Don ex G. Don).

Shasta red fir forests occur in a wide elevation band similar to that of mountain hemlock (1200 to 2100 m) in southwest Oregon, and Shasta red fir commonly co-occurs with mountain hemlock. White fir is common at elevations between 600 and 1800 m, overlapping with both Shasta red fir and mountain hemlock (Bower et al. 2012). Shasta red fir is generally the dominant tree in the overstory, and it is also generally abundant in the understory. White fir and Douglas-fir are often present on warmer sites, and mountain hemlock is often present on cooler sites (Atzet et al. 1996). Western white pine is common on some sites, while lodgepole pine occurs in areas where cold air pools. Common understory species include Sadler oak (*Quercus sadleriana* R. Br. ter), pinemat manzanita (*Arctostaphylos nevadensis* A. Gray), thinleaf huckleberry, Oregon boxwood (*Paxistima myrsinites* (Pursh) Raf.), common prince's-pine, and one-sided pyrola.

Pacific silver fir forests extend through the higher elevations of Umpqua National Forest (from about 1200 to 1900 m) and extend south into the northern portion of the High Cascades Ranger District of Rogue River-Siskiyou National Forest (Atzet et al. 1996). At lower elevations, Pacific silver fir is bordered by western hemlock and white fir forests and at higher elevations by Shasta red fir and mountain hemlock forests. Douglas-fir, an early-seral species, is the dominant overstory tree in Pacific silver fir forests, primarily because of frequent fire. Western hemlock is present on warmer sites, and mountain hemlock is present on cooler sites. Common understory species include thinleaf huckleberry, dwarf bramble (*Rubus lasiococcus* A. Gray), dwarf Oregon grape (*Berberis nervosa* Pursh), and vanillaleaf (*Achlys triphylla* (Sm.) DC.). Pacific silver fir is likely limited by drought and frequent fire in southwest Oregon (Atzet et al. 1996).

Lodgepole pine forests are found on Mount Mazama pumice and ash deposits in broad, flat valley bottoms surrounding Diamond Lake and the Rogue River and its major tributaries east of Prospect (Atzet et al. 1996). Forests are relatively continuous around Diamond Lake but are fragmented along the Rogue River, occurring in areas of cold air accumulation and deep pumice. Lodgepole pine forests also occur on high-elevation flats adjacent to Crater Lake National Park and in isolated frost pockets. Elevation ranges from about 1300 to 1800 m in the Cascades. Lodgepole pine is the dominant overstory species in these forests and is also abundant in the understory. White fir and western hemlock occur on warmer sites, and mountain hemlock and Shasta red fir occur on cooler sites. Grouse huckleberry and pinemat manzanita are frequently found in the understory. Except for locations with cold air accumulation, lodgepole pine forests are generally replaced at lower elevations by white fir or western hemlock forests, and at upper elevations by Shasta red fir or mountain hemlock forests (Atzet et al. 1996).

Potential future changes—

Duration of snowpack is the primary factor controlling establishment and survival of trees and other species in the subalpine zone, although wind limits tree distribution and growth in exposed settings, especially at higher elevations. Limiting factors vary spatially with respect to topography (north versus south aspects, concavities versus convexities) (Peterson 1998), affecting snow distribution, temperature, and species dominance (Millar et al. 2004, Peterson et al. 2002, Woodward et al. 1995).

Both MC2 and LANDIS-II suggest that there will be a significant reduction in climatically suitable habitat for high-elevation forests. This result is consistent with other climate change vulnerability assessments conducted for southwest Oregon (Myer et al. 2013). The extent and duration of snowpack have already decreased in the Cascade and Siskiyou Mountains and are expected to decrease further with each passing decade (Dalton et al. 2017; Mote et al. 2005, 2018). Warmer temperatures will result in more precipitation falling as rain rather than snow, earlier snowmelt, and longer growing seasons, which in turn are likely to (1) decrease meadow habitat as conifers establish and advance from the forest edge (Holtmeier and Broll 2005, Peterson et al. 2002, Rochefort and Peterson 1996, Woodward et al. 1995, Zald et al. 2012, Zolbrod and Peterson 1999), and (2) increase tree growth of conifer species (Peterson 1998, Peterson et al. 2002). Earlier spring snowmelt could result in a longer summer dry period, and area burned by high-severity fires may increase.

Dominant species in the subalpine zone may experience increased competition from species that are currently dominant at lower elevations (Briles et al. 2008, Walther et al. 2005). In MC2, moist coniferous forest replaces subalpine forest, suggesting that species such as Douglas-fir, western hemlock, and white fir could increase in abundance in the future (table 5.3), as these are the species that currently occur on warmer sites in high-elevation forests. Paleoecological studies similarly suggest that pines, Douglas-fir, white fir, and cedar replaced subalpine parklands in the Siskiyou Mountains during warmer and drier periods in the past (Briles et al. 2008). If wildfire becomes more common across Oregon as expected, it may result in younger age cohorts and smaller tree sizes in the long term (Kerns et al. 2017).

Lodgepole pine forests are likely to expand with increased fire frequency in the future, as this species is well-adapted to stand-replacement fires (Lotan et al. 1985), even in the absence of serotinous cones in the region. Lodgepole pine is also characteristically disturbed by mountain pine beetle, and periodic epidemic beetle episodes will continue. Increased winter beetle survival may occur, yet area-wide epidemics also require concurrence with suitable arrays of susceptible host material and favorable weather. Recent mountain pine beetle epidemics in the Rocky Mountains and western Canada have been partly attributed to increasing temperatures releasing the insects from climatic constraints (mainly lethal winter cold) (Bentz et al. 2010). However, in the SWOAP assessment area, low winter temperatures did not reach limiting levels historically (Weed et al. 2015) and are not expected to do so in the future. Mountain pine beetle readily colonizes all pine species, and thus adjacent or mixed populations of western white and whitebark pines may incur somewhat elevated mortality owing to spillover from beetle activity in lodgepole pine. In addition, white pine blister rust infection increases the probability of attack by mountain pine beetle (Six and Adams 2007); an increase in the incidence or severity of this disease in whitebark pine may lead to additional beetle-caused mortality.

Although much attention has been focused on the movement of treeline in mountains, it has rarely fluctuated more than 100 m during the Holocene throughout North America (Rochefort et al. 1994). In contrast, tree density and proportion of trees and herbaceous/grass species in the forest-meadow mosaic are a more dynamic component of subalpine ecosystem function, fluctuating considerably in response to decadal- to centennial-scale climatic variation (Klasner and Fagre 2002, Woodward et al. 1995) and to disturbance (Little et al. 1994). Warmer temperatures and longer growing seasons will likely lead to forest expansion into some high-elevation meadows, but increased fire frequency will likely decrease forest encroachment in meadows.

Moist Forests

Description—

Southwest Oregon is the southern end of the range of moist western hemlock forest types. In the Cascade Range, western hemlock forests are abundant on the Cottage Grove and North Umpqua Ranger Districts and adjacent BLM-administered lands in the Roseburg District. These forests extend south through Umpqua National Forest to the High Cascades Ranger District of Rogue River-Siskiyou National Forest (Atzet et al. 1996). Western hemlock forests are likely limited by dry conditions in the SWOAP assessment area. They transition to white fir forests to the south. Along the coast, western hemlock forests extend south into the Gold Beach Ranger District of Rogue River-Siskiyou National Forest and adjacent lands and transition to the tanoak types where temperatures are warmer. Douglas-fir forest types occur on hotter, drier sites, and Pacific silver fir and Shasta red fir forests occur at higher elevations on cooler sites. Western hemlock forests occur from near sea level up to about 1500 m, with a peak in occurrence at about 760 m (Atzet et al. 1996, Devine et al. 2012).

With the relatively high fire frequency in the SWOAP assessment area, Douglas-fir, an early-seral species, is often dominant. Western hemlock is the dominant tree species in the understory and is more abundant in older stands with low disturbance frequency. Western redcedar occurs in wetter areas of the Cascades, and white fir or Pacific silver fir are present in higher elevation, cooler areas. Tanoak may be present in the coastal Siskiyou Mountains, and Port Orford cedar is common on ultramafic soils. Common understory species include salal (*Gaultheria* *shallon* Pursh), Pacific rhododendron, giant chinquapin, and common whipplea (*Whipplea modesta* Torr.) (Atzet et al. 1996).

Along the coast, mostly west of the Gold Beach Ranger District of Rogue River-Siskiyou National Forest, Sitka spruce (*Picea sitchensis* (Bong.) Carrière) forests occur below 300 m. Late-seral stands are dominated by Sitka spruce and western hemlock, with some Douglas-fir. In early-seral stands, Douglas-fir occurs with red alder and western hemlock. Red alder is common in riparian areas. The understory is often dominated by salmonberry (*Rubus spectabilis* Pursh), salal, western swordfern (*Polystichum munitum* (Kaulf.) C. Presl), and Oregon oxalis (*Oxalis oregana* Nutt.).

On warmer sites in the coastal Siskiyou Mountains, moist tanoak and Douglas-fir forests are characterized by persistent tanoak following disturbance, but tanoak is generally replaced by conifers, especially Douglas-fir, over time. Many stands are two-storied, with tanoak beneath an overstory of Douglas-fir, occasionally with sugar pine. Several other tree species may be present, often including bigleaf maple, Pacific madrone, and canyon live oak. The species-rich understory often includes dwarf Oregon grape, red huckleberry (*Vaccinium parvifolium* Sm.), poison oak (*Toxicodendron diversilobum* (Torr. & A. Gray) Greene), and salal.

Potential future changes—

In response to increasing temperature and fire frequency, moist forest in the SWOAP assessment area will likely continue to be dominated by Douglas-fir and other early-seral species. Fire- and drought-intolerant species, including western hemlock, Pacific silver fir, and western redcedar, are likely to decrease in abundance (table 5.3) (Chmura et al. 2011). Paleoecological evidence suggests that during warm and dry periods of the past, Douglas-fir was favored in moist forest, and western hemlock decreased in abundance (Long et al. 1998). Tanoak may be favored by increasing fire frequency in the Siskiyou Mountains (Wanket 2002), but wetter springs may favor expansion of sudden oak death, which can infect and kill tanoak. Red alder is likely to expand with increasing disturbance in coastal locations (Long et al. 1998).

Both MC2 and LANDIS-II projected increasing productivity in moist forest types with warming climate because of increased growing season length, adequate moisture levels, and increased atmospheric CO_2. However, moisture may become limiting for tree establishment and growth on drier sites with increased evapotranspiration and summer water deficit (McKenzie and Littell 2017, Restaino et al. 2016). Thus, some moist forest sites may shift from growth being energy limited (limited by temperature and length of the growing season) to water limited (McKenzie et al. 2001).

Fire frequency is projected to increase in moist forests (figs. 5.22 and 5.27), and fire severity will likely continue to be high with high productivity and fuel loading (fig. 5.23). Sites that were previously too wet and cool to burn may experience high-severity fires (Case et al. 2019). Hardwood species such as tanoak and shrub species such as *Ceanothus* sp. may successfully compete with conifer tree seedlings in areas that experience multiple high-severity wildfires, particularly on drier sites (Serra-Diaz et al. 2018, Tepley et al. 2017).

Mesic Forests

Description—

Mesic white fir-grand fir forests occur on environmentally varied sites throughout the SWOAP assessment area, covering a wide elevational band from 300 up to 2000 m, with a maximum occurrence around 1400 m (Bower et al. 2012). White fir and grand fir often intermix and hybridize throughout southwest Oregon. Douglas-fir dominates most stands, usually mixed with white fir and, to a lesser extent, incense cedar. In colder areas, Shasta red fir may be the dominant early-seral overstory species. White fir and Shasta red fir are dominant in later-seral stages, in which long-lived Douglas-fir may be present. Western hemlock is often present in wetter areas of the Cascade and Siskiyou Mountains, and Pacific silver fir, mountain hemlock, Shasta red fir, and lodgepole pine may be present in higher elevation, cooler areas (Atzet et al. 1996). Brewer spruce (*Picea breweriana* S. Watson) may also be present in cold, dry areas of the Siskiyous. Tanoak occurs in lower elevation white fir forests of the Siskiyous, and Port Orford cedar may be common on ultramafic soils. Common understory species include dwarf Oregon grape, common prince's-pine, Pacific rhododendron, and salal. Giant chinquapin and common whipplea are common on dry sites.

Dry tanoak-Douglas-fir forests occur on moderately dry sites in southwest Oregon. Tanoak is persistent following disturbance in these areas, but is generally replaced by conifers, especially Douglas-fir, over time. Many stands are two-storied, with tanoak beneath an overstory of Douglas-fir, occasionally with sugar pine. Several other tree species may be present, often including Pacific madrone, canyon live oak, and California black oak. The understory is often densely shrubby, with tanoak, giant chinquapin, poison oak, dwarf Oregon grape, hairy honeysuckle (*Lonicera hispidula* (Lindl.) Douglas ex Torr. & A. Gray), and others.

Potential future changes—

With higher temperatures, higher area burned, and increasing drought stress in the future, mesic forests in southwest Oregon could transition to more xeric forest (Lenihan et al. 2003, 2008). Both LANDIS-II projections and paleoecological studies (Mohr et al. 2000) suggest that white fir/grand fir abundance will decline with drier conditions and increased fire frequency. Fire- and drought-tolerant species, such as Douglas-fir, incense cedar, and sugar pine, are likely to increase in abundance in mesic forests.

Douglas-fir will likely continue to dominate most stands, as it can tolerate both fire and moderate drought (table 5.3). Incense cedar will likely do well under future climatic conditions because it is able to withstand extreme heat and drought, it has thick, fire-resistant bark, and its seedlings germinate and establish under a variety of conditions (Briles et al. 2005). This species grew at least 500 m above its present range in the early Holocene during a warmer and drier interval (Briles et al. 2005). Sugar pine is also resistant to low- to moderate-severity fires. However, sugar pine is highly susceptible to white pine blister rust, and seedlings are not drought tolerant (Habeck 1992). Brewer spruce is sensitive to evaporative stress; high evaporative demand (rate of water loss from a wet surface) causes stomatal closure and limited photosynthesis (Waring et al. 1975). Thus, Brewer spruce is likely to decline where evaporative demand increases significantly.

Fire return intervals are projected to decrease in mesic forests (figs. 5.22 and 5.27). More frequent severe fire will probably decrease the fraction of old-growth forest patches and connectivity of these patches across the landscape (McKenzie et al. 2004). Increased area burned and drought severity will also likely favor shrubs and larger shrub patch size in these forests (Airey Lavaux et al. 2016, Minor et al. 2017). Hardwood species such as tanoak, oaks (e.g., canyon live oak, California black oak), and giant chinquapin are able to survive fire by resprouting from basal buds following mortality of the aboveground stems (Tappeiner et al. 1990). Many shrub species are also able to reestablish after fire from long-lived refractory seed banks or by basal resprouting (Keeley et al. 1991). Hardwoods may impede the development of conifer forests in large, high-severity patches (Airey Lavaux et al. 2016, Donato et al. 2009a). However, high-intensity fire can consume or kill seeds stored in the upper soil profile and kill shallow belowground plant parts. Repeated fires at short intervals can deplete seed stores and belowground plant resources (Zedler et al. 1983), and high-intensity fire can destroy tanoak burl buds, prohibiting resprouting.

Increasing summer drought stress will decrease growth for many species in mesic forests (Restaino et al. 2016), and increase vulnerability to insects and disease, possibly causing tree mortality in some locations (Allen et al. 2015). Second-growth forests may be particularly vulnerable to drought, fire, and insect outbreaks in the future because of their low species and structural diversity and high density.

Drought stress converts the fir engraver from a secondary bark beetle with sporadic and mostly sublethal impact into a primary tree killer capable of prolonged and expansive epidemics (Ferrell 1991, Ferrell et al. 1994). This is likely in the SWOAP assessment area, where average annual precipitation is 64 cm or less. The variation in annual mortality owing to fir engraver estimated by aerial detection surveys is correlated with annual precipitation data from Medford, Oregon (fig. 5.28). In addition to drought and disease, fire injury also may induce fir engraver attack. With projected increases in temperature, drought episodes, and the extent of wildfire, significant disturbance to fir forests by fir engraver may become more frequent.

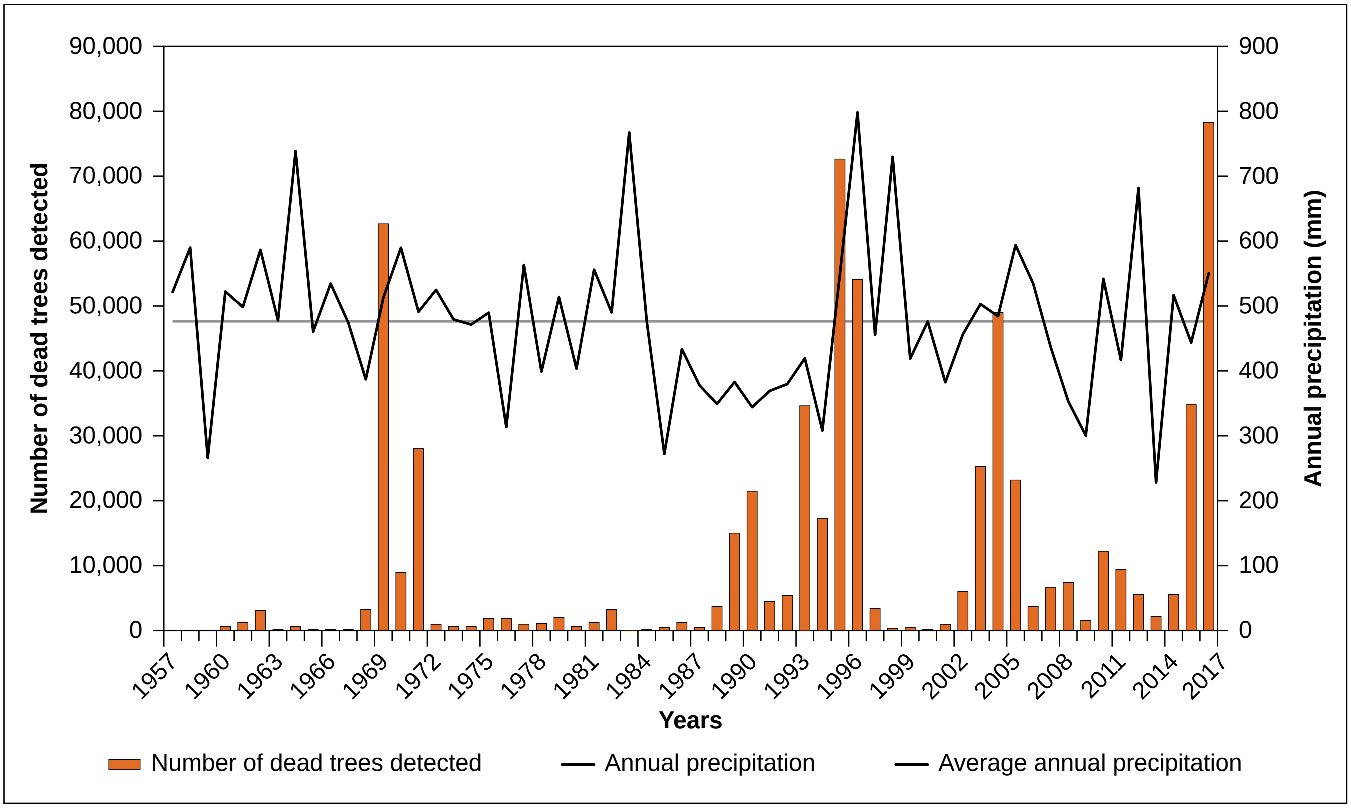

Figure 5.28—True fir mortality attributed to the fir engraver in southwest Oregon (orange bars), as measured in annual aerial surveys by the U.S. Forest Service Forest Health Protection, and annual precipitation (black line) at Medford International Airport. True fir mortality has increased in recent years, particularly after years with below-average precipitation.

Forests and Woodlands on Ultramafic Soils

Description—

In southwest Oregon, distinct forest communities occur on ultramafic soils developed from serpentine, peridotite, and similar bedrock. These soils are high in magnesium, iron, silica, nickel, and chromium and are toxic or limiting for many plant species. Jeffrey pine is a characteristic species, and Douglas-fir and incense cedar occur in most stands. Several other conifers are locally important, including Port Orford cedar, western white pine, and knobcone pine (*Pinus attenuata* Kral). Most stands consist of scattered trees over a continuous and dense shrub layer. The understory is variable, depending on local environment, but often includes otherwise rare species such as hoary manzanita (*Arctostaphylos canescens* Eastw.), whiteleaf manzanita (*A. viscida* Parry), dwarf silk-tassel (*Garrya buxifolia* A. Gray), prostrate ceanothus (*Ceanothus prostratus* Benth.), and dwarf ceanothus (*C. pumilus* Greene). Idaho fescue (*Festuca idahoensis* Elmer) may be abundant on very dry sites.

Potential future changes—

Some serpentine endemic herbs and forbs may be at risk in a changing climate. Damschen et al. (2010) found greater shifts in the Siskiyou Mountains in understory plant species richness and cover on serpentine compared to nonserpentine soils (between 1949 and 2007), and greater cover declines in serpentine endemic herbs and forbs than generalists. Specifically, increased drought stress may cause declines of some species that currently characterize serpentine soils, and endemic species confined to specific soils may have fewer chances to migrate to suitable sites (Damschen et al. 2010).

However, many species that characterize serpentine plant communities are likely to have greater tolerance to drought because of morphological adaptations (e.g., reduced root growth, and small, thick, hairy leaves) (Briles 2008, Damschen et al. 2010). Serpentine soils are generally thin with low moisture-holding capacity and abundant bare soil, resulting in rapid and early drying and relatively low plant cover (Briles 2008). In addition, serpentine species are nutrient limited, with low calcium and high magnesium and nickel concentrations (Eskelinen and Harrison 2015).

When water and nutrients are jointly limiting to plant community productivity and composition, climate change may have only weak effects (Eskelinen and Harrison 2015, Grime et al. 2008). In serpentine grasslands of northwest California, Eskelinen and Harrison (2015) found that water or nutrient additions alone had little effect on biomass, but adding both together increased biomass by more than 500 percent and led to high species turnover. Thus, a reduction of water alone with climate change may not affect plant communities on serpentine soils as much as plant communities on more productive soils. This is consistent with the paleoecological record for the region, which shows limited species change on serpentine soils with climatic variation in the past (Briles 2017).

Although changes in plant community composition may be more limited on serpentine soils, some changes are likely in a warming climate. For example, Damschen et al. (2010) found that conifers have decreased and shrubs have increased in abundance on serpentine soils in the region over the past five decades, which is consistent with patterns reported by Briles (2008) in the warm, dry period of the Holocene. In the future, increased fire activity will also likely favor shrubs over conifers on serpentine sites, with the notable exception of the early-seral and serotinous knobcone pine, which may increase in abundance with increased fire. In the 2002 Biscuit Fire, low-productivity sites with low tree densities on ultramafic soils experienced the highest rates of conifer crown damage (Thompson and Spies 2009). These sites were found to have high shrub cover, and there was a positive relationship between shrub cover and crown damage (Thompson and Spies 2009). As fire frequency increases, shrub species will have an advantage over most conifers, particularly those that are not drought and fire tolerant. Invasion of invasive annuals, particularly annual grasses, could also promote more frequent fire as the annual grasses increase fuel continuity and are more flammable than woody plants.

Dry Forests

Description—

Dry Douglas-fir forests occur on well-drained soils in southwest Oregon, often on south aspects, where the hot, dry microclimate gives Douglas-fir a competitive advantage over species such as western hemlock and white fir. These forests can be found on dry sites at high elevations or intermixed with western hemlock and tanoak forests. Although other conifer and hardwood species may occur in these forests, Douglas-fir dominates the overstory of late-seral stages. Ponderosa pine and incense cedar are long-lived, early-seral species in many stands. Pacific madrone, canyon live oak, sugar pine, California black oak, and Oregon white oak occur occasionally in the overstory or as smaller trees. The understory is generally shrubby, including dwarf Oregon grape, vine maple, salal, and creambush oceanspray (*Holodiscus discolor* (Pursh) Maxim.).

Dry ponderosa pine forests occur near valley bottoms, at slightly higher elevations than Oregon white oak woodlands, primarily in the southeastern portion of the SWOAP assessment area. Small pockets of ponderosa pine forests occasionally occur at higher elevations on south aspects with shallow, rocky soils. On warmer and wetter sites, ponderosa pine and Douglas-fir dominate the overstory. The understory is often dominated by ponderosa pine and Douglas-fir, with incense cedar, canyon live oak, and sugar pine also occurring frequently. Pacific madrone, Oregon white oak, giant chinquapin, and bigleaf maple are sometimes present. Poison oak is the only commonly occurring shrub. Many grasses may be present (Atzet et al. 1996). On cooler and drier sites, the overstory is dominated by California black oak, and the understory is dominated by ponderosa pine. Douglas-fir is often present, but at low abundance. Deerbrush (*Ceanothus integerrimus* Hook. & Arn.) and common snowberry (*Symphoricarpos albus* (L.) S.F. Blake) are common shrubs.

Potential future changes—

Warmer conditions, greater summer water deficit, and increased fire frequency may result in shifts from dry forest to woodlands or shrublands in the driest portions of the dry forest range in southwest Oregon. LANDIS-II projected a 15 percent reduction in forest area (table 5.2), particularly in hotter, drier scenarios, with shifts occurring in the drier, interior portions of the assessment area (primarily in the southeastern portion) (fig. 5.24), where fire return intervals are projected to decrease (fig. 5.27). Another LANDIS-II-based analysis concluded that a third of the Klamath region (northern California and southwest Oregon) could transition from conifer forest to shrub-hardwood-chaparral because of increased fire activity coupled with lower postfire conifer establishment (Serra-Diaz et al. 2018). Drought stress inhibited forest regeneration on the driest sites in the region after fires over the past several decades, and the area potentially inhospitable to seedling establishment is likely to expand in the future (Tepley et al. 2017). Large, high-severity fire patches may further inhibit forest development and result in long-term shrub or hardwood dominance (Airey Lavaux et al. 2016, Donato et al. 2009a).

In locations that retain (or shift to) dry forest, increased fire frequency will likely influence forest structure. High fuel levels because of fire exclusion in dry forest are likely to initially lead to larger fires with large high-severity patches. However, over many decades, more frequent low- and mixed-severity fires may reduce fuels in dry forests, leading to lower intensity fires and a finer scale patch mosaic. More frequent fire will likely decrease tree density in dry forests, and the extent of shrub and hardwood patches will likely increase. Shrubs and grasses may become more dominant in forest understories. Tree-canopy base heights will likely increase as frequent fires remove lower branches.

Occurrence and productivity of Douglas-fir may be limited by drought on drier sites (Restaino et al. 2016). Other, more drought-tolerant species, such as ponderosa pine, incense cedar, and oaks, may become more dominant in dry forests, albeit at

Table 5.2—Percentage change in forested area for three future points in time under contemporary and four future climate scenarios[a]

	Change in forested area		
	2025	**2065**	**2105**
		Percent	
Contemporary	0	0	1
MIROC5 (warmer and drier)	-1	-1	-9
CNRM (warmer and wetter)	-1	-2	-5
CanESM2 (hotter and wetter)	-2	-2	-14
Access (hotter and drier)	-2	-3	-14

[a] Trends in temperature and precipitation for each future climate scenario are indicated in parentheses after the scenario title.

lower densities (table 5.3). Tree growth is often negatively correlated with summer temperature and positively correlated with precipitation for dry forest species, including ponderosa pine (Carnwath et al. 2012, Knutson and Pyke 2008, Kusnierczyk and Ettl 2002), and 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). Thus, tree growth of dry forest species will decrease. Tree mortality may also increase in some locations because of the interacting effects of drought, disturbance, and insects (McKenzie et al. 2009).

The flatheaded fir borer (Buprestidae) was identified in the 1970s as a primary cause of Douglas-fir mortality in the Klamath-Siskiyou Ecoregion (through aerial detection surveys). This unusual impact by a woodborer species in conifers is chronic at low levels and escalates during and just after drought. It is especially common in and around the interior valleys of the SWOAP assessment area at elevations of 1050 m or less (USDA FS 2019). The species is also common on dry sites where soil water-holding capacity is low, along stand edges, in Oregon white oak stands, and in dense 90- to 150-year-old Douglas-fir stands. Recent intense droughts have been followed by significantly increased Douglas-fir mortality, although this is less closely tied to precipitation compared with the fir engraver (fig. 5.29).

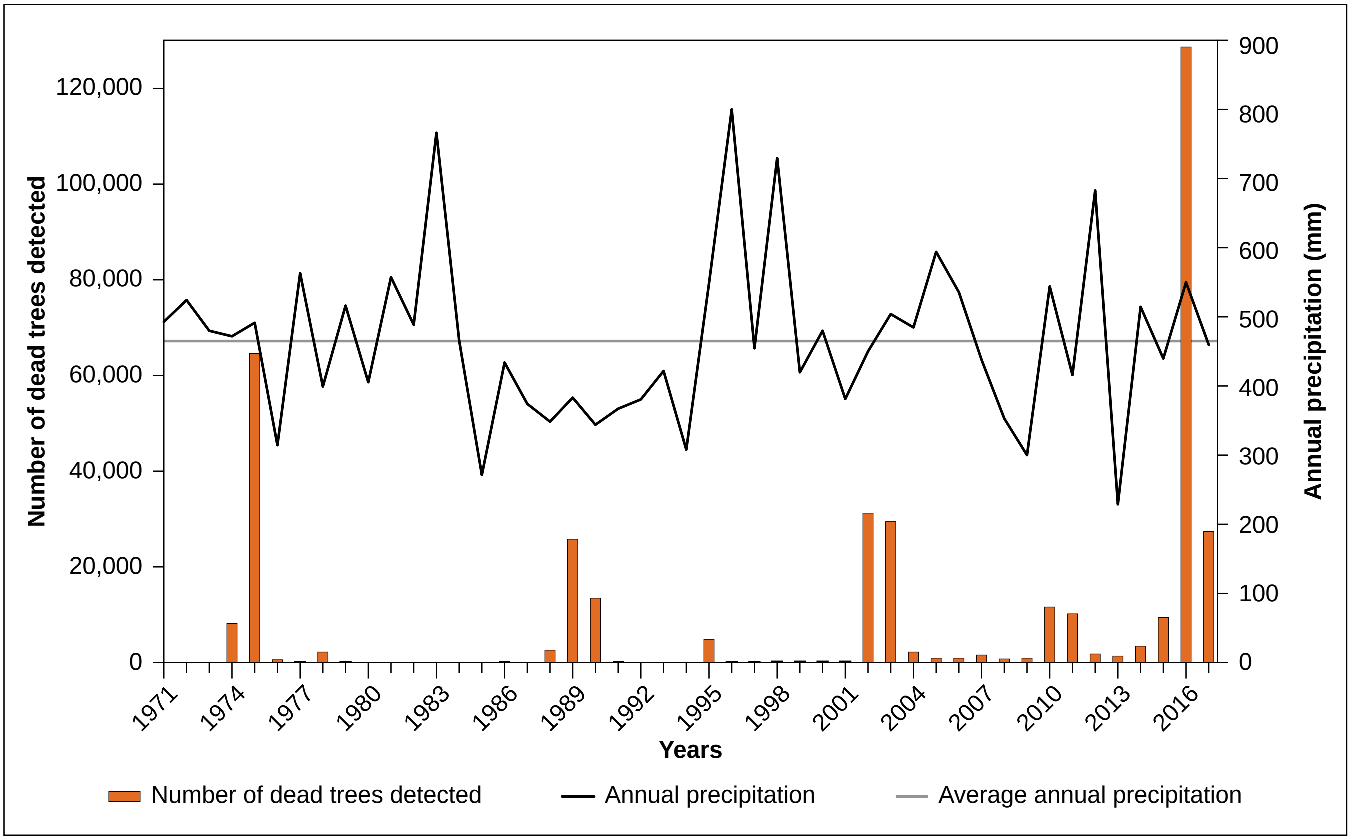

Figure 5.29—Douglas-fir mortality attributed to the flatheaded fir borer in southwest Oregon (orange bars), as measured in annual aerial detection surveys by the U.S. Forest Service Forest Health Protection, and annual precipitation at Medford International Airport (black line).

Fire suppression, missed fire intervals, lack of disturbance, shade tolerance, and weather favorable to regeneration during the Little Ice Age (that ended in the mid-19th century) have all contributed to a high density of Douglas-fir in this vegetation type, often on sites that are less suitable for other species. It is in these conditions that flatheaded fir borer is killing Douglas-fir. Under a hotter and drier climate with more frequent and severe droughts, this insect-caused mortality is expected to increase and move upward in elevation, perhaps altering the distribution and reducing the abundance of Douglas-fir at lower elevations.

Increasing aridity and more extreme weather events will likely increase host tree stress, providing opportunities for Douglas-fir beetle populations to increase and attain epidemic status (Agne et al. 2018). Epidemics of Douglas-fir beetle elsewhere in western North America (including Oregon), and the abundance of Douglas-fir in the SWOAP assessment area, suggest there is potential vulnerability to disturbance in dry forest types. At the lowest elevations, Douglas-fir may escape predation by Douglas-fir beetle owing to high temperatures creating discordant population development or interfering with adult diapause that requires an unattainable duration of low winter temperatures. However, Douglas-fir may be greatly reduced by flatheaded fir borer in those locations.

Woodlands

Description—

In the hotter and drier portions of southwest Oregon, Oregon white oak woodlands are common within valleys and the lower mountain slopes at the margins of valleys, most often occurring on south-facing slopes or other hot, dry microclimates. Ponderosa pine is commonly present (Gilligan and Muir 2011), as well as California black oak, Pacific madrone, and incense cedar. Some woodland sites are too warm and dry to support Douglas-fir, but it can occur in relatively moist sites where fire has been excluded. The understory is generally shrubby and often includes poison oak, whiteleaf manzanita, buckbrush (*Ceanothus cuneatus* (Hook.) Nutt.), birch-leaf mountain-mahogany (*C. betuloides* Nutt.), deerbrush, western serviceberry (*Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roem.), and hollyleaved barberry (*Berberis aquifolium* Pursh) (Gilligan and Muir 2011).

Douglas-fir encroachment has occurred in many white oak woodlands over the past 50 years owing to fire exclusion (Gilligan and Muir 2011). In woodlands sampled by Gilligan and Muir (2011), located in Applegate Valley and the BLM Butte Falls Resource Area, most stands had not experienced fire in the past 70 years. It is likely that patches of open oak woodland were historically more common.

Potential future changes—

Expansion of woodland types is likely with hotter and drier conditions in the future in southwest Oregon (Myer et al. 2013). MC2 projected expansion of woodland types in the SWOAP assessment area under several (mostly warmer and drier) climate projections; expansion of woodland types was most often at the expense of dry forest. Similarly, LANDIS-II projected loss of conifer forest cover and expansion of several hardwood types. Paleoecological studies suggest that Oregon white oak moved upslope in response to drought in the past in the Klamath (Mohr et al. 2000) and Trinity Mountains (Daniels et al. 2005) in northwest California. A climate envelope modeling study for the Rogue Basin in southwest Oregon also suggested that southwest Oregon will continue to provide habitat for Oregon white oak and California black oak under multiple climate scenarios (Schindel et al. 2013). However, sudden oak death could affect California black oak in southwest Oregon in the future (Koch and Smith 2012).

Historically, oak woodlands were maintained by relatively frequent fire; fire frequency of less than 10 years is required to prevent the development of conifers (Agee 1993). With more frequent fire in a warming climate, conifer encroachment could be reduced, favoring development of relatively open oak woodlands. However, fire exclusion has resulted in high fuel loading, so subsequent fires will probably be high severity (Cocking et al. 2014). Resprouting hardwoods are resilient to fire. However, nonnative annual grass species can establish following wildfire and thinning treatments in areas where conifers have encroached in shrub-dominated oak systems (Perchemlides et al. 2008, Riegel et al. 1992). Thus, effects of fire exclusion and nonnative species may limit the capacity of oak woodlands to adapt to changing climate and disturbance regimes.

Shrublands

Description—

The northernmost extent of chaparral shrublands occurs in southwest Oregon (Detling 1961). These shrublands are dominated by buckbrush and whiteleaf manzanita at low and mid elevations, and greenleaf manzanita (*Arctostaphylos patula* Greene) at higher elevations (Duren et al. 2012). Common shrubs include poison oak, birch-leaf mountain-mahogany, Klamath plum (*Prunus subcordata* Benth.), western serviceberry, and deerbrush.

Chaparral shrubs are adapted to fire and quickly establish after fire via sprouting or a long-lived soil seed bank (Keeley 1991). Once established, shrubs impede tree seedling establishment and development of forests (Conard and Radosevich 1982, Nagel and Taylor 2005). Patches of chaparral, tens to hundreds of hectares in size, were part of historical landscapes in fire-prone forests (Airey Lauvaux et al. 2016). These patches were likely maintained by relatively low-frequency (compared to the surrounding forest), high-intensity fire (Airey Lauvaux et al. 2016). However, many areas historically dominated by shrublands have now converted to conifers in areas where fire has been excluded (Duren et al. 2012).

Potential future changes—

With increasing fire frequency and summer water deficit in a warming climate, shrublands will likely expand in the drier portions of southwest Oregon (table 5.3) (Airey Lavaux et al. 2016, Myer et al. 2013, Tepley et al. 2017). The LANDIS-II model projected forest loss and expansion of a shrub, chaparral, and hardwood type in dry (interior) portions of the assessment area. MC2 also projected expansion of shrublands in hotter and drier scenarios. Paleoecological studies in the region suggest that chaparral expanded during warm and dry periods in the past (Daniels et al. 2005).

As climatic water deficit increases, areas at the dry end of the present distribution of conifer forests may shift to shrublands after severe fire. Chaparral shrub species establish well in forests burned at high severity (Airey Lavaux et al. 2016). Repeated fire could perpetuate chaparral vegetation because short intervals between severe fires and drought conditions do not allow for forest establishment (Airey Lavaux et al. 2016).

Nearby trees provide the seed source for conversion of chaparral to forest (Airey Lavaux et al. 2016). However, in large, high-severity fire patches, long distances to local tree seed sources could slow or prevent establishment of forests. Conversion to shrubland would likely occur with increasing loss of mature forest in high-severity fire and increasing frequency of short-interval, high-severity reburns, with each successive fire killing more regenerating conifers and potential seed trees (Tepley et al. 2017). Drought conditions will likely further limit tree seedling regeneration on dry sites.

Special Habitats

Riparian Areas

The primary effects of climate change on riparian areas in southwest Oregon will likely be mediated through disturbance. Increased winter flooding may occur in some riparian areas as a result of lower snowpack and increased intensity of winter precipitation events (Hamlet et al. 2013) (chapter 3). Increased peak flows would affect erosion and sedimentation, which could in turn affect channel form and the fluvial dynamics of streams and their riparian zones (Capon et al. 2013).

Fires generally burn with lower severity in southwest Oregon riparian areas compared to uplands and affect soil to a lesser extent (Halofsky and Hibbs 2008). However, fire exclusion has resulted in denser forests in some riparian areas and adjacent uplands (Messier et al. 2012), and climate change will likely increase area burned. More frequent fire is likely to favor hardwood species (e.g., red alder, white alder [*Alnus rhombifolia* Nutt.]) and shade-intolerant conifers.

Riparian vegetation depends on the presence of flowing water. With climate change, summer streamflows will likely decrease because of earlier snowmelt and earlier runoff (Luce and Holden 2009, Safeeq et al. 2013, Stewart et al. 2005). Increasing temperature and evapotranspiration and decreasing summer streamflows may lead to drying in some riparian areas (Dwire and Mellmann-Brown 2017); some intermittent reaches may become ephemeral, and some perennial reaches may become intermittent. Drying in riparian areas could decrease the extent of the riparian zone in some locations or result in shifts in riparian plant community composition. Drier conditions and more frequent fire in riparian areas may favor upland-associated species (e.g., conifers) over those typically associate with riparian areas (e.g., deciduous hardwoods), particularly along smaller streams.

Species that rely specifically on cold, flowing water are particularly vulnerable to warming and drying in riparian areas. Shifts in riparian vegetation will depend on elevation, location within a watershed, and land use. However, shifts to more drought-tolerant species can be expected, and shifts to more disturbance-tolerant species, such as red alder, may occur with increased flooding, wildfire, and insect outbreaks. Nonnative species may also become more competitive in riparian areas with increased opportunities for invasion after disturbance (Catford et al. 2013). Changes in riparian plant species composition and reduced riparian extent could result in direct losses of the quantity and quality of ecological contributions of riparian vegetation, such as wildlife habitat, shade over streams, and buffer capacity for maintenance of water quality (Capon et al. 2013, Dwire and Mellmann-Brown 2017).

Some riparian areas in southwest Oregon are dominated by Port Orford cedar, a near-endemic species to the Klamath-Siskiyou ecoregion. Port Orford cedar and other species provide dense shade over streams, contributing to cool stream temperatures and high water quality. Port Orford cedar is affected by root rot caused by the nonnative waterborne fungus *Phytophthora lateralis*. The disease is spread by mud on vehicles and hiking boots and can cause high mortality in Port Orford cedar stands. Forest Service and BLM lands in the region contain infected Port Orford cedar in several locations. Port Orford cedar is fire tolerant, and seedlings can establish on mineral soil after fire, so increased fire may not negatively affect this species unless fire suppression facilitates the spread of root rot.

Wetlands and Groundwater-Dependent Ecosystems

Higher temperatures, reduced snowpack, and increased evapotranspiration may also have significant effects on wetlands and groundwater-dependent ecosystems in southwest Oregon. Less water during the summer would alter local hydrology, potentially reducing the duration and depth of standing water, and increasing water temperature in wetlands and groundwater-dependent systems (Lee et al. 2015). This could affect local distribution and abundance of plant species associated with these ecosystems (Dwire and Mellmann-Brown 2017), as well as aquatic fauna (especially amphibians).

Many wetlands are groundwater-dependent, and snowpack is the main source of groundwater recharge in montane areas (Winograd et al. 1998). Reduced snowpack with climate change will likely decrease the length of time aquifer recharge can occur, potentially leading to faster runoff, less groundwater recharge, and less groundwater to support springs and groundwater-dependent wetlands (Dwire and Mellmann-Brown 2017). Some groundwater-dependent wetlands may decrease in size or completely dry out in summer. However, effects will vary depending on hydrogeologic setting (Drexler et al. 2013). Some groundwater resources may be less sensitive to climate change than surface water, depending on local and regional geology, and surrounding land and water use (Tague and Grant 2009); slowly infiltrating precipitation that includes both rain and snow could recharge groundwater aquifers as effectively as rapid, seasonal snowmelt runoff (Dwire and Mellmann-Brown 2017).

Ephemeral or intermediate wetlands at higher elevations are expected to be highly sensitive to a warmer climate; some ephemeral montane wetlands may disappear, and some intermediate montane wetlands may become ephemeral (Lee et al. 2015). Some wetlands, especially those connected to deep groundwater sources (as opposed to surface water-fed wetlands), may experience earlier drawdown and reach their minimum water level earlier, but without drying out (Lee et al. 2015). Wetlands at lower elevations will be vulnerable to increasing water demands, pressure for increased diversion or water development, and other land use activities that require water (Dwire and Mellmann-Brown 2017).

Serpentine fens—

Fens are wetlands that exist in the presence of cold, flowing water at or near the surface. Serpentine fens are considered minerotrophic because water (from streams or springs) flows over rocks or other minerals and acquires dissolved chemicals, which raise the nutrient levels and reduce the acidity of the water. Serpentine fens, also known in earlier literature as mountain bogs or mires, are ecologically isolated wetlands, typically in montane forests. Groundwater is typically within 20 to 40 cm of the surface during the growing season (Aldous and Bach 2014). Fen systems have been further categorized as hillslope, terrace, or streamside types (Sweeney 2003).

In the Siskiyou-Klamath Mountains, where a predominance of serpentine- or peridotite-derived soils are found, fens contain endemic (box 5.1) and rare species (Jules et al. 2011, Schuller et al. 2010), including Oregon bensoniella (*Bensoniella*

Box 5.1

Endemic Plants

Endemic plants are species found only in specific or local habitats or geographic areas and are usually rare, and may therefore be vulnerable to land use activities and other stressors (Harrison et al. 2009, Jules et al. 2011). Table 5.4 provides a list of endemic taxa in the Klamath-Siskiyou Ecoregion. Drying and warming climatic conditions will likely reduce most populations of these mesophytic species, but most of these taxa likely have some resilience to changing climate based on (1) their survival of past evolutionary stressors, and (2) potential benefits from reduced spread of invasive, nonnative plant species in a drier climate (Harrison et al. 2009). A generalized response of these endemic species to climate change is difficult to infer owing to their individual habitat requirements. Vegetation type, hydrologic circumstances, and the unique geological setting in which these species currently are found may be important to monitor in the future to assess effects of changing climate on these species.

Table 5.4—Endemic taxa within the Klamath-Siskiyou region[a]

Family	Species	Habitat	Status	Reference
Asparagaceae	*Hastingsia bracteosa* S. Watson	Serpentine bogs and fens	Regional endemic; threatened (Oregon)	Meyers et al. 2015, Peck 1961
Liliaceae	*Calochortus indecorus* Ownbey & M. Peck	Wetland edges and wet meadows	Endangered (Oregon); extinct?	Dyrness et al. 1975, Meyers et al. 2015
	C. greenei S. Watson	Shrubby hillsides, grass woodland	Status uncertain	Baldwin et al. 2012
	C. coxii M.R. Godfrey & Callahan	Serpentine grasslands and woodlands	Endangered (Oregon)	Meyers et al. 2015
	C. nitidus Douglas	Open grasslands	Extirpated (Jackson County, Oregon)	Meyers et al. 2015
	C. umpquaensis Fredricks	Serpentine meadows	Narrow endemic; endangered (Oregon)	Meyers et al. 2015
	Erythronium citrinum S. Watson	Serpentine woodlands and open slopes	Local endemic, Siskiyou Mountains	Baldwin et al. 2012, Dyrness et al. 1975, Meyers et al. 2015
	Fritillaria gentneri Gilkey	Dry woodlands, Siskiyou Mountains	Endangered (Oregon)	Meyers et al. 2015
	Lilium occidentale Purdy	Saturated sedges or margins of fen systems, forest gaps	Rare, over collected; endangered (Oregon)	Baldwin et al. 2012, Meyers et al. 2015

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Table 5.4—Endemic taxa within the Klamath-Siskiyou region[a] (continued)

Family	Species	Habitat	Status	Reference
	Lilium pardalinum ssp. *shastense* (Eastw.) M.W. Skinner	Wet meadows, stream sides/ riparian	Regional endemic	Baldwin et al. 2012, Meyers et al. 2015
	Lilium pardalinum ssp. *vollmeri* (Eastw.) M.W. Skinner	Mountain springs, stream sides, and bogs	Regional endemic, Siskiyou Mountains	Baldwin et al. 2012, Meyers et al. 2015
Orchidaceae	*Cypripedium californicum* A. Gray	Serpentine fens and wet meadows, seepage slopes	Serpentine endemic	Baldwin et al. 2012, Meyers et al. 2015
	C. montanum Douglas ex Lindl.	Dry slopes, mixed evergreen or conifer forests	Rare	Baldwin et al. 2012, Meyers et al. 2015
Asteraceae	*Microseris howellii* A. Gray	Open or forested serpentine slopes	Threatened (Oregon); Josephine and Curry Counties	Baldwin et al. 2012 (see p. 388), Meyers et al. 2015 (see page 557)
	Rudbeckia glaucescens Eastw.	Serpentine fens, seeps	Broad endemic, Southwest Oregon, Northwest California	Baldwin et al. 2012, Safford et al. 2005
Gentianaceae	*Gentiana setigera* A. Gray	Wet mountain meadows and serpentine fens	CNPS 1B.2	Baldwin et al. 2012, Meyers et al. 2015, Safford et al. 2005, Sweeney 2003

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oregona (Abrams & Bacig.) C.V. Morton), Siskiyou Indian paintbrush (*Castilleja miniata* ssp. *elata* (Piper) Munz), California lady's slipper (*Cypripedium californicum* A. Gray), mountain lady's slipper (*C. montanum* Douglas ex Lindl.), cream fawnlily (*Erythronium citrinum* S. Watson), oppositeleaf lewisia (*Lewisia oppositifolia* (S. Watson) B.L. Rob.), redwood lily (*Lilium rubescens* S. Watson), Howell's silverpuffs (*Microseris howellii* A. Gray), western ragwort (*Packera hesperia* (Greene) W.A. Weber & Á. Löve), Grants Pass willowherb (*Epilobium oreganum* Greene), and Mendocino gentian (*Gentiana setigera* A. Gray). These taxa can persist in the otherwise toxic soils associated with the serpentinite rock, which typically contain higher magnesium-to-calcium ratios and higher concentrations of heavy metals such as boron, lead, nickel, and cadmium than soils found on nonserpentine sites.

Table 5.4—Endemic taxa within the Klamath-Siskiyou region[a] (continued)

Family	Species	Habitat	Status	Reference
Onagraceae	*Epilobium oreganum* Greene	Serpentine fens	Regional endemic; CNPS 1B.2	Baldwin et al. 2012, Schuller et al. 2010
Orobanchaceae	*Castilleja miniata* ssp. *elata* (Piper) Munz	Serpentine fens	Regional endemic; endangered CNPS 2B.2	Baldwin et al. 2012
Ranunculaceae	*Enemion occidentale* (Hook. & Arn.) J.R. Drumm. & Hutch.	Chaparral, oak woodland, coniferous forest	Regional endemic northern California, southwest Oregon	Baldwin et al. 2012
Rosaceae	*Drymocallis ashlandica* (Greene) Rydb.	Wet meadows	Locally restricted endemic	Baldwin et al. 2012 (see p. 1175)
Sarraceniaceae	*Darlingtonia californica* Torr.	Serpentine fens and related wetlands	Widespread but vulnerable owing to unique habitat	Baldwin et al. 2012
Saxifragaceae	*Bensoniella oregona* (Abrams & Bacig.) C.V. Morton	Dry to wet meadows, bogs.	Threatened, CNPS 1B.1	Baldwin et al. 2012
Violaceae	*Viola primulifolia* var. *occidentalis* A. Gray	Marshes and serpentine fens with *Darlingtonia*	Endangered Oregon candidate; CNPS 1B.2	Baldwin et al. 2012, Sweeney 2003

[a] Status in Oregon per Oregon Department of Agriculture, Endangered and Threatened Plant Species, OAR 603-073-0070. CNPS indicates status as determined by the California Native Plant Society (2018).

Sweeney (2003) identified the main threats to serpentine fens in the Klamath-Siskiyou region. These threats include mining-related disturbances, high-severity fire, livestock overgrazing, road building, increased off-road vehicle activity, and alteration of the hydrologic regime. The long-term detrimental impacts of increased fire frequency in these habitats could be limited by low fuel loading and the ability of most species to sprout from perennial rootstock. Species sensitivity to fire will depend on canopy closure requirements of some of the fen taxa, such as Grants Pass willowherb, which is highly correlated with some canopy shading. In addition, encroachment by trees and shrubs into fen ecosystems with continued drier and warmer conditions could increase fuel loading, with resultant longer term smoldering, greater soil heating, and more extensive impacts into these otherwise low-fuel habitats than in the past (Jules et al. 2011). Decomposition of deeper, previously anoxic peat layers deeper in fen systems will likely result from drier climatic conditions. This potentially will add additional combustibles to the drier surface vegetation, increasing fuel in fens and promoting long-term smoldering (Ćížková et al. 2013).

Direct loss of serpentine fens may result from fireline construction in the immediate habitat areas, with secondary impacts resulting from altered drainage patterns and surface or subsurface hydrologic flows. Increased sediment deposition after fire on the slopes containing these wetlands will also impair hydrologic function, leading to increased woody plant encroachment into the previous fen peatland systems (Ćížková et al. 2013). Any upslope hydrologic changes associated with future shifts to a drier climate will likely reduce habitat in the absence of adequate groundwater supply to the fen systems (Aldous and Bach 2014). Livestock grazing-related impacts may become more pronounced in a warmer climate as animals penetrate fens and meadow areas. The maintenance of these groundwater-dependent fens depends on preserving the integrity of hydrologic flows in the regional landscape (Aldous and Bach 2014).

Individual fens may be further isolated in the future (Ćížková et al. 2013), reducing genetic diversity of the remaining populations. This may reduce populations of pollinators, with subsequent decline in genetic diversity between and within the plant populations in these otherwise ecologically isolated endemic plants (Fielder et al. 2011). How these historical threats and potential future threats yet identified might be affected by climate change is key in understanding the conservation of the serpentine fen systems of the Klamath-Siskiyou region.

Adapting Vegetation Management to Climate Change

Based on the vulnerability assessment information presented in this chapter, and on documented adaptation principles (e.g., Millar et al. 2007, Peterson et al. 2011b, Swanston et al. 2016), adaptation options for southwest Oregon were identified by participants in a workshop that took place in Grants Pass, Oregon, in April 2018. Adaptation options were aimed at reducing the negative effects of climate change and facilitating transition of systems to changing conditions. Workshop participants identified strategies, or general approaches, for adapting vegetation management to climate change (table 5.5). Participants also identified more specific on-the-ground tactics, or actions, associated with each adaptation strategy and considered the implementation of those tactics, specifically opportunities for implementation, and locations or situations in which tactics can be applied.

These strategies and tactics, intended to guide both short- and long-term planning and management, were required to be feasible with respect to budget and level of effort, and to be acceptable within current policies. Adaptation strategies and tactics were focused on addressing key climate change sensitivities for vegetation

Table 5.5—Forest vegetation adaptation options for southwest Oregon

Sensitivity to climate change	Adaptation strategy	Adaptation tactic
Hotter and drier conditions will increase forest drought stress, lead to reduced forest productivity, and increase susceptibility to secondary stressors such as disease, insects, and hydraulic failure.	Increase drought resilience and forest vigor.	• Manage vegetation density to reduce soil moisture stress. • Facilitate conversion to suitable species and vegetation communities (considering natural range of variability). • Leverage disturbance events to restore ecosystem function. Be ready for rapid response. • Increase the amount of thinning and possibly alter thinning prescriptions (e.g., consider lower tree densities).[a] • Use girdling, falling and leave trees, prescribed burns, and wildland fire to reduce stand densities and drought stress.[a] • Maximize early-successional tree species diversity by retaining minor species during precommercial thinning activities to promote greater resilience to drier conditions.[a] • Consider including larger openings in thinning prescriptions and planting seedlings in the openings to create seed sources for native drought-tolerant species.[a] • Reduce density of postdisturbance tree planting.[a] • Plant resistant species or genotypes where species-specific insects or pathogens are a concern.[a] • Increase stand-scale biodiversity and minimize monocultures.[a] • Treat existing pathogen outbreaks with more aggressive management.[a]
	Maintain and enhance forest productivity regardless of tree species; focus on functional ecosystems and processes.	• Manage species densities to maintain tree vigor and growth potential.[a] • Prepare for species migration by managing for multiple species across large landscapes.[a] • Maintain soil productivity through appropriate silvicultural practices.[a]
	Increase forest landscape resilience to large and extensive insect or pathogen outbreaks.	• Design forest gaps that create establishment opportunities.[a] • Increase diversity of patch sizes.[a] • Consider planting desired species (assisted migration) rather than relying on natural regeneration and migration.[a]
	Recognize natural role of insect disturbances, and identify areas at high risk.	• Tolerate some natural mortality.[a] • Implement prescribed burning in areas affected by insect outbreaks.[a] • In dry forest, restore low-severity fire and early-successional species.[a]
	Promote diversity of forest age and size classes.	• Diversify large contiguous areas of single age and size classes.[a]
	Increase resistance to invasion by nonnative insects.	• Assertively apply early detection and rapid response to limit nonnative insects.[a]
Climate change will likely lead to changes in disturbance regimes.	Promote conditions to facilitate response or transition while maintaining function. Increase understanding of disturbance processes and patterns.	• Monitor disturbance events. Identify trends and use information to improve forecasting. • Align planning process to proactively address shifting disturbance regimes. • Promote social acceptance and public awareness of management.

Table 5.5—Forest vegetation adaptation options for southwest Oregon (continued)

Sensitivity to climate change	Adaptation strategy	Adaptation tactic
Climate change will increase the potential for mortality events and regeneration failures.	Promote regeneration of older trees to ensure adaptation of progeny to future conditions.	• Thin older forests to reduce fire hazard, protect older trees, and support regeneration.[a]
	Use judiciously managed relocation of genotypes where appropriate.	• Modify seed zone guidelines to a variety of genotypes rather than just one.[a]
	Protect genotypic and phenotypic diversity	• Protect trees that exhibit adaptation to water stress (e.g., trees with low leaf-area-to-sapwood ratios); collect seed for future regeneration.[a] • Maintain variability in species and in tree architecture in some locations.[a]
	Use tree improvement programs to ensure availability of drought-tolerant tree species and genotypes.	• Develop seed orchards that contain a broader range of tree species and genotypes than in the past.[a]
Increased temperatures and lower snowpack will result in more fire (larger aerial extent and more high-severity patches) and more area in recently burned or early-successional stages.	Plan and prepare for greater area burned.	• Anticipate more opportunities to use wildfire for resource benefit.[a] • Plan postfire response for large fires.[a] • Consider using prescribed fire to facilitate transition to a new fire regime in drier forests.[a] • Consider planting fire-tolerant tree species after fire in areas with increasing fire frequency.[a] • Manage forest restoration for future range of variability.[a]
	Increase resilience of existing vegetation by reducing hazardous fuels and forest density and maintaining low densities.	• Thin and burn to reduce hazardous fuels in the wildland-urban interface.[a] • Increase intentional use of lightning-ignited fires and management of reignition of lightning-ignited fires.[a] • Consider using more prescribed fire where scientific evidence supports change to a more frequent fire regime.[a] • Use prescribed fire to maintain structure and promote fire-tolerant conifer species.[a] • Increase interagency coordination.[a] • Conduct thinning treatments (precommercial and commercial).[a] • Use regeneration and planting to influence forest structure.[a]
	Increase resilience through postfire management.	• Consider climate change in postfire rehabilitation.[a] • Determine where native seed may be needed for postfire planting.[a] • Anticipate greater need for seed sources and propagated plants.[a] • Increase postfire monitoring in areas not currently monitored.[a]
	Manage forest vegetation to reduce severity and patch size; protect refugia (e.g., old trees).	• Map fire refugia.[a] • Use gaps in silvicultural prescriptions.[a] • Identify processes and conditions that create fire refugia.[a]
	Use high-severity wildfires as opportunities to “reset the clock.”	• Use postfire timber harvest to prevent uncharacteristic reburns.[a] • Allow some burned areas to regenerate naturally.[a]

Table 5.5—Forest vegetation adaptation options for southwest Oregon (continued)

Sensitivity to climate change	Adaptation strategy	Adaptation tactic
	Manage forest landscapes to encourage fire to play a natural role.	• Implement fuel breaks at strategic locations.[a] • Create incentives to encourage wildland fire use.[a] • Implement strategic density management through forest thinning.[a] • Incorporate climate change in the Wildland Fire Decision Support System.[a] • Push boundaries of prescribed burning (e.g., burn earlier in spring, later in summer).[a]
Higher temperatures may increase stress for some species in cold upland and subalpine forests.	Protect rare and disjunct tree species.	• Plant and encourage regeneration of rare and disjunct species in appropriate locations.[a]
	Protect cold upland and subalpine forests by restoring forests at lower elevations, thus reducing spread of large crown fires.	• Create targeted fuel breaks at strategic landscape locations.[a] • Thin dry forests to densities low enough to reduce fire intensity and spread.[a]
	Accelerate restoration of cold upland and subalpine forests where appropriate.	• Increase the availability of nursery stock and seed for tree species in cold upland and subalpine forests.[a]
Disturbances will change large-scale patterns, structure, species composition, relative abundance, and species distribution patterns.	Increase knowledge of patterns, characteristics, and rates of change in species distributions.	• Expand long-term monitoring programs.[a]
	Create landscape patterns that are resilient to past and expected disturbance regimes.	• Continue research on expected future disturbance regimes; evaluate potential transitions and thresholds.[a] • Improve communication across boundaries.[a] • Manage for diversity of structure and patch size with fire and mechanical treatments.[a]
Climate change will likely result in increased tree mortality and loss of site conditions that support vulnerable species.	Promote resiliency in communities with vulnerable species and increase resistance to mountain pine beetle.	• Identify sites that are less likely to be affected by climate change (e.g., refugia), and focus on those sites for restoration.[a]
Large-scale disturbances (beetles, fire, white pine blister rust) will affect whitebark pine.	Increase competitive ability and resilience of whitebark pine to changing disturbance regimes.	• Control beetles.[a] • Daylight (thin) to reduce competition (usually involves removing subalpine fir).[a] • Regenerate rust-resistant strains, increase seed sources, maintain cache sites.[a] • Create fuelbreaks.[a]

Table 5.5—Forest vegetation adaptation options for southwest Oregon (continued)

Sensitivity to climate change	Adaptation strategy	Adaptation tactic
Climate change may threaten endemic, refugia, or relict species.	Conserve genetic and phenotypic diversity and increase species' resilience to conditions based on climate change projections.	• Develop a gene conservation plan for ex situ collections for long-term storage.[a] • Identify areas important for in situ gene conservation.[a] • Maintain a tree seed inventory with high-quality seed for a range of species, particularly species that may do well in the future under hotter and drier conditions.[a] • Use seeding of native plant species in areas with nonnative species.[a] • Prepare for species migration by managing for multiple species across large landscapes.[a] • Plant and encourage regeneration of rare and disjunct species in appropriate locations.[a] • Collect seed for a wide range of seed zones and species.[a] • Use prescribed fire or wildland fire to maintain and promote fire-dependent native species.* • Use shaded fuel breaks or other tactics to protect populations that are vulnerable to fire or repeated fire disturbances. • Modify seed-zone guidelines to move seed zones to locations that are appropriate in elevation and temperature, and work with area geneticists to determine appropriate locations. • Modify genetic movement guidelines to allow more flexibility.
Climate change will increase invasive species establishment.	Minimize establishment and spread of invasive species.	• Implement early detection and rapid response for invasive species treatment.[a] • Coordinate invasive species management, funding, and support between agencies.[a] • Include invasive species prevention strategies in all projects.[a] • Inventory regularly to detect new populations and species.[a] • Plan for extreme events.[a] • Maintain permits for aggressive treatment of invasive species (e.g., burning and herbicides).[a] • Emphasize use of plant species that will be robust to climate change in restoration projects.[a] • Promote weed-free seed.[a] • Prevent nonnative plant introductions during projects.[a] • Ensure weed-free policies are included in planning documents.[a] • Coordinate weed-free seed standards and regulations among agencies.[a] • Expand weed-free feed lists to include additional nonnative species.[a] • Incorporate a seasonal outlook to determine which and when invasive species control activities have highest success. • Plant native species to compete with invasive species.
Earlier flowering may lead to phenological mismatches such that pollinators are not present when flowering begins.	Maintain and increase genetic diversity. Try to minimize mismatches in timing between flowering and pollinator timing.	• Create different microsites to modify phenology within a species (e.g., sun versus shade, wet versus dry) • Consider creating larger openings to offset loss of fruit production owing to phenological mismatches. • Thin to increase and prolong snow cover. • When planting, use diverse genetic material within a species as well as for different species.

[a] Indicates adaptation strategies and tactics from the Climate Change Adaptation Library for the Western United States (http://adaptationpartners.org/library.php) identified as relevant to southwest Oregon by workshop participants.

in southwest Oregon, including changing disturbance regimes (fire, insects, disease, drought, invasive species establishment); the potential for mortality events and regeneration failures; changing species distribution; threats to endemic and relict species; and phenological mismatches between flowering plants and pollinators. These adaptation strategies and tactics are summarized below and in table 5.5.

Increasing temperatures and drought stress will likely decrease productivity in dry forests (Littell et al. 2010) and increase susceptibility to secondary stressors, such as insects (Hicke et al. 2016, Millar and Stephenson 2015, Young et al. 2017). Reducing vegetation density with thinning treatments can decrease intertree competition for water and light and increase growth and vigor of residual trees. Thus, thinning can improve both the resistance and resilience of trees to drought (Bottero et al. 2017, Clark et al. 2016, D'Amato et al. 2013, Sohn et al. 2016, Vernon et al. 2018), where drought resistance is the ability of trees to survive and maintain growth during drought, and drought resilience is the ability of trees to survive and resume pre-drought growth rates after the event. Reductions in forest stand density, coupled with hazardous fuels treatment, can also increase forest resilience to wildfire (Agee and Skinner 2005; Hessburg et al. 2015, 2016). In southwest Oregon, thinning treatments can be prioritized in areas where tree encroachment with fire suppression has occurred (e.g., Douglas-fir in dry forests and oak woodlands) and where drought stress is expected to be most severe (e.g., on south-facing slopes and on soils with low water-holding capacity).

Similarly, prescribed fire reduces stand densities in dry forests, so prescribed fire can increase resilience to both wildfire and drought (Johnson et al. 2007, Keeley et al. 2009, Peterson et al. 2011a). Prescribed fire is likely to be most effective in vegetation types that historically experienced frequent, low- to mixed-severity fire and that have been affected by fire exclusion (e.g., dry and mesic forests and oak woodlands). Although it may be feasible to reduce effects of drought and fire at the stand or project level, the spatial scale of treatments would need to be increased considerably, and maintained over time (Elkin et al. 2015, Sohn et al. 2016), to function effectively at a large spatial scale (Halofsky et al. 2016). The potential expansion of the use of prescribed fire as a management tool would require several changes, including increased public acceptance of smoke during the fall, winter, and spring months, and less restrictive air quality regulations around smoke. The Oregon Environmental Quality Commission approved new smoke rules in 2019 (OR DEQ 2019) that should make it easier to use prescribed fire. Agencies could work to promote social acceptance and awareness of management with the public through partnerships and collaborative groups. Increasing the scale of prescribed fire and managed wildland fire for resource benefits may also require increased acceptance of risk on the part of land management agencies. Thus, incentives may be needed to promote fire use (table 5.5).

Managers may also reconsider postwildfire forest restoration actions in dry forests, particularly in high-severity patches. Potential adaptation strategies include planting at lower densities than would have been prescribed in the past, varying planting densities by site microclimate, and using the concept of individuals, clumps, and openings. These strategies will take advantage of landscape position and microclimate to increase forest resilience to a changing climate and create spatial discontinuity in fuels (North et al. 2019).

Preparing for disturbance will also be important in a changing climate (Keane et al. 2017, Millar et al. 2007). Managers suggested that planning processes could be aligned to allow them to proactively address shifting disturbance regimes (table 5.5). Monitoring of disturbance events (e.g., with Forest Health Protection aerial detection surveys [USDA FS 2019]) and identifying trends could also help in development of disturbance forecasting tools, allowing managers to better anticipate when and where disturbance events may occur.

Some management actions can increase ecosystem resilience to native insect outbreaks. For example, restoring historical fire regimes in dry forests and oak woodlands, reducing Douglas-fir encroachment in dry vegetation types (e.g., dry forest and oak woodlands), and increasing diversity of forest structure and age and size classes may help to minimize the impacts of insect outbreaks (Churchill et al. 2013), such as flatheaded fir borer outbreaks. Increasing tree species diversity may also help to improve resilience to insect outbreaks (Dymond et al. 2014), particularly in low-diversity stands.

Fire and other large-scale disturbance events provide opportunities to plant diverse species and genotypes (including genotypes adapted to drought) and modify forest structure. Through postfire management, managers may be able to help transition ecosystems to warmer conditions by promoting species and genotypes tolerant of future conditions in a particular forest type and setting. Managers may want to consider modifying seed transfer guidelines to allow more flexibility (table 5.5). The Seedlot Selection Tool (https://seedlotselectiontool.org/sst/) can help identify seedling stock that will be adapted to a given site in the present and the future. However, planting may not be successful in all locations and in all postdisturbance periods. For example, plantings are unlikely to be successful during severe or extended drought.

In general, regeneration in the driest topographic locations may be slower in a warming climate than in the past. Some areas are likely to convert from forest to nonforest vegetation, particularly at lower elevations. Managers may need to consider where they will try to forestall change and where they may need to allow conversions to occur (Rother et al. 2015).

Many plant species will be subjected to increasing stress in a changing climate, and some species and genotypes may be unable to adapt to rapid warming.

Managers identified adaptation options to maintain particular species or community types of concern. For example, prescribed fire could be used to promote fire-dependent native species in southwest Oregon habitats, including meadows, huckleberry habitats, dry mixed-conifer forest that includes pine, oak woodlands, serpentine areas and fens, and beargrass habitats. Shaded fuel breaks or other tactics could be used to exclude fire from populations that are vulnerable to fire or repeated high-severity fire (table 5.5). These populations occur in the Kalmiopsis Wilderness and riparian old-growth areas.

Reducing the effects of existing nonclimatic stressors on ecosystems, such as invasive species, will increase ecosystem resilience to climatic changes (Joyce et al. 2009). Tactics to minimize establishment and spread of invasive species include early detection-rapid response for new invasions, implementing weed-free policies, preventing invasive plant introductions during projects, and planting locally adapted, native species to compete with invasives (ecologically based invasive plant management) (table 5.5). These tactics can be focused in high-priority locations such as serpentine sites, riparian areas, research natural areas, botanical areas, wilderness, locations with rare species, areas that do not have invasive species present, and areas important to American Indian tribes.

A changing climate has led to a decline of pollinators in some communities (Potts et al. 2010) and may lead to phenological mismatches between pollinators and host plants (Forrest 2015). To minimize mismatches in timing between flowering and pollinator timing, managers can create different microsites to change phenology within a species (e.g., create moderately sized forest openings to increase snow accumulation (Varhola et al. 2010), keep soils moister and cooler, and delay plant and pollinator emergence). After disturbances, managers can plant diverse genetic material within a species, as well as a variety of different species, to increase the chance of phenological overlap between flowering plants and pollinators.

Summary and Conclusions

Higher temperatures, soil moisture deficits, and wildfire will affect species composition and structure of vegetation across southwest Oregon. Increased temperatures and reduced snowpack may lead to significant reduction in climatically suitable habitat for high-elevation forests. Dominant species in the subalpine zone may experience increased competition from species that are currently dominant at lower elevations, including Douglas-fir, western hemlock, and white fir. Earlier snowmelt and longer growing seasons may increase tree growth but will also lengthen the summer dry period. Area burned by high-severity fires may increase.

Moist and mesic forests in southwest Oregon will likely continue to be dominated by Douglas-fir and other early-seral species with increasing temperature and disturbance rates. Fire- and drought-intolerant species, including western hemlock, Pacific silver fir, and western redcedar, are likely to decrease in abundance in moist forests, and white fir may decrease in mesic forests. Tanoak may be favored by increasing fire frequency in the Siskiyou Mountains, and red alder is likely to expand with increasing disturbance in coastal locations. Mesic forests could transition to more xeric forest limited by summer drought stress and maintained by more frequent fire.

Shifts from dry forest to woodlands or shrublands may occur in the driest portions of the current dry-forest range. Drought stress and large, high-severity fire patches may impede forest development in some locations. Conversion to shrubland would likely occur with increasing loss of mature forest in high-severity fire, and increasing frequency of short-interval, high-severity reburns will likely kill more regenerating conifers and potential seed trees with each successive fire. Tree growth will likely be reduced for dry forest species. Tree mortality may also increase in some locations because of the interacting effects of drought, disturbance, and insects.

Overall, southwest Oregon may have high resilience to climate change because of the topographic heterogeneity and varied microclimates that characterize the region, which create climate refugia and allow for species persistence (Briles 2017). For example, north aspects may be refugia for species limited by drought stress in drier locations. However, dispersal to newly suitable habitats may be limiting, particularly in landscapes fragmented by developed lands. Where fuels have accumulated as a result of fire exclusion, forests and woodlands are at risk of high-severity fire (Sensenig et al. 2013). Second-growth forests may be particularly vulnerable to drought, fire, and insect outbreaks in the future because of their high density and low structural diversity. Interactions among multiple stressors may result in rapid changes in forest ecosystem composition and structure, as well as ecosystem services (Millar and Stephenson 2015).

Using thinning and prescribed fire in dry forests to reduce risk of high-severity fire and increase resilience to climate change was a clear focus of adaptation actions developed by resource managers in the southwest Oregon workshop, as it has been in other similar efforts (Halofsky et al. 2016, Keane et al. 2017, Kerns et al. 2017). Other adaptation options were focused on postfire management to help ecosystems transition to new conditions, promoting plant species or community types of concern, and reducing the effects of existing nonclimatic stressors on ecosystems. Managers will need to consider multiple values, ecosystem services, and ecosystem stressors (e.g., fire, insects, disease, and invasive species) in determining the type, extent, and intensity of adaptation actions with climate change (Halofsky et al. 2016).

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Chapter 6: Climate Change Effects on Wildlife in Southwest Oregon

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Introduction

Wildlife communities in southwest Oregon reflect the substantial climate gradients and complex topography, geology, and ecology of the region. Bounded by the Pacific Ocean on the west and the Cascade Range on the east, the current climate encompasses cool and moist near the coast, hot and dry in the interior valleys, and relatively cold with abundant snow at the Cascade Crest (chapter 2). Floristically, the region combines elements of the Oregon Coast and Cascade Ranges, California north coast, and eastern Oregon ecological communities, with a large number of species indigenous to the Siskiyou Mountains (DellaSala 1999, Franklin and Dyrness 1973, Whittaker 1960). This environmental and floristic diversity combines with a long history of human-caused and natural disturbances to produce complex landscape patterns and rich ecological communities. Approximately 374 species of terrestrial vertebrates occur in this area, including 240 species of birds, 98 mammals, 21 amphibians, and 20 reptiles (Oregon Explorer 2018).

The climate in southwest Oregon has been changing and is expected to continue to change in coming years (Retallack et al. 2016) (chapter 2). Projections indicate that this region will experience increased temperatures year-round, with more very hot days in summer and fewer below-freezing days in winter. Projections of future precipitation are uncertain (chapter 2). The total annual amount of precipitation may not change much, but seasonal variability may be amplified, with more flooding in winter and drought in summer. Amount and duration of snow cover will be substantially reduced, with important implications for hydrology, particularly in historically snow-dominated subbasins (chapter 3). These effects are already being realized within the Southwest Oregon Adaptation Partnership (SWOAP) assessment area (chapter 2). Temperatures have become warmer, and snowmelt is occurring earlier. The summer wildfire season has gotten longer, and mean annual area burned by wildfires has increased (chapter 5). These trends are all expected to continue, with anticipated increases in wildfire frequency, length of fire season, and annual area burned.

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The changing climate can have both direct and indirect impacts on wildlife. Direct physiological effects of exposure to warmer temperatures have the potential to cause thermal stress in animals, with potentially fatal consequences (Bernardo and Spotila 2006). However, all species have physiological and behavioral adaptations that contribute to thermoregulation, and sensitivity to thermal stress is highly variable across species. For example, ectotherms (cold-blooded amphibians and reptiles) are generally more sensitive than endotherms (warm-blooded mammals and birds) (Kearney et al. 2009), larger bodied animals are generally more sensitive than smaller bodied species (Speakman and Król 2010), species with flexible activity periods may be less sensitive than obligate diurnal or nocturnal species (McCain and King 2014), and species that are specialized for cool habitats are likely to be particularly vulnerable (Bernardo and Spotila 2006).

Although the physiological effects of warmer temperatures are likely to be important for some species, the most widespread effects of climate change on animals are expected to be the result of changes in the complex relationships between animals and their habitats (Cahill et al. 2013, Ockendon et al. 2014). Habitat for a species is an area that encompasses the necessary combination of resources and environmental conditions that promote occupancy, survival, and reproduction of that species (Morrison et al. 2006). Typical wildlife habitat elements include food, water, shelter (including resting, nesting, and denning sites); security from predators and competitors; and proper spatial arrangement of those features. While vegetation cover types are often highly correlated with the availability of habitat elements for many animals, and can serve as simple and effective surrogates for resource management and planning, the functional elements and ecological interactions that comprise wildlife habitat are more complex than the presence of particular vegetation cover. Climate change has the potential to alter those complex ecological relationships in subtle but important ways.

Climate change effects will also interact with nonclimate stressors to determine outcomes for wildlife. Habitat loss and fragmentation owing to human land uses (primarily urban and agricultural development) have been a leading cause of wildlife species declines over the past century or more (Wilcove et al. 1998, Young et al. 2016). Those pressures will continue, and associated threats to wildlife are likely to be amplified by additional stresses associated with climate change (Ceballos et al. 2017). 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 and other land uses (IPCC 2014, Melillo et al. 2014). These pressures are likely to contribute to continuing habitat loss, fragmentation of remaining habitats, and fewer opportunities for organisms to move between habitat patches (reduced landscape permeability) as they seek to adapt to changing conditions.

Likely consequences of these combined impacts will be altered wildlife communities and species distribution (i.e., range shifts) as animals attempt to respond by moving or changing their behavior in response to new environmental and resource conditions. At global and continental scales, many species are moving north, moving up in elevation, and shifting behaviors earlier in the year (Chen et al. 2011, Hitch and Leberg 2007, Lawler et al. 2009, Princé and Zuckerberg 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 have been observed to respond to climate change effects at broad scales through altered distribution, but also at fine scales through altered foraging and thermoregulatory behaviors (Carroll et al. 2015, Rapacciuolo et al. 2014, Rowe et al. 2015). Availability of thermal refugia and other key habitat elements, particularly food and water, are likely to be critical for species persistence in a warming environment (e.g., Carroll et al. 2015, Simpson 2009).

Assessment Approach

The goal of this chapter is to synthesize information on how local wildlife communities in southwest Oregon are expected to be affected by projected climate change through the 21st century. In the sections below, we synthesize information on projected changes in climate, vegetation, and hydrology in relation to the common wildlife habitat elements associated with five broad focal habitats found in the SWOAP assessment area (table 6.1):

- Conifer forests, including coastal conifer forests, interior mixed conifer–hardwood forests, and montane conifer forests
- Early-seral forests and brushfields
- Oak woodlands, savannahs, and grasslands
- Wetlands, riparian areas, and open water
- Subalpine forest, woodlands, and meadows

For each focal habitat, we provide a brief description of its current distribution, key ecological features, characteristic wildlife species, and nonclimate stressors (also see summary in table 6.1). We report the percentage of each focal habitat within a 10-km buffer of SWOAP federal land ownerships (hereafter referred to as the SWOAP assessment area) based on Oregon Gap Analysis Project (GAP) maps (USDI GS 2016) of associated NatureServe ecological types (NatureServe 2013). For our assessment of expected changes in vegetation and related wildlife habitat elements, we rely heavily on vegetation-change modeling conducted with the MAPSS-CENTURY 2 (MC2) dynamic global vegetation model and other information presented in the vegetation and disturbance chapter of this document (chapter 5). We encourage

Table 6.1—Summary of focal wildlife habitats, characteristic species, key habitat elements, exposure, sensitivity, adaptive capacity, nonclimate stressors, and potential adaptation strategies for the Southwest Oregon Adaptation Partnership climate vulnerability assessment

Focal habitat	Characteristic species^{ab}	Habitat elements	Exposure	Sensitivity	Adaptive capacity	Other stressors	Adaptation strategies
Coastal conifer forest	**Marbled murrelet, Pacific fisher, northern spotted owl, olive-sided flycatcher, band-tailed pigeon, black swift, clouded salamander**, Del Norte salamander, northern flying squirrel	• Moderate to closed, multilayer canopy • Multi-aged with large-tree component characterized by redwood and spruce • Snags and down logs • Evergreen hardwood component	The current distribution is limited to the coast, but MC2 projections suggest broad range expansion to the east, particularly in the second half of the century.	This habitat has a high-severity fire regime. Increasing fire frequency and severity may change seral-stage distributions and result in reduced old-forest structure and spatial heterogeneity. Insects and disease may be increasingly important.	Potential exists for upward-elevation shifts as species composition changes in colder forest types.	• High-severity fire • Roads • Wood harvest • Recreation • Sudden oak death	• Promote tree species and genetic diversity in expected transitional areas. • Identify and protect disturbance refugia to maintain old-forest structure or other important ecological features. • Conserve big trees. • Promote landscape heterogeneity in post-disturbance landscapes.
Mixed conifer–hardwood forest	**Marbled murrelet, Pacific fisher, northern spotted owl, olive-sided flycatcher, band-tailed pigeon, black swift, clouded salamander**, Siskiyou Mountains salamander, black salamander, northern flying squirrel	• Deciduous hardwood component • High tree species diversity, including both conifers and hardwoods (e.g., Pacific madrone)	MC2 projects broad conversion of interior areas to coastal warm conditions.	This habitat has a mixed- or low-severity fire regime, with a long history of human-caused fire. Fire exclusion has increased the risk of high-severity fire, which will increase with amplified summer drought.	Resilience may be increased with fuel reduction and prescribed fire treatments.	• High-severity fire • Roads • Wood harvest • Recreation • Wildland-urban interface	• Identify strategies to reduce the risk of high-severity fire, including fuel reduction and prescribed fire treatments.
Montane conifer forest	**Chestnut-backed chickadee, Pacific fisher, northern goshawk, northern spotted owl, olive-sided flycatcher, band-tailed pigeon, black swift, pine siskin, clouded salamander**, Siskiyou Mountains salamander	• Moderate to closed, multilayer canopy • Multi-aged with big-tree component characterized by Douglas-fir • Snags and down logs • Multiscale spatial and structural heterogeneity	MC2 projections suggest broad conversion to warm coastal forest in low and mid-elevations, particularly in the second half of the century.	This habitat has a mixed-severity fire regime. Increasing fire frequency and severity may alter seral-stage distributions and result in loss of old-forest structure and spatial heterogeneity. Insect and disease processes may be increasingly important.	Potential for upward shifts, though loss of suitable area at lower elevations will exceed area available for expansion at higher elevations.	• High-severity fire • Roads • Wood harvest • Recreation	• Promote tree species and genetic diversity in expected transitional areas. • Identify and protect disturbance refugia to maintain old-forest structure or other important ecological features. • Conserve big trees. • Promote landscape heterogeneity in post-disturbance landscapes.

Table 6.1—Summary of focal wildlife habitats, characteristic species, key habitat elements, exposure, sensitivity, adaptive capacity, nonclimate stressors, and potential adaptation strategies for the Southwest Oregon Adaptation Partnership climate vulnerability assessment (continued)

Focal habitat	Characteristic species^{ab}	Habitat elements	Exposure	Sensitivity	Adaptive capacity	Other stressors	Adaptation strategies
Oak/savanna woodland	**Lewis' woodpecker,** California scrub-jay, wild turkey, oak titmouse, western gray squirrel, Columbian white-tailed deer	• Oak trees: mast-producing, abundant cavities, diverse canopy structure • Diverse spatial pattern: interspersion with savanna or grassland	MC2 projected slight decrease in woodland area, though oaks are expected to expand owing to their resilience to drought and disturbance.	Increased susceptibility to sudden oak death, increased frequency and severity of summer drought events, and increased fire frequency and severity could increase oak mortality.	Active management to maintain woodland structure may be feasible in some areas. There is potential for up-slope range shift.	• Sudden oak death • Invasive species • Land use change • Recreation • High-severity fire	• Identify strategies to maintain oak structure and reduce drought stress (e.g., prescribed fire, control of conifer encroachment). • Control invasive plants. • Maintain landscape permeability (for range shift and seasonal migration).
Wetlands/ riparian/ lacustrine	**Oregon spotted frog, Cascades frog, clouded salamander, Pacific chorus frog, northwestern salamander, western pond turtle,** northern waterthrush, American beaver	• Moving and still water • High water table • Deciduous trees and shrubs • Abundant snags and logs • Important connectivity and microclimate values	These habitats are found in all vegetation types. The degree of exposure depends on topography and hydrology. Snow-dominated mid- and high-elevation subbasins may be most exposed to change.	These types are sensitive to extreme precipitation events (flooding or drought). Extreme flooding events can damage habitat structure. Persistent drought can reduce functional area of these habitats.	Adaptive capacity is limited by hydrologic and topographic context.	• Invasive species • Land use change • Grazing • Roads • Recreation • High-severity fire • Water use	• Consider downstream hydrologic function in landscape and road planning. • Limit disturbance impacts. • Protect microclimate characteristics. • Encourage beaver colonization to enhance water retention and groundwater recharge. • Control invasive species.

Table 6.1—Summary of focal wildlife habitats, characteristic species, key habitat elements, exposure, sensitivity, adaptive capacity, nonclimate stressors, and potential adaptation strategies for the Southwest Oregon Adaptation Partnership climate vulnerability assessment (continued)

Focal habitat	Characteristic species[ab]	Habitat elements	Exposure	Sensitivity	Adaptive capacity	Other stressors	Adaptation strategies
Mid-elevation early seral and grasslands	**White-tailed kite, Oregon vesper sparrow, western bumblebee, mardon skipper,** rufous hummingbird, mountain quail, gray flycatcher, western bluebird, pocket gopher, Cassin's finch, American kestrel	• Diverse and highly productive understory and deciduous shrubs • Biological legacies (snags, logs, and remnant large trees) • Mixed-severity disturbance patches that contribute to landscape heterogeneity	These habitats are distributed across a broad elevation range. They are generally disturbance-dependent types. Increased summer drought stress may contribute to increased high-severity fire and potential for reburn.	Area could increase with increasing fire frequency and severity. Tree encroachment may increase with lengthened growing season and increased moisture stress. Physiological heat stress may increase with warming summer temperatures. Reburns may contribute to loss of structure and landscape heterogeneity.	Animals associated with early-seral conditions tend to be good dispersers. Thermal refugia (e.g. logs, burrows, shading vegetation) may become more important with warming temperatures.	• Roads • Invasive species • Recreation • Herbicide use in forest management	• Recognize the biological significance of early-seral and grassland as unique habitats. • Retain and promote structural and spatial heterogeneity across scales by retaining biological legacies and mixed-severity disturbance patches. • Encourage recruitment of tree species and genetic diversity in post-disturbance landscapes where appropriate.
Subalpine forest, woodland, and meadows	**Blue grouse,** great gray owl, American marten, **snowshoe hare, varied thrush,** Vaux's swift, Clark's nutcracker, Townsend's solitaire, ermine, Sierra Nevada red fox, **American pika,** yellow-bellied marmot, gray-crowned rosy finch	• Winter deep snow and subnivian habitats • Patchy forests, with sharply conical canopy structure, creating many openings • Meadow-woodland interface and whitebark pine • Diverse herbaceous vegetation in meadows • Rock and talus features	MC2 projects complete loss of this habitat by the end of the century. Extent, depth, and duration of winter snow will be reduced.	Improved growing conditions may contribute to encroachment by mid-elevation species. Drought and heat stress could reduce resistance to insect and disease outbreaks. These habitats will be subject to increased summer temperatures and drought stress, as well as reduced winter snowpack. Summer heat, drought stress, and disease could reduce whitebark pine survival. Tree encroachment from lower elevations will reduce woodland extent.	There will be minimal opportunity for upward range shifts. Some meadow and woodland structure might be maintained by prescribed fire or vegetation management. Fine-scale thermal refugia may become increasingly important.	• High-severity fire • Recreation • Problematic natives (insect and disease outbreaks) • Invasive species • Recreation	• Consider strategies to increase landscape heterogeneity and reduce risk of large-scale high-severity fire and insect disturbances. • Retain canopy cover in hydrologically sensitive and deep snow areas. • Use prescribed fire and wildfire to reduce tree encroachment into meadows where appropriate. • Control invasive plants. • Consider recreation impacts and concentration of winter recreation activities as opportunities decline.

[a] Valued species from the Southwest Oregon Adaptation Partnership list are indicated in boldfaced type.
[b] See appendix 6.1 for scientific names of all species listed in this table.

readers to refer to that chapter for a thorough discussion of the vegetation modeling and associated uncertainties. We discuss exposure, sensitivity, and adaptive capacity (Foden et al. 2013) for each focal habitat to evaluate potential climate change vulnerability for wildlife communities associated with that habitat. We recognize that this terminology has most often been used in wildlife literature to describe the climate change vulnerability of individual species (e.g., Case et al. 2015). In the following sections, we adjust the standard meanings of these terms to provide a framework for discussing general patterns of climate change vulnerability for wildlife associated with the focal habitat groups as follows:

- Exposure: How much will climatic conditions or climate-driven processes produce change in areas occupied by groups of species associated with a focal habitat?
- Sensitivity: What are the general patterns by which those changes may affect critical wildlife habitat elements (food, water, shelter, security, and configuration) and key population processes (including survival, reproduction, and metapopulation dynamics)?
- Adaptive capacity: Are there common opportunities for species associated with the focal habitat to adjust in ways that compensate for climatic effects (e.g., availability of alternative resources, range shifts)?

We conclude each focal habitat section by providing a short list of general climate adaptation strategies that might address climate change vulnerabilities for that community. Many of these adaptation strategies overlap with current management priorities addressing resilience to disturbance and conservation of biodiversity. Primary sources of information used for this assessment include U.S. Department of Agriculture, Forest Service (U.S. Forest Service) potential vegetation maps,[2] Oregon GAP/LANDFIRE National Terrestrial Ecosystems maps derived from 2011 remote-sensing imagery (USGS 2016), and NatureServe ecological types (NatureServe 2013) for descriptions of the focal habitats; Oregon Explorer Wildlife Viewer (Oregon Explorer 2018) and Johnson and O'Neil (2001) for species lists and habitat associations; Forest Service Pacific Northwest Region Terrestrial Restoration and Conservation Strategy (USDA FS 2011) for nonclimate stressors; and Forest Service and Bureau of Land Management (BLM) Interagency Special Status and Sensitive Species Program (ISSSSP) lists to identify sensitive wildlife (https://www.fs.fed.us/r6/sfpnw/issssp). We encourage readers to check the ISSSSP website for updated sensitive species lists.

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[2] Simpson, M. [N.d.]. Unpublished data and map of vegetation series and subseries across the Pacific Northwest. Bend, OR: 97701. 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.

Several other approaches for assessing the vulnerability of individual wildlife species to climate change impacts are available. These include the System for Assessing Vulnerability of Species (SAVS) (Bagne et al. 2011), the NatureServe Climate Change Vulnerability Index (NatureServe 2018), and the Climate Change Sensitivity Database (Case et al. 2015). These tools use a variety of life history information to evaluate sensitivity of individual species to climate change effects. These formalized reasoning structures are useful tools, and we encourage managers to use them when exploring climate vulnerability for individual species of interest (see Lankford et al. 2014 for a discussion of considerations for the application of these tools).

Our approach in this chapter is more community oriented in an effort to provide land managers with a framework for considering shared climate change vulnerabilities for groups of species associated with common habitat conditions. We recognize that climate change effects and adaptive responses will be unique for each species, and wildlife communities of the future may be very different than those with which we are currently familiar, but species associated with certain habitat conditions often share common climate vulnerabilities and potential adaptation strategies. A primary assumption of our approach is that land managers will be most likely to maximize biodiversity values in a rapidly changing landscape by providing diverse and abundant wildlife habitat components (e.g., food, water, shelter) in configurations that allow animals to access those resources. We recognize that our approach may not address all species or all environmental conditions found within the SWOAP assessment area, but we hope to provide managers with a framework for considering the vulnerability of wildlife populations within their units and identifying appropriate adaptation actions.

Analysis Area

Vegetation in the SWOAP assessment area is predominantly coniferous and mixed conifer–hardwood forest or woodland, with important components of grassland, meadow, and chaparral. Diverse communities from several Western U.S. floristic provinces intermingle in the complex environmental and geomorphologic gradients that characterize the landscape. The complex topographic setting, ecological diversity, and proximity to the ocean (chapter 1) have allowed for persistence of localized ecological communities amid broad climatic changes in the past.

The interaction between climate and human activities has shaped landscape patterns and wildlife communities in southwest Oregon over many thousands of years. The earliest documented human occupancy in southwest Oregon was about 13,000 calendar years before present (cal yr BP) in the Rogue and Umpqua River drainages (Aikens et al. 2011). Hunting remains from the mid- to late-Holocene (7600 to 1700 cal yr BP) reflect the importance of deer (see app. 6.1 for scientific names of all species listed in this chapter) in providing food and clothing for these people, as well as the importance of elk, American beaver, pocket gopher, mountain lion, canids (dog, coyote, or gray wolf), fox, western pond turtle, and salmon (Aikens et al. 2011). Ancient village sites were frequently associated with deer wintering areas (Aikens et al. 2011). Native fire management in western Oregon was well established by about 3500 cal yr BP. Savannah and grassland communities were likely maintained or enhanced by intentional burning to provide big game forage, enhance food plant production, and maintain safety from raiders.

Human-caused landscape change accelerated with Euro-American settlement of southwest Oregon in the mid- to late 1800s. Early trading routes and fur trapping in southwest Oregon contributed to substantial declines in beavers and fur-bearing carnivores. Later establishment of livestock grazing further contributed to removal of large carnivores from the landscape. Agricultural development, commercial timber harvest, and associated urban and residential growth were facilitated by the development of railroads in the late 1800s. This legacy of railroad development and the consequent checkerboard federal land ownership pattern is one of the most important factors that has shaped the modern landscape in southwest Oregon (USDI BLM 1987). Conversion of valley bottoms to urban, residential, and agricultural land uses contributed to substantial reduction of oak woodland and native grassland habitats. Widespread commercial timber harvest through most of the 20th century converted much of the lower elevation forested landscape to younger forest, favoring commercially valuable species (e.g., Douglas-fir). By the mid-20th century, Interstate 5 had replaced the railroad as the primary transportation corridor through southwest Oregon and remains an important driver of human development patterns and wildlife habitat fragmentation.

There are currently four federally listed threatened species in the SWOAP assessment area: marbled murrelet, vernal pool fairy shrimp, Oregon spotted frog, and northern spotted owl. There is one federally listed endangered species: gray wolf. There are two species proposed for listing as federally threatened: Pacific fisher and coastal marten. Additionally, there are 28 other terrestrial vertebrates identified on the ISSSSP list for the SWOAP assessment area, including 17 birds, 7 mammals, 3 amphibians, and 1 reptile. There are also 54 invertebrates on the ISSSSP list that occur within the SWOAP assessment area, including 26 slugs or snails (order Gastropoda), 10 caddisflies (order Trichoptera), and 7 butterflies (order Lepidoptera).

Focal Wildlife Habitats

Conifer Forest

Conifer and mixed conifer–hardwood forests encompass 55 percent of the SWOAP assessment area (USDI GS 2016). For the purposes of this review, we address three general forest types: warm coastal conifer forest, interior mixed conifer–hardwood forest, and montane conifer forest. However, the diverse topography and disturbance history in southwest Oregon create conditions where these ecological communities can co-occur and be intermixed at relatively fine scales based on topography and soil conditions. As is common with ecological classifications, there is substantial mixing and overlap in species composition and ecological function between related types. Although abundance of different wildlife species varies across forest types, the distribution of most species is not limited to a specific forest type.

Several reviews of wildlife habitat attributes of western Oregon conifer forests are available (Brown 1985, Johnson and O’Neil 2001, Ruggiero et al. 1991, Spies et al. 2018). Common wildlife habitat elements across conifer forest types in the SWOAP assessment area include live and dead trees, down wood, shrubs, understory vegetation, fungi, a mixture of coniferous and deciduous trees, and unique abiotic features including talus, cliffs, and caves (Brown 1985, Johnson and O’Neil 2001). The spatial arrangement and structure of living and dead trees determine characteristics of the forest canopy and openings that provide patches of shrub and herbaceous vegetation. Large live trees, snags, and logs with a variety of damage or decay characteristics provide unique structures and microclimates that are important for foraging, resting, nesting, and denning for many species. Altman and Alexander (2012) identified the following important habitat components for birds in different conifer forest developmental stages west of the Cascade Range:

- Old forest: large snags, large trees, shrub/hardwood understory component, and mid-story tree layers
- Mature/young forest: closed canopy, open mid-story, deciduous understory, and forest floor complexity
- Young/pole forest: deciduous canopy trees

Coastal conifer forest description—

Coastal conifer forest is concentrated along the Pacific coast, comprising 14 percent of the SWOAP assessment area (USDI GS 2016). Coastal forests are characterized by a moderate maritime climate with abundant precipitation. Winters are warm and wet. Summers are relatively cool and dry. Summer fog is an important source of moisture on the outer coast. Rugged topography and proximity to the Pacific Ocean create an exceptionally strong climate gradient across southwest Oregon. The major potential vegetation zones for coastal conifer forest are Douglas-fir–tanoak and western hemlock (see footnote 2). The corresponding NatureServe ecological type is predominantly Mediterranean California mixed-evergreen forest, with smaller amounts of North Pacific lowland mixed hardwood–conifer forest and woodland, California coastal redwood forest, and North Pacific hypermaritime western redcedar–western hemlock forest.

These forests are dominated by evergreen conifers, including Douglas-fir and Port Orford cedar, mixed with evergreen hardwoods, including tanoak, canyon live oak, and Pacific madrone (Franklin and Dyrness 1973, NatureServe 2013). Sitka spruce mixed with western hemlock and red alder occurs in wet valley bottom sites near the coast in the central and northern portions of the assessment area. Patches of redwood forest present in valley bottoms in the southwest corner of the assessment area represent the northernmost extent for these iconic trees. Serpentine (ultramafic) soils are common in portions of the Siskiyou Mountains where they have a major effect on vegetation and wildlife habitat characteristics (chapter 5). Vegetation is invariably stunted on serpentine sites in comparison with vegetation on adjacent nonserpentine soils.

Forests closest to the coast generally have a low-frequency and high-severity fire regime, with historical fire return intervals of up to 250 years or more (Spies et al. 2018). Strong topographic and climatic gradients contribute to increasingly heterogeneous disturbance patterns as one moves inland and summer conditions become hotter and drier. Mixed- or low-severity and high-frequency fire regimes become predominant on southern exposures and upper slopes away from the coast (see chapter 5).

Unique habitat structures provided by coastal conifer forest include very large trees, verdant herbaceous and shrub vegetation in the understory, and complex vertical canopy structure (Spies et al. 2002). The mixture of conifer and hardwood tree species common in coastal forests provides complex patchiness that supports abundant insect and small mammal populations that in turn provide prey for birds (e.g., Pacific-slope flycatcher, northern spotted owl) and mesocarnivores (e.g., Pacific marten). Marbled murrelets nest in large trees with natural platforms of vegetation and moss accumulations on robust horizontal branches within about 50 km of the ocean (Raphael et al. 2018). This marine bird forages on ocean fish throughout the year, continuing to commute to marine foraging areas during incubation and for feeding and provisioning young (Raphael et al. 2018). The Pacific (coastal) marten and the Humboldt subspecies of the coastal marten are also restricted to coastal conifer forest (Moriarty et al. 2016, USDI FWS 2018). Cool, moist microsites protected by forested talus and down wood combined with abundant water sources and precipitation provide important habitat components for plethodontid salamanders and other amphibians, including coastal tailed frog, Del Norte salamander, southern torrent salamander, Pacific giant salamander, clouded salamander, Dunn's salamander, western red-backed salamander, and rough-skinned newt (Nussbaum et al. 1983, Welsh and Lind 1991).

Interior mixed-conifer forest description—
Interior mixed conifer forest is distributed throughout the central portion of the SWOAP assessment area, particularly in the Rogue River and Umpqua River valleys, encompassing 14 percent of the assessment area (USDI GS 2016). With less moderating effect from proximity to the ocean than the coastal forest, these low- to mid-elevation forests are relatively warm and wet during the winter months, but quite hot and dry during the summer. Winter snow is uncommon except at higher elevations. Topography is rugged, contributing to substantial microclimate and ecological heterogeneity. Distribution of interior mixed conifer forest overlaps with disturbance-maintained oak woodland communities (discussed below). The predominant potential vegetation type for interior mixed forests is Douglas-fir (see footnote 2). Predominant NatureServe ecological types are Mediterranean California dry-mesic, mixed conifer forest and woodland and North Pacific dry Douglas-fir-(madrone) forest and woodland.

These drier forest types are largely dominated by Douglas-fir but may also be mixed with white fir, ponderosa pine, Jeffrey pine, Pacific madrone, and tanoak (Franklin and Dyrness 1973, Halofsky et al. 2016). Deciduous California black oak and Oregon white oak are more common in interior mixed forest than in coastal forests. Fire is the predominant disturbance in this portion of the landscape. These forests are characterized by mixed- or high-frequency and low-severity fire regimes. Landscape patterns are strongly influenced by fine-scale topographic characteristics, with ridgetops and southern exposures more likely to have open-canopy conditions, and northern exposure lower slope settings more likely to have closed-canopy characteristics. Historical fire return intervals were generally 10 to 80 years. Lightning ignitions are more frequent here than in other parts of the region (Spies et al. 2018). Intentional burning by native residents prior to Euro-American settlement was also common (Aikens et al. 2011). Fire exclusion has contributed to encroachment of true firs in these areas, reducing landscape heterogeneity and increasing the risk of high-severity fire.

Important wildlife habitat attributes of interior mixed hardwood-conifer forest include pine-oak canopy/subcanopy trees, dense shrub understory, interspersed shrub-herbaceous understory, forest canopy edges, montane brushfields, and postfire early-seral patches (brushfields and early-seral habitats are addressed below) (Altman and Alexander 2012). Large oak trees can develop robust horizontal branches or cavities that are frequently used as resting sites by Pacific fisher (Thompson et al. 2015). Over half of all Pacific fisher dens found in the lower elevations of the Ashland watershed are in California black oak, and approximately 90 percent of all rest sites for fisher are in Douglas-fir mistletoe structures.[3] Acorns provide a seasonally abundant food resource used by many species. Deciduous trees and shrubs support a diverse assemblage of herbivorous insects such as caterpillars (Lepidoptera), an important prey for many insectivores, especially Neotropical migrant birds (Altman and Alexander 2012, Miller and Hammond 2007). Hardwood trees also make important contributions to cavity and snag resources in conifer forests. Pacific madrone, bigleaf maple, and Oregon white oak tend to form natural cavities in live trees, providing a higher density of nesting and roosting opportunities for secondary cavity-using species than live conifers.

The mixed conifer–hardwood forests of southwest Oregon have high wildlife species richness compared to other forest types in the Pacific Northwest (Altman and Alexander 2012, Olson et al. 2001). Many forest birds find suitable habitat at the juxtaposition of the canopy and forest openings where increased sunlight supports greater foliage and insect density (Altman and Alexander 2012). Bird richness generally increases with increasing hardwood cover in mixed forests. Drier sites in interior mixed forest generally have a greater abundance and diversity of reptiles compared to the coastal or montane forests, including northern alligator lizard, western fence lizard, ringneck snake, and sharptail snake (Welsh and Lind 1991).

Montane conifer forest description—

Montane conifer forest is the predominant forest type found at moderate elevations (between about 800 and 1300 m) in the Cascades and Coast Range, and at higher elevations in the Siskiyou Range (above about 1200 m). Montane conifer forest comprises 27 percent of the SWOAP assessment area (USGS 2016). The predominant potential vegetation type is cedar-hemlock in the north and grand fir/white fir in the south. NatureServe ecological types are predominantly North Pacific maritime dry-mesic Douglas-fir-western hemlock forest and Mediterranean California mesic mixed conifer forest and woodland, with a smaller amount of

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[3] Clayton, D. 2019. Personal communication. Wildlife biologist, Rogue-River Siskiyou National Forest, 3040 Biddle Road, Medford, OR 97504 (dave.clayton@usda.gov).

North Pacific maritime mesic-wet Douglas-fir-western hemlock forest. Common overstory tree species include Douglas-fir, western hemlock, grand fir, and white fir. Bigleaf maple and red alder can add a deciduous component in some areas.

Montane forests generally have mixed- or low-frequency and high-severity fire regimes. Fire exclusion and discontinuation of burning by American Indians have contributed to encroachment of late-seral true firs and increased the risk of large-scale, high-severity fire in these landscapes, although the effects of fire exclusion have not been as great as in forests with more frequent fire regimes (Halofsky et al. 2018b). Lightning strikes are relatively abundant in southern Oregon compared to other parts of the Pacific Northwest, particularly in the northeastern portion of the SWOAP assessment area (Spies et al. 2018).

Montane forests are generally cooler and have a reduced hardwood component compared to coastal or interior mixed forests. Oaks are not common overstory trees. Key habitat features for older montane forests include moderate to closed, multilayer canopy; trees of a variety of ages, including some big, old trees; snags and down logs; and multiscale spatial and structural heterogeneity. Salal and huckleberry are important fruiting shrubs.

Characteristic wildlife species across conifer forests in southwest Oregon include northern spotted owl (box 6.1), Pacific fisher, and American marten (Johnson and O'Neil 2001). Threatened northern spotted owls are found in structurally diverse conifer forest throughout the SWOAP assessment area. Northern flying squirrels, bushy tailed woodrats, and dusky footed woodrats are important prey for northern spotted owls in southwest Oregon. Other small mammals associated with montane conifer forests in the SWOAP assessment area include deer mice, Douglas squirrel, Pacific shrews, Trowbridge's shrew, and western red-backed vole (Corn and Bury 1991). Partners in Flight identified four focal bird species associated with old-growth multilayered or late-successional forest conditions: pileated woodpecker, brown creeper, Pacific-slope flycatcher, and varied thrush (Altman and Alexander 2012). Several species of bats utilize the diversity of structures in these old forests for roosting, while canopy gaps provide aerial foraging opportunities (Arnett and Hayes 2009, Ober and Hayes 2008). Terrestrial mollusks (slugs and snails) achieve their greatest abundance and diversity in these conifer forests where abundant forest floor litter and down wood provide cool, moist microenvironments. Mollusks play important roles in the forest ecosystem by facilitating decomposition and nutrient cycling and serving as prey for a variety of other species, including amphibians, reptiles, birds, and small mammals (Jordan and Black 2012).

Box 6.1

Northern Spotted Owls

Northern spotted owls are an iconic old-forest species found in southwest Oregon (fig. 6.1). They were listed as threatened under the U.S. Endangered Species Act in 1990, and their conservation was a primary consideration in the development and implementation of the Northwest Forest Plan in 1994 (Lesmeister et al. 2018). At the time of listing, the primary threat to northern spotted owls was loss of old-forest habitat owing to timber harvest. In recent years, wildfire has overtaken timber harvest as the primary cause of habitat loss in southwest Oregon (Davis et al. 2016).

The effects of wildfire on northern spotted owls and their habitat are complex. The owls are strongly associated with moderate to closed canopy and structurally diverse forest for nesting and roosting (Lesmeister et al. 2018). These forests provide suitable cavities or platforms for nesting, moderate thermal environments for roosting, and security from predators such as great horned owls. But spotted owls will also use a variety of forest conditions for foraging, including some recently burned forests. Spotted owls can persist in landscapes with recent low- or mixed-severity fire, where suitable nesting and roosting habitat patches are intact, but large-scale high-severity disturbances that remove nesting and roosting habitat across large areas are detrimental to owl persistence (Dugger et al. 2016).

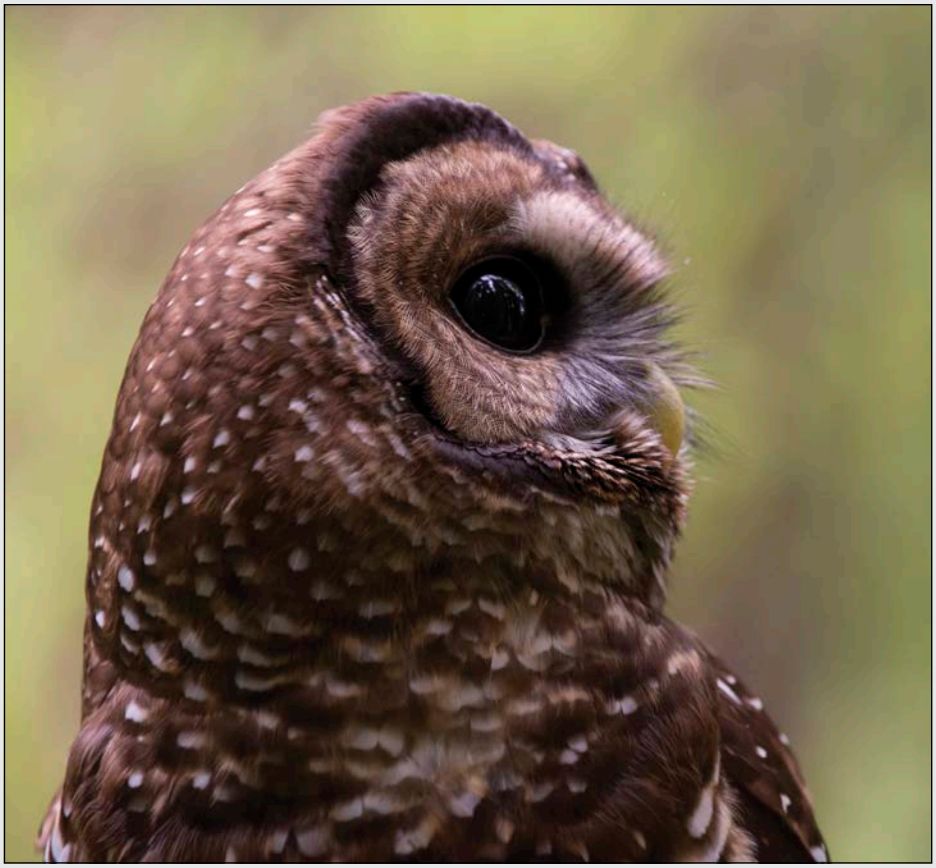
Competition with barred owls is another important stressor (Lesmeister et al. 2018). Barred owls were historically found in eastern North America and recently expanded their range into Western forests (Livezey 2009). They have become increasingly common throughout the range of the northern spotted owl over the past 25 years. Barred owls are slightly larger, are more aggressive, use a broader variety of forest conditions than spotted owls, and can displace spotted owls from areas of otherwise suitable habitat (Wiens et al. 2014). A combination of habitat loss and competition with barred owls has contributed to a long-term decline in northern spotted owl numbers throughout its range (Dugger et al. 2016).

Climate change is likely to contribute to spotted owl population declines through altered wildfire frequency, weather, and prey availability. Projected increases in fire frequency are expected to contribute to ongoing loss of nesting and roosting habitat (Davis et al. 2016). Spotted owl survival rates have been shown to be reduced by winter storms and summer drought, so warmer,

Continued on next page

wetter winters and hotter, drier summers are expected to decrease spotted owl survival and reproduction in the future (Glenn et al. 2010, 2011). An important consequence of increased summer drought may be decreased abundance of primary prey for northern spotted owls, particularly northern flying squirrels and woodrats. Decreased prey abundance coupled with increased competition from barred owls could be particularly detrimental for spotted owls.

Adaptation strategies for spotted owls have focused on habitat conservation and recruitment of old-forest habitat structure (Lehmkuhl et al. 2015). Identifying and conserving habitat in topographic settings that are most likely to serve as disturbance and climate refugia is an important consideration for these strategies (Morelli et al. 2016, Olson et al. 2012). The rapid growth of barred owl populations throughout the range of the northern spotted owl, combined with other climate-related stressors, suggests that habitat conservation alone may not be sufficient to sustain spotted owl populations (Lesmeister et al. 2018).



U.S. Forest Service

Figure 6.1—Northern spotted owl.

Nonclimate stressors—

Nonclimate stressors in conifer forests in southwest Oregon include historical fire suppression, land use change, timber harvest, roads, recreation, and tree pathogens (USDA FS 2011). Fire has played an important ecological role in this region. Historical fires contributed to a landscape mosaic of forest development stages and diverse postdisturbance successional pathways (Spies et al. 2018). Fire suppression has contributed to changes in landscape pattern, stand structure, and tree species composition that have increased vulnerability of many areas to large-scale and high-severity wildfire, and that vulnerability has been amplified by climate-induced increases in fire frequency and severity (discussed below). These changes have been most pronounced in the interior mixed conifer–hardwood forest where historical fire return intervals were relatively short. Fire exclusion has had less impact in montane and coastal forests with low-frequency fire regimes, where the duration of fire suppression has not exceeded the historical fire return interval (Halofsky et al. 2018b).

Other important drivers of landscape patterns in southwest Oregon have been commercial timber harvest and land uses that convert forest to urban or agricultural uses. Forest fragmentation patterns that result from timber harvest often reflect land ownership, particularly in areas with checkerboard federal lands. Historical timber harvest practices in many areas have contributed to the development of even-age stands dominated by a few commercially valuable tree species, with few biological legacies (e.g., large snags, logs, and old live trees).

Endangered Species Act (ESA)-listed species found in conifer forests in the SWOAP assessment area include northern spotted owls and marbled murrelets (both threatened). The west coast population of fisher was proposed for listing as threatened in 2014, but the proposed rule was withdrawn in 2016 (50CFR17 2016). Pacific (coastal) martens have also been proposed for listing under the ESA (Linnell et al. 2018, USDI FWS 2018). ISSSSP species include three birds (purple martin, black swift, white-headed woodpecker), two amphibians (black salamander, Siskiyou Mountains salamander), and four mammals (pallid bat, Townsend's big-eared bat, fringed myotis, Pacific marten). Thirteen invertebrates associated with conifer forests are also on the ISSSSP list, including Johnson's hairstreak (lepidopterid), Cooley's lace bug, Oregon giant earthworm, Oregon axetail slug, and 10 species of snails (gastropods).

Exposure—

The total area within the SWOAP landscape capable of supporting forest under future climate projections is not expected to change dramatically, though substantial changes in the distribution of forest types and disturbance regimes are expected (chapter 5). Forest potential vegetation types are projected to expand slightly based on MC2 vegetation modeling (from encompassing 88 percent of the assessment area under

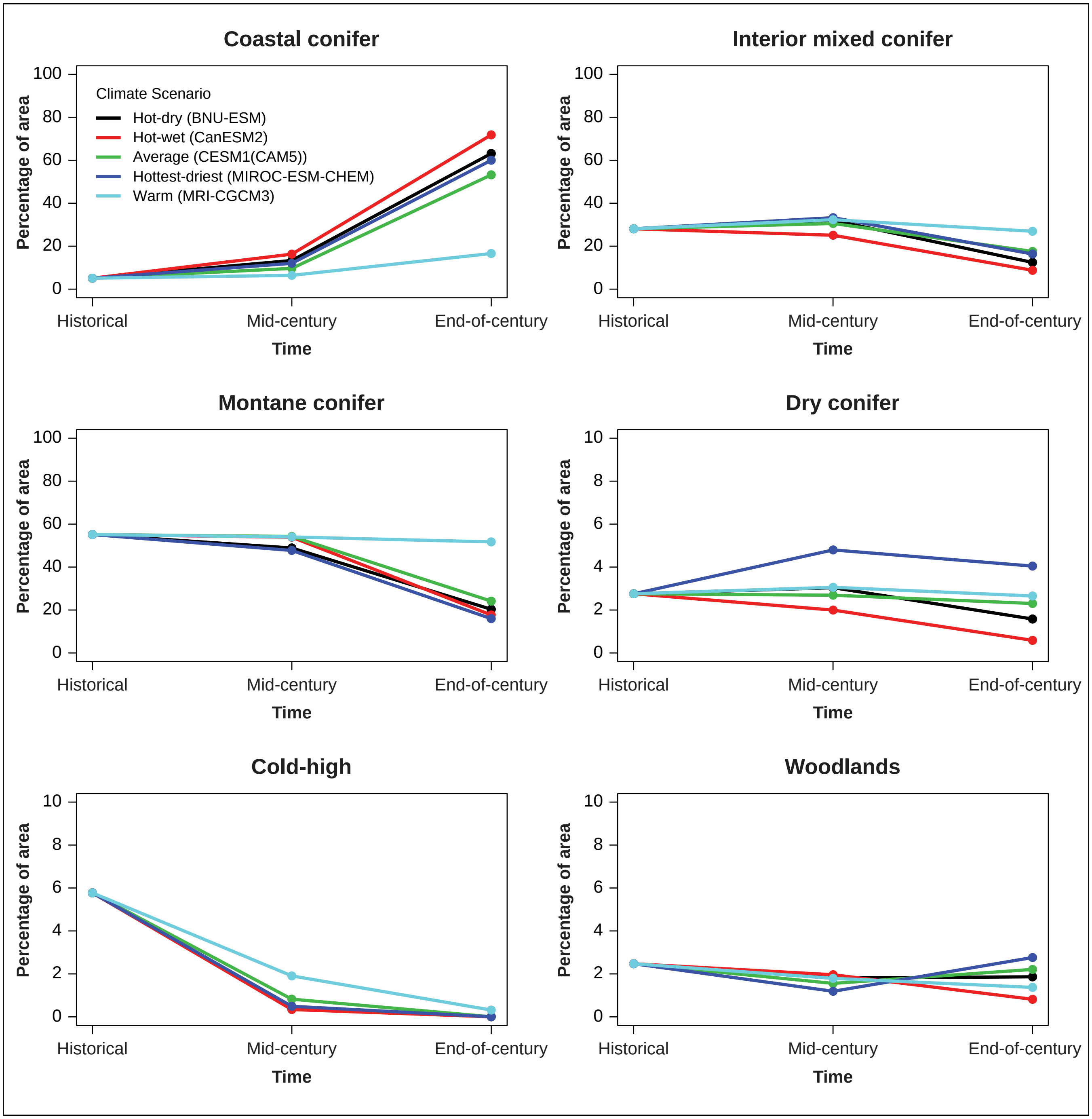


Figure 6.2—Change in the proportion of the Southwest Oregon Adaptation Partnership assessment area with vegetation types capable of supporting focal wildlife habitats based on MC2 projections, using five future climate scenarios representing a range of potential climate outcomes projected for mid century (2050) and end of century (2070).

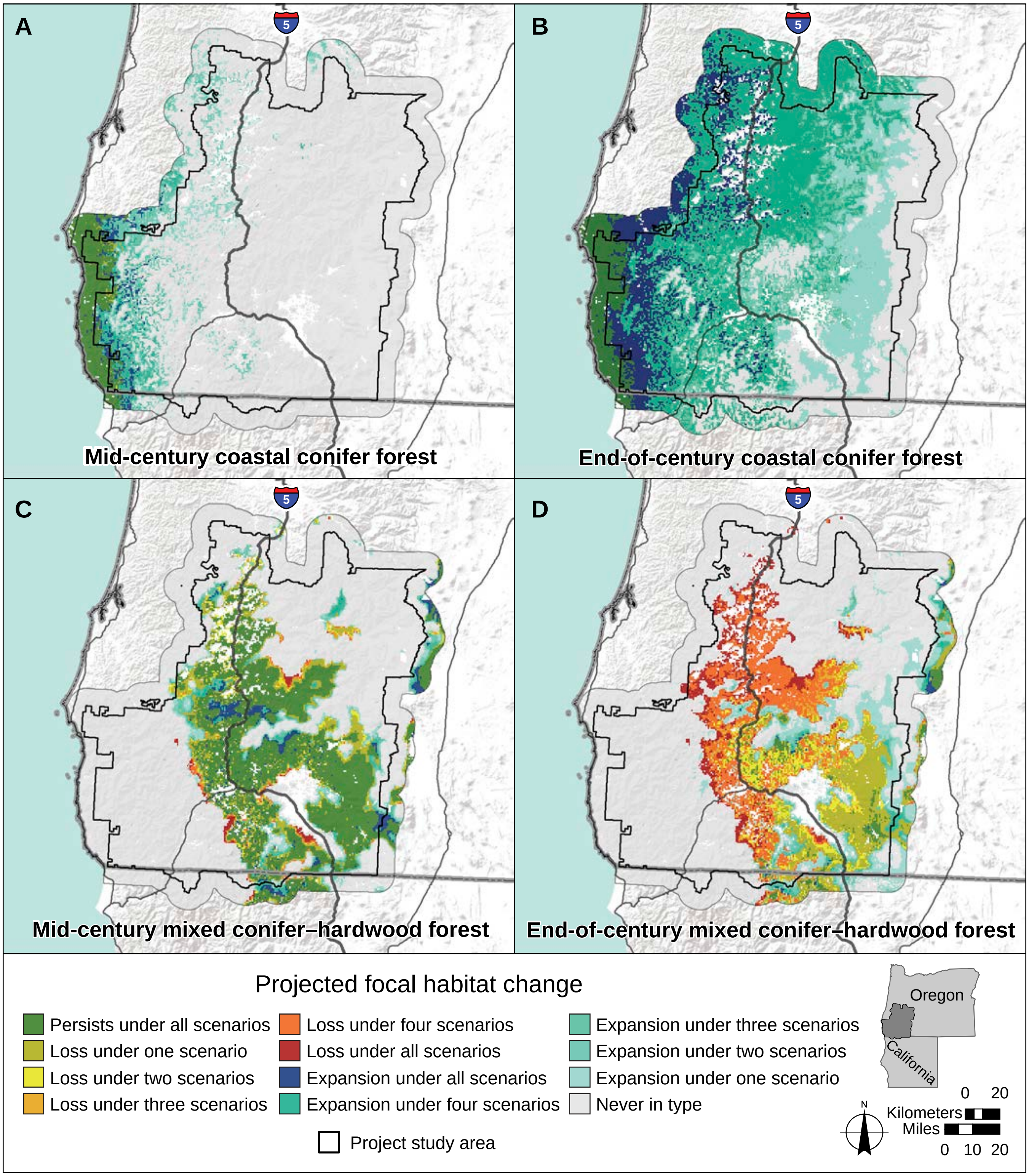


Figure 6.3—Number of climate scenarios (out of the five scenarios presented in fig. 6.2) that produce persistence, expansion, or loss (contraction) of coastal conifer and mixed hardwood-conifer focal habitats at mid-century (2050) and end of century (2070).

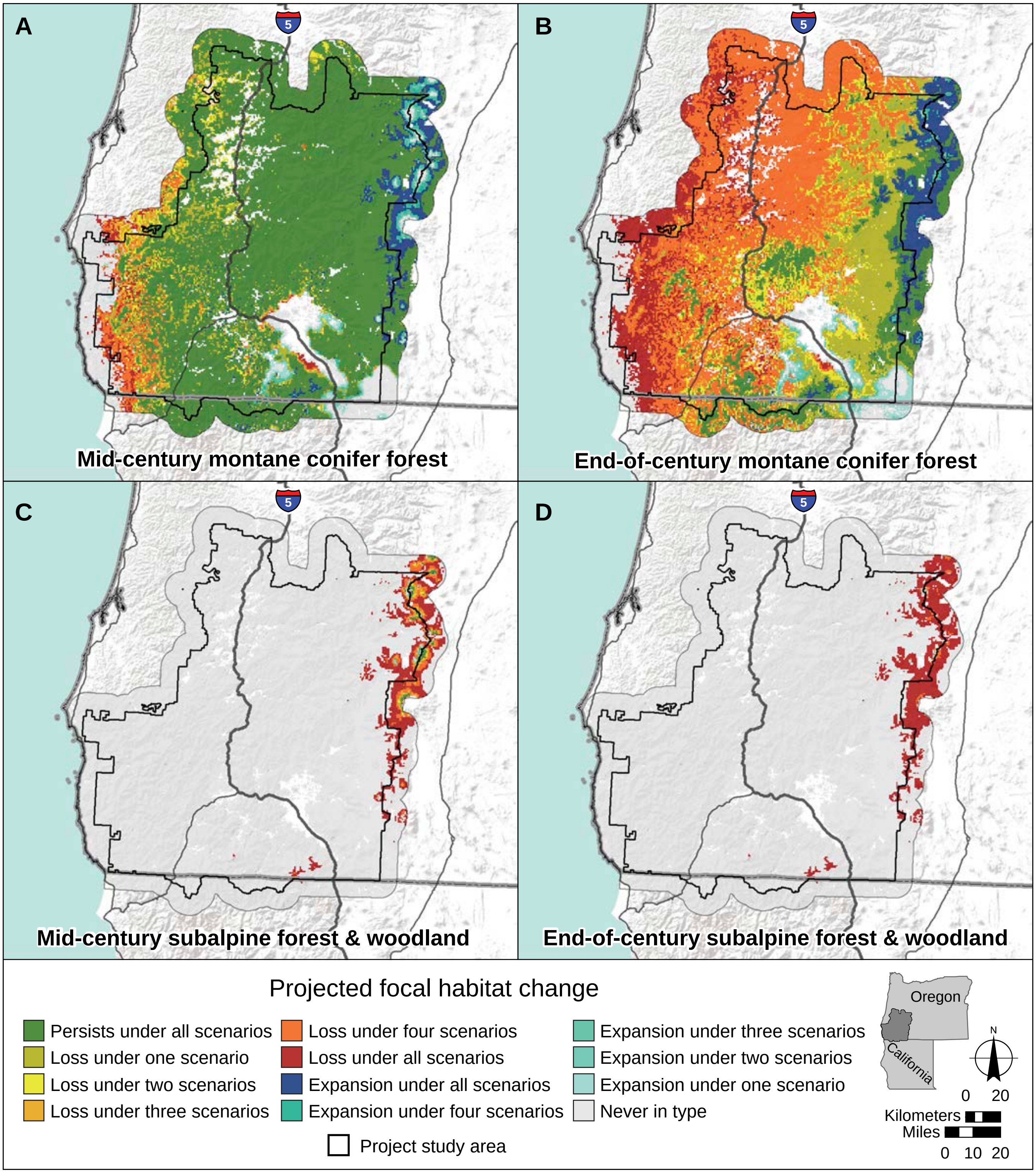


Figure 6.4—Number of climate scenarios (out of the five scenarios presented in fig. 6.2) that produce persistence, expansion, or loss (contraction) of montane conifer forest and subalpine forest and woodland focal habitats at mid-century (2050) and end of century (2070).

historical conditions to about 95 percent at the end of the century) (fig. 6.2). However, future disturbances will determine how much of the potential forest area actually sustains closed-canopy forest conditions into the future. Ecological characteristics of forested areas are also projected to change (figs. 6.3 and 6.4).

There was general consensus across MC2 simulations that climate conditions associated with warm coastal forest will expand eastward (expanding from 5 percent of the assessment area under historical conditions to 53 percent of the assessment area under end-of-century projections), while the area with climate conditions associated with interior mixed conifer–hardwood and montane forest will decrease (see fig. 6.2). The projected decrease in montane conifer forest area occurs even with upward expansion of montane forest conditions into areas that have historically supported subalpine communities. The predicted expansion of warm coastal conifer forest is due to projected temperature increases, loss of winter frost, and longer growing season (conditions similar to recent climate patterns along the coast), but the models may not be capturing other important characteristics of this type, including the limited distribution of coastal fog.

Although warmer conditions, lack of frost, and longer growing seasons are projected to expand eastward, it may be unrealistic to expect that ecological communities currently found in coastal forests will follow. The modeled eastward expansion of the climate conditions associated with warm coastal conifer forest may produce novel ecological associations as these conditions spread inland. Changes in timing of precipitation, coupled with warmer summer temperatures, are expected to increase summer drought stress. Fire season length and annual area burned have increased in recent years and are expected to continue to increase (chapter 5).

Sensitivity—

Although the area capable of supporting conifer forest is projected to remain about the same, the future distribution and characteristics of forest wildlife habitats in southwest Oregon will be determined mostly by large-scale disturbance processes, particularly fire. Increased summer drought is projected to amplify the risk of high-severity fire throughout western North America (Wehner et al. 2017). Recent large-scale fires in southwest Oregon (e.g., the Chetco Bar Fire in 2017, and the Klondike and Taylor Fires in 2018) highlight the importance of these disturbances. High-severity fire has the potential to affect wildlife populations by reducing spatial and structural heterogeneity of forest habitats at large scales and may increase fragmentation and isolation of old-forest patches.

Although it is important to recognize that postfire landscapes have unique biodiversity values in their own right (see the discussion of early-seral and brushfield habitats below), structurally diverse closed-canopy forest may become increasingly rare with more frequent and severe disturbance. Reduced availability of closed-canopy forest and associated large trees, snags, and logs that provide thermal microrefugia may increase vulnerability to thermal stress for many species, including plethodontid (lungless) salamanders, small mammals, and mesocarnivores. Specialized old-forest species, including northern spotted owls (see box 6.1) and marbled murrelets, will likely be particularly sensitive to loss of old-forest nesting structures and thermal refugia.

Future changes in the frequency and severity of fire will be particularly important determinants of habitat characteristics for forest wildlife. Forests follow a variety of successional pathways after disturbance, depending on several factors, including the severity of the disturbance, the forest structures that remain after the disturbance (biological legacies), availability of tree seed sources, and site productivity characteristics (Spies et al. 2018). Habitat characteristics available to wildlife in these postdisturbance landscapes will be determined to a large degree by these successional pathways. A primary concern for mixed conifer forests in southwest Oregon is that repeated disturbances can cause transition of once-forested areas to chaparral or other ecological stable states. Repeated fire may kill conifers and remove seed sources, and resprouting tanoak and other shrub species can dominate postdisturbance landscapes, delaying or preventing conifer regeneration (Airey Lauvaux et al. 2016).

Ecological change in unburned forests may be relatively subtle owing to long tree lifespans, but there may be important impacts to wildlife habitat components even without large-scale tree mortality. Altered temperature and seasonal precipitation patterns could contribute to changes in timing and abundance of plant, fungus, and insect food availability. Reduced availability of plant and fungus food for small mammals can potentially have cascading effects on mesocarnivore populations dependent on small mammals for prey. Small mammals also serve as important seed-dispersal vectors, so reduced small mammal populations could affect seed dispersal processes. The combined effects of a longer warm season and carbon dioxide fertilization could change insect population composition and abundance, with important implications for their predators, including small mammals, birds, and bats. Drought-induced tree mortality may contribute to short-term increases in snag and log abundance but would eventually lead to a longer term decline in availability of such structures if the number of large live trees that serve as snag and log replacements is reduced (van Mantgem et al. 2009).

Interactions between tree pathogens and climate also can potentially affect wildlife habitat elements by killing trees and changing tree species composition. Sudden oak death (SOD) currently occurs primarily in the moist tanoak vegetation type within 15 km of the coast, but this pathogen can potentially spread if warmer conditions facilitate eastward expansion (Standiford and Purcell 2015). Increased SOD could adversely affect wildlife that rely on mast-producing oaks. Widespread reduction of oaks in mixed conifer forests can potentially affect small mammal populations, with cascading effects for their predators, including northern spotted owls and other mesocarnivores.

Adaptive capacity—

The heterogeneity and intermixing of the forest communities in southwest Oregon may provide opportunities for individual animal species to adjust to climate change in novel ways. Animals are likely to change seasonal movement and behavior patterns in response to extended growing seasons and warmer winters. Adaptive capacity of wildlife associated with coastal conifer forest habitats may be influenced by individual species ability to physiologically tolerate temperature and precipitation changes, behaviorally adapt to those changes, and move in response to changes in climate, forest structure, and food availability.

Management practices that promote the development and retention of large live trees, snags, and logs provided by early-seral, fire-resistant species, including Douglas-fir, ponderosa pine, and oaks, are likely to be important in these increasingly fire-prone forests. Fragmented land ownership patterns will continue to pose substantial challenges for efforts to restore or develop sustainable forest structure and configuration patterns for increasingly disturbance-prone interior mixed forests. Montane forest occupies a wide elevation range and may expand upward in elevation. Again, disturbance resilience and retention of large live and dead tree structures will maximize the availability of nesting and resting structures that provide thermal microrefugia for many species.

The topographic heterogeneity and diversity of the intermixed forest communities in southwest Oregon, in combination with the moderating influence of the Pacific Ocean, are likely to provide increased climate resilience for southwest Oregon ecosystems compared to other regions in North America (Buttrick et al. 2015, Olson et al. 2012). Availability of fine-scale thermal microrefugia provided by shading vegetation, large logs, snags, and cavities in large live trees may increase in importance as animals seek to adjust their behavior to manage thermal stress. Special habitat features, including talus, cliffs, and water features (e.g., seeps and springs), may also become increasingly important. The topographic complexity of the SWOAP assessment area may provide opportunities for animals to track suitable microclimate conditions (Frey et al. 2016). Maintaining or enhancing landscape connectivity patterns to facilitate range shifts or seasonal movements that allow animals to adjust to increasing temperatures will likely increase in importance (box 6.2).

Box 6.2

Habitat Connectivity

Providing animals with opportunities to move in response to changes in habitat conditions and resource availability is an important component of climate change adaptation (Heller and Zavaleta 2009). Climate change is expected to alter timing and abundance of critical habitat elements, including food and shelter. Ensuring that animals are able to move through the landscape at fine spatial scales allows animals to find and use those resources. Maintaining habitat connectivity at a broader scale can help reduce extinction risks associated with small, fragmented populations, as well as provide opportunities for animal populations to alter their range in response to changing climatic conditions. Maintaining connectivity will be especially important for conserving species associated with contracting habitat types (e.g., closed canopy, structurally diverse conifer forest).

Three habitat connectivity assessments have been conducted at statewide or regional scales that encompass the SWOAP assessment area. Hatch et al. (2009) used a combination of geographic information system and professional opinion methods to identify highway segments that were potential barriers for animal movement at a statewide scale. McRae et al. (2016) conducted a coarse-filter assessment of human-caused barriers throughout the Pacific Northwest. Carroll et al. (2018) evaluated regional-scale connections between areas with current climate conditions and areas that will support those conditions in the future.

These assessments all highlighted the important role that the SWOAP assessment area plays as the primary link between the Cascade Range and Coast Ranges in Oregon and California. Common patterns highlighted in these analyses suggest substantial barrier effects along the Interstate-5 and associated developed areas near Roseburg, Grants Pass, Medford, and Ashland, Oregon; U.S. Highway 199 southwest of Grants Pass; and Oregon Highway 62 north of Medford may also contribute to barrier effects for sensitive wildlife. These analyses suggest that Siskiyou Summit, Wolf Creek Pass, and the Buck Creek–Thief Creek area south of Cottage Grove provide critical linkages for connectivity (fig. 6.5).

A climate-connectivity assessment conducted by Carroll et al. (2018) highlights these high-elevation and mid-slope locations as connectors between areas with similar current and future climatic conditions. Ongoing work being conducted by the Oregon Department of Fish and Wildlife and the Oregon Wildlife Habitat Connectivity Consortium will provide additional information on existing habitat connectivity patterns and conservation priorities in the SWOAP assessment area.

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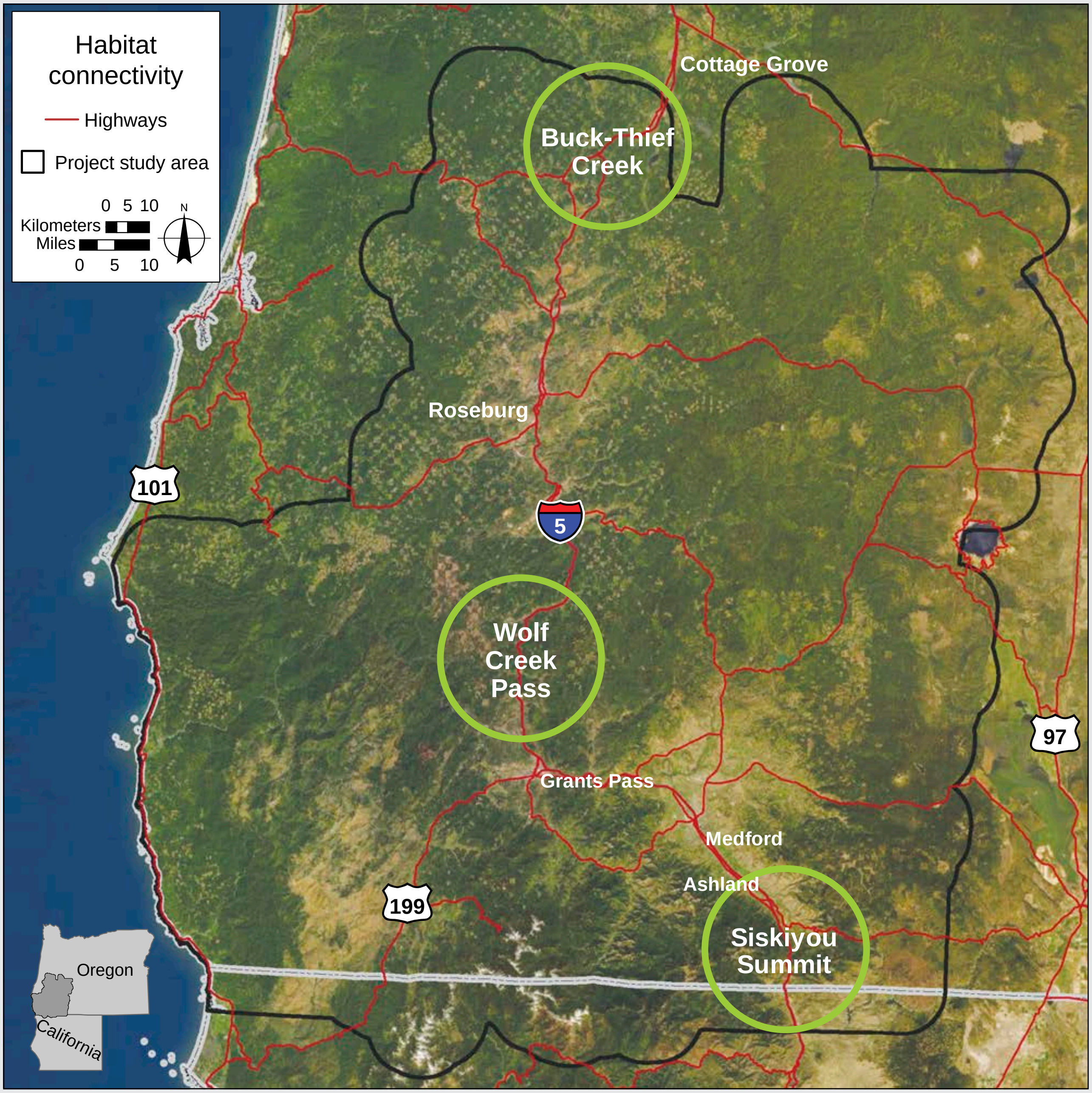

Figure 6.5—Potentially important habitat connectivity links suggested by connectivity assessments that encompass the Southwest Oregon Assessment Project assessment area (Carroll et al. 2018, Hatch et al. 2007, McRae et al. 2016). Potential linkage areas are identified by light green circles.

Potential adaptation strategies:

- Promote landscape patterns that are resilient to current and anticipated disturbance regimes.
- Control invasive species.
- Manage motorized recreation, grazing, and other human stressors.
- Coordinate with adjacent land managers to restore landscape patterns that are resilient to disturbance, address potential land use conversion pressures, and maintain landscape permeability for range shifts and seasonal migration.
- Identify and protect or enhance wet areas and available water sources.
- Identify and protect thermal refugia (e.g., cliffs, talus, and deep soils).
- Identify and protect potential disturbance refugia (i.e., landscape settings that have relatively low probability of high-severity disturbance occurrence).

Early-Seral Forest and Brushfields

Early-seral forests and brushfields are distributed across forested vegetation types throughout the SWOAP assessment area. Early-seral forest areas are also referred to as preforest to highlight the dominance of herb and shrub vegetation rather than trees (Swanson et al. 2014). The primary difference between early-seral forests and brushfields is that brushfields can represent a relatively stable ecological state, whereas early-seral forests move through a variety of successional pathways to become dominated by trees over time. Early-seral and brushfield ecological types comprise about 16 percent of the assessment area based on the 2011 GAP map (USDI GS 2016), although this is probably an underestimate owing to recent wildfire effects. Because early-seral and brushfield habitat components are found across a variety of forested and nonforested vegetation types, distribution is not represented well by potential vegetation type. Predominant NatureServe types are harvested and recently burned forest (14 percent of the assessment area), as well as chaparral types (2 percent of the assessment area combined) (NatureServe 2013).

A key wildlife habitat component of early-seral and brushfield communities is productive herbaceous and shrub vegetation that produces abundant forage, fruit, and nectar resources for vertebrates and invertebrates. These rich food resources support a diverse community of insects, small mammals, birds, and ungulates, which in turn provide prey for predators of all sizes. Early-seral or preforests support diverse wildlife communities, processes, and structures that reflect both the nature of the disturbance the landscape has experienced and the ecological characteristics of the landscape prior to the disturbance (DellaSala et al. 2014, Swanson et al. 2011).

Biological legacies, including snags, logs, and remnant live trees with defects, provide important structural diversity in postdisturbance landscapes. The spatial and structural diversity provided by remnant forest patches or isolated large trees provide a unique juxtaposition of habitat components, particularly after mixed-severity disturbances (Swanson et al. 2011, 2014). Standing snags provide nesting and foraging resources for primary cavity excavators, including hairy woodpecker, downy woodpecker, and red-breasted sapsucker. The cavities created by these species create unique habitat structures used by secondary cavity-nesting birds and small mammals. Postdisturbance conditions set the stage for subsequent forest development successional pathways (Spies et al. 2018).

Key wildlife habitat components of brushfields similarly include large patches of productive herbaceous or deciduous vegetation, fruiting plants, nectar-producing flowers, fungi, forbs, grasses, shrubs of different sizes and growth forms, and scattered or clumped trees (Altman 2000, Johnson and O'Neil 2001). Scattered large trees or forest edges can contribute to structural and spatial diversity. Deep soils can provide suitable conditions for burrowing animals. Chaparral brushfields are often fire-induced seral types, especially in moist areas (e.g., nearer the coast). Because most shrub dominants sprout after fire, successive burns can eliminate conifers and increase shrub density, resulting in a self-reinforcing stable ecological state (Airey Lauvaux et al. 2016). Chaparral is most abundant in the Rogue and Illinois Valleys where the climate is very warm and relatively dry. Montane brushfields occur naturally at higher elevations where soils and other conditions (e.g., south aspects, harsher climate) are more suitable for lower growing shrubby vegetation than large trees and dense forests.

Early-seral and brushfield habitats support a diverse wildlife community. Burrowing animals such as pocket gophers and ground squirrels can be particularly abundant in postdisturbance areas. Deer mice, golden-mantled ground squirrels, and particularly chipmunks provide important seed-dispersal functions in postdisturbance landscapes (Briggs et al. 2009). Recently disturbed patches can provide high-quality herbaceous and shrub forage for ungulates, including mule deer and elk. These abundant small mammal and ungulate populations in turn support predator communities, including red-tailed hawks, great horned owls, coyotes, mountain lion, and gray wolves. Birds commonly associated with chaparral habitats include western scrub-jay, spotted towhee, California towhee, lesser goldfinch, dusky flycatcher, green-tailed towhee, and fox sparrow (Altman 2000). Lazuli buntings demonstrate a strong positive response to early-successional conditions following fires (Altman and Alexander 2012). Nectar-producing flowers provide important food resources for a variety of insects, including butterflies. Insects provide a variety of ecosystem services, including pollination, nutrient cycling, and serving as prey for a wide variety of birds, mammals, and amphibians.

Nonclimate stressors—

Nonclimate stressors for early-seral forests include forest management practices, invasive species, roads, recreation, herbivory, and repeated high-severity fire (USDA FS 2011). Postdisturbance forest management practices (i.e., timber harvest, planting, and herbicide use) can have important effects on early-seral habitat characteristics and forest development. Harvest of dead or dying trees or remnant patches of unburned forest can remove biological legacies and simplify the postdisturbance landscape. Invasive plants, including invasive annual grasses, can alter species composition, reduce species richness, reduce forage availability, and increase fire frequency. Roads can facilitate dispersal of invasive plants by vehicles. Animals can be particularly vulnerable to human disturbance in areas where visual cover is reduced. Herbivory by domestic and wild animals (including deer and elk) can have substantial effects on species composition and vegetation structure. High-severity fire, particularly in areas that experience subsequent reburning of sprouted shrubs, can eliminate tree seed sources and contribute to conversion of areas from forest to permanent brushfield communities.

Early-seral habitats are important areas for declining invertebrate pollinators. Potential drivers of pollinator declines include habitat loss and fragmentation, agrochemicals, pathogens, alien species, climate change, and interactions among those factors (Goulson et al. 2015, Hallmann et al. 2017, Potts et al. 2010). Several rare invertebrate species are found in the SWOAP assessment area. Franklin's bumblebee is a narrowly distributed species historically found only in Douglas, Jackson, and Josephine Counties in Oregon, and Siskiyou and Trinity Counties in California, and has not been detected since 2006, when one individual was found near Mount Ashland (Arnold et al. 2006, Kevan 2008). Mardon skippers occur in four localized but widely disjunct populations (Miller and Hammond 2007). The southern Oregon Cascade population occurs in open, montane meadows with bunchgrasses along the summit of the Cascade Mountains in Jackson, Klamath, and Siskiyou Counties in Oregon and northern California. Most populations are located within Cascade-Siskiyou National Monument and Rogue River-Siskiyou and Fremont-Winema National Forests. Another population is found associated with serpentine soils in Siskiyou National Forest. Although fire historically facilitated the creation of early-seral habitat for mardon skippers, the population has become so reduced and fragmented that fire is now considered a serious risk for the remaining populated patches (Miller and Hammond 2007).

No ESA-listed species are specifically associated with early-seral or brushfield habitats in the SWOAP assessment area. ISSSSP species associated with early-seral habitats include white-tailed kite, Oregon vesper sparrow, Columbian white-tailed deer, California shield-backed bug, Franklin's bumblebee, western bumblebee, hoary elfin, Oregon branded skipper, coastal greenish blue butterfly, mardon skipper, coronis fritillary, and Siskiyou short-horned grasshopper. Several generalist bats included on the ISSSSP list also use early-seral habitats in the SWOAP assessment area, including pallid bat, Townsend's big-eared bat, and fringed myotis.

Exposure—

The area of early-seral forest and brushfields is expected to increase within the SWOAP assessment area with more frequent fire. MC2 projections do not provide much information on the future distribution of these habitat conditions because early-seral forests and brushfields have a patchy distribution throughout forested vegetation types. Exposure to climate change impacts for wildlife associated with these habitat types will reflect the general patterns within the assessment area of increased temperature, amplified seasonal precipitation patterns, and increased frequency of wildfire. Animals associated with early-seral habitats may be more exposed to direct effects of climate change because of the rarity of shading and sheltering structures compared to other habitats.

Sensitivity—

The sensitivity of wildlife associated with early-seral forests and brushfields to climate change effects may be mitigated by ecological traits common in this community. Animals associated with early-seral, postfire habitats tend to be good dispersers with relatively high reproductive rates (adaptations to take advantage of transient early-seral habitat conditions). These traits may facilitate adaptation to local conditions under future climates. Projected increases in fire frequency and historical vegetation responses to warming climates suggest that early-seral conditions are likely to increase in area, possibly contributing to an abundance of habitat for associated animals. However, increased fire frequency and severity may contribute to more, but less diverse, early-seral area. Higher severity fire and reburns may remove biological legacies (e.g., snags, logs, and remnant live trees) and residual tree patches.

Species dependent on herbaceous vegetation in early-seral and meadow habitats may be sensitive to changes in the timing of forage availability and plant development. An extended growing season may change growth forms and timing of availability of forage and pollen resources. Forage may be more abundant during the fall, winter, and spring as the growing season is extended, but forage quality and availability may decrease through the summer with amplified summer drought. Changes in plant phenology and timing of forage quality and quantity will be important for species dependent on these resources. Phenological mismatches between plants and specialized pollinators are a particular concern, with the potential to cascade through food webs. For example, altered plant phenology may affect insect populations, which have the potential to affect migratory bird populations (Ockendon et al. 2014).

Projected increases in net primary productivity (chapter 5) may promote shrub and sprouting hardwood growth, providing habitat for shrub-associated species, potentially reducing conifer regeneration and increasing reburn potential. Accelerated shrub growth may pressure managers to increase use of herbicides to promote tree regeneration. Postdisturbance colonization by invasive plants has the potential to reduce plant species diversity and consequently affect food and fine-scale structural diversity. Invasive species, particularly annual grasses, are likely to be increasingly problematic (Bachelet et al. 2011).

Adaptive capacity—

Area occupied by early-seral habitats is likely to increase. Recognizing the important contribution that high-quality early-seral habitat can make to large-scale biodiversity may be increasingly important for future wildlife conservation in southwest Oregon. Large-scale spatial and structural heterogeneity, including biological legacies such as snags, logs, remnant live trees and patches of undisturbed vegetation, can contribute to the diversity of food and shelter resources for many species. A key challenge will be to develop strategies to maintain spatial and structural heterogeneity in landscapes that are likely to experience more frequent wildfire.

Pre- and postdisturbance silvicultural treatments will probably play an important role in these strategies. Predisturbance thinning and prescribed burning treatments designed to increase the resilience of forest structure have the potential to enhance postdisturbance spatial heterogeneity. Some postdisturbance removal of unburned smaller snags and logs may also be appropriate to reduce fuels that increase the potential for high-severity reburn. Both strategies may be important for providing diverse, high-quality early-seral habitat under intensifying disturbance regimes. Presence of fine-scale thermal refugia—for example, remnant large live trees, large snags and logs, deep soils, talus, and cliffs—is likely to become increasingly important.

Wildlife species are likely to alter their seasonal movement patterns in response to food availability. Ungulates may spend more time on higher elevation summer ranges or could stop migrating entirely if forage quality and availability is better at higher elevation sites. Climate change effects will continue to interact with nonclimate stressors, contributing to pollinator declines (Goulson et al. 2015).

Potential adaptation strategies:

- Recognize the important biodiversity values of high-quality early-seral habitat.

- Identify pre- and postdisturbance management practices that will serve the goal of retaining spatially and structurally diverse early-seral habitat given intensifying disturbance regimes.
- Identify and protect unique habitat features to provide thermal refugia, including deep soils, talus, and cliffs.
- Control invasive plants.
- Provide wildlife with opportunities to find and track transient early-seral habitat characteristics by mitigating or preventing human-created barriers to movement.

Oak Woodlands, Savannahs, and Grasslands

Oak woodlands, savannas, and low-elevation grasslands are generally found in the interior valleys and Siskiyou Mountains, below about 800 m. Oak woodlands occur in the California oak potential vegetation type or as a seral stage within the Douglas-fir type (see footnote 2). We include low-elevation grassland communities in this section because oak woodlands and grasslands are often intermixed and share herbaceous vegetation characteristics. The distinction among woodlands, savannahs, and grasslands is primarily a function of the abundance of trees, typically Oregon white oak, California black oak, or ponderosa pine. Oak woodland and grassland vegetation types encompass 11 and 1.5 percent of the assessment area, respectively (USDI GS 2016). Predominant NatureServe ecological types for oak woodlands are Mediterranean California dry-mesic mixed conifer forest and woodland, and Mediterranean California lower montane black oak-conifer forest and woodland (NatureServe 2013). The NatureServe type for low-elevation grasslands is Willamette Valley upland prairie and savanna (NatureServe 2013).

Key oak woodland wildlife habitat elements include acorns, cavities, trees, shrubs, interspersed grass and herbaceous vegetation, snags, brush piles, and proximity to water or riparian areas (Altman 2000, California Partners in Flight 2002). Oak trees provide a variety of unique wildlife habitat elements, including abundant cavities, diverse canopy structure, and an acorn food crop (McShea and Healy 2002). Oak woodlands typically have interspersed grass and shrub patches, providing an important juxtaposition of wildlife habitat elements (California Partners in Flight 2002). The historical fire regime was high frequency and low severity. Without frequent fire, oak woodlands can be quickly encroached upon by conifers and build up fuel loads that can cause tree mortality when fires occur (Cocking et al. 2015).

Lewis' woodpecker, white-breasted nuthatch, western gray squirrels, and Columbian white-tailed deer are characteristic species of oak woodlands. Oak woodland focal species identified by California Partners in Flight (2002) that occur within the SWOAP assessment area include acorn woodpecker, blue-gray gnatcatcher, western scrub-jay, oak titmouse, and western bluebird. Black-throated gray warbler is frequently associated with a robust deciduous subcanopy of California black oak (Marshall et al. 2006). Miller and Hammond (2007) identified 25 species of butterflies and moths associated with oak woodlands. These species are specialist feeders on various oaks and are dependent on the persistence of oak woodlands along the west coast. Oak foliage provides the primary food for the caterpillar stage in many of these species.

Altman (2000) provided the following description of the diverse bird communities associated with different lowland native grasslands and savanna conditions:

Dry prairie-associated species include Oregon vesper sparrow, streaked horned lark, grasshopper sparrow, and western meadowlark. Where a scattered shrub component occurs, species diversity may increase to include lazuli buntings which nest in the shrubs, and species abundance may increase for some of the obligate species, such as Oregon vesper sparrow and western meadowlark, which use the shrubs as singing perches.

Nonclimate stressors—

Nonclimate stressors for oak woodlands, savannas, and grasslands include conversion to urban or agricultural land uses, lack of oak regeneration, encroachment by conifers, altered fire regimes, overgrazing, invasive species, and SOD (California Partners in Flight 2002, Standiford and Purcell 2015). Deep-soiled valley bottom native grasslands have been affected in southwest Oregon, and across much of western North America, owing to their desirability for agriculture and residential development (Altman 2000, 2011). Many valley bottom areas that historically supported woodland or grassland habitat have been converted to agriculture, urban, or residential land uses (Altman 2011, California Partners in Flight 2002). Fire exclusion, grazing, and invasive species are also stressors in native grasslands (Johnson and O'Neil 2001). Because of their proximity to urban areas and easy access, oak woodlands can experience heavy recreational use. Hiking, biking, equestrian sports, motorized recreation, and hunting are all popular activities in oak woodlands.

Many of the bird species associated with western oak woodlands have experienced population decreases and range contractions (Altman 2011). The general pattern in the Pacific Northwest has been a southward contraction of several species ranges, probably as a result of extensive urbanization and development in the Puget Trough and Willamette Valley, where oak woodlands were once common (Altman 2011). Within the SWOAP assessment area, SOD is present only in tanoak near the coast at this time but has potential to spread if warmer conditions facilitate eastward expansion (Standiford and Purcell 2015). Conifer encroachment resulting from fire suppression or timber production has also been an important factor contributing to oak woodland and grassland declines and has contributed to an increased risk of high-severity fire in these landscapes (Altman 2011, California Partners in Flight 2002). Frequent fires historically acted to thin out the understory of shrubs and small trees and reduce competition for soil nutrients and water among larger established oaks. In northern California, fire suppression has led to increased densities and occurrence of Douglas-fir at lower elevations, while oaks have declined (Cocking et al. 2015).

Invasive species can have substantial impacts on wildlife habitat values in oak woodlands and grasslands. European invasive annual grasses have replaced native perennial grasses in many areas (Standiford and Purcell 2015). The invasive annual grasses compete for soil moisture with oak seedlings. Overgrazing by cattle has directly and indirectly facilitated the spread of invasive annual grasses and the associated decline of native perennial grasses (Standiford and Purcell 2015). Cattle can also reduce oak regeneration by consuming young oak shoots.

One ESA-listed species is associated with oak woodlands in the SWOAP assessment area: Columbian white-tailed deer (endangered). The historical range of streaked horned lark (threatened) also overlaps the assessment area. ISSSSP species associated with oak woodlands include Lewis' woodpecker, grasshopper sparrow, merlin, American peregrine falcon, bald eagle, pallid bat, Townsend's big-eared bat, and fringed myotis.

Exposure—

Future projections for the extent of oak woodlands and grasslands in southwest Oregon are uncertain, but the paleoecological record suggests that oak woodlands and grasslands may expand as temperature and summer drought stress increases (chapter 5). Interpretation of future oak woodland area projections based on the MC2 vegetation model outputs is complicated because mid-elevation oak woodland vegetation types are combined into a single category with high-elevation subalpine types. However, oak woodlands commonly occur as a disturbance-maintained community in dry forest potential vegetation types. The LANDIS-II vegetation model and the paleoecological record suggest that the area of oak woodlands is likely to increase in a warmer climate (chapter 5). This expansion may be facilitated and maintained by more frequent low- and moderate-severity fire.

Sensitivity—

Oaks are early-seral, fire-tolerant, and drought-resistant species. These traits may benefit wildlife associated with oaks under future climate conditions. Increased fire frequency may favor oaks and serve to maintain open woodland habitat, providing that large oak trees are able to survive initial fires in areas that have very high fuel loads. However, increased growth of invasive annual grasses could reduce fire resilience and affect overall biodiversity in these habitats. These effects on herbaceous vegetation have the potential to produce cascading effects through the food web, as changes in plant food availability affect insect and small mammal consumers and their predators. More frequent and severe fires could reduce the availability of snags, logs, and other structures that provide fine-scale thermal refugia. The potential for increased susceptibility to SOD with warmer, wetter conditions is a particular concern in southwest Oregon (Standiford and Purcell 2015). Amplified summer drought seems unlikely to disadvantage native prairie and savanna communities, but drought may have greater impact on less drought-tolerant trees and forest species (Bachelet et al. 2011).

Adaptive capacity—

The SWOAP assessment area is at the northern end of several oak woodland and other California ecological types (NatureServe 2013). The current geographic distribution of oak habitats (abundant to the south) and the paleoecological record suggest that oak woodlands may be well adapted to warmer and seasonally drier future conditions (chapter 5). The area of oak woodland may expand at the expense of mixed-conifer forest within the SWOAP assessment area, depending on transitional disturbance processes and availability of seed sources. The facultative relationship between oaks and caching animals for dispersal of acorns may become increasingly important for expansion of oak woodlands in the future. Active management (thinning and prescribed fire) to promote the development and retention of oak woodland and savannah habitats may be desirable for some areas that are at risk of high-severity fire, particularly in wildland-urban interface areas where a combination of safety, aesthetics, and biodiversity are highly valued.

Bachelet et al. (2011) proposed six “climate smart” conservation strategies for prairies in the Pacific Northwest that are also pertinent to oak woodlands and savannahs: (1) utilize the full geographic and climatic range of prairies and oak savannas within the region, (2) use habitat heterogeneity to sustain populations and functions in place, (3) manage current sites adaptively and strategically expand prairie conservation areas, (4) establish new prairies and oak savannas on lands that become suitable as a result of climate change, (5) use ecosystem services from prairies and oak savannas to enhance opportunities for conservation and restoration, and (6) monitor climate and threshold responses of biological communities. Invasive species control is likely to be an ongoing and growing challenge that will be amplified by climate change (Dennehy et al. 2011).

Potential adaptation strategies:

- Implement prescribed fire and thinning to maintain native oak woodland habitat.
- Manage oak woodlands in wildland-urban interface areas with frequent prescribed fire to reduce the risk of high-severity fire while providing aesthetic, recreation, and biodiversity values.
- Control invasive species (e.g., invasive annual grasses).
- Manage motorized recreation, grazing, and other human stressors.
- Coordinate with adjacent land managers to address potential land use conversion pressures and maintain landscape permeability for range shifts and seasonal migration.
- Mitigate barriers associated with transportation networks and urban or agricultural land uses to provide for seasonal movements and range shifts.
- Identify and protect or enhance wet areas and available water sources.

Wetland, Riparian, and Open Water

Riparian, wetland, and open-water habitats support complex and diverse communities of flora and fauna because they are at the interface between aquatic and terrestrial systems (Gregory et al. 1991). These habitats occur in all potential vegetation types in southwest Oregon (we do not identify specific associations with NatureServe vegetation types because of the broad distribution of riparian communities across types). The distribution of wetland, riparian, and open-water habitat is primarily determined by 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. Wildlife communities associated with riparian habitats have been described by Kauffman et al. (2001).

Key ecological features of riparian, wetland, and open-water habitats include moving and still water, riparian vegetation, woody debris, including snags and logs, diverse and abundant invertebrate and plant foods, linear and connected spatial patterns (habitat connectivity), and a cool moist microclimate (Kauffman et al. 2001, USDA FS 2011). A unique characteristic of riparian systems is that they occupy the lowest topographic positions relative to surrounding areas, so they have substantial nutrient and energy inputs (organic matter simply falls or 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 (e.g., red alder) 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. These areas also provide unique patterns of elevational connectedness. Streamside shading vegetation, along with evaporative cooling from open water and cold air drainage, contribute to unique cool microhabitats.

Cold, moving-water streams provide habitat for amphibians and aquatic invertebrates and are most likely to occur in mid- and high-elevation forested settings that provide the proper stream gradient and forest shading to maintain cold-water temperatures. Cold, moving-water stream habitats are typically found in moist grand fir, western hemlock, mountain hemlock, and Pacific silver fir potential vegetation series, primarily along the west slope of the Cascades in the SWOAP assessment area. Summer cold-water flows often depend on high-elevation snowmelt but may also be found in spring-fed streams.

Herbaceous wetlands are predominantly found in seasonally flooded sites where standing freshwater may be present through part of the year, and soils stay saturated throughout the growing season. Vegetation in these wetlands is generally a mix of emergent herbaceous plants and grasses. Vernal pools are unique wetland features that support specialized biotic communities (USDI FWS 2005).

Characteristic species of wetland, riparian, and open-water habitats in southwest Oregon include Cascades frog, Oregon spotted frog, Pacific chorus frog, northwestern salamander, western pond turtle, northern waterthrush, and American beaver. Altman (2000) provided the following description of the lowland riparian bird community in western Oregon:

> We considered 49 species to be highly associated breeding species in riparian forest and shrub habitats. Many of these species are generalists that also occur as breeders in other habitat types (e.g., American robin, Bewick's wren, Swainson's thrush). However, others such as red-eyed vireo, yellow warbler, yellow-breasted chat, warbling vireo, and Bullock's oriole are obligate or near obligate to riparian habitat. Most species are primarily insectivores that take advantage of the high insect productivity that occurs in riparian habitats. In general, the greater the structural layering and complexity of the habitat, the greater the insect productivity, and the greater the bird species diversity. Many studies have reported higher species richness, abundance, or diversity in riparian zones than adjacent habitats, particularly at lower elevations. Other riparian associated bird species are tied to unique features such as nesting cavities provided by snags (e.g., downy woodpecker, black-capped chickadee, tree swallow), nectar of flowering plants in the understory (e.g.,

rufous hummingbird), fruit from berry-producing plants in the understory and subcanopy (e.g., cedar waxwing), or a dense, diverse shrub layer (e.g., Swainson's thrush).

Several animal species serve important keystone ecological functions in riparian areas. Climate change vulnerability for anadromous fish is addressed elsewhere in this volume (chapter 4), but it is important to note that these fish are a key part of a complex food web that has historically supported animals of all sizes. American beavers are another keystone species, whose habit of dam construction can substantially influence the hydrology and water-retention capability of stream networks, with cascading effects on wildlife habitat characteristics and biodiversity.

Nonclimate stressors—

Nonclimate stressors for wetlands and riparian habitats include invasive species, land use change, grazing, roads, recreation, fire, and human water use (USDA FS 2011). Invasive species can alter community interactions, reduce food availability, and change habitat structure. Concentrated use 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 have substantial impacts on riparian systems by changing flooding and debris flow patterns (Jones et al. 2000). Riparian and open-water settings are particularly attractive for human recreational and residential development. Such use can contribute to the loss of riparian vegetation, soil compaction, loss of dead wood habitat elements, and high levels of human disturbance (Gaines et al. 2003).

The historical role of fire in riparian areas is complex (Olson and Agee 2005). The relatively cool and moist conditions found in riparian areas can contribute to fire refugia patterns (Camp et al. 1997), but when conditions are very dry, and high-severity fire spreads into riparian areas from the adjacent landscape, riparian areas can burn at high intensities and even function as "wicks," rapidly moving fire through the landscape (Pettit and Naiman 2007). Fires of different severity can have different effects on stream and riparian food webs. High-severity wildfire can stimulate aquatic productivity and increased invertebrate prey abundance in some circumstances, potentially increasing food availability for terrestrial wildlife (Malison and Baxter 2010).

Two ESA-listed species are associated with wetland, riparian, or open-water habitats within the SWOAP assessment area; vernal pool fairy shrimp (threatened) are found in the Agate Desert prairie near Medford (USDI FWS 2005), and the Oregon spotted frog is found immediately adjacent to the Rogue Basin and is suspected to occur within the valley. ISSSSP species associated with wetland, riparian, or open-water habitats include bald eagle, purple martin, tricolored blackbird, bufflehead, yellow rail, harlequin duck, northern waterthrush, horned grebe, red-necked grebe, foothill yellow-legged frog, western pond turtle, pallid bat, Townsend's big-eared bat, and fringed myotis. Merlin and American peregrine falcon are other ISSSSP species that frequently use wetland, riparian, or open water habitats. The ISSSSP list also includes 35 other invertebrate species associated with wetland, riparian, or open water habitats.

Exposure—
This type is found in all potential vegetation zones in the SWOAP assessment area. The degree of exposure to climate change effects will largely be determined by changes in hydrology. Projections suggest that the western half of the assessment area may see minimal and local changes in hydrology, consisting primarily of higher rainfall intensity during winter months and less precipitation during the summer (chapters 2 and 3). The higher elevation portions of the assessment area along the Cascade Crest, and some parts of the Siskiyou Range are expected to experience a shift from winter snow to winter rain-dominated systems, with increased peak flows during the winter and decreased low flows during the summer (chapter 3). Increased variability and potential for extreme precipitation events will contribute to the risk of damaging floods. Increased fire frequency and severity also have the potential to affect riparian areas, particularly if high-severity fire is carried into these areas from adjacent portions of the landscape. Cold, moving-water habitat conditions are expected to be very exposed to climate change impacts because of their 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 in historically snow-dominated subwatersheds (chapter 3).

Sensitivity—
Decreased summer streamflow and decreased groundwater availability have the potential to contribute to the decline of wetland, riparian, and open-water habitats owing to seasonal drying. Changes in seasonal water availability and water temperature may affect aquatic insect populations that provide prey for insectivorous wildlife. Increased vulnerability to drying may be important for amphibian species that have been restricted to shallower fishless ponds owing to the introduction of predatory trout in larger lakes (Ryan et al. 2014). Distribution of cold, moving-water streams is likely to decrease as water temperatures increase and summer flows decrease. 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 severity of fire or winter flooding could also contribute to increased stream temperatures and loss of nesting and resting structures for wildlife (e.g., shrubs, snags, and logs). More frequent and intense winter flood events have the potential to bury or scour riparian vegetation and damage or remove large-tree and large-wood habitat components.

Adaptive capacity—

The adaptive capacity of wetland, riparian, and open-water areas and associated wildlife is limited by the hydrologic and topographic context in which they exist. The linear, attitudinally connected pattern of riparian habitats may provide for upward range shifts for associated species to track cooler climatic conditions. Strategies to maintain instream flow, groundwater recharge, and protect riparian vegetation should be developed based on the unique landscape and hydrology characteristics of the areas under consideration. Management strategies to retain or restore keystone species that contribute to hydrologic and nutrient cycling functions (e.g., salmon and beaver) may become increasingly important. However, because beavers can greatly influence habitat, including flooding of streamside wetlands and removal of large live trees, selection of appropriate areas for beaver reintroduction needs to be carefully considered.

Potential adaptation strategies:

- Limit direct disturbance impacts from road construction and recreation sites.
- Consider downstream hydrologic function in landscape and road planning.
- Consider relocating roads and recreation developments away from floodplains.
- Manage grazing in sensitive areas to maintain wildlife habitat.
- Protect microclimate characteristics by retaining shading vegetation.
- Encourage beaver colonization to maximize water retention and groundwater recharge where appropriate.
- Consider connectivity of riparian habitat conditions along stream networks to provide for animal movement and range shifts.
- Promote landscape patterns that protect riparian and wetland areas from high-severity fire.
- Consider strategies for protecting key areas from flood damage by increasing upslope water retention capacity (e.g., beavers) and minimizing extent of impervious surfaces.
- Identify and protect cold, moving-water habitats in groundwater-dominated stream systems.
- Remove invasive species.

Subalpine Forests, Woodlands, and Meadows

Subalpine forests, woodlands, and meadows within the SWOAP assessment area are concentrated above 1500 m along the Cascade Crest at the eastern edge of the assessment area. A few patches are also present in the highest elevations of the Siskiyou Mountains near Mount Ashland. The predominant NatureServe types corresponding to these habitats are North Pacific mountain hemlock forest, north Pacific dry-mesic silver fir-western hemlock-Douglas-fir forest, northern California mesic subalpine woodland, and north Pacific maritime mesic subalpine parkland. Approximately 6 percent of the SWOAP assessment area falls within these types (USDI GS 2016). Most of the area of subalpine forests and parklands within the SWOAP assessment area overlaps with the buffered assessment area included in the South Central Oregon Adaptation Partnership (SCOAP) assessment (Halofsky et al. 2018a). Singleton et al. (2018) provided an assessment of climate change vulnerability for wildlife communities associated with high-elevation habitats (including cold forests, woodlands, and meadow/grassland/barren areas) for the SCOAP assessment area that encompasses most of the high-elevation habitat within the SWOAP assessment area. Readers may wish to review Singleton et al. (2018) for a more extensive assessment of these high-elevation habitats.

A primary characteristic that distinguishes high-elevation habitats from others in the SWOAP assessment area is a deep persistent wintertime snowpack. The deep snowpack provides unique under-snow (subnivian) habitat characteristics and security from common meso-carnivores that are not well adapted for travel in deep snow conditions (e.g., bobcats and coyotes). Heavy snow loads influence tree crown development in high-elevation forests, often producing more sharply conical forms with less canopy connectivity compared to mid-elevation forests, producing a fine-scale mix of forest, shrub, and herbaceous patches. Trees become less dominant with increasing elevation as woodland, and then meadow conditions become more common. Wildlife and habitat characteristics of these high-elevation habitats were reviewed by Martin (2001).

Characteristic wildlife species associated with spatially and structurally diverse high-elevation cold forests include great gray owl, American marten, blue grouse, and varied thrush. Wildlife species associated with high-elevation woodlands include Clark’s nutcracker, mountain bluebird, Townsend’s solitaire, Sierra Nevada red fox, and ermine. Snowshoe hare is a particularly important prey species for avian and mammalian predators in high-elevation forest and woodland habitats. Characteristic species of subalpine meadows and rockfields include American pika, yellow-bellied marmot, American pipit, and gray-crowned rosy finch. Seasonally abundant flowering plants in subalpine meadows support a variety of pollinating species, including the western bumblebee. High-elevation meadows and grasslands also have notable overlap in bird species composition with low-elevation grasslands and shrublands, including chipping sparrow, Oregon vesper sparrow, and savannah sparrow, as well as wide-ranging species, including prairie falcons, golden eagles, red-tailed hawks, and common ravens. Many species associated with high-elevation habitats are seasonal migrants (e.g., gray-crowned rosy finches, elk). Other species have unique adaptations for cold, snowy environments, including seasonal coloration changes or morphological adaptations for traveling on or under the snowpack (e.g., snowshoe hare and ermine).

Nonclimate stressors for high-elevation cold habitats include forest insects and disease, and recreation (USDA FS 2011). Invasive species and herbivory are other important stressors for high-elevation meadows. White pine blister rust is a fungal infection that has affected whitebark pine populations across western North America, with associated impacts to Clark's nutcrackers (McKinney et al. 2009). High-elevation cold habitats are predominantly located in roadless or wilderness areas, and thus roads and wood harvest are not widespread stressors. The historical fire regime of high-elevation cold forests in the SWOAP assessment area was characterized by infrequent high-severity fires (>100-year return intervals) (Agee 1993). Because of the long fire return interval for high-elevation cold forests, fire exclusion has not contributed to substantial changes in vegetation structure, in contrast to at lower elevations. High-elevation woodlands are also highly valued recreation areas with unique aesthetic characteristics. Vegetation damage and soil compaction can be problems in areas with high levels of recreational use (Gaines et al. 2003). Motorized winter recreation may contribute to snow compaction and reduction of subnivian habitat values in heavily used areas.

No ESA-listed species are associated with subalpine habitats in the SWOAP assessment area. Two ISSSSP species are primarily associated with subalpine habitats: Sierra Nevada red fox and gray blue butterfly. Several other ISSSSP species use subalpine habitats in addition to other habitats: merlin, American peregrine falcon, bald eagle, pallid bat, Townsend's big-eared bat, fringed myotis, Pacific marten, wolverine, Sierra Nevada red fox, Crater Lake tightcoil, Klamath taildropper, and western bumblebee.

Exposure—

The high-elevation cold habitat types and associated wildlife species will have a high degree of exposure to projected changes in climate. Approximately 6 percent of the SWOAP assessment area is in this type based on historical MC2 vegetation model estimates. These conditions are completely lost by late in the 21st century under most of the future MC2 scenarios, with most of that loss occurring by mid-century, owing to conversion to montane coniferous forest (figs. 6.2 and 6.4).

Higher temperatures will likely lengthen the growing season by reducing snow cover duration and warming soils. These changes are likely to favor lower elevation vegetation because of faster growth and potentially more seedling establishment.

There may also be increased potential for large-scale, high-severity fire in high-elevation habitats with increased summer drought. The historical disturbance regime in high-elevation cold forests was characterized by very infrequent, large-scale, high-severity fire events. Late-seral tree species (e.g., subalpine fir and Pacific silver fir) in this type are not resilient to fire. A particular risk to this type may be potential for high-severity fire to spread into these stands from adjacent mid-elevation forest during extreme events. Increased summer temperatures and drought stress may result in direct tree mortality or increased vulnerability to insects and diseases. High-elevation meadow/grassland/barren areas will likely experience increased summer temperatures and drought stress. A predominant climate change effect in cold forests will be that extent, depth, and duration of winter snow will be reduced or lost.

Sensitivity—

Loss of winter snowpack will affect wildlife associated with cold forests. Adaptations for cold, snowy environments may be disadvantageous in a warmer, snowless future. Winter warming, with fewer very cold or even below-freezing days, may be particularly important, potentially producing changes in winter thermoregulatory behaviors. Loss of winter snowpack may particularly affect wildlife that use subnivian habitats (e.g., meadow voles) or are sensitive to competition or predation from common meso-carnivores. For instance, American marten use deep snow areas where bobcats are unlikely to occur for wintertime movements and have been found to be absent from some areas that have had recently diminished snowpack (Moriarty et al. 2015).

Vegetation model projections indicate a broad transition from cold forest and woodland to montane conifer forest conditions under future climates (chapter 5). However, encroachment by lower elevation tree species may be offset by increased wildfire, insect, and disease disturbances. Milder winters, longer frost-free seasons, and summer drought stress can contribute to increased severity of forest insect and disease outbreaks (Weed et al. 2013). More severe droughts may also contribute to direct tree mortality (Allen et al. 2015, Clark et al. 2016). Recent losses of whitebark pine caused by white pine blister rust and mountain pine beetle may be an example of such a process (Keane et al. 2015).

Increased summer temperatures and drought stress may cause changes in herbaceous vegetation and subalpine wetlands. Seasonal availability of plant and insect foods may become limited by water availability as the frost-free season lengthens and potential for summer drought increases. Warmer winter temperatures and reduced depth and duration of snowpack have the potential to substantially affect resident mammal communities. Loss of subnivian habitats may reduce protection from predation and increase winter thermal stress. Despite projections indicating the potential for complete elimination of climatically suitable conditions for subalpine meadow communities, the future distribution of these habitat conditions will to some extent be determined by tree establishment and disturbance processes. High-elevation meadow communities may be maintained by drought or regular fire, though habitat conditions may become more similar to dry grasslands or early-seral forest.

Longer summer seasons may contribute to altered migration timing and duration of residency for elevational migrants. Migratory deer and elk populations may change the timing of migration or stop migrating altogether with extended seasons of forage availability. Such changes in migration could 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 changes in food availability. Emerging phenological mismatches between high-elevation vegetation and invertebrate pollinators may be a particular concern for high-elevation herbaceous communities. Recreation pressures on higher elevation areas could increase as people seek cooler settings for recreation throughout the year. Winter recreation pressures in particular may become more concentrated as snowpack diminishes and snow-based recreational opportunities are reduced (chapter 7).

Adaptive capacity—

Animals, plants, and other organisms associated with high-elevation habitats will have limited opportunities for upward range shifts. Organisms associated with these habitats are generally better adapted to cold than warm extremes. Availability of thermal microrefugia (e.g., burrows, cavities, large logs, or shading vegetation) may be particularly important for short-term species persistence. Patchy woodland spatial patterns may be possible to maintain in some areas through regular fire or manual removal of encroaching trees. Some fundamental changes in high-elevation woodlands may be unavoidable, including loss of snowpack depth and duration, and changes in tree and herbaceous species composition.

Animals that are seasonal migrants or whose breeding range overlaps both high-elevation cold woodlands and low-elevation temperate woodlands (e.g., Townsend's solitaire and mountain bluebird) may be better adapted to future warmer conditions than year-round residents. Even Clark's nutcrackers may be able to adapt to a future without whitebark pine if other food sources, like ponderosa pine seeds, are available (Schaming 2016). 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 voles) may be especially sensitive. Habitat structure changes may be determined to a large degree by disturbance processes. If increased fire frequency and severity offset tree growth and encroachment, these habitat characteristics may be sustained on the landscape. However, substantial changes in seasonal temperature and snowpack characteristics are unavoidable.

Potential adaptation strategies:

- Consider the use of prescribed fire and wildfire in appropriate settings to reduce the risk of large-scale, high-severity fire moving into cold forest from lower elevation.
- Consider manual removal of conifers encroaching into open subalpine woodlands or meadows.
- Identify and protect climate and disturbance refugia where old-forest structure is most sustainable.
- Develop strategies to retain forest canopy cover in hydrologically sensitive and deep snow areas.
- Use tree retention, snow fencing, or other methods to retain snowpack and associated moisture.
- Monitor summer and winter recreation, and address impacts on wildlife as needed.

Adapting Wildlife Habitat Management to Climate Change in Southwest Oregon

In April of 2018, land managers from SWOAP met in Grants Pass, Oregon, for a workshop to identify potential climate adaptation options for wildlife habitat management. Workshop participants identified strategies, or general approaches, for adapting wildlife habitat management to climate change (table 6.2). Participants also identified more specific on-the-ground tactics, or actions, associated with each adaptation strategy and considered the implementation of those tactics, specifically opportunities for implementation, and locations or situations in which tactics can be applied. These strategies and tactics, intended to guide both short- and long-term planning and management, were required to be feasible with respect to budget and level of effort, and to be acceptable within current policies. Themes from workshop discussions are described below.

Thermal and other types of refugia (e.g., moisture, disturbance) are likely to be critical in providing for species persistence with climate change (Morelli et al. 2016). A first step in protecting key refugia is to identify and map them (table 6.3). Managers can then prioritize locations and take steps to maintain and protect key refugia. For example, managers could consider manipulating particular vegetation

Table 6.3—Wildlife adaptation options for southwest Oregon

Sensitivity to climate change	Adaptation strategy	Adaptation tactic

Climate change may alter refugia availability at different scales	Provide hiding cover, thermal refugia, and opportunities for movement	• Map thermal and important refugia types.
		• Identify, restore, and maintain special habitat features. Consider possibilities for artificial habitat as appropriate.
		• Consider species life histories and other stressors when implementing projects.
		• Maintain landscape permeability for animal movement by:
		  • Providing passage structures across major highways
		  • Closing roads
		  • Maintaining elevational connectivity

Climate change may reduce habitat connectivity	Provide opportunities for wildlife to move	• Identify and repair barriers. • Highlight and recognize importance of updated and relevant data (inventory) relative to travel planning. • Consider connectivity during project planning.
Climate change may lead to loss of spatial and structural heterogeneity	Provide opportunities for recruiting and retaining habitat components most difficult to replace	• Promote landscape patterns that are resilient under current and future disturbance regimes. • Recruit and maintain old-forest characteristics while improving structural and spatial heterogeneity. • Work with fuels specialists and fire programs to implement burn prescriptions that maintain down wood for wildlife and soil health. • Take advantage of landscape physiography to maintain diversity; identify climate and disturbance refugia.
Climate change may change species composition and competitive interactions	Develop a monitoring strategy that assesses change over the long term	• Keep track of what is abundant, what is not, and what is changing. Keep an eye out for surprises. • Use early detection/rapid response for nonnative invasive species. • Consider road and trail closures or seasonal restrictions.

Climate change may change food availability and trophic disruption	Recruit and retain spatial patterns that are resilient to disturbances, maintain habitat and structural heterogeneity and diversity, and maintain landscape permeability	• Identify and map important food sources at multiple trophic levels:
		  • Consumers that have a narrow diet
		  • Specialized consumers of uncommon species
		  • Consumers of common species
		  • Food species that may be abundant now and may no longer be available for multiple species in the future.
		• Identify and develop strategies to control or eradicate species that may displace forage species (i.e., earthworms, false brome, giant knotweed, knapweed).
		• Maintain a landscape that is likely to support mixed-severity fire:
		  • Consider using prescribed fire that mimics mixed-severity fire
		  • Conduct mechanical treatments to break up contiguous fuels prior to prescribed fire or wildland fire for resource benefit.
		• Develop stand- and project-level prescriptions to maintain heterogeneity.
		• Maintain high-quality, early-seral habitats across the landscape with vegetation and structural legacies.

Table 6.3—Wildlife adaptation options for southwest Oregon (continued)

Sensitivity to climate change	Adaptation strategy	Adaptation tactic
Snowpack depth may decrease and duration may shorten	Develop mitigation measures and strategies to compensate for loss of snowpack location and duration	• Consider where new or rerouted trails and roads are located. Consider closure or seasonal restrictions. • Consider where and when winter recreation special uses and events occur. • Maintain thermal and security refugia.

Climate change may alter riparian and wetland habitats	Identify, retain, and restore riparian and wetland habitat for wildlife	• Maintain and restore wetlands for amphibian habitat:
		  • Remove nonnative species
		  • Restore floodplain function
		  • Reintroduce beaver when consistent with management objectives
		• Maintain and restore streamside and riparian habitats:
		  • Reduce human stressors (e.g., recreation) in sensitive areas to maintain wildlife habitat.
		  • Maintain riparian vegetation to provide wildlife habitat and stream shading.

Climate change may lead to loss of habitat structure and spatial heterogeneity	Increase resilience of late-successional habitat and structure (shrub and forest) and surrounding habitat	• Protect, maintain, and recruit legacy structures (e.g., large trees, snags, down wood):
		  • Reduce litter around base of legacy trees prior to prescribed fire.
		  • Reduce fuels before prescribed fire or wildlife.
		  • Develop burn prescriptions with the intent of protecting legacy trees.
		  • Identify areas on the landscape that are more likely to maintain late-successional forest.
		  • Maintain 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 wildland fire for resource benefit. Consider how fire suppression may affect wildlife habitat.

characteristics, including vegetation structure and fuel loading, to maintain or enhance refugial characteristics (Morelli et al. 2016). Increasing vegetation variability (e.g., with varied stand densities, gaps, riparian vegetation) can increase spatial variability in local climate and create refugia. The diverse landscape physiography of southwest Oregon can be used to promote diversity of habitat conditions and refugia.

Increasing habitat connectivity is a commonly cited primary climate change adaptation strategy for wildlife (e.g., Mawdsley et al. 2009) (box 6.2). Tactics to maintain landscape permeability for animal movement include providing passage structures across major highways, closing roads, identifying and repairing barriers to movement, maintaining elevational connectivity, and considering connectivity during project planning (table 6.3). 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).

Changing severity and frequency of fire with climate change will likely decrease area and connectivity of some habitats, notably late-successional and mature forest (Chmura et al. 2011). Late-successional forests, and important habitat structures associated with these forests (e.g., large trees, snags, and down wood), are difficult to replace because they require decades to centuries to develop. Managers can protect late-successional forest habitat by recruiting and maintaining old-forest characteristics. Simultaneously recruiting and retaining spatial and structural heterogeneity will help to provide diverse and abundant food resources. Fuel reduction and strategic placement of fuel breaks could help to lower fire severity and protect valued habitats (Peterson et al. 2011). Managers may want to consider protection of old trees in burn prescriptions (e.g., by removing litter around the base of trees) (Halofsky et al. 2016).

In wetland, riparian, and open-water habitats, reducing existing stressors will likely help increase resilience to climate change. Managers may want to consider relocating roads and recreation developments away from floodplains to reduce their effects on riparian, wetland, and aquatic habitats (Peterson and Halofsky 2018). In areas where upland, invasive, or undesirable species are outcompeting natives, restoring riparian and wetland-obligate species may help to restore ecological function. Riparian zones will probably burn more frequently with warming climate, and thus managers may want to manage upland vegetation to reduce impacts in riparian areas (Luce et al. 2012). In some riparian areas, managers may want to thin dense forests or reintroduce fire to help facilitate the transition to future conditions (Halofsky et al. 2016). Promoting connectivity of riparian habitat conditions along stream networks can help facilitate animal movement and range shifts (Mawdsley et al. 2009). Encouraging beaver colonization can help to maximize water retention and groundwater recharge but does have the potential to conflict with other resource objectives, including conservation of sensitive streamside habitats (Pollock et al. 2014, 2015).

In high-elevation habitats, climate change will probably alter species composition of both plants and animals because of decreasing snowpack, changes in timing of snowmelt, and increasing temperatures that allow less specialized species to move into subalpine ecosystems (chapter 5). Minimizing new stressors on high-elevation ecosystems may help to increase their resilience. As snow-based recreation is concentrated into smaller areas, efforts to minimize human impacts may be needed. Development of a consistent monitoring framework that can capture ecosystem changes with shifting climate is a key adaptation approach for high-elevation and other critical habitats (Halofsky and Peterson 2016).

Conclusions

Wildlife in southwest Oregon will be exposed to a variety of climate change effects during the 21st century. Although vegetation model projections do not suggest a wholesale change in biomes for much of the SWOAP assessment area over the next 60 to 80 years (chapter 5), the availability of important wildlife habitat elements is likely to change with extended growing seasons, more frequent and severe summer drought, and increased wildfire. Wildlife that have specialized ecological relationships will be sensitive to anticipated habitat changes. Old-forest species that require large trees for nesting structures and multilayered canopies for thermal moderation (e.g., Pacific marten, northern spotted owl, marbled murrelet) will be particularly sensitive if these habitat characteristics are lost.

Changes in the timing and abundance of food resources may have cascading effects in food webs in southwest Oregon. Species such as invertebrate pollinators that rely on abundant pollen resources from flowering plants at specific times in their annual life cycles are sensitive to changes in the timing and abundance of those resources (Potts et al. 2010). Higher order predators will likely be sensitive to changes in invertebrate or small mammal prey (Ockendon et al. 2014). This assessment has focused on climate change impacts within the SWOAP assessment area, but it is important to note that many species also rely on resources outside of the area. For example, migratory birds that breed in southwest Oregon will be sensitive to a variety of stressors in winter ranges and along migratory routes that are outside the scope of this assessment.

The adaptive capacity of wildlife in southwest Oregon is expected to be strongly influenced by the ability of individual species to physiologically tolerate extreme temperatures, behaviorally adapt to those temperatures, and move in response to altered habitat structure and food. Availability of fine-scale thermal microrefugia (e.g., burrows, talus slopes, or shading vegetation) is likely to become more important as animals attempt to behaviorally adapt to warmer temperatures. Species that are able to alter their behavior and habitat selection patterns to minimize thermal stress may be more likely to persist. Opportunities for seasonal movements and range shifts will be particularly important for species trying to adapt to hotter and drier seasonal conditions. Human-created barriers to animal movement (e.g., urban development and major highways) have the potential to negatively affect opportunities for elevational shifts.

At a broader scale, identifying and protecting climate refugia across large landscapes may be an important principle for developing climate change adaptation strategies that conserve wildlife habitat (Morelli et al. 2016). Site features of potential climate refugia in southwest Oregon include north aspects, valley bottoms and steep canyons, and sinks and basins (Dobrowski 2011, Olson et al. 2012). These settings provide moderated climate environments because they are shadier and exist where cool air predictably pools in the lower sites. Analysis of topographic complexity, soils, and barriers to movement conducted by Buttrick et al. (2015) suggests relatively high resilience to climate change impacts for the Klamath and Siskiyou Ranges and along the Cascades Crest within the SWOAP assessment area, compared to other areas in the Pacific Northwest. Olson et al. (2012) conducted a climate change refugia assessment for the Klamath-Siskiyou Ecoregion that encompassed the western portion of the SWOAP assessment area. These analyses highlighted the role of the Klamath, Siskiyou, and Cascade Ranges for providing opportunities for lower elevation species to shift upward and northward (box 6.2).

The old-growth forests of the Klamath region of northern California and southern Oregon have high biodiversity, as the rugged mountains of this region have created climatic and disturbance refugia that contribute to high levels of endemism and diversity (DellaSala 1999, Whittaker 1960). In southwest Oregon, variation in precipitation and temperature yield sharp contrasts in the water balance, which may correlate with variation in forest structure (van Mantgem and Sarr 2015). This diversity is likely to be an important advantage for climate change adaptation in this area. However, species associated with cold and snowy habitats at higher elevations in these mountains have no opportunities for shifting their ranges upward, and connectivity to cold habitats to the north is limited. Prospects for such high-elevation species are poor.

Managers are likely to face many important information gaps as the climate warms, and animal behavior and ecological relationships change in response. Our understanding of animal life histories, habitat associations, food needs, movement patterns, and distribution based on historical studies could be undermined by changes associated with a warming climate. Systematic, large-scale, and collaborative multispecies monitoring efforts will be necessary to detect expected changes in species distribution and abundance. New multispecies monitoring methods, including camera surveys, acoustic surveys, and environmental DNA sampling, are likely to be increasingly important tools for addressing these information needs.

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Appendix 6.1: Common and Scientific Names of Species Mentioned in This Chapter

Common name	Scientific name
Acorn woodpecker	*Melanerpes formicivorus* Swainson
American beaver	*Castor canadensis* Kuhl
American kestrel	*Falco sparverius* L.
American marten	*Martes americana* Turton
American peregrine falcon	*Falco peregrinus anatum* Bonaparte
American pika	*Ochotona princeps* Richardson
American pipit	*Anthus rubescens* Tunstall
American robin	*Turdus migratorius* L.
Bald eagle	*Haliaeetus leucocephalus* Linnaeus
Band-tailed pigeon	*Patagioenas fasciata* Say
Bewick’s wren	*Thryomanes bewickii* Audubon
Bigleaf maple	*Acer macrophyllum* Pursh
Black-capped chickadee	*Poecile atricapillus* L.
Black salamander	*Aneides flavipunctatus* Strauch
Black swift	*Cypseloides niger* Gmelin
Blue-gray gnatcatcher	*Polioptila caerulea* Linnaeus
Black-throated gray warbler	*Setophaga nigrescens* J.K. Townsend
Blue grouse	*Dendragapus obscurus* Say
Bobcat	*Lynx rufus* Schreber
Brown creeper	*Certhia americana* Bonaparte
Bufflehead	*Bucephala albeola* L.
Bullock’s oriole	*Icterus bullockii* Swainson
Bushy-tailed woodrat	*Neotoma cinerea* Ord
California black oak	*Quercus kelloggii* Newberry
California scrub jay	*Aphelocoma californica* Vigors
California shield-backed bug	*Vanduzeeina borealis* Van Duzee
California towhee	*Melozone crissalis* Vigors
Canyon live oak	*Quercus chrysolepis* Liebm.
Cascades frog	*Rana cascadae* Slater
Cassin’s finch	*Haemorhous cassinii* S.F. Baird
Cedar waxwing	*Bombycilla cedrorum* Vieillot
Chestnut-backed chickadee	*Poecile rufescens* J.K. Townsend
Chipmunk	*Tamias* spp. Illiger
Chipping sparrow	*Spizella passerina* Bechstein
Clark’s nutcracker	*Nucifraga columbiana* A. Wilson
Clouded salamander	*Aneides ferreus* Cope
Coastal greenish blue butterfly	*Plebejus saepiolus littoralis* J. Emmel, T. Emmel and Mattoon in T. Emmel
Coastal tailed frog	*Ascaphus truei* Stejneger

Common name	Scientific name
Columbian white-tailed deer	*Odocoileus virginianus leucurus* Douglas
Common raven	*Corvus corax* L.
Cooley’s lace bug	*Acalypta cooleyi* Drake
Coronis fritillary	*Speyeria coronis coronis* Behr
Coyote	*Canis latrans* Say
Crater Lake tightcoil	*Pristiloma crateris* Pilsbry
Del Norte salamander	*Plethodon elongatus* Van Denburgh
Deer mouse	*Peromyscus maniculatus* Wagner
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Douglas’s squirrel	*Tamiasciurus douglasii* Bachman
Downy woodpecker	*Picoides pubescens* L.
Dunn’s salamander	*Plethodon dunni* Bishop
Dusky flycatcher	*Empidonax oberholseri* A.R. Phillips
Dusky-footed woodrat	*Neotoma fuscipes* Baird
Elk	*Cervus elaphus* L.
Ermine	*Mustela erminea* L.
Foothill yellow-legged frog	*Rana boylii* Baird
Fox sparrow	*Passerella iliaca* Merrem
Franklin’s bumblebee	*Bombus franklini* Frison
Fringed myotis	*Myotis thysanodes* Miller
Golden eagle	*Aquila chrysaetos* L.
Grand fir	*Abies grandis* (Douglas ex D. Don) Lindl.
Grasshopper sparrow	*Ammodramus savannarum* J.F. Gmelin
Gray wolf	*Canis lupus* L.
Gray-crowned rosy finch	*Leucosticte tephrocotis* Swainson
Gray blue butterfly	*Plebejus podarce* C. Felder and R. Felder
Gray flycatcher	*Empidonax wrightii* S.F. Baird
Great gray owl	*Strix nebulosa* J.R. Forster
Great horned owl	*Bubo virginianus* J.F. Gmelin
Green-tailed towhee	*Pipilo chlorurus* Audubon
Ground squirrel	*Spermophilus* spp. F. Cuvier
Hairy woodpecker	*Picoides villosus* L.
Harlequin duck	*Histrionicus histrionicus* L.
Hoary elfin	*Callophrys polios maritima* J. Emmel, T. Emmel and Mattoon in T. Emmel
Horned grebe	*Podiceps auritus* L.
Huckleberry	*Vaccinium* spp. L.
Jeffrey pine	*Pinus jeffreyi* Balf.
Johnson’s hairstreak	*Callophrys johnsoni* Skinner
Klamath tail-dropper	*Prophysaon coeruleum* Cockerell
Lazuli bunting	*Passerina amoena* Say

Common name	Scientific name
Lesser goldfinch	*Spinus psaltria* Say
Lewis' woodpecker	*Melanerpes lewis* G.R. Gray
Marbled murrelet	*Brachyramphus marmoratus* Gmelin
Mardon skipper	*Polites mardon* W.H. Edwards
Meadow voles	*Microtus* spp. Schrank
Merlin	*Falco columbarius* L.
Mountain bluebird	*Sialia currucoides* Bechstein
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carrière
Mountain lion	*Puma concolor* L.
Mountain pine beetle	*Dendroctonus ponderosae* Hopkins
Mountain quail	*Oreortyx pictus* Douglas
Northern alligator lizard	*Elgaria coerulea* Wiegmann
Northern flying squirrel	*Glaucomys sabrinus* Shaw
Northern goshawk	*Accipiter gentilis* L.
Northern spotted owl	*Strix occidentalis caurina* Merriam
Northern waterthrush	*Parkesia noveboracensis* J.F. Gmelin
Northwestern salamander	*Ambystoma gracile* Baird
Oak titmouse	*Baeolophus inornatus* Gambel
Olive-sided flycatcher	*Contopus cooperi* Nuttall
Olympic salamander	*Rhyacotriton olympicus* Gaige
Oregon axetail slug	*Carinacauda stormi* Leonard, Chichester, Richart and Young
Oregon branded skipper	*Hesperia colorado oregonia* W.H. Edwards
Oregon giant earthworm	*Driloleirus macelfreshi* Smith
Oregon spotted frog	*Rana pretiosa* Baird and Girard
Oregon vesper sparrow	*Pooecetes gramineus affinis* G.S. Miller
Oregon white oak	*Quercus garryana* var. *garryana* Douglas ex Hook
Pacific chorus frog	*Pseudacris regilla* Baird and Girard
Pacific fisher	*Pekania pennanti* Erxleben
Pacific giant salamander	*Dicamptodon tenebrosus* Baird and Girard
Pacific madrone	*Arbutus menziesii* Pursh
Pacific marten	*Martes caurina* Merriam
Pacific shrew	*Sorex pacificus* Coues
Pacific silver fir	*Abies amabilis* Douglas ex J. Forbes
Pacific-slope flycatcher	*Empidonax difficilis* S. F. Baird
Pallid bat	*Antrozous pallidus* LeConte
Pileated woodpecker	*Dryocopus pileatus* L.
Pine siskin	*Spinus pinus* A. Wilson
Pocket gopher	*Thomomys* spp. Wied-Neuwied
Ponderosa pine	*Pinus ponderosa* C. Lawson
Port Orford cedar	*Chamaecyparis lawsoniana* (A. Murray) Parl.

Common name	Scientific name
Prairie falcon	*Falco mexicanus* Schlegel
Purple martin	*Progne subis* L.
Red alder	*Alnus rubra* Bong.
Red-breasted sapsucker	*Sphyrapicus ruber* Gmelin
Red-eyed vireo	*Vireo olivaceus* L.
Red-necked grebe	*Podiceps grisegena* Boddaert
Red-tailed hawk	*Buteo jamaicensis* Gmelin
Ringneck snake	*Diadophis punctatus* L.
Rough-skinned newt	*Taricha granulosa* Skilton
Rufous hummingbird	*Selasphorus rufus* Gmelin
Salal	*Gaultheria shallon* Pursh
Savannah sparrow	*Passerculus sandwichensis* J.F. Gmelin
Sharptail snake	*Contia tenuis* Baird and Girard
Sierra Nevada red fox	*Vulpes vulpes necator* Merriam
Siskiyou Mountains salamander	*Plethodon stormi* Highton and Brame
Siskiyou short-horned grasshopper	*Chloealtis aspasma* Rehn and Hebard
Sitka spruce	*Picea sitchensis* (Bong.) Carrière
Snowshoe hare	*Lepus americanus* Erxleben
Spotted towhee	*Pipilo maculatus* Swainson
Streaked horned lark	*Eremophila alpestris strigata* Henshaw
Subalpine fir	*Abies lasiocarpa* (Hook.) Nutt.
Sudden oak death	*Phytophthora ramorum* Werres et al.
Swainson’s thrush	*Catharus ustulatus* Nuttall
Tanoak	*Notholithocarpus densiflorus* (Hook. & Arn.) Rehder
Townsend’s big-eared bat	*Corynorhinus townsendii* Cooper
Townsend’s solitaire	*Myadestes townsendi* Audubon
Tree swallow	*Tachycineta bicolor* Vieillot
Tricolored blackbird	*Agelaius tricolor* Audubon
Trowbridge’s shrew	*Sorex trowbridgii* Baird
Varied thrush	*Ixoreus naevius* Gmelin
Vaux’s swift	*Chaetura vauxi* J.K. Townsend
Vernal pool fairy shrimp	*Branchinecta lynchi* Eng, Belk and Eriksen
Warbling vireo	*Vireo gilvus* Vieillot
Western bluebird	*Sialia mexicana* Swainson
Western bumblebee	*Bombus occidentalis* Greene
Western fence lizard	*Sceloporus occidentalis* Baird and Girard
Western gray squirrel	*Sciurus griseus* Ord
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg
Western meadowlark	*Sturnella neglecta* Audubon
Western pond turtle	*Actinemys marmorata* Baird and Girard
Western red-backed salamander	*Plethodon vehiculum* Cooper

Common name	Scientific name
Western red-backed vole	*Myodes californicus* Merriam
Western scrub-jay	*Aphelocoma californica* Vigors
Whitebark pine	*Pinus albicaulis* Engelm.
White-breasted nuthatch	*Sitta carolinensis* Latham
White fir	*Abies concolor* (Gordon & Glend.) Lindl. ex Hildebr.
White-headed woodpecker	*Picoides albolarvatus* Cassin
White pine blister rust	*Cronartium ribicola* A. Dietr.
White-tailed kite	*Elanus leucurus* Vieillot
Wild turkey	*Meleagris gallopavo* L.
Wolverine	*Gulo gulo* L.
Woodrat	*Neotoma* spp. Say and Ord
Yellow-bellied marmot	*Marmota flaviventris* Audubon and Bachman
Yellow-breasted chat	*Icteria virens* L.
Yellow rail	*Coturnicops noveboracensis* Gmelin
Yellow warbler	*Setophaga petechia* L.

Chapter 7: Climate Change Effects on Outdoor Recreation in Southwest Oregon

David L. Peterson, Michael S. Hand, Joanne J. Ho, and S. Karen Dante-Wood[1]

Introduction

The Southwest Oregon Adaptation Partnership (SWOAP) is a science-management partnership with the U.S. Department of Agriculture, Forest Service (U.S. Forest Service)—Rogue River-Siskiyou and Umpqua National Forests, Pacific Northwest and Rocky Mountain Research Stations, and Pacific Northwest Region; U.S. Department of the Interior—Bureau of Land Management (BLM) Medford and Roseburg Districts, and National Park Service Oregon Caves National Monument and Preserve; and University of Washington. These organizations have a strong focus on sustainable recreation, encompassing a range of recreational settings, opportunities, and access. Managing for sustainable recreation means providing economic opportunities for local communities and tourism-related enterprises. In southwest Oregon, more than $30 million is spent annually on visits to recreation destinations managed by the Forest Service. Recreation is also a component of social sustainability, connecting people to nature and encouraging outdoor activities that promote physical and mental health (Bowler et al. 2010, Kondo et al. 2018, Kuo 2015, Thompson Coon et al. 2011). Recreation helps people understand their natural resource and cultural environments and to engage in stewardship of the natural world. The wide-ranging benefits provided by publicly managed outdoor recreation in southwest Oregon are supported by diverse activities available throughout the year (table 7.1).

As climate change alters the conditions of biophysical systems, it also directly affects the ability of public land management agencies to consistently provide high-quality outdoor recreation opportunities to the public (Loomis and Richardson 2006, Richardson and Loomis 2004). Changing climatic conditions may alter the supply of and demand for outdoor recreation opportunities, directly and indirectly affecting visitor-use patterns and the ability of recreationists to obtain desired benefits derived from publicly managed lands in the future (Bark et al. 2010, Matzarakis and de Freitas 2001, Morris and Walls 2009).

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Table 7.1—Dominant seasons for different recreation activities

Recreation activity	Winter	Spring	Summer	Autumn
Boating		✓	✓	✓
Camping, picnicking		✓	✓	✓
Cycling (mountain biking, road biking)		✓	✓	✓
Fishing		✓	✓	✓
Hiking, backpacking (including long-distance hiking)		✓	✓	✓
Horseback riding		✓	✓	✓
Motorized recreation (snowmobiles)	✓			
Motorized recreation (off-road vehicles)		✓	✓	✓
Nonmotorized winter recreation (downhill skiing, cross-country skiing, fat-tire bikes, dog sledding, sledding/tubing, general snow play, mountaineering)	✓			
Recreation residences	✓	✓	✓	✓
River rafting			✓	
Scenic driving (nature viewing)	✓	✓	✓	✓
Special forest products (e.g., mushrooms, pine cones)		✓	✓	✓
Swimming			✓	
Other forest uses (Christmas tree harvest, firewood cutting)	✓	✓	✓	✓

Note that activities may differ somewhat from categories in National Visitor Use Monitoring data (table 7.2).

Analysis of historical visitation patterns at outdoor recreation areas managed by the National Park Service suggests that visitation levels will increase as temperatures increase (Fisichelli et al. 2015). This is largely attributed to the fact that most parks see their highest visitation levels in the summer. Consequently, as the “shoulder seasons” have a longer duration of conditions conducive to typical warm-weather activities (snow- and ice-free conditions and warmer temperatures in spring and autumn), visitation levels will increase. Similar findings have been found for studies focused on specific regions of the country such as Alaska (Albano et al. 2013) and the Southeastern United States (Bowker et al. 2013). Like visitation levels, the aggregate benefits provided by outdoor recreation opportunities are expected to increase as the climate warms because increases in warm-weather activities will outweigh decreases in winter activities (Hand and Lawson 2018, Hand et al. 2018, Loomis and Crespi 2004, Mendelsohn and Markowski 2004).

Broad trends in recreation participation under climate change are becoming better understood at the regional and subregional scales (Hand and Lawson 2018, Hand et al. 2018), including in the Pacific Northwest (Hand et al. 2019). This chapter describes the broad categories of outdoor recreation activities believed to be sensitive to climate change and assesses the likely effects of projected climate change on both visitor-use patterns and the ability of outdoor recreationists to obtain desired experiences and benefits.

Relationships Between Climate Change and Recreation

The supply of, and demand for, outdoor recreation opportunities are sensitive to climate through (1) a direct effect of changes in temperature and precipitation on decisions by recreationists to visit, or not visit, a site (Loomis and Crespi 2004, Mendelsohn and Markowski 2004, Shaw and Loomis 2008) and (2) an indirect effect of climate on the physical and biological characteristics of recreation settings (fig. 7.1). For example, warming winter temperatures have a direct effect on individual recreationist decisions to visit, or not visit, a site. Whether that effect is positive or negative will depend on a variety of factors specific to individual recreationists. In the same example, warming temperatures in the winter months will reduce skiing opportunities, indirectly and negatively affecting the supply of outdoor recreation opportunities dependent upon skiing (Wobus et al. 2017). This indirect pathway connects climatic conditions to the conditions of an outdoor recreation setting and to the ability of that setting to provide outdoor recreation opportunities.

The 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, Klos et al. 2014, Smith et al. 2016, Stratus Consulting 2009,

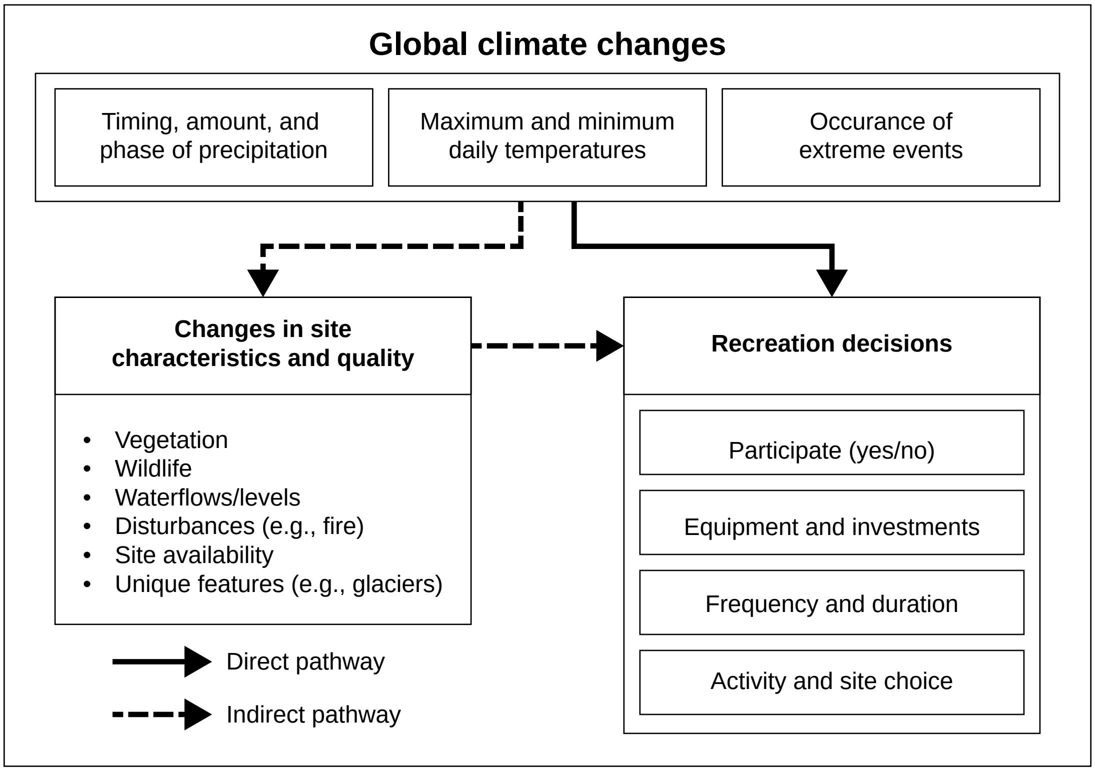

Figure 7.1—Direct and indirect effects of climate on recreation decisions.

Wobus et al. 2017). Warm-weather activities are also sensitive to direct effects of climate change. Increased minimum temperatures have been associated with increased national park visits in Canada, particularly during nonpeak "shoulder" seasons (Scott et al. 2007). The number of projected warm-weather days is positively associated with expected visitation for U.S. national parks (Albano et al. 2013, Fisichelli et al. 2015), although visitation is expected to be lower under extreme-heat scenarios (Richardson and Loomis 2004). Mendelsohn and Markowski (2004) used a travel cost approach to measure changes in the value of multiple sites to infer that temperature and precipitation directly affect the comfort and enjoyment that participants derive from engaging in an activity on a given day.

Indirect effects tend to be important for recreation activities and opportunities that depend on ecosystem components such as wildlife, vegetation, and surface water. Cold-water fishing in southwest Oregon is expected to decline in the future because of climatic effects on temperature and streamflow that threaten coldwater fish species habitat (Jones et al. 2013) (chapter 4). Surface-water area and streamflows are important for water-based recreation (e.g., boating). Recreation visits to sites with highly valued natural characteristics, such as subalpine parklands and popular wildlife species (chapters 5 and 6), may be reduced under some future climate scenarios if the quality of those characteristics is threatened (Scott et al. 2007). The indirect effects of climate on disturbances, including wildfire (chapter 5) and flooding (chapter 3), may also play a role in recreation behavior (Sanchez et al. 2016), with the effects on recreation varying over space and time (Englin et al. 2001, Loomis and Crespi 2004).

Recreation Participation and Management

Recreation is an important component of public land management in southwest Oregon. For lands managed by the Forest Service, sustainable recreation serves as a guiding principle for planning and management purposes (USDA FS 2010, 2012b), recreation is included among other major multiple uses of national forests, such as timber products and livestock grazing. In the Forest Service, sustainable recreation seeks to "sustain and expand benefits to America that quality recreation opportunities provide" (USDA FS 2010). 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 7.1).

The BLM uses an outcome-focused management approach that emphasizes opportunities that allow visitors and local communities to achieve a desired set of individual, social, economic, and environmental benefits. Planning for recreation resources fulfills the BLM mission to sustain the health, diversity, and productivity of public lands for the use and enjoyment of present and future generations (USDI

Box 7.1

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: modern developed, rural, roaded natural, semiprimitive motorized, semiprimitive nonmotorized, and primitive

Setting characteristics that define ROS include the following:

- 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 or management activities)

The ROS is helpful for determining the types of recreation opportunities that can be provided. After a decision has been made about the opportunity desired in an area, the ROS provides guidance about appropriate planning approaches and standards by which each factor should be managed. Decisionmaking criteria include (1) 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 achieve several goals:

- 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 recreation sites and opportunities, and to allocate improvements and maintenance within the broader task of sustainable management of large landscapes.

BLM 2011). By increasing and improving collaboration with community networks of service providers, the BLM helps communities produce greater well-being and socioeconomic health, delivering recreation experiences to visitors while sustaining the distinctive character of recreation settings (USDI BLM 2014).

The National Park Service focuses special attention on visitor enjoyment of the parks while recognizing that it is necessary to preserve natural and cultural resources and values for the enjoyment, education, and inspiration of present and future generations (USDI NPS 2006). Recreational resources are managed to connect people with natural resources and cultural heritage, and to adapt to changing social needs and environmental conditions, while providing economic benefits to local communities (Cui et al. 2013).

People participate in a wide variety of outdoor recreation activities throughout southwest Oregon (fig. 7.2). The National Visitor Use Monitoring (NVUM) survey, conducted by the Forest Service to monitor recreation visitation and activity on national forests, identifies 27 recreation activities in which visitors participate (see table 7.2). These include a wide variety of activities and ways that people enjoy and use national forests and other public lands. Current recreation visitation activities and expenditures illustrate the importance and diversity of recreation in this region.

Rogue River-Siskiyou and Umpqua National Forests together had over 2.4 million visits in 2008 (table 7.2). The BLM Medford and Roseburg Districts together had nearly 2 million visitors in fiscal year 2016 (tables 7.3 and 7.4). Oregon Caves National Monument and Preserve visitors have ranged from 70,000 to 95,000 over the past 20 years (fig. 7.3).

The activities listed in table 7.1 account for the primary recreation activities by visitors to national forests that are most likely affected by climate change:[2]

- **Warm-weather activities** are the most popular and include hiking/walking, viewing natural features, developed and primitive camping, bicycling, backpacking, horseback riding, picnicking, and other nonmotorized uses. Of these, viewing natural features was the most popular, and was the primary recreation objective for 24 percent of visitors in Rogue River-Siskiyou National Forest, and 26 percent of visitors in Umpqua National Forest (table 7.2).

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[2] Recreation categories used by the Forest Service in the NVUM survey are used here to organize information about climate change effects. These categories do not correspond directly with those used by the BLM or NPS for recreation, and no attempt is made here to reconcile the different categories or to report BLM and NPS data in greater detail.

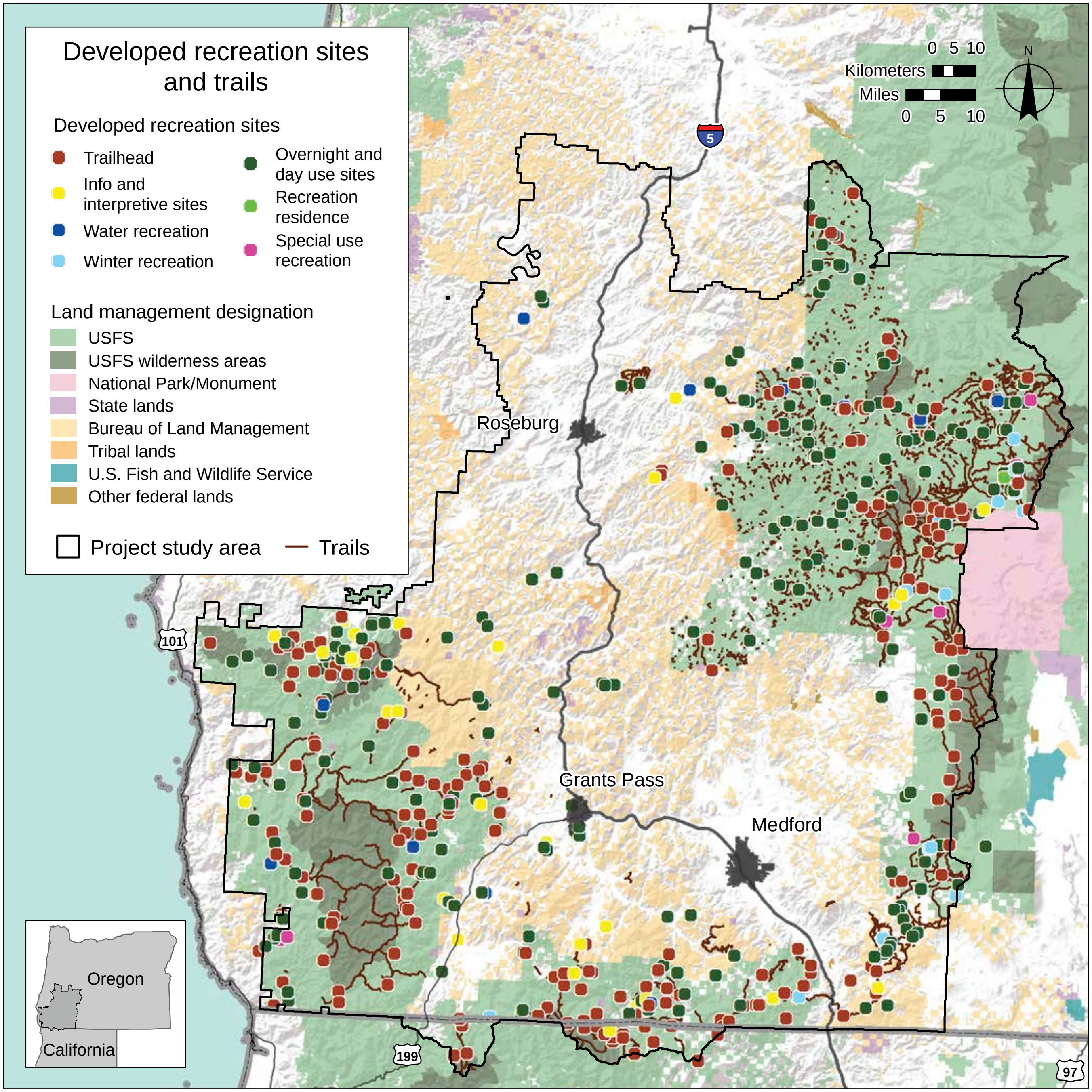

Figure 7.2—Recreation sites and trails on federal lands in southwest Oregon. USFS = U.S. Forest Service.

Table 7.2—Participation in different recreational activities in Rogue River-Siskiyou and Umpqua National Forests[a]

	Visitors for whom this was their primary activity				
	Rogue River–Siskiyou National Forest		Umpqua National Forest		Relationship to climate and environmental conditions
	Percent	*Number*	*Percent*	*Number*	
Warm-weather activities:					Participation typically occurs during warm weather; dependent on the availability of snow- and ice-free sites, dry weather with moderate daytime temperatures, and the availability of sites where air quality is not impaired by smoke from wildfires.
Hiking/walking	19.6	230,442	20.9	259,578	
Viewing natural features	24.3	284,769	26.1	323,334	
Developed camping	4.0	47,163	7.7	95,128	
Bicycling	0.5	5,970	2.0	24,288	
Other nonmotorized	2.2	26,268	2.6	32,384	
Picnicking	0.1	597	0.1	1,012	
Primitive camping	5.3	62,088	4.0	49,082	
Backpacking	1.0	11,343	3.3	40,480	
Total	57.5	674,610	67.3	833,382	
Winter activities:					Participation depends on the timing and amount of precipitation as snow and cold temperatures to support consistent snow coverage; inherently sensitive to climate variability and interannual weather patterns.
Downhill skiing	5.1	60,297	0.0	0	
Snowmobiling	0.6	6,567	1.1	13,156	
Cross-country skiing	7.2	84,774	0.2	3,036	
Total	12.9	151,638	1.3	16,192	
Wildlife 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 (wildfire, invasive species, insect outbreaks) may affect amount, distribution, and spatial heterogeneity of suitable habitat.
Hunting	1.7	19,701	4.5	55,660	
Fishing	8.5	99,699	9.1	113,344	
Viewing wildlife	13.3	156,414	14.1	175,076	
Total	23.5	275,814	27.8	344,080	
Gathering forest products	2.3	27,462	1.6	20,240	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:					Participation requires sufficient water flows (in streams) and levels (in lakes). 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 activities	1.0	11,343	0.8	10,120	
Motorized activities	2.8	32,835	1.2	15,180	
Total	3.8	44,178	2.0	23,300	

[a] USDA FS (n.d.). Includes data from Rogue River-Siskiyou and Umpqua National Forests, National Visitor Use Monitoring survey. The survey was administered for these forests in 2012. Annual visitation use estimate for Rogue River-Siskiyou National Forest in fiscal year 2012 was 597,000 and for Umpqua National Forest in fiscal year 2012 was 506,000 (USDA FS, n.d.).

Table 7.3—Visits in fiscal year 2016 (October 1, 2015–September 30, 2016) to the Bureau of Land Management Medford District, Oregon[a]

Site type	Ashland Resource Area		Cascade-Siskiyou National Monument		Butte Falls Resource Area		Grants Pass Resource Area	
	Percent	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*
Campground	NA	NA	3.1	6,210	1.3	600	2.0	7,969
Dispersed use	90.0	316,651	83.1	164,670	68.2	31,019	94.9	368,305
Off-highway vehicle area	2.2	7,859	NA	NA	NA	NA	NA	NA
Picnic area	0.2	650	2.4	4,833	NA	NA	0.5	1,775
Specialized sport site	3.2	11,347	11.4	22,500	NA	NA	NA	NA
Trailhead	4.2	14,746	NA	NA	21.2	9,650	0.9	3,627
Water access	0.2	600	NA	NA	9.3	4,214	1.6	6,303
Total	100	351,853	100	198,213	100	45,483	100	387,979

NA = not applicable.

Source: Bureau of Land Management Recreation Management Information System (October 1, 2015–September 30, 2016).

Table 7.4—Visits in fiscal year 2016 (October 1, 2015–September 30, 2016) to the Bureau of Land Management Roseburg District, Oregon

Site type	South River field office		Swiftwater Resource Area	
	Percent	*Number*	*Percent*	*Number*
Boat launch	NA	NA	1.3	9,715
Campground	NA	NA	6.9	51,459
Dispersed use	71.0	164,473	47.4	354,218
Geological	0.1	223	NA	NA
Information center	1.8	4,153	NA	NA
Intensive use area	NA	NA	11.8	87,990
Off-highway vehicle area	NA	NA	NA	NA
Picnic area	8.5	19,833	3.3	24,674
Specialized sport site	NA	NA	NA	NA
Trailhead	NA	NA	4.6	34,640
Water access	NA	NA	3.1	22,970
Wildlife viewing	NA	NA	5.9	44,341
Other	18.5	42,852	15.6	116,608
Total	100.0	231,534	100.0	746,615

NA = not applicable.

[a] From the Bureau of Land Management Recreation Management Information System (October 1, 2015–September 30, 2016).

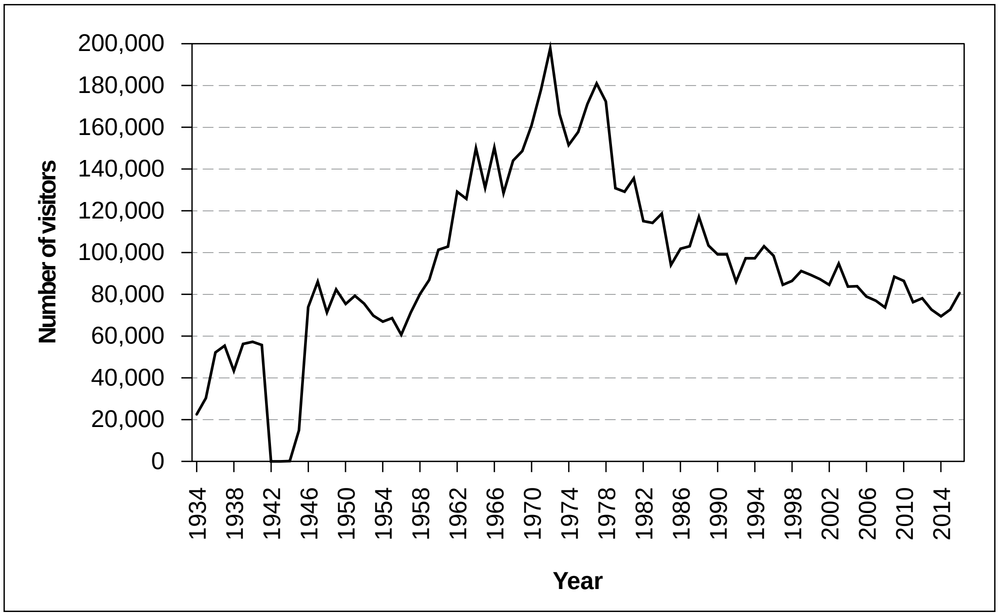

Figure 7.3—Visitor data for Oregon Caves National Monument and Preserve (from NPS, n.d.).

- **Snow-based winter activities** include downhill skiing, snowmobiling, and cross-country skiing. They were the primary activities for 13 percent of visitors in Rogue River-Siskiyou National Forest, but account for only slightly more than 1 percent in Umpqua National Forest.
- **Wildlife-related activities** were the second-most popular category after warm-weather activities, including hunting, fishing, and viewing wildlife. Wildlife activities accounted for 24 percent of visits in Rogue River-Siskiyou National Forest, and 28 percent of visits in Umpqua National Forest. Of these, viewing wildlife was the most popular, with 13 percent of visits in Rogue River-Siskiyou National Forest, and 14 percent of visits in Umpqua National Forest.
- **Gathering forest products** such as berries and mushrooms was the primary activity for 2 percent of visitors in both Rogue River-Siskiyou and Umpqua National Forests.
- **Water-based activities** such as boating and swimming comprised a relatively small amount of total recreation, with 4 percent of visits in Rogue River-Siskiyou National Forest and 2 percent of visits in Umpqua National Forest.

Nonlocal visitors spent $5.6 million while visiting Rogue River-Siskiyou National Forest and $17.1 million in Umpqua National Forest in 2008 (table 7.5).[3] We focus on spending by nonlocal visitors because these individuals spend money in local communities that would not have occurred otherwise. “Gas and oil” was the

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[3] Economic data on recreation for BLM and NPS units are not available.

Table 7.5—Estimated total annual expenditures by visitors to southwestern Oregon national forests[a]

	Nonlocal spending[b]				Local spending			
	Rogue River-Siskiyou NF		Umpqua NF		Rogue River-Siskiyou NF		Umpqua NF	
Spending category	Total annual expenditures	Spending by category	Total annual expenditures	Spending by category	Total annual expenditures	Spending by category	Total annual expenditures	Spending by category
	Dollars	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*
Motel	934,233	16.8	3,229,376	18.8	58,838	0.7	23,095	0.8
Camping	308,606	5.5	1,052,817	6.1	222,120	2.6	102,104	3.6
Restaurant	953,325	17.2	2,718,021	15.9	1,141,809	13.6	361,778	13.0
Groceries	971,300	17.5	3,054,849	17.8	1,712,080	20.4	649,367	23.4
Gas and oil	1,558,228	28.0	4,451,535	26.0	3,128,769	37.2	1,079,274	38.9
Other transportation	20,106	0.4	118,994	0.7	9,805	0.1	9,590	0.3
Entry fees	266,179	4.8	574,732	3.3	939,744	11.2	175,690	6.3
Recreation and entertainment	211,512	3.8	691,449	4.0	370,084	4.4	66,888	2.4
Sporting goods	204,439	3.7	651,939	3.8	746,517	8.8	268,674	9.6
Souvenirs and other expenses	129,029	2.3	584,725	3.4	77,240	0.9	39,396	1.4
Total	5,556,958	100	17,128,437	100	8,407,006	100	2,775,856	100

[a] Includes data from Rogue River-Siskiyou and Umpqua National Forests, National Visitor Use Monitoring Program, based on a survey in 2012.

[b] Nonlocal refers to trips that required traveling more than 80 km.

NF = National Forest.

highest spending category at 28 percent ($1.6 million) in Rogue River-Siskiyou National Forest and 26 percent ($4.4 million) in Umpqua National Forest. Lodging, restaurants, and groceries were the second-highest spending categories. The remaining expenditure categories of other transportation, entry fees, recreation and entertainment, sporting goods, and souvenirs comprised 15.4 percent of all spending for Rogue River-Siskiyou National Forest, and 14.7 percent for Umpqua National Forest.

On BLM lands, dispersed use accounted for the vast majority of visitor activity, ranging from 47 to 95 percent, depending on the management unit. Dispersed use includes a wide range of activities (e.g., camping, hiking, sightseeing) that do not occur in locations designated for specific types of uses (e.g., campgrounds). Hiking on designated trails was a major activity only in Butte Falls Resource Area, where 21 percent of visits to this area are for hiking. The primary activities at Oregon Caves National Monument and Preserve are organized tours of the marble cave and hiking on local forest trails. The 1600-ha forest area that was acquired in 2014 will expand opportunities for recreational activities at Oregon Caves in the future.

Climate Change Vulnerability Assessment

All outdoor recreation activities depend to some degree, directly or indirectly, on environmental conditions that are determined by climate. For example, skiing opportunities depend on the availability of areas with snow-covered terrain, which is determined by patterns of temperature and snowfall. As climate change affects seasonal trends in temperature and precipitation in southwest Oregon, the availability of some sites for snow-based recreation is expected to decline (Luce et al. 2018).

To assess how recreation patterns may change in southwest Oregon, categories of outdoor recreation activities that may be sensitive to climate change were identified (fig. 7.4). For the purposes of the recreation assessment, an outdoor recreation activity is sensitive to climate change if altered environmental conditions that depend on climate would result in a significant change in the demand for or supply of that outdoor recreation activity.

The recreation activities identified in the NVUM survey are grouped into five climate-sensitive categories of activities, plus an “other” category of activities that are less sensitive to climate. Each category includes activities that would likely be affected by changes to climate and environmental conditions in similar ways. Box 7.2 lists the activities that comprise the climate-sensitive categories and summarizes their expected sensitivity to climate change. The categories were developed to capture the most common recreation activities on public lands in southwest Oregon that would be affected by climate change.

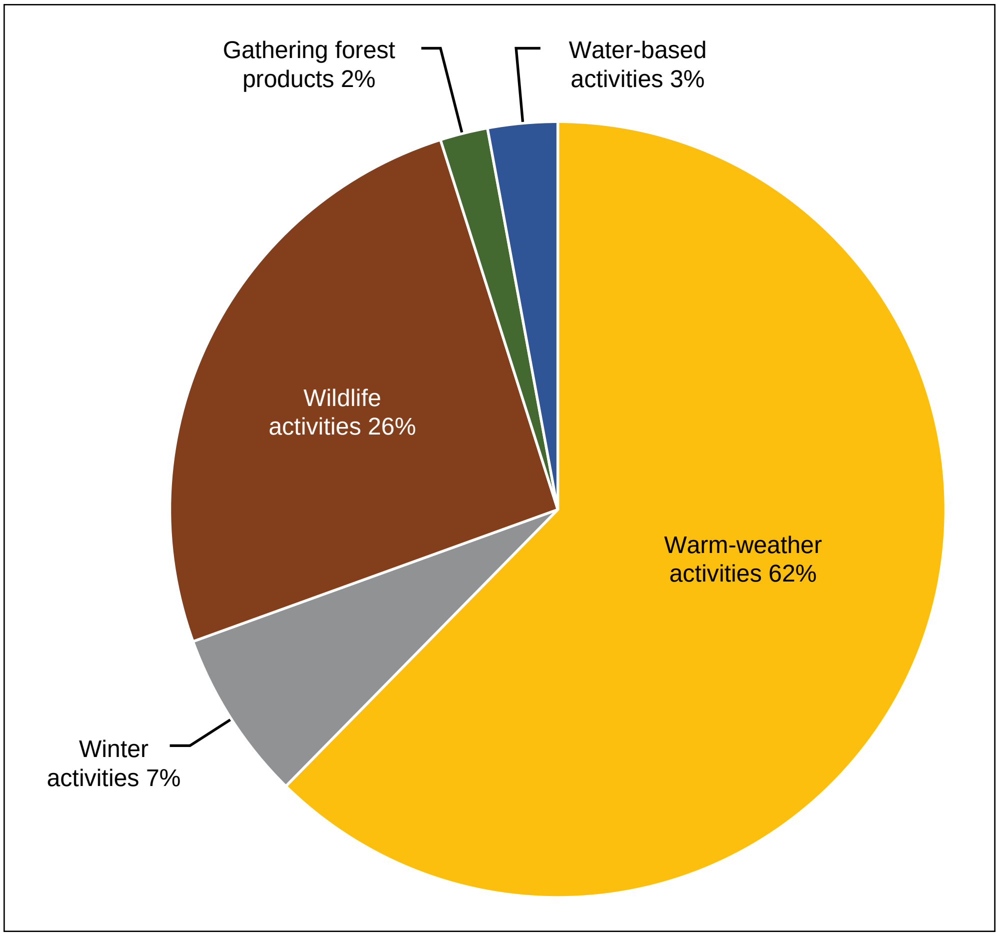

Figure 7.4—Percentage of total visits to national forests in southwest Oregon by climate-sensitive primary activity (USDA FS, n.d.; National Visitor Use Monitoring Program). https://www.fs.fed.us/recreation/programs/nvum. (23 August 2020).

The overall effect of climate change on recreation activity is likely to differ between warm-weather activities (increase in participation) and snow-based activities (decrease in participation).[4] In general, warmer temperatures and increased season length appropriate for warm-weather activities will increase the duration and quality of weather for activities, such as hiking, camping, and mountain biking. In contrast, reduced snowpack will decrease the duration and quality of conditions for downhill skiing, cross-country skiing, and snowmobiling. However, these general findings mask potential variation in the effects of climate on recreation between

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[4] Warm-weather activities and snow-based activities are used as general categories in this assessment to facilitate aggregation of recreational endeavors that typically occur during warm weather (hiking, camping, etc.) and when snow is available (downhill skiing, snowmobiling, etc.). Note that warm-weather activities can occur (but are less likely) in winter, and that some snow-based activities can occur (but are less likely) in summer.

Box 7.2

Summary of Climate Change Effects on Recreation

All categories of recreation considered to be potentially sensitive to the effects of climate change in southwest Oregon were aggregated into five activity categories. Positive (+) and negative (-) signs indicate expected direction of effect on overall benefits derived from recreation activity; (+/-) indicates that both positive and negative effects may occur.

Warm-weather activities (hiking, camping, sightseeing, etc.)—
- Magnitude of climate effect: moderate (+)
- Likelihood of climate effect: high
- Direct effects: warmer temperature (+), higher likelihood of extreme temperatures (-)
- Indirect effects: increased frequency and extent of wildfire (+/-), increased smoke from wildfire (-)

Snow-based activities (downhill skiing, cross-country skiing, snowmobiling, etc.)—
- Magnitude of climate effect: high (-)
- Likelihood of climate effect: high
- Direct effects: warmer temperature (-), reduced precipitation as snow (-)
- Indirect effects: increased frequency and extent of wildfire (+/-)

Continued on next page

types of activities and geographic locations. For example, if insufficient snow is available for skiing at a particular location, a recreationist may choose to ski at another location or go hiking instead.

This section provides an assessment of the likely effects of climate on major climate-sensitive recreation activities in the region. 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 outdoor 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 southwest Oregon, as detailed in the other chapters contained in this volume, are paired with the recreation literature to link expected responses of recreation behavior to specific expected climate effects.

Wildlife activities—
- Magnitude of climate effect: terrestrial wildlife: low (+); fishing: moderate (-)
- Likelihood of climate effect: moderate
- Direct effects: warmer temperature (+), higher incidence of low streamflow (fishing -), reduced snowpack (hunting -)
- Indirect effects: increased frequency and extent of wildfire (terrestrial wildlife +/-), increased smoke from wildfire (-); reduced cold-water habitat, incursion of warm-water-tolerant species (fishing -)

Gathering forest products—
- Magnitude of climate effect: low (+/-)
- Likelihood of climate effect: moderate
- Direct effects: warmer temperature (+)
- Indirect effects: increased frequency and extent of wildfire

Water-based activities (excluding fishing)—
- Magnitude of climate effect: moderate (+)
- Likelihood of climate effect: moderate
- Direct effects: warmer temperature (+), higher likelihood of extreme temperatures (-)
- Indirect effects: lower streamflows and reservoir levels (-), increase in algal blooms (-)

Current Conditions and Existing Stressors

Managing recreation on public lands is a complex enterprise that differs from year to year and season to season. It includes (1) maintaining standard opportunities and facilities (e.g., hiking trails, primitive campgrounds), (2) providing access for harvesting animals and plants, (3) regulating access for motorized vehicle use (e.g., off-highway vehicles, snowmobiles), and (4) coordinating with concessionaires who operate ski resorts and other facilities with significant cashflow.

Providing high-quality opportunities and facilities for a diverse population of recreationists in southwest Oregon—including diversity of activities, as well as ethnic and economic diversity (Burns et al. 2008)—is a significant challenge, and responding to the effects of a warmer climate will require monitoring how opportunities and demands for recreation change. Because most recreation occurs during warm weather, federal agencies hire additional staff for the summer season to assist with all aspects of recreation. In recent years, declining budgets have made it difficult to employ a sufficient seasonal workforce to accommodate recreation demands, especially during the shoulder seasons (late spring, early autumn).

Current climatic and environmental conditions in southwest Oregon are characterized by high variability within and between years. These variable climatic and environmental conditions include temperature, precipitation, waterflows and water levels, wildlife distributions, vegetative conditions, and wildfire activity. Most recreationists are accustomed to making decisions with a significant degree of uncertainty about conditions at the time of participation.

Increased population, particularly in proximity to public lands, can strain visitor services and facilities because of increased use, and projected population increases in southwest Oregon may exacerbate these effects. Increased use can reduce site quality because of crowding (Manning 2011, Yen and Adamowicz 1994). The physical condition of recreation sites and natural resources is constantly changing owing to human and natural forces. Recreation sites and physical infrastructure need maintenance, and deferred or neglected maintenance may increase congestion at other sites that are less affected, or increase hazards for visitors who continue to use degraded sites. Unmanaged recreation can create hazards and contribute to natural resource degradation (USDA FS 2010). This stressor may interact with population growth and maintenance needs if degraded site quality or congestion encourages users to engage in recreation that is not supported or appropriate at certain sites or at certain times of the year. Natural hazards and disturbances may create challenges for the provision of recreation opportunities. For example, wildfire affects recreation demand (as a function of site quality and characteristics) but may also damage physical assets or exacerbate other natural hazards such as erosion (chapter 3).

Warm-Weather Activities

Warm-weather activities are the most common form of recreation in southwest Oregon (tables 7.2 through 7.4). Warm-weather recreation is sensitive to the availability of snow- and ice-free trails and sites, and the timing and number of days with temperatures within minimum and maximum comfortable range (which may vary with activity type and site). The number of warm-weather days has been shown to be a significant predictor of expected visitation behavior (Richardson and Loomis 2004), and studies of national park visitation show that minimum temperature is a strong predictor of monthly visitation patterns (Albano et al. 2013, Fisichelli et al. 2015, Scott et al. 2007).

Participants are also sensitive to site quality and characteristics, such as the presence and abundance of wildflowers, conditions of trails, vegetation, and availability of shade. The condition of features that are sensitive to climate change, especially snow, may affect the desirability of certain sites (Scott et al. 2007). Forested areas are positively associated with warm-weather activities, such as camping, backpacking, hiking, and picnicking (Loomis and Crespi 2004), and will be sensitive to a warmer climate (USDA FS 2012a). A significant number of recreation sites near streams in southwest Oregon will have a higher probability of winter flooding and erosion in the future (fig. 7.5), the result of reduced snowpack at higher elevations (chapter 3), which will affect both access and public safety.

A longer wildfire season (chapter 5) is expected to have a major impact on participation in warm-weather activities in southwest Oregon through altered site quality and characteristics. (fig. 7.6). The presence of recent wildfires has differential effects on the value of hiking trips (positive) and mountain biking (negative), although recent wildfire activity tends to decrease the number of visits (Hesseln et al. 2003, 2004; Loomis et al. 2001). The severity of fire may also matter; high-severity fires are associated with decreased recreation visitation, whereas low-severity fires are associated with slight increases in visitation (Starbuck et al. 2006). Recent fires are associated with initial reductions in camping (Rausch et al. 2010) and backcountry recreation (Englin et al. 1996) that attenuate over time. Research in Yellowstone National Park showed that visitation tends to be lower following months with high wildfire activity, although there is no discernable effect of previous-year fires (Duffield et al. 2013).

Overall demand for warm-weather activities is expected to increase owing to the direct effect of climate change on season length. Temperatures are expected to increase significantly in southwest Oregon (chapter 2), 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 (Albano et al. 2013, Fisichelli et al. 2015). For example, higher **minimum** temperatures are associated with an increased number of hiking days (Bowker et al. 2012). Higher **maximum** summer temperatures are associated with reduced participation in warm-weather activities (Bowker et al. 2012), so extreme heat would probably reduce visitation in some cases (Richardson and Loomis 2004). Extreme heat may shift demand to cooler weeks at the beginning or end of the warm-weather season, or shift demand to alternative sites that are less exposed to extreme temperatures (e.g., at higher elevations, near lakes and rivers).

Indirect effects of climate change on forested areas may have a negative effect on warm-weather recreation if site availability and quality are compromised. The overall effect on warm-weather recreation in southwest Oregon will depend on

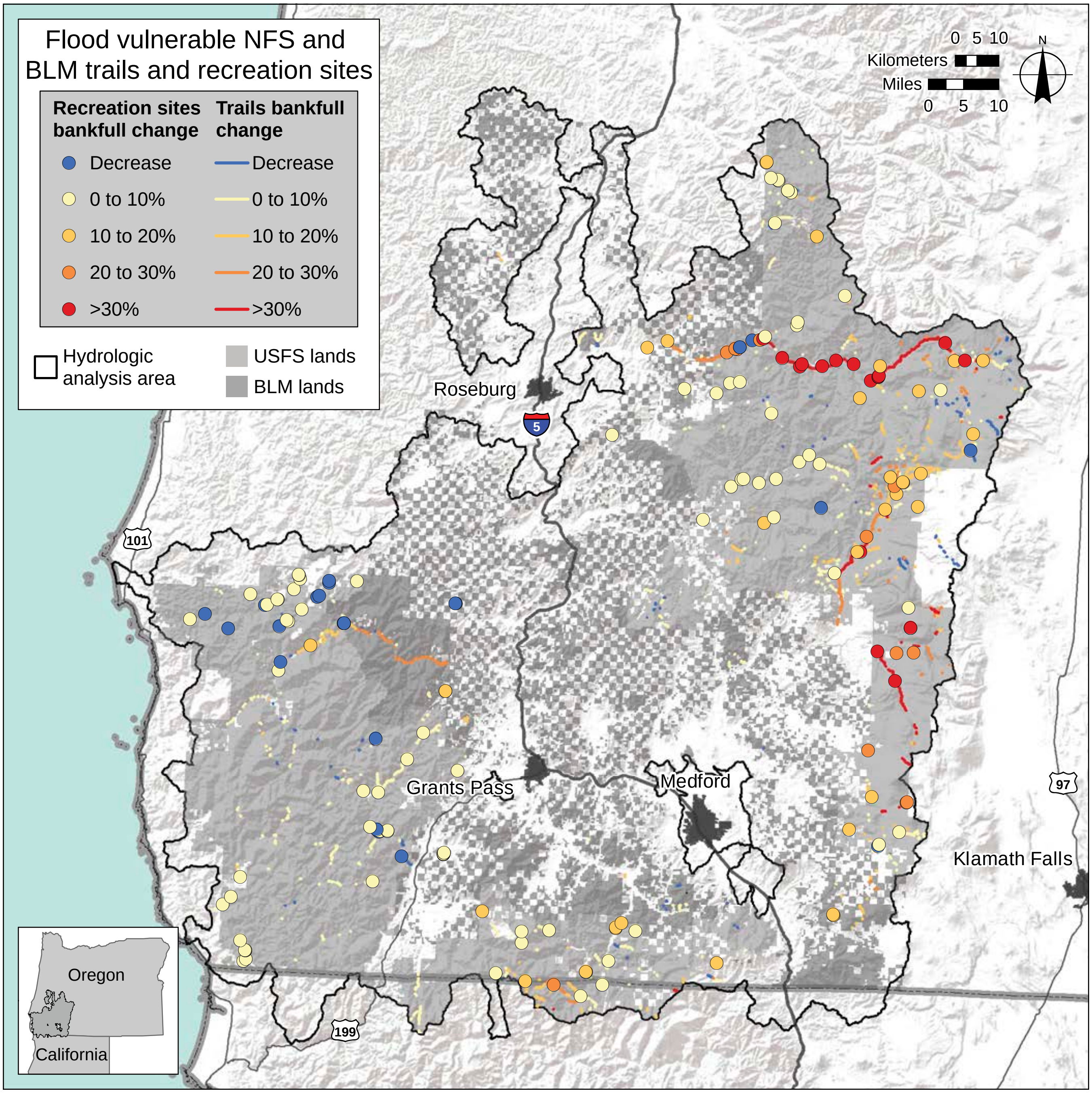

Figure 7.5—Recreation sites and trails within 90 m of a stream that are expected to be affected by higher streamflows. Model projections of bankfull flow in the 2080s are based on Variable Infiltration Capacity model projections under the A1B greenhouse gas emission scenario (see chapter 3). Yellow to red colors indicate projected increases in bankfull flow. NFS = National Forest System, BLM = Bureau of Land Management, USFS = U.S. Forest Service.

Shannon Browne

Figure 7.6—The Biscuit Fire, which occurred in Rogue River-Siskiyou National Forest in 2002, has had a long-term effect on the recreational landscape of the Vulcan Lakes trail. Increasing wildfires in a warmer climate may cause safety concerns, reduce access, and impair air quality and vistas for hikers.

local effects of climate on forest resources. Potential increases in the likelihood of extreme wildfire activity may reduce demand for warm-weather activities in certain years because of degraded site desirability, impaired air quality from smoke, and limited site access caused by fire management activities (fig. 7.4). Southwest Oregon is expected to experience an increase in area burned by wildfire, average fire size, and perhaps fire severity (chapter 5), which tend to have a negative effect on recreation visitation and benefits derived from recreation (but with some variability as noted above).

Adaptive capacity among recreationists is high because of the large number of potential alternative sites, ability to alter the timing of visits, and ability to alter capital investments (e.g., appropriate gear). However, benefits derived from recreation may decrease even if substitute activities or sites are available (Loomis and Crespi 2004). For example, some alternative sites may involve higher costs of access (because of remoteness or difficulty of terrain). In addition, limits on ability to alter seasonality of visits may exist (e.g., the timing of scheduled academic breaks). Although the ability of recreationists to substitute sites and activities is well established, how people substitute across time periods or between large geographic regions (e.g., choosing a site in northern Oregon instead of southwest Oregon) is poorly quantified (Shaw and Loomis 2008).

In summary, projected climatic changes are expected to result in a moderate increase in warm-weather recreation activity and benefits derived from these activities in southwest Oregon. Longer warm-weather seasons will increase the number of days when warm-weather activities are viable and increase the number of sites available during shoulder seasons. The effects of a longer season may be offset somewhat by negative effects on warm-weather activities during extreme heat, drought, and wildfire activity. The likelihood of effects on warm-weather recreation is high, because 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. The climate scenarios outlined in chapter 2 differ in their projection of the magnitude of warming, but they all project rising temperatures. Indirect effects on recreation, primarily through wildfire effects, may be harder to project with certainty and precision (particularly at small spatial scales).

Snow-Based Activities

Winter recreation sites in southwest Oregon exhibit a wide range of site characteristics, attracting visitors from local communities and throughout the region. Mount Ashland Ski Resort, located at the highest point in the Siskiyou Mountains in Rogue River-Siskiyou National Forest, is the only ski resort in southwest Oregon. Although downhill skiing is popular, cross-country skiing accounts for considerably more recreation activity, with access at Sno-Parks and along roads. Snowmobiling accounts for a small proportion of winter recreation.

Snow-based recreation is highly sensitive to variations in temperature and the amount and timing of precipitation as snow (Wobus et al. 2017). Seasonal patterns of temperature and snowfall determine the likelihood of a given site having a viable season (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).

A warmer climate is expected to reduce the season length and the likelihood of reliable winter recreation seasons in southwest Oregon, especially at lower elevation sites (Dawson et al. 2009, Hamlet 2000, Mote et al. 2008, Scott and McBoyle 2007, Scott et al. 2008, Stratus Consulting 2009, Wobus et al. 2017), although a range of effects at local scales is possible because of variation in location and elevation of recreation sites (fig. 7.7). Warmer winter temperatures are expected to reduce the proportion of precipitation as snow, even if the total amount of precipitation does not deviate significantly from historical norms (chapters 2 and 3). The rain-snow

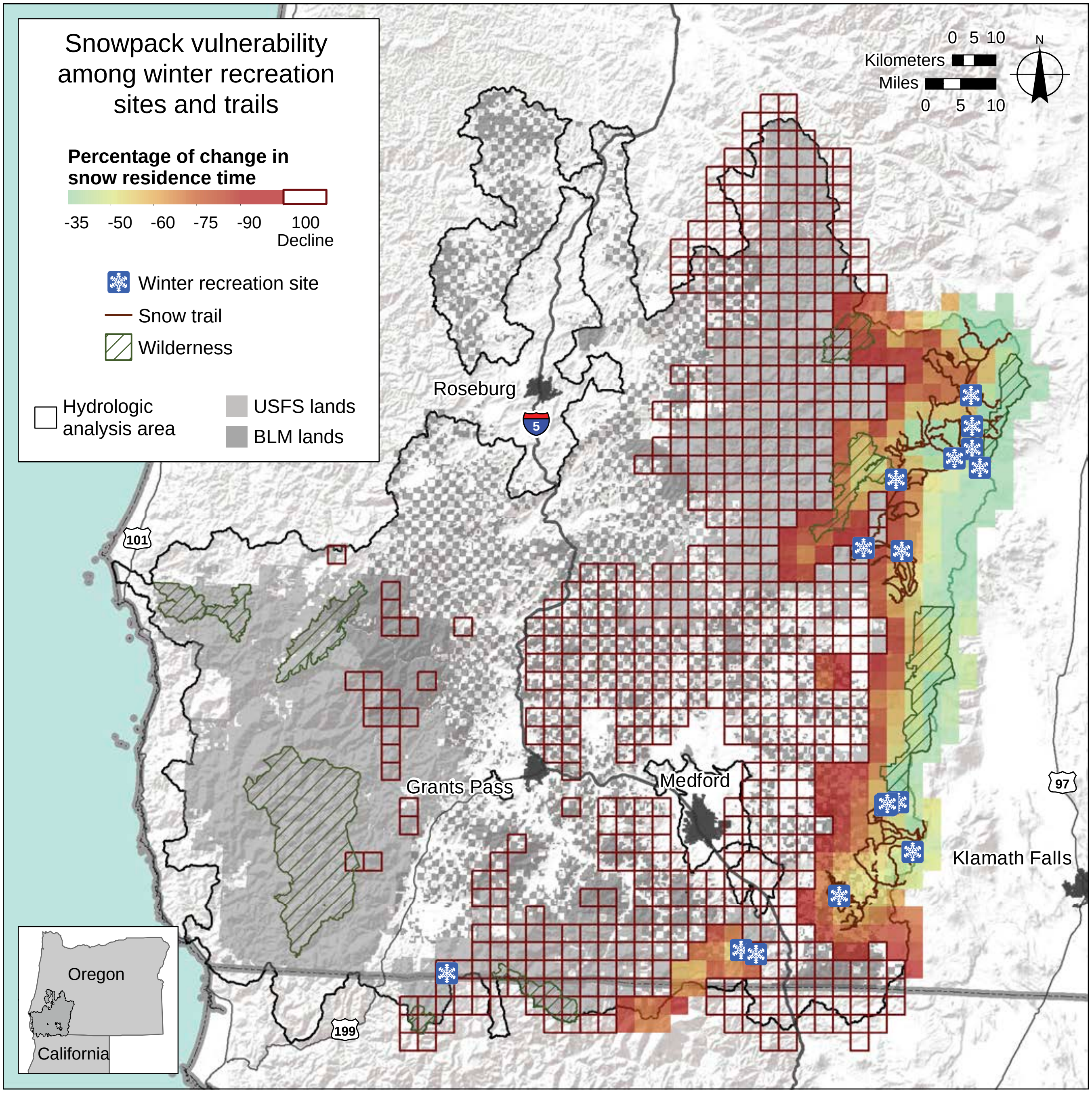

Figure 7.7—Locations where snow residence time is expected to decrease significantly (more than 35 percent), thus affecting snow-related activities on federal lands. Change in snow residence time is based on a 3 °C increase in December through March average temperature at Snow Telemetry stations in the Southwest Oregon Adaptation Partnership assessment area (from Luce et al. 2014). USFS = U.S. Forest Service, BLM = Bureau of Land Management.

transition zone (i.e., where precipitation is more likely to be snow rather than rain for a given time of year) is expected to move to higher elevations, particularly in late autumn and early spring (Klos et al. 2014). This effect places lower elevation sites at risk of shorter or nonexistent winter recreation seasons (fig. 7.8), although the highest elevation areas in the region remain snow-dominated for a longer portion of the season in future climate scenarios.

Snow-based recreationists have moderate capacity to adapt to changing conditions given the number of winter recreation sites in the region. For undeveloped or minimally developed site activities (e.g., cross-country skiing, backcountry skiing, snowmobiling, snowshoeing), recreationists may seek higher elevation sites with a greater likelihood of viable seasons (Hand and Lawson 2018). Although developed downhill skiing requires fixed improvements, potential adaptations include snowmaking and new run development at higher elevation (Scott and McBoyle 2007). Warmer temperatures and increased precipitation as rain may increase availability of water for snowmaking in the near term during winter. However, warmer temperatures may reduce the number of days per season when snowmaking is viable, and increased occurrence of rain on snow would reduce snow quantity and quality.

Jim Cronan

Figure 7.8—Low snowpacks, which are expected to be more common in a warmer climate, can reduce the duration, quality, and safety of skiing in some locations.

Although far fewer people participate in snowmobiling than in skiing (table 7.2), snowmobiling is locally important as a recreational activity and economic driver in small communities (White et al. 2016). One study suggests that snowmobiling may be more vulnerable than downhill skiing to reduced snowpack in a warmer climate (Scott et al. 2008).

Changes in snow conditions in southwest Oregon relative to other regions may also be important. If other locations experience relatively large climate effects on snow-based recreation, recreationists may view sites in southwest Oregon as a substitute for sites in other locations (Hand and Lawson 2018) (or vice versa), although interregional substitution patterns for recreation activities are poorly understood (Shaw and Loomis 2008).

In summary, the magnitude of climate-related effects on snow-based winter activities is expected to be high. Warmer temperatures are likely to shorten winter recreation seasons and reduce the likelihood of viable seasons at lower elevation sites. Developed sites may have limited ability to adapt to these changes unless additional areas are available for expanded development and expansion is feasible. The likelihood of negative effects is expected to be high for snow-based recreation, although variation across sites is possible because of differences in location and elevation. Climate models generally project warming temperatures and a higher elevation rain-snow transition zone, which would expose a larger land area to the risk of shorter seasons.

Wildlife-Dependent Activities

Wildlife-dependent recreation activities involve terrestrial or aquatic animals as a primary component of the recreation experience. Wildlife recreation can involve consumptive (e.g., hunting) or nonconsumptive (e.g., wildlife viewing, birding, catch-and-release fishing) activities. Distinct from other types of recreation, wildlife activities depend on the distribution, abundance, and population health of desired target species. These factors influence activity “catch rates,” that is, the likelihood of harvesting or seeing an individual of the target species. Sites with higher catch rates can reduce the costs associated with a wildlife-dependent activity (e.g., time and effort tracking targets) and enhance overall enjoyment of a recreation day for that activity (e.g., greater number of views of highly valued species).

Participation in wildlife-dependent 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). Altered habitat, food sources, streamflow, and water temperature (for aquatic species) may alter wildlife abundance and distribution, which in turn influence expected catch rates and wildlife recreation behavior.

Wildlife-dependent activities in southwest Oregon may also be sensitive to other direct and indirect climate change effects. Lower availability of highly valued target species (e.g., coastal cutthroat trout (*Oncorhynchus clarkii clarkii* Richardson) for cold-water anglers) (chapter 4) may reduce the ability of anglers to obtain desired benefits from engaging in fishing (Pitts et al. 2012). Increased wildfire occurrence may be beneficial for mule deer (*Odocoileus hemionus* Rafinesque) and elk (*Cervus elaphus* L.) populations in some habitats (chapter 6), thus increasing the success of hunters. The diversity of game species present can also affect hunt satisfaction (Milon and Clemmons 1991) and enjoyment of nonconsumptive wildlife-dependent activities such as birding (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 exact relationship may be activity or species specific. Some activities (e.g., big game hunting) may be enhanced by cold temperatures and snowfall to aid in field dressing, packing out harvested animals, and tracking. Other activities may be sensitive to climate change effects similar to those for warm-weather recreation (see above), in which moderate temperatures and snow- and ice-free sites are desirable.

Warming temperatures projected for southwest Oregon are expected to increase participation in terrestrial wildlife activities because of an increased number of days that are desirable for wildlife-dependent outdoor recreation. In general, warmer temperatures are associated with higher participation in and number of days spent hunting, birding, and viewing wildlife (Bowker et al. 2012). However, hunting that occurs during discrete seasons (e.g., elk 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 decline as warmer weather persists later into the fall and early winter and the likelihood of snow cover decreases, reducing harvest rates. This issue is also relevant for outfitters who operate under legal hunting/fishing seasons and may also operate under special-use permits with specific dates and areas.

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) (chapter 5). 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 (chapters 5 and 6).

Higher temperatures are expected to decrease populations of native coldwater fish species as climate refugia retreat to higher elevations (chapter 4). This change favors increased populations of fish species that can tolerate warmer temperatures. However, it is unclear whether shifting populations of species (e.g., substituting other fish species for cutthroat trout) will affect catch rates, because relative abundance of fish may not necessarily change.

Increased interannual variability in precipitation and reduced snowpack could cause higher peak flows in winter and lower low flows in summer, creating stress for fish populations during different portions of their life histories (chapter 4). The largest patches of habitat for coldwater species will be at higher risk of shrinking and fragmentation. Mountain lakes currently used for ice fishing will have a decreased period of time available for this activity. Increased incidence and severity of wildfire may increase the likelihood of secondary erosion events that degrade streams and riparian habitat (chapter 3). 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.

An interesting context for the future of hunting and fishing in a warmer climate is an ongoing decrease in hunting participation. In 1975, 18.9 percent of Oregon residents had a hunting license and 34.6 percent had a fishing license. Data from 2013 show the figures down to 8.3 percent for hunting licenses and 17.4 percent for fishing licenses (Darling 2014). The effects of climate change on animal populations (chapter 6), in addition to the demand for harvesting animals, will influence wildlife-dependent recreation.

In summary, the magnitude of climate-related effects on activities involving wildlife is expected to be low overall for terrestrial wildlife activities and moderate for fishing. Ambiguous effects of vegetative change on terrestrial wildlife populations and distribution suggest that conditions may improve in some areas and deteriorate 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 are likely to be reduced as cold water refugia shrink to higher elevations and are eliminated in some areas. Coldwater species tend to be high-value targets, indicating that this habitat change will decrease benefits enjoyed by anglers. Warm-water tolerant species may increasingly provide targets for anglers, mitigating reduced benefits from fewer coldwater species. Warmer temperatures and longer seasons encourage additional participation, but indirect effects of climate on low streamflows and reservoir levels could reduce opportunities, especially during years with low precipitation. The likelihood of climate-related effects on wildlife activities is expected to be moderate for both terrestrial and aquatic wildlife activities. Uncertainties exist about the magnitude and direction of indirect effects of climate on terrestrial habitat and the degree to which changes in available target species affect participation.

Forest Product Gathering

Forest product gathering accounts for a small portion of primary visit activities in southwest 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 such as huckleberries (*Vaccinium* spp.), although resource constraints may not exist at current participation levels. In addition, traditional foods (often called “first foods”) have high cultural value for American Indians and rural residents. In recent years, seeds collected from native plants are increasingly used for restoration of native vegetation where nonnative vegetation have become prevalent.

Forest product gathering is sensitive primarily to climatic and vegetative conditions that support the distribution and abundance of target species (Hand and Lawson 2018; Hand et al. 2018, 2019). 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 resulting from warming temperatures and increased interannual variation in precipitation may alter the geographic distribution and productivity of some target species over many decades (chapter 5). Increased incidence and severity of wildland fires may eliminate sources of forest products immediately after fire, but encourage 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 with a high probability of vegetative transition to less productive vegetation types (Hand et al. 2019).

Recreationists engaged in forest product gathering may have the ability to select different gathering sites as the distribution and abundance of target species change, although these sites may increase the costs of gathering. Those who engage in gathering as a secondary activity may choose alternate activities to complement primary activities. Commercial products serve as an imperfect substitute for some forest products such as Christmas trees.

In summary, the magnitude of climatic effects on forest product gathering is expected to be low. This activity is among the less common primary recreation activities in the region, although it may be more often engaged in as a secondary activity. Longer warm-weather seasons may expand opportunities for gathering in some locations, although these seasonal changes may not correspond with greater availability of target species. The likelihood of effects is expected to be moderate, although significant uncertainty exists regarding direct and indirect effects on forest product gathering. Vegetative changes caused by climate changes and disturbances may alter abundance and distribution of target species, although the magnitude and direction of these effects is unclear.

Water-Based Activities (Excluding Fishing)

Apart from angling, water-based activities comprise a small portion of primary recreation activity participation on federal lands in southwest Oregon. Upper reaches of streams and rivers are generally not desirable for boating and floating. Lakes and reservoirs provide opportunities for motorized and nonmotorized boating, and swimming, although boating may commonly be paired with fishing. Existing stressors include the occurrence of drought conditions that reduce water levels and site desirability in some years, and disturbances that can alter water quality (e.g., erosion events following wildfires).

The availability of suitable sites for nonangling, water-based recreation is sensitive to reductions in water levels caused by warming temperatures, increased variability in precipitation, and decreased precipitation as snow. Reductions in surface-water area are associated with lower participation in boating and swimming (Bowker et al. 2012, Loomis and Crespi 2004, Mendelsohn and Markowski 2004), and streamflow is positively associated with number of days spent rafting, canoeing, and kayaking (Loomis and Crespi 2004, Smith and Moore 2013). 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).

River recreation, in particular commercial and private rafting, is vulnerable to the effects of climate change on drought (especially low streamflow) (fig. 7.9) and wildfire (e.g., degraded scenery, reduced access). River rafters prefer mid-season, intermediate water levels and warm weather over turbulent, cold spring runoff or

U.S. Geological Survey

Figure 7.9—Low water levels, as shown here on the Rogue River in 2013, can reduce the quality of whitewater rafting, as well as reduce habitat quality for fish species that need cold water.

late-season low water (Yoder et al. 2014). A warmer climate will shorten the period of time when desirable conditions are available. Quality whitewater rafting requires different conditions than floating the river. This can be a dilemma in locations where whitewater and family float trips are both popular activities and outfitter/guide companies depend on appropriate streamflows for a positive experience (Associated Press 2012). These issues are compounded when threatened/endangered fish species are present, potentially reducing rafting seasons for commercial river outfitters, because low streamflow puts salmon redds at risk in addition to reducing the quality of rafting conditions.

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 in southwest Oregon (chapter 3); this will reduce site quality and suitability for certain activities. Increased demand for surface water by downstream users may exacerbate reduced water levels in drought years. Warmer temperatures are expected to increase the demand for water-based recreation as the viable season lengthens but can also increase undesirable algal blooms (e.g., Hand and Lawson 2018, Moore et al. 2008). On a national basis, projections of changes in water-based activities in response to climate change tend to be small compared to the effects of broad population and economic shifts on these activities (Bowker et al. 2012), although it is unclear if this is true in southwest Oregon.

In summary, climate change is expected to have a moderate effect on water-based activities. Increasing temperatures and longer warm-weather seasons are likely to increase demand, although the incidence of extreme temperatures may dampen this effect in certain years. A higher likelihood of lower streamflows and reservoir levels 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. Altered timing of snowmelt may increase the likelihood of negative effects on water-based activities (through lower summer flows and reservoir levels), which may offset increased recreation resulting from warmer temperatures.

Summary of Climate Change Vulnerabilities

Several recreation activities are considered highly sensitive to changes to climatic and environmental conditions. However, recreation in southwest Oregon is diverse, and the effects of climate are likely to vary among 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 because longer warm-weather seasons will make more recreation sites available for longer periods of time. Participation is also expected to increase because of gradual growth in population size. Increased participation in warm-weather activities is likely to be offset somewhat by decreased snow-based winter activities. Receding snow-dominated areas and shorter seasons in the future are likely to reduce the opportunities (in terms of available days and sites) for winter recreation.

Beyond these general conclusions, the details of changes in recreation patterns in response to climate change are complex. Recreation demand is governed by several economic decisions with multiple interacting dependencies on climate. For example, decisions about whether to engage in winter recreation, 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 climatic and environmental characteristics. On the supply side, site availability and quality depend on climate, but the effect may differ from one location to another. Thus, climatic effects on recreation depend on spatial and temporal relationships among sites, environmental conditions, and human decisions. Long-term monitoring data on recreation that take climate into account are needed to quantify these relationships.

Uncertainty derives from unknown effects of climate on site quality and characteristics that are important for some recreation decisions (e.g., indirect effects of climate on vegetation, wildlife habitat, and species abundance and distribution). The exact effects of climate on target species or other quality characteristics are difficult to predict and are likely to be diverse across the region, yet these characteristics play a large role in recreation decisions for some activities. Another source of uncertainty is how people will adapt to changes when making recreation decisions. Substitution behavior between regions and over time is not well understood (Shaw and Loomis 2008, Smith et al. 2016). This may be important for southwest Oregon if in the future some sites experience relatively little effect from climate change compared with sites in other regions.

Substitution will be an important adaptation mechanism for recreationists. Some popular activities may have several alternate sites, and the timing of visits may be altered to respond to climate changes. However, spatial and temporal substitution may represent a loss in benefits derived from recreation even if it appears that participation changes little (Loomis and Crespi 2004); the new substitute site may cost more to access or have lower quality than the preferred site prior to climate change. This represents a decrease in benefits to the person engaging in recreation.

Adapting Recreation Management to Climate Change

Warming temperatures (chapter 2) will be the primary driver of climate change effects on recreation in southwest Oregon. Increasing length of the snow-free season will likely shift use toward summer recreation, which may lead to new pressures on certain types of recreational activities. Warming is likely to extend seasons of use for warm-weather activities, which may expose erosion-prone roads and wildlife habitats that were previously protected from recreational use by snow coverage during much of the year. Shifting from snow to rain may lead to increased erosion, landslides, and road and trail failures, which would increase the risk to public safety and increase the need for road and trail maintenance (chapter 3). With higher temperatures, timing of peak streamflow will affect the seasonality of whitewater rafting. Riparian and other sensitive areas may see greater use during times of low flow as more people seek shade and cooler sites.

Organizational flexibility and responsiveness to changes will help adapt recreation management to climate change in southwest Oregon, and most adaptation strategies are focused on providing sustainable levels of recreation opportunities (table 7.6). Redirecting recreational use to optimize recreational opportunities, as well as protecting areas that are vulnerable to damage by recreationists, will help maintain the quality of recreational experiences in the future. Public safety may also be a concern as disturbance patterns change, and maintenance of roads and other infrastructure could be a costly addition to existing responsibilities for resource managers.

Adaptation tactics focus on adjusting the capacity of recreation sites and increasing flexibility of the availability of those sites based on variable weather conditions from year to year. Access to some areas may need to be restricted in order to protect resources, especially when roads, trails, and facilities are not yet open, and may not be safe, in years when snow melts early. Efforts are needed to identify recreation sites that are likely to incur heavier use in a warmer climate, then ensure that infrastructure and staffing are sufficient to support that use, or alternatively, that access is dispersed to locations that can sustain more use. Greater flexibility in the seasonality of staffing, permitting, and concessionaire contracts will be needed in order to adjust to altered recreational demands and opportunities in the future.

To date, on-the-ground adaptation actions for recreation have rarely been documented (except perhaps at ski resorts that have increased snow making and have transitioned to multiseason recreation). However, during this and other recent climate change vulnerability assessments (e.g., Hand et al. 2019), we observed that recreation managers are acutely aware of how both (short-term) weather and (long-term) climate challenge the ability of federal agencies to operate sustainable recreation programs. We are optimistic that adaptation options will be increasingly implemented and tested over the next decade, with successful options and new ideas being shared among management units.

Table 7.6—Recreation adaptation options for southwest Oregon

Sensitivity to climate change	Adaptation strategy	Adaptation tactic
Increasing length of the snow-free season will increase demand for summer recreation access. This may increase user conflicts and human-animal interactions. Projected population growth will increase pressure on recreation sites.	Provide sustainable recreation opportunities in response to changing demand.	• Direct and focus recreation use on less vulnerable areas. • 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.[a] • Plan for fire, flood, and geohazard evacuation, and effects on public safety. • Develop hazard-tree management strategies and vegetation management plans for campgrounds. • Adjust timing of actions, such as road and trail closures, food storage orders, and special-use permits.[a]
	Align human uses with new patterns of seasonality.	• Develop capacity for flexibility in seasons (opening dates for campgrounds, access to trails, road closures).[a] • Evaluate potential conflicts for different resources, especially increased human incursion into wildlife habitats and increased human-wildlife encounters.
As seasons of use extend, snow may no longer limit access and protect erosion-sensitive roads and wildlife habitats.	Manage access to protect resources and investments.	• Add gates or obstructions to close areas that may be at risk; use a multiple-gate system to open lower trails but close off higher elevation trails. • Add gates to closed areas that may be muddy; harden roads that are likely to see muddy-season use.[a] • Use social media and real-time information to communicate to the public the impacts of out-of-season or nonseasonally appropriate recreation.[a] • Develop flexible travel management plans and staffing to accommodate flexible dates for road openings.[a]
Increased erosion and landslides will lead to more trail failures, and increased soil saturation will increase the need for trail maintenance.	Increase resilience of trail systems to saturated soils and erosion, and minimize risks to public safety.	• Identify, inventory, and monitor vulnerable trails; include assessment of wildfire risk. • Increase restoration and erosion control in revegetation projects.[a] • Reduce erosion by building protection into trail design.[a] • Evaluate and monitor timing of visitor use relative to hydrologic dynamics.[a] • Consider crowd-sourcing data collection for issues on roads and trails (e.g., landslides, washouts, disturbance events).
Seasonality of whitewater rafting will shift with increasing temperatures and altered timing of peak streamflows.	Increase management flexibility and facilitate transitions to meet user demands and expectations.	• Vary permit season to adapt to changes in peak flow and duration.[a] • Educate the public about changing river conditions.[a] • Manage road vulnerability to sustain access and shuttling of people and equipment.
Increased use will occur in riparian and other sensitive areas because of low flows and higher temperatures (people seeking shade and cooler sites).	Plan for changes in recreation demand.	• Reconsider campground locations to optimize comfort during hot climates (e.g., in the shade and near water). • Intentionally locate sites to minimize impacts of dispersed camping.[a] • Identify places where there will be loss of water-based recreation, or where more recreation will be concentrated; identify alternate areas for recreation that are less sensitive.

Table 7.6—Recreation adaptation options for southwest Oregon (continued)

Sensitivity to climate change	Adaptation strategy	Adaptation tactic
Higher temperatures will lead to an increase in recreation demand, but lack of summer precipitation will reduce suitable sites for water-based recreation.	Increase flexibility in water-based recreation site management and facility design.	• Increase length of boat ramps.[a] • Actively manage shoreline areas and dry lake areas.[a] • Increase flexibility in opening and closing facilities based on weather conditions. • Add language to concessionaire contracts to allow for seasonal flexibility.[a] • Communicate with users via phone app.[a] • Manage lake and river access capacity.[a] • Manage public expectations of site availability.[a] • Evaluate resorts and recreation residences near water edges and shorelines for functionality of septic systems, vault toilets, and pit toilets.[a]
	Proactively manage for risks to public health and safety.	• Increase communication with the public on the health risk of algae blooms in lakes.[a]
Recreation use patterns will change (year-round seasons for nonsnow activities, shift in snow-dependent activities, altered uses and demand).	Increase flexibility and capacity for managing recreation resources to meet shifting demands.	• Develop budget strategies to support longer and overlapping use seasons. • Pursue additional grant funding and partnerships and opportunities for new fees (e.g., something similar to Adventure Pass, parking fees); leverage outfitting and guiding funds. • Increase flexibility for year-round use of facilities: • Redevelop/harden/mitigate existing or new sites (e.g., integrate summer uses into ski area operations). • Pave access roads for winter and wet uses. • Install gates or other access control where snow no longer closes areas. • Change types of infrastructure (e.g., marinas used to be static but now need to be flexible). • Increase capacity at existing sites to accommodate longer use seasons.[a]
Extended shoulder seasons may lead to overlapping seasonal recreation uses traditionally limited to strictly summer or winter. Different and potentially more recreational opportunities may emerge.	Anticipate increased and shifting seasonal recreation patterns.	• Estimate areas and individual sites that will have increasing pressure in shoulder seasons. • Identify emerging recreation opportunities, and shift marketing to take advantage of these opportunities to benefit communities.[a] • Manage roads for year-round access (e.g., install gates). • Identify and direct access to desirable locations; ensure adequate infrastructure in targeted locations. • Locate facilities near roads accessed during the off-season.[a] • Increase staffing capacity and partner staff presence in areas where motorized uses increase; consider leveraging partnerships to increase volunteer presence.[a]
Water demands from recreation may degrade habitat for aquatic and wildlife species.	Manage recreation use and infrastructure to minimize effects from changes in human use.	• Inventory and track the heaviest use or damage in dispersed camp areas; prevent expansion by placing rocks or block access. • Mitigate impacts of recreation; enforce occupancy limits.[a]

[a] Indicates adaptation tactics cited in the workshop based on tactics in the Climate Change Adaptation Library for the Western United States (http://adaptationpartners.org/library.php).

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Chapter 8: Climate Change Effects on Ecosystem Services in Southwest Oregon

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Introduction

Ecosystem services are the benefits 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 inadequately considered in resource decisionmaking. The MEA drew attention to these critical goods and services by highlighting their importance in four primary categories: (1) **provisioning services** such as food, fiber, energy and water; (2) **regulating services** including erosion and flood control, water purification and temperature regulation; (3) **cultural services** such as spiritual connections with the land, history, heritage, and recreation; and (4) **supporting services** or the foundations of systems such as soil formation, nutrient cycling, and pollination.

The effects of climate change on ecological systems will alter the ability of those systems to provide goods and services over time. Differential effects on ecosystem components, individual species, and species interactions will have implications for water availability and quality, regulation of flows and flood prevention, pollinator/plant relationships, forest products, and other benefits (Montoya and Raffaelli 2010, Mooney et al. 2009). A greater incidence of extreme climatic and disturbance events could significantly alter the ability of systems to provide goods and services on which people rely. Understanding the biological underpinnings of ecosystem services can help reduce the negative effects of climate change, increase resilience, and facilitate adaptation over time (Seidl et al. 2016).

Efforts to integrate ecosystem services into policy and practice in federal agencies have increased in recent years. In 2013, the U.S. Department of Agriculture, Forest Service (U.S. Forest Service) chartered the National Ecosystem Services Strategy Team, composed of scientists and resource managers within the National

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Forest System (NFS), State and Private Forestry, and the Pacific Northwest Research Station. This group was tasked with finding opportunities to incorporate ecosystems into U.S. Forest Service programs and operations. The team has the lead in responding to a presidential memorandum issued in October 2015 instructing federal agencies to incorporate ecosystem services into decisionmaking and requiring each agency to develop a plan for doing so.

The Forest Service 2012 Planning Rule (36 CFR 219) requires national forests to take ecosystem services into consideration in revising land management plans. This chapter highlights the priority climate change considerations for ecosystem services that may be considered during forest planning. From an operational standpoint, climate change vulnerability assessments are intended to inform the revision of land management plans by analyzing potential climate change effects. By including ecosystem services in climate change vulnerability assessments, the information gathered can more easily be incorporated once plan revision begins.

Ecosystem services included in this chapter were selected in consultation with staff from the Rogue River-Siskiyou National Forest, Umpqua National Forest, and Bureau of Land Management (BLM) Medford District. Based on a qualitative literature analysis along with available data within the assessment area, this chapter focuses on a subset of services based on their importance in the southwest Oregon landscape in order to make meaningful inferences about the effects of climate change. This mirrors the criteria outlined in the 2012 Planning Rule directives, which advises resource managers to focus on key ecosystem services in forest plan revision that are important outside the planning area and can be affected by Forest Service decisionmaking. Ecosystem services covered in this chapter are representative of all four categories (provisioning, regulating, cultural, supporting), thus providing a broad perspective on potential resource benefits.

Forest Products

One of the primary responsibilities of the U.S. Forest Service is to ensure a sustainable supply of forest products. National forests in the Southwest Oregon Adaptation Partnership (SWOAP) assessment area provide wood products, including timber, biomass, posts and poles, and firewood. Broadly speaking, climate change is expected to affect timber and forest products through altered vegetation structure and growth, as well as altered disturbance regimes (chapter 5). Increased physiological stress associated with higher temperatures and lower soil moisture is expected to result in decreased tree growth (Restaino et al. 2016) in most low-elevation species. Increased frequency or severity of drought-induced disturbances, such as insect outbreaks (Hicke et al. 2006) and wildfire (McKenzie et al. 2004), are also anticipated to cause widespread mortality (see chapter 5). Projections of the effects of climate change suggest that significant changes in dominant vegetation will likely occur, with transitions typically catalyzed by disturbance (chapter 5).

Lower growth and higher mortality rates will alter the productivity of forests, 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 empirical evidence for this relationship is equivocal (Kirilenko and Sedjo 2007). Across the SWOAP assessment area landscape, productivity is expected to increase in some areas, although the magnitude and location depend on the vegetation model and emission scenario used in the analysis (chapter 5).

Biophysical changes in forest vegetation will have implications for local and regional socioeconomic conditions, affecting industries and communities that depend on timber and nontimber harvests. Climate change is expected to alter supply and demand of timber products in the global market, with cascading effects on prices (Kirilenko and Sedjo 2007).

Current Levels of Use

Forest products for the SWOAP assessment area are important for both commercial and noncommercial uses (box 8.1). Figure 8.1 shows timber production in counties on NFS and BLM land in the study area. The number of permits sold for nontimber forest products reveal the variety of ways in which the forest is being utilized (figs. 8.2 through 8.5). Firewood collecting, Christmas tree cutting, bough collection, and mushroom hunting are among the most popular activities.

Box 8.1

Employment and Labor Income From Forest Products

Public lands contribute to economic activity in the areas surrounding them by providing recreation opportunities, forest products, and water supplies, as well as investments in restoration, among many other benefits. The U.S. Forest Service annually calculates its contributions to employment in terms of jobs (full time, part time, temporary, seasonal) and income (wages, salaries and benefits for wage earners plus income to sole business proprietors). Although these estimates do not capture all the economic contributions provided by ecosystem services, they are a reasonable approximation of how the agency brings work to local communities.

In 2016, Rogue River-Siskiyou National Forest supported an estimated 2,330 jobs and $111 million in labor income to the local area from its forest products program (USDA FS 2016). Umpqua National Forest contributed 1,350 jobs and $61 million in labor income to local communities (USDA FS 2016). In 2012, the Bureau of Land Management Medford District timber program contributed 340 jobs and $15.8 million to the local economy (USDI BLM 2016). Climate-induced shifts in species distribution and productivity could affect the socioeconomic contributions of federal forest products programs.

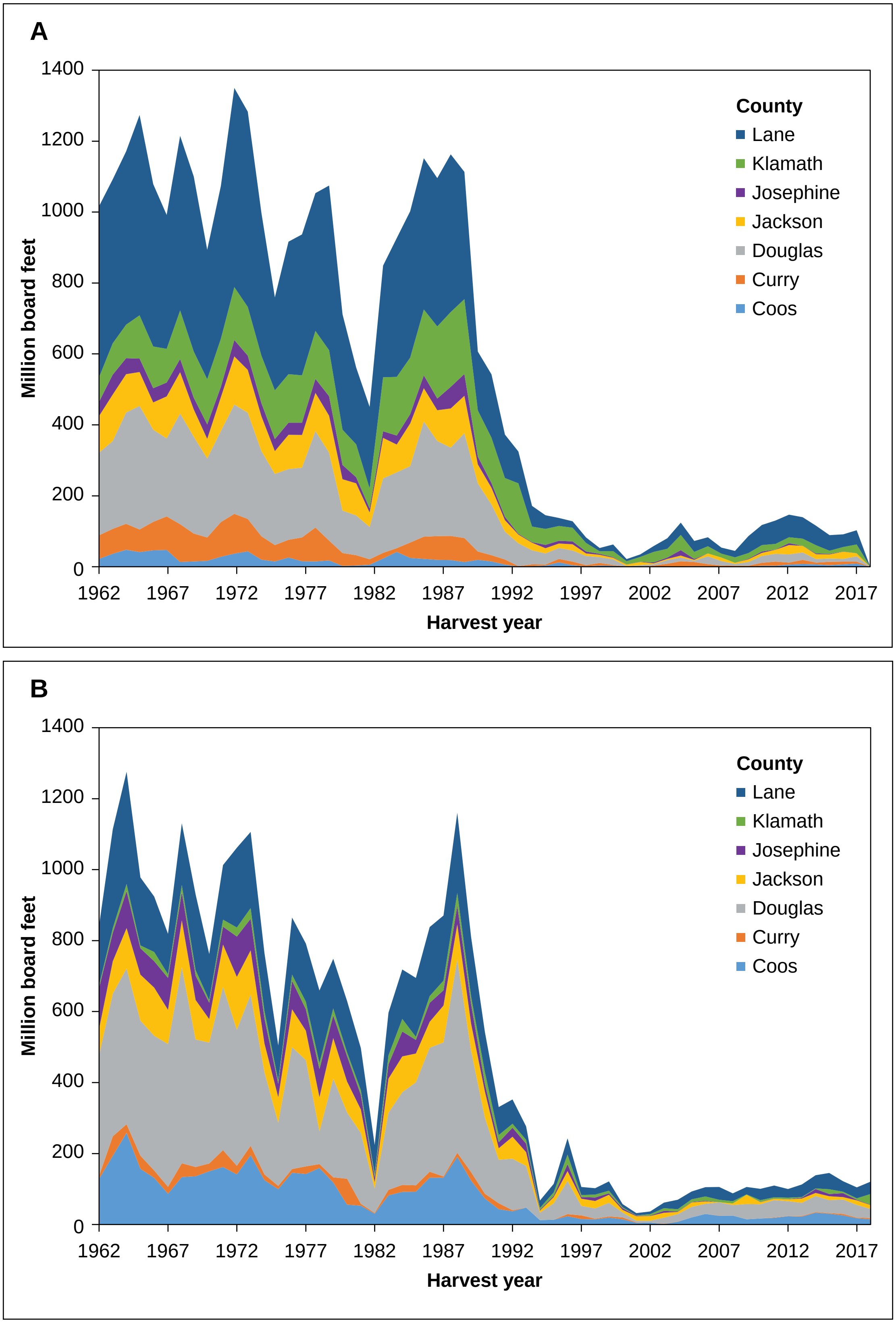

Figure 8.1—Annual timber product output from (A) National Forest System lands and (B) lands administered by the Bureau of Land Management in the Southwest Oregon Adaptation Partnership assessment area, 1962–2016, cumulative by county. Data are from Oregon Department of Forestry annual harvest reports for the State of Oregon.

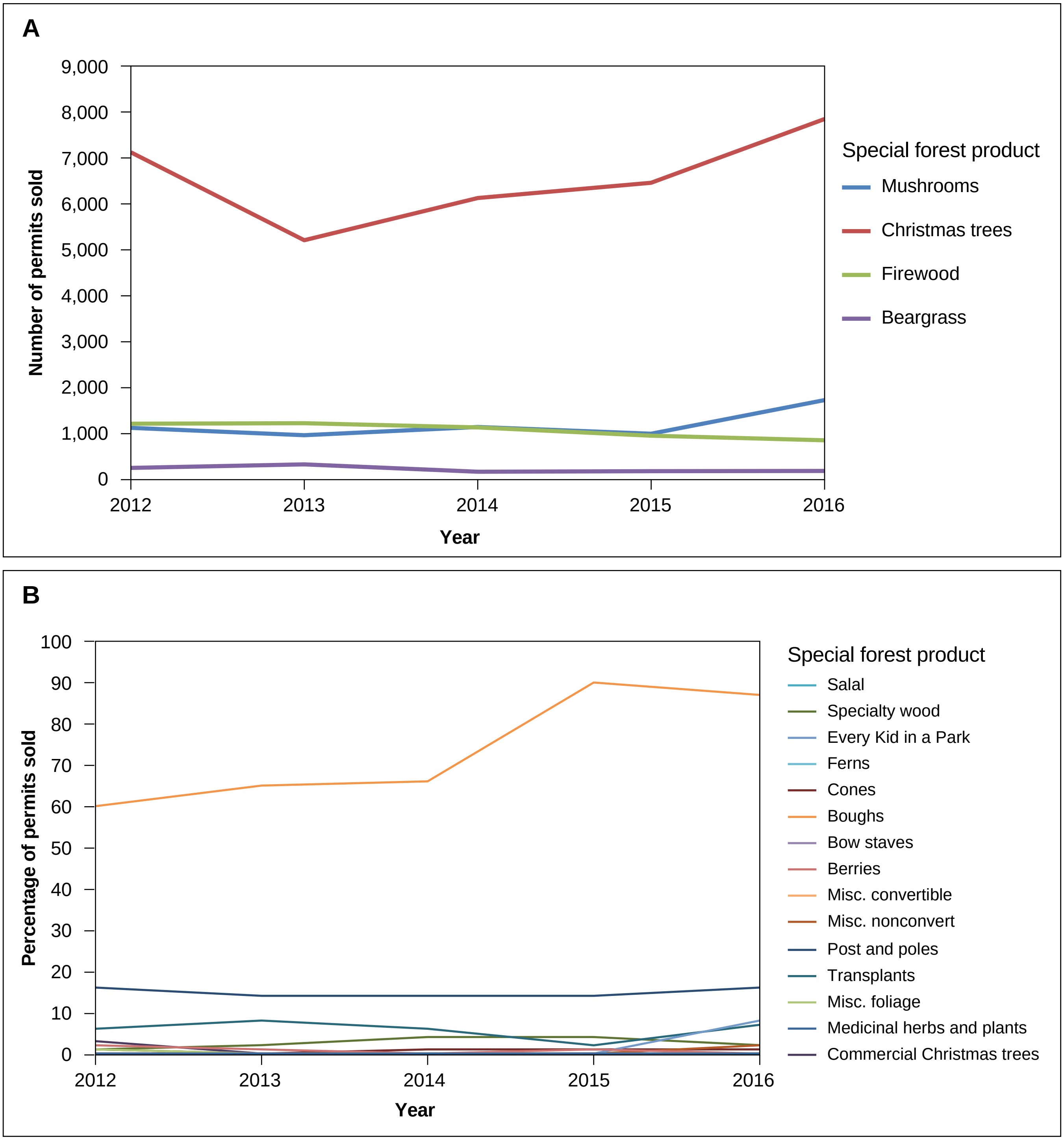

Figure 8.2—Special forest products permits sold: (A) mushrooms, Christmas trees, firewood, and beargrass, and (B) other less common special forest products for Rogue River-Siskiyou National Forest, fiscal years 2012–2016.

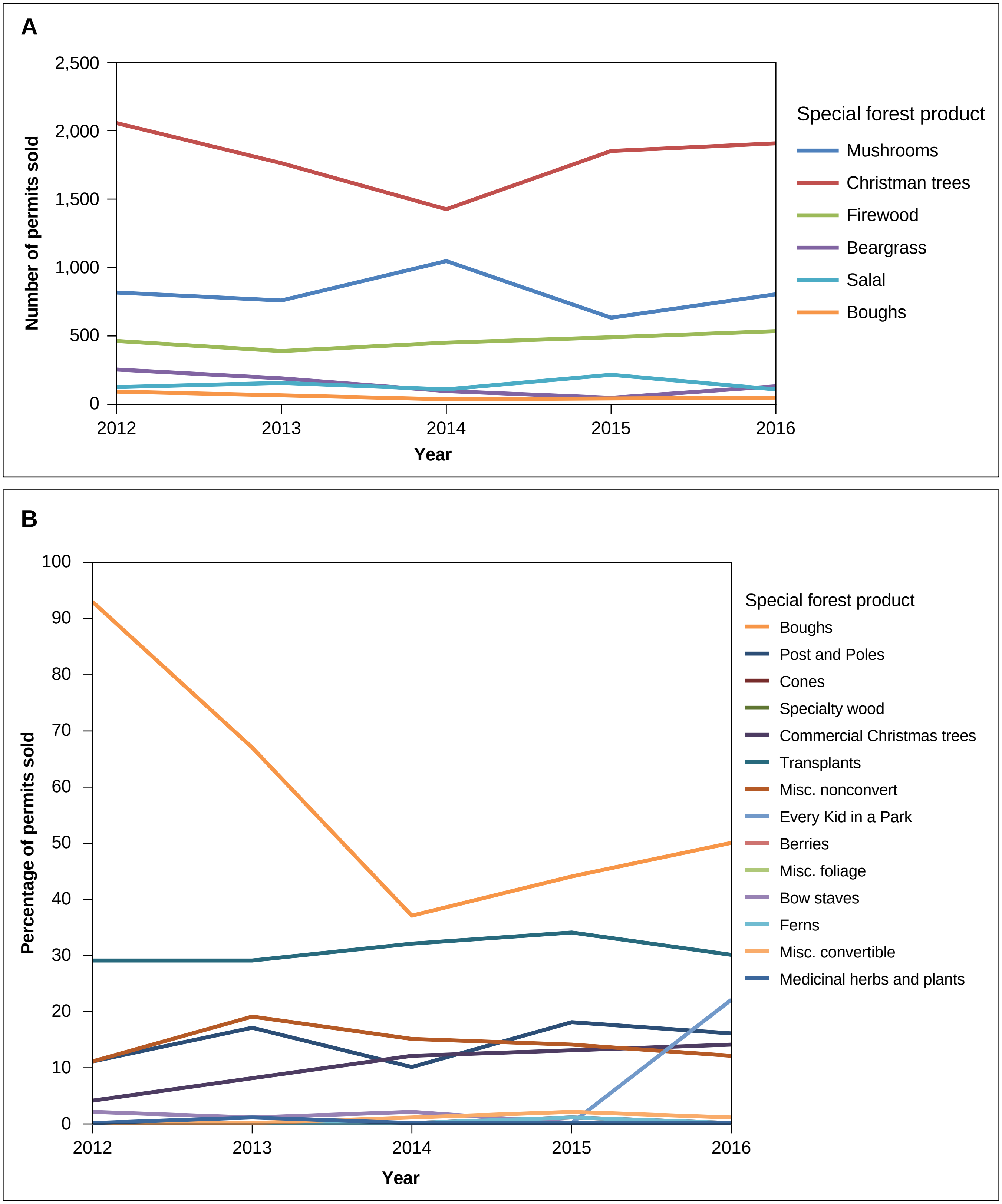

Figure 8.3—Special forest products permits sold: (A) mushrooms, Christmas trees, firewood, beargrass, salal, and boughs, and (B) other less common special forest products for Umpqua National Forest, fiscal years 2012–2016.

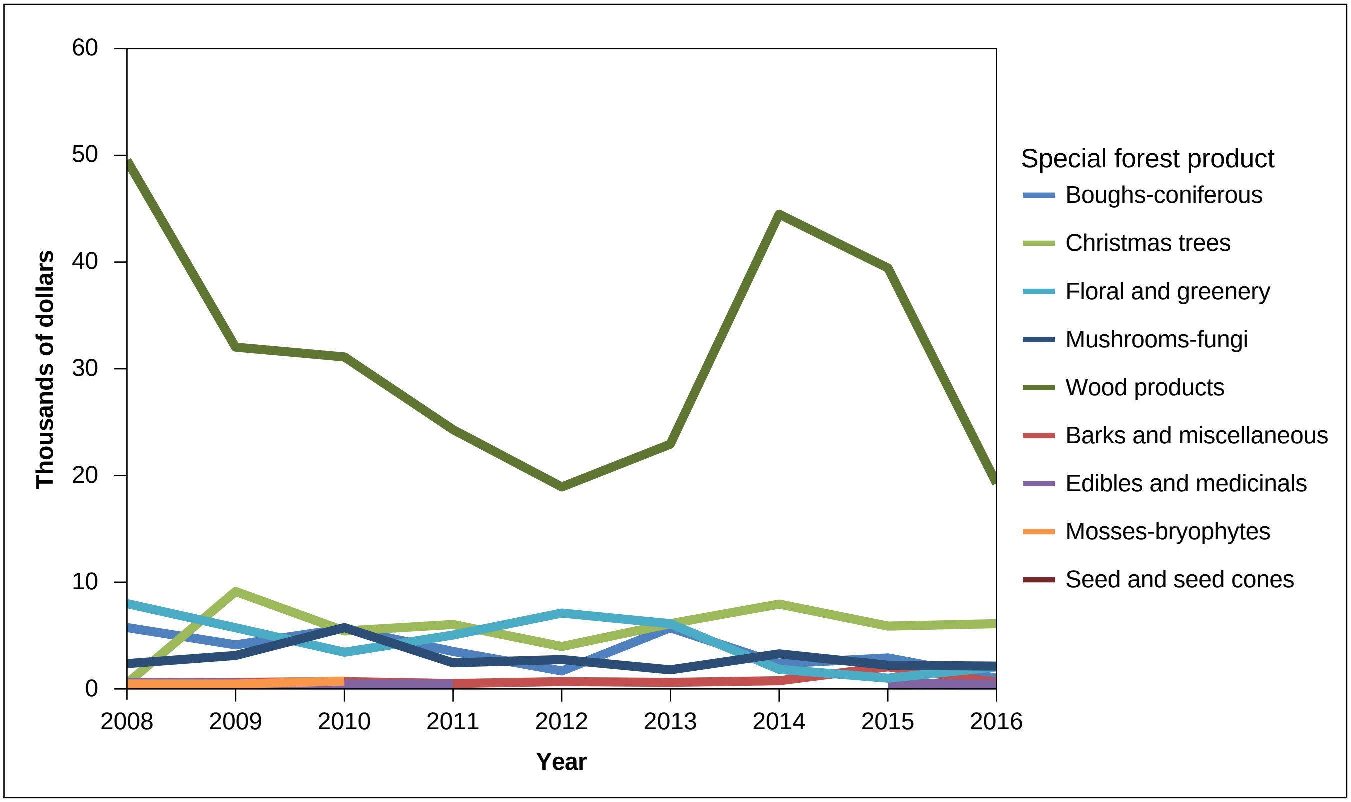

Figure 8.4—U.S. dollar value of special forest products sold for the Bureau of Land Management Medford District, fiscal years 2008–2016 (nominal values).

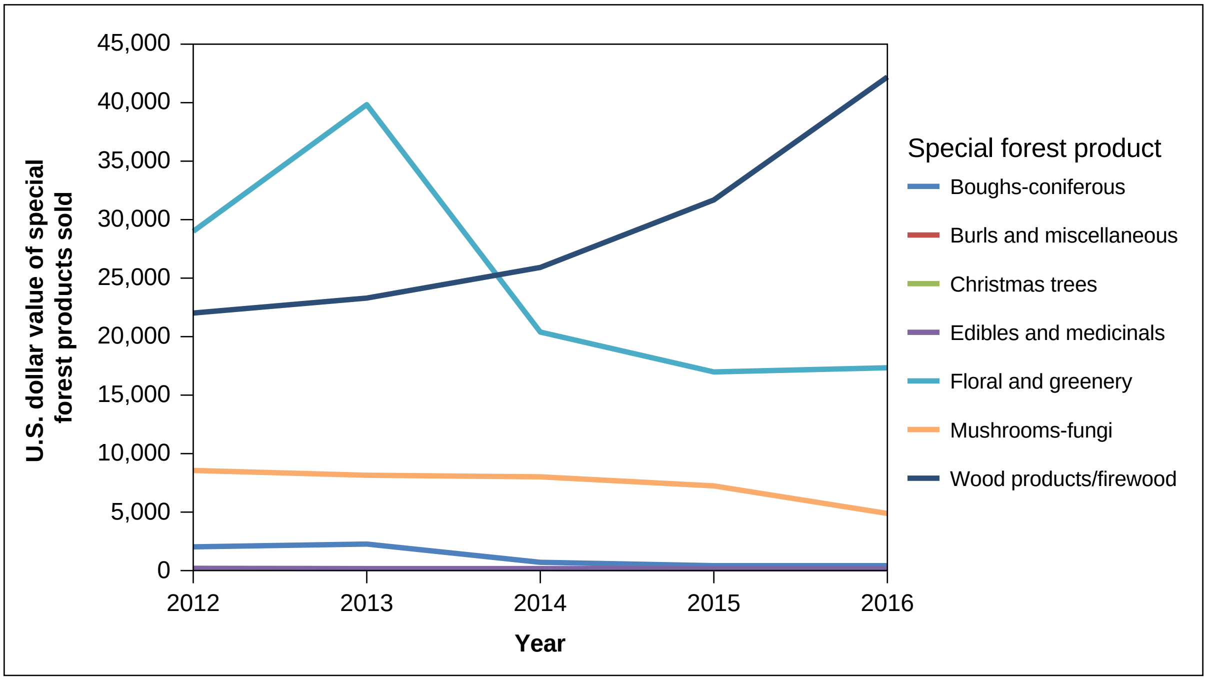

Figure 8.5—Dollar value of special forest products sold for the Bureau of Land Management Roseburg District, fiscal years 2012–2016 (nominal values).

Climate change may affect these special forest products through access and availability. Each plant species that provides these products will respond individually to climate change, affecting the quantity, quality, and seasonality of plant materials. The magnitude and rate of changes are uncertain, and spatial and temporal patterns are likely to be obscured by interannual variation.

Access to these forest products will also be affected by shifting human demography and recreation patterns, as well as climate change effects on road access. User group conflicts, particularly in years of low production of products for which demand is high, will likely continue in some locations and may increase if yields are low for several consecutive years. Shifting recreation patterns (chapter 7) may also affect special forest product gathering. This could mean more intense gathering in the shoulder (spring and fall) seasons when staffing and infrastructure might not be in place to support this activity.

Grazing

Forage for livestock is a significant ecosystem service in the SWOAP assessment area (table 8.1). The 2012 agricultural census indicated that the counties served by the SWOAP national forests (Douglas, Jackson, Josephine, Klamath, and Lane) represented more than 13 percent of cattle and calves sales in Oregon. Cattle and calves are the top agricultural commodity in the state, with about $9.1 million in estimated value (Oregon Department of Agriculture 2016).

Altered winter and spring precipitation could translate into substantial effects on rangeland vegetative species composition and distribution (chapter 5), with implications for forage availability and quality. Unmanaged or excessive grazing, as well as other historical activities, have 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 disrupt ecosystem structure and function. Cheatgrass has been associated with higher fine fuel amounts, higher fuel continuity, and lower fuel moisture, thereby increasing the flammability of fuels (Davies and Nafus 2013). In a warmer climate, it is possible that cheatgrass, and possibly other invasive annual grasses, will increase in extent in southwest Oregon (chapter 5).

Rangeland managers may need to shift the duration and timing of grazing as conditions change. Some studies suggest that dormant season (winter) grazing could reduce the spread of nonnative grasses and wildfire probability (Davies et al. 2015). Most models indicate that altered plant species composition, abundance, and distribution will likely occur in lands currently grazed (chapter 5). Continued development

Table 8.1—Grazing animal unit months (AUMs) and allotments for fiscal year 2017 for national forest (NF) and Bureau of Land Management (BLM) units in the Southwest Oregon Adaptation Partnership assessment area

Forest/district	Class	Livestock permitted	Livestock authorized	AUMs permitted	AUMs authorized
Rogue River-Siskiyou NF	Cattle	3,378	3,452	15,987	14,953
Rogue River-Siskiyou NF	Horse	10	8	61	41
Umpqua NF	Cattle	182	137	1,612	1,249
Medford BLM	Cattle	NA	NA	NA	9,047

	Allotments			
Forest/district	Active	Vacant	Closed	Combined
Rogue River-Siskiyou NF	26	7	2	1
Umpqua NF	5	2	0	0
Medford BLM	40	4	NA	NA

NA = not available.

and refinement of ecological site descriptions will help provide land managers the information needed for evaluating land use, capability to respond to different management activities or disturbance processes, and ability to sustain productivity over the long term (USDA NRCS 2018). Adaptive management will be necessary to manage sites that become increasingly sensitive to climate change, such as riparian areas, wetlands, springs, and groundwater-dependent ecosystems (chapter 5). Maintenance of sustainable ranching in southwest Oregon will be of primary concern in the conservation of open and undeveloped space (and associated ecosystem services).

Forest Carbon

Carbon sequestration refers to the long-term uptake and storage of carbon by forests in biomass and soils. The cycling of carbon through a forest ecosystem is a dynamic process involving carbon uptake via photosynthesis and growth, and carbon release via respiration, decomposition, and disturbance. As a regulating ecosystem service, carbon sequestration by forests helps to maintain or reduce atmospheric CO_2 concentrations (USDA FS 2015).

Currently, forests of North America, including most forests on NFS lands, are a net carbon sink, meaning they are taking up and storing more carbon than they are releasing (Pan et al. 2011). The carbon taken up by U.S. forests is equivalent to approximately 12 percent of U.S. total annual CO_2 emissions (US EPA 2015), making forests the country's largest terrestrial carbon sink. The NFS accounts for about 20 percent of all forest land area in the United States and about 25 percent of all carbon stored in U.S. forests (excluding interior Alaska) (USDA FS 2015). The

Pacific Northwest region of the United States includes extensive areas of old forests containing some of the highest forest carbon densities in the country.

The long-term capacity of forest ecosystems and harvested wood products to take up and store carbon depends on their health, resilience, adaptive capacity, and utilization of timber (McKinley et al. 2011). Under a changing climate, forests are increasingly affected by many factors such as multiyear droughts, insect and disease epidemics, wildfires, and large storms (Cohen et al. 2016, Westerling et al. 2006). For example, over the past few decades, southwest Oregon has experienced several large and severe wildfires, including the 2002 Biscuit Fire, which burned nearly 200 000 ha, and the 2017 Chetco Bar Fire, which burned more than 70 000 ha. Natural and human-caused disturbances can cause both immediate and gradual changes in forest structure, which in turn affect forest carbon dynamics by transferring carbon between different ecosystem and atmospheric carbon pools.

Forests are highly dynamic systems that continuously repeat the natural progression of establishment, growth, death, and recovery, while cycling carbon throughout the ecosystem and the atmosphere. Typically, management activities aiming to restore and maintain healthy forest structure and composition (e.g., prescribed fire, hazardous fuels reduction, and thinning treatments) represent a short-term loss of carbon from the ecosystem through the removal or burning of biomass (Birdsey and Pan 2015, Nunery and Keeton 2010). However, these short-term losses reduce large pulses of carbon to the atmosphere over the long term, reducing the risks of larger and more severe wildfires and improving forest health (Stephens et al. 2012). Furthermore, when forests are disturbed through natural processes or management activities, the carbon that is initially removed is eventually replaced as forests recover and continue to take up and store carbon over time.

Wood harvested from the forest, especially timber used for durable structures, can be reservoirs of long-term carbon storage (Bergman et al. 2014). Durable wood products can be used in place of other products, such as concrete and steel, that require significantly more energy to be produced, thus releasing more carbon into the atmosphere (Lippke et al. 2011). Furthermore, harvested wood and residues may also be used as bioenergy, displacing the use of alternate fossil fuel sources (e.g., coal, natural gas, oil). The combustion of fossil fuels and fossil fuel-intensive products represents an open-loop system in which geologic carbon is transferred to the atmosphere and will never be recovered. In contrast, forests and their products embody a closed-loop system in which emissions associated with harvests and product use are eventually recovered as forests regrow.

In response to a growing need for guidance on carbon management and stewardship, the Forest Service created a set of preliminary “carbon principles” (USDA FS 2015):

- Emphasize ecosystem function and resilience (function first).
- Recognize carbon sequestration as one of many ecosystem services (one of many services).
- Support diversity of approaches (diverse approaches).
- Consider system dynamics and scale in decisionmaking (scale and timeframe).
- Use the best information and analysis methods (decision quality).

These general principles are intended to assist all U.S. Forest Service programs and authorities with carbon stewardship. The second principle recognizes the importance of considering carbon sequestration in the context of other ecosystem services (USDA FS 2015). The Forest Service promotes integrating climate adaptation and mitigation, and balancing carbon uptake and storage with a wide range of public benefits. The goal is to maintain and enhance net sequestration across all pools and age classes. This includes protecting existing stocks, as well as building resilience through adaptation, restoration, and reforestation. Current carbon estimates are most useful for understanding patterns and trends at large spatial scales. Estimates at the scale of the national forest are typically useful for context but not useful for project-scale applications.

Baseline Forest Carbon Estimates

The Forest Service has developed a nationally consistent assessment framework for reporting carbon components within each national forest. Estimates of total ecosystem carbon and stock change (flux) have been produced at the scale of the national forest across the entire country, relying on a consistent methodology using the Carbon Calculation Tool (Smith et al. 2010) that essentially summarizes the available plot-scale data from the Forest Inventory and Analysis (FIA) program (USDA FS 2015).

Baseline estimates, produced by the U.S. Forest Service Office of Sustainability and Climate, Research and Development, and other collaborators, include carbon stocks and trends for 2005–2013 for seven ecosystem carbon pools in national forests: aboveground live tree, belowground live tree, standing dead, understory, down dead wood, forest floor, and soil organic carbon, as well as storage in harvested wood products where data are available.

Figure 8.6 displays carbon stock trends for the Rogue River and Siskiyou portions of the Rogue River-Siskiyou National Forest and for Umpqua National Forest. Carbon storage on Umpqua National Forest increased from 139 Tg in 2005 to 142 Tg in 2013. During this period, total forest ecosystem carbon generally increased in the Rogue River portion of the Rogue River-Siskiyou National Forest, but decreased in the Siskiyou portion.

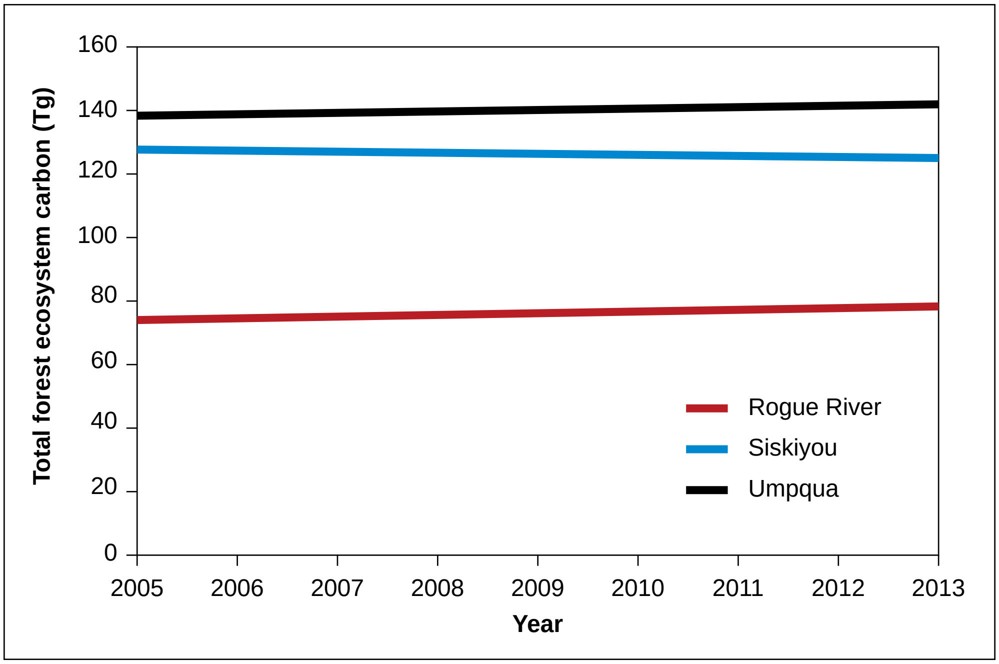

Figure 8.6—Total forest ecosystem carbon in teragrams (Tg) for the Rogue River and Siskiyou portions of Rogue River-Siskiyou National Forest and for Umpqua National Forest in the U.S. Forest Service Pacific Northwest Region (2005–2013).

Carbon Storage in U.S. Forest Service-Harvested Wood Products

Harvested wood products (HWP), such as lumber, panels, and paper, can account for a significant amount of offsite carbon storage. Estimates of this contribution are important for national-level accounting and regional reporting (Bergman et al. 2014, Skog 2008). Products derived from the harvest of timber from national forests reduce carbon emissions by substituting for more energy-intensive materials including concrete, steel, and plastics. In addition, much of the carbon lost onsite from harvest can be recovered through regrowth, effectively closing the carbon cycle.

The Forest Service baseline assessments of forest ecosystem carbon (USDA FS 2015) also contain an assessment of carbon storage in harvested wood products across all national forests in Oregon and Washington from 1909 to 2012. A production accounting approach (Skog 2008) was used to track the entire life cycle of carbon from harvest to timber products to primary wood products to end use to disposal (Butler et al. 2014). Regional data on harvest volumes were documented in detailed cut-and-sold reports (USDA FS 2013).

Historical trends can help forest managers contextualize the importance of sequestration through wood production. In the Pacific Northwest Region of the U.S. Forest Service, sequestration resulting from timber harvest remained below 0.75 Tg carbon (C)[2] from 1909 to 1930, decreasing further during the Great Depression (see timber harvest trends in fig. 8.1a). World War II stimulated harvest levels up to 2.1 Tg C by 1944, then levels fell to 1.4 Tg in 1946. The 1960s and 1970s experienced a rapid increase in harvest levels, peaking in 1973 at 8.3 Tg C. The following decade experienced declining harvest levels, reaching 3.2 Tg C in 1982. Harvests rose to 8.1 Tg C in 1987 but then declined in the early 1990s. By 1997, levels fell to 1.1 Tg C and remained below 1 Tg C since 2001. However, harvest levels since 2006 have been slowly increasing (Butler et al. 2014) (fig. 8.1a).

As more and more commodities are produced and stay in use, the amount of carbon stored in products accumulates rapidly (fig. 8.7). Furthermore, although products may be retired in solid waste disposal sites (SWDS), they decompose quite slowly, causing carbon to continue to be stored for many decades. Thus, the cumulative storage in Oregon and Washington HWP peaked in 1994 at approximately 144 Tg C. Following the rapid decline in harvests in the early 1990s (fig. 8.1a), the HWP pool including in-use and SWDS has decreased to approximately 131 Tg C (fig. 8.8).

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[2] One teragram of carbon (Tg C) is equivalent to 1 million megagrams of carbon (Mg C).

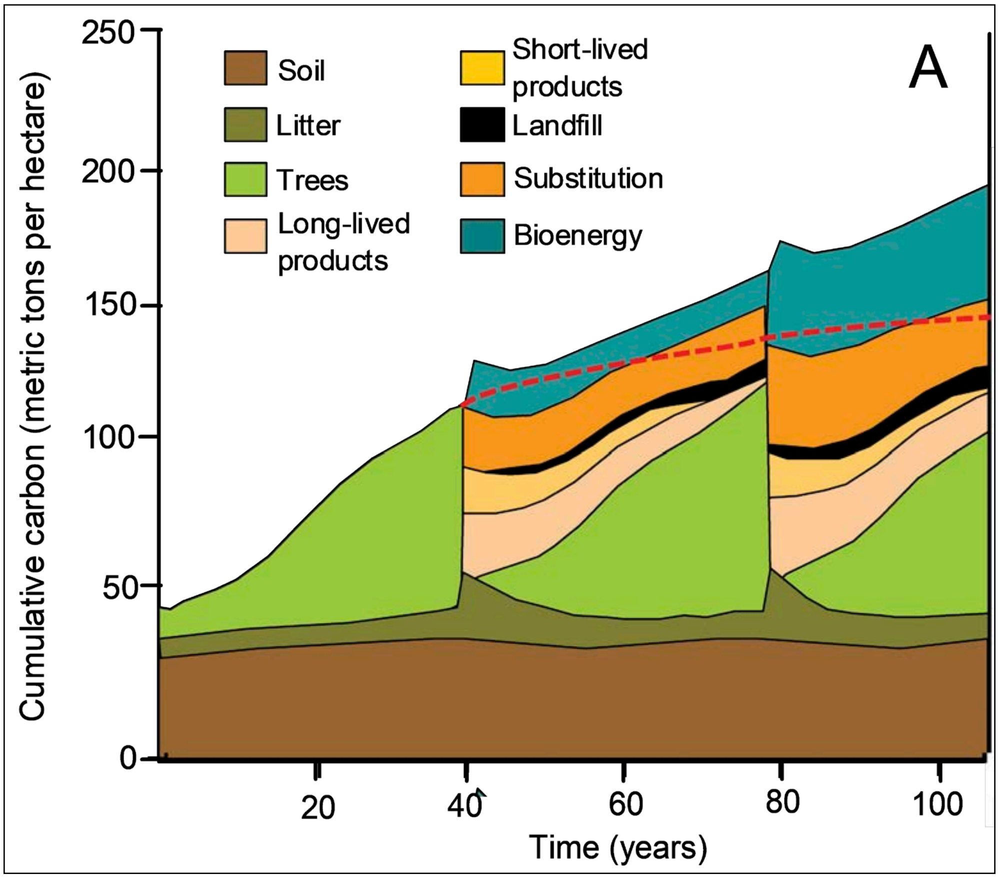

Figure 8.7—Carbon balance from a hypothetical forest management project in which the forest is harvested roughly every 40 years from land that started with low forest carbon stocks. This figure accounts for forest regrowth and carbon stored in wood products in use and landfills as well as the prevented release of fossil fuel carbon (also counted as stored carbon) via product substitution and biomass energy. It illustrates how forests can continue to accrue carbon over time with forest management. Figure is from McKinley et al. (2011) and adapted from IPCC (2007).

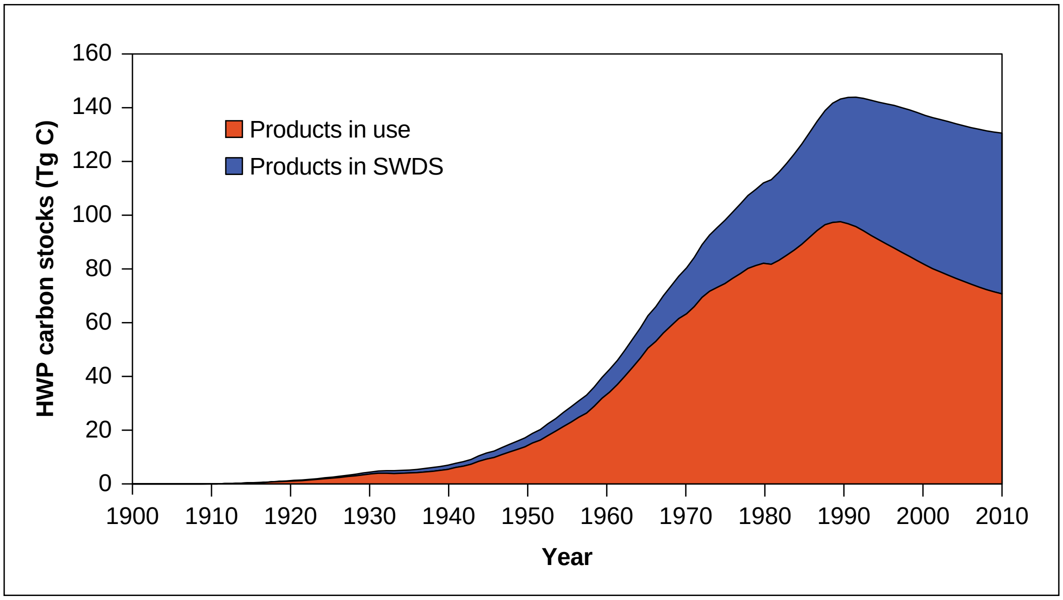

Figure 8.8—Cumulative total carbon stored in harvested wood products (HWP) manufactured from U.S. Forest Service Pacific Northwest Region timber. Carbon in HWP includes both products that are still in use and carbon stored at solid waste disposal sites (SWDS), including landfills and dumps (Butler et al. 2014). Note that 1 million megagrams of carbon (Mg C) is equivalent to 1 teragram of carbon.

Effects of Climate Change on Forest Carbon

Although the baseline assessments that rely on FIA data alone are useful in understanding carbon trends (USDA FS 2015), the assessments do not include an analysis of factors that have directly influenced forest carbon dynamics on national forests. The Forest Service expanded on the baseline assessments by developing unit-scale assessments detailing how forest carbon stocks are influenced by timber harvest, natural disturbances (fire, insects, abiotic), climate variability, increasing atmospheric CO_2 concentrations, and nitrogen deposition (Birdsey et al. 2019, Dugan et al. 2017, Healey et al. 2014, Raymond et al. 2015). Like the baseline assessments, these expanded assessments (Birdsey et al. 2019) rely on FIA data but also integrate datasets, including up-to-date, high-resolution disturbance maps based on Landsat satellite imagery (Healey et al. 2018), as well as maps of climate variables and atmospheric concentrations within a carbon modeling framework. Given limitations of the FIA data, including a lack of temporal sensitivity to recent disturbances, and the use of these additional datasets and modeling tools, there may be some discrepancies between the trends documented in baseline assessments and those in the expanded assessments of carbon (Dugan et al. 2017).

Although periodic larger and more severe fires occurred on Umpqua National Forest since 1990 (e.g., 2002, 2009, 2010), disturbances have been relatively small, affecting less than 1 percent of the forested area annually. Likewise, aside from the widespread and fairly high magnitude (greater than 50 percent change in canopy cover) Biscuit Fire in 2002, which burned 200 000 ha in southwest Oregon, disturbances from 1990 to 2011 on Rogue River-Siskiyou National Forest have affected a small percentage of the forested area (fig. 8.9). More recently, southwest Oregon has experienced particularly

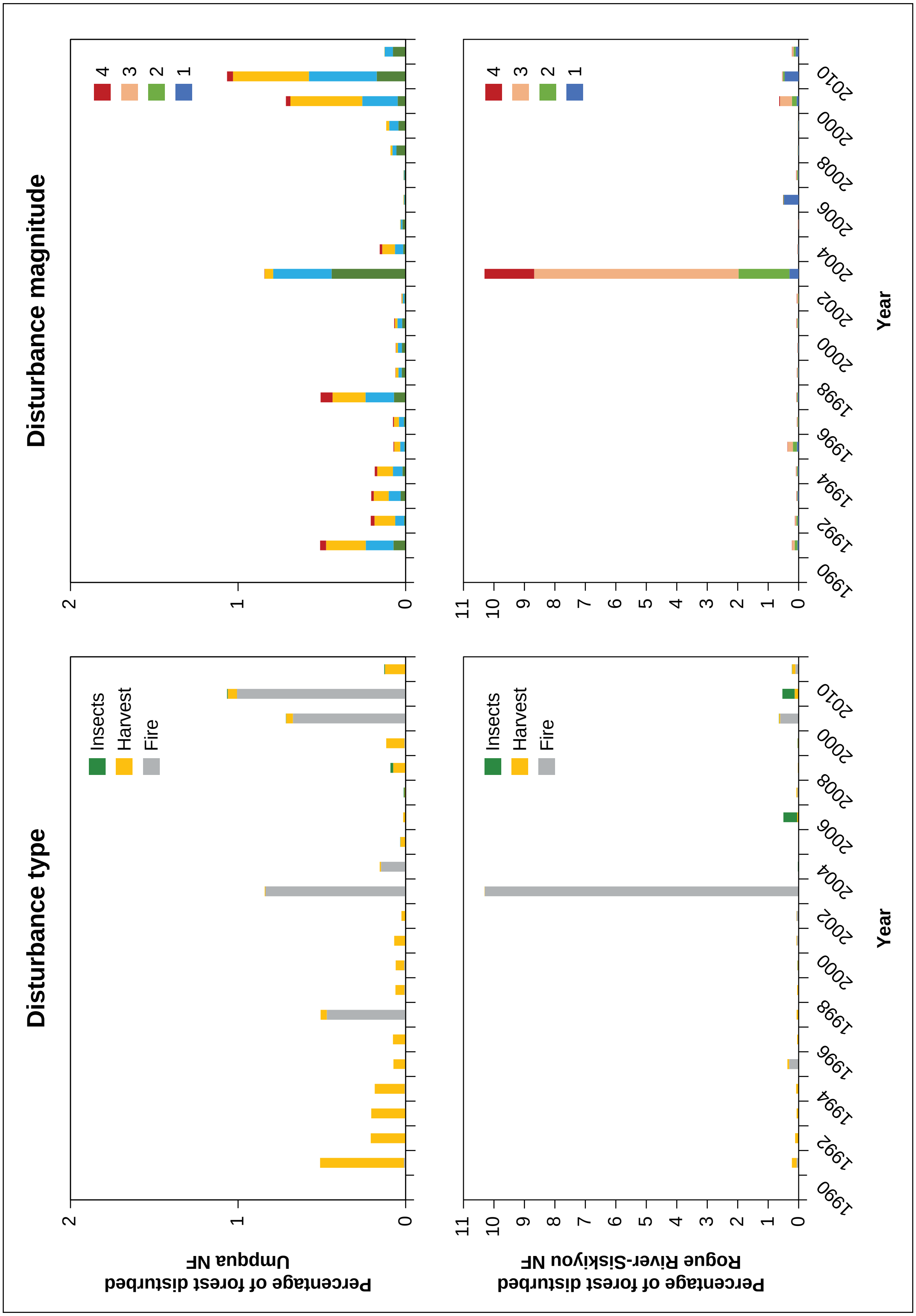

Figure 8.9—Percentage of the forested area disturbed from 1991 to 2011 on the Umpqua and Rogue River-Siskiyou National Forests (NFs) by disturbance types, including fire, harvests, and insects, and magnitude of disturbances, characterized by percentage change in canopy cover, categorized as follows: (1) 0 to 25 percent, (2) 25 to 50 percent, (3) 50 to 75 percent, and (4) 75 to 100 percent.

widespread and intense wildfires. For example, in 2017, the Chetco Bar and Umpqua North Complex fires burned nearly 100 000 ha. Furthermore, future fire projections indicate a significant increase in annual area burned and fire potential in the Western United States owing to a warming climate (Kitzberger et al. 2017, McKenzie et al. 2004).

Although disturbances were quite small in most years, the few large fire years on Umpqua National Forest and Rogue River-Siskiyou National Forest have had a significant effect on carbon trends (fig. 8.10). This is partially because the effect of a disturbance is felt beyond the year it occurs, as a result of a gradual release of fire-killed material, partially offsetting the carbon gained through regrowth. If disturbances had not occurred from 1990 to 2011, nonsoil carbon stocks 2011 would have been 4 percent higher in on Umpqua National Forest and 13 percent higher on Rogue River-Siskiyou National Forest (fig. 8.10). However, if the analysis were extended to include more recent large and severe fires, the lost potential carbon storage would likely exceed 4 and 13 percent, respectively.

In addition to directly altering carbon stocks and emissions in the short term, disturbances also affect forest age structures and long-term carbon trends. For example, stand-age distribution for Umpqua National Forest in 2011 shows that roughly 70 percent of the forest is greater than 100 years old (fig. 8.11a). Although these older forests store more carbon, they generally have lower productivity on account of increased mortality and respiration associated with decaying wood.

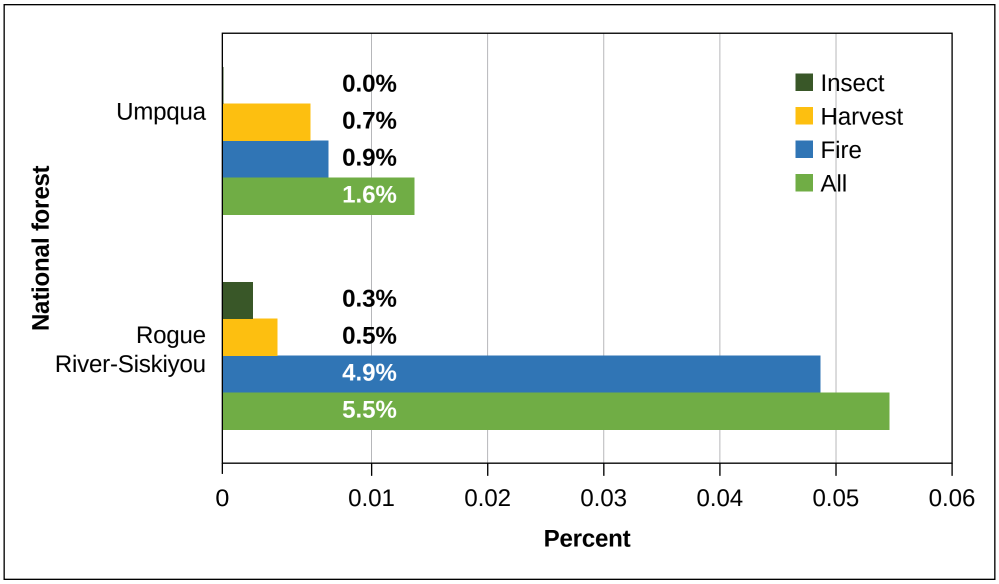

Figure 8.10—The degree to which 2011 carbon storage on each national forest was reduced by disturbances occurring from 1990 to 2011. Results were derived through the ForCaMF system (Healey et al. 2014) and include all nonsoil ecosystem pools. In some cases, disturbances classified as wind may actually be from other storm effects, such as ice damage.

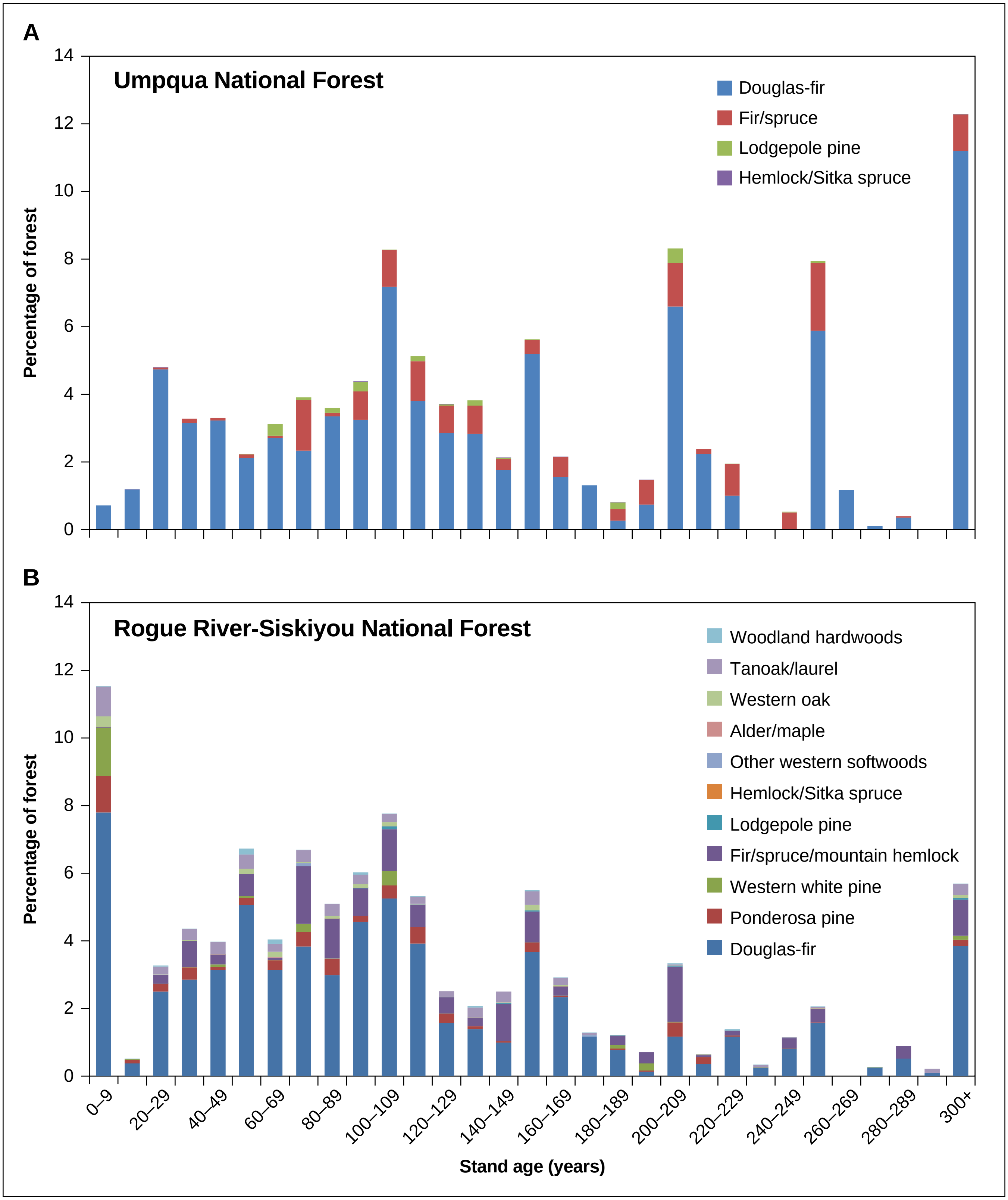

Figure 8.11—Age class distribution in 2011 displaying the percentage of forested area of each forest type in 10-year age classes for (A) Umpqua National Forest and (B) Rogue River-Siskiyou National Forest.

As forests continue to age and their productivity declines, the uptake of CO_2 can slow, suggesting that forest carbon accumulation may decline in the future. However, the 2011 age structure for Rogue River-Siskiyou National Forest has some older forests (40 percent of the forest is greater than 100 years old), but also shows a large peak of recently established stands (greater than 11 percent of the forest), representing regrowth after the 2002 Biscuit Fire (fig. 8.11b).

Although the Biscuit Fire affected a significant portion of the national forest and caused an initial reduction in carbon storage, forests are recovering. The presence of these younger, productive stands suggests that forest carbon stocks may rebound in coming decades if these stands are able to survive. However, the 2017 Chetco Bar Fire burned about 40 000 ha of the Biscuit Fire area. This reduced the area of young regenerating stands, potentially delaying the recovery of carbon stocks.

Disturbances have been the dominant factor affecting forest carbon accumulation over the past few decades, more recently causing declines in carbon storage resulting from large wildfires (fig. 8.10). The decline in carbon stocks may have been partially offset as a result of enhanced growth from CO_2 fertilization and nitrogen deposition (Birdsey et al. 2019). However increasing temperature and decreasing precipitation trends over the past few decades have caused climate to have a negative effect on carbon accumulation; high temperatures increase respiration, and low soil moisture slows growth rates. Projected warming and declines in precipitation may continue to stress forests and cause a decline in carbon sequestration. A warmer climate will also increase the length of the fire season, increasing the frequency and extent of wildfires, which in turn delay carbon uptake and storage, at least temporarily.

BLM Carbon Estimates

Carbon stock information is available for both forested and nonforested areas on the BLM Roseburg and Medford Districts. These estimates include carbon stored in the same pools as described for the Forest Service, plus an estimate of the carbon stored in nonforested areas, such as shrublands. In 2013, the BLM Medford District stored 94 Tg C, and the Roseburg District stored 64 Tg C (BLM 2016). Nonforested areas stored an estimated 0.5 Tg C and 0.1 Tg C on the Medford and Roseburg Districts, respectively. The Medford District stores more carbon than the Roseburg District because it is approximately twise as large. However, carbon density is higher on the Roseburg District (63.1 Mg C ha^{-1}) than on the Medford District (48.6 Mg C ha^{-1}).

BLM Harvested Wood Products

Estimates for BLM harvest levels within the SWOAP assessment area are available for 1962–2016. Harvest levels were highest from the mid-1960s into the late 1970s, removing 450 000 to 665 000 Mg C yr^{-1}, with the exception of 1975, which saw only 277 000 Mg C removed. Harvest levels fluctuated until the late 1980s, when they again reached levels seen in the earlier period (fig. 8.1b). Harvest levels dropped significantly through the 1990s and early 2000s to as low as 16 300 Mg C in 2001. Harvest levels have been climbing slowly since but remain well below the levels seen in the late 1960s and early 1970s.

Climate Change Effects

Recent climate changes have also played a role in forest disturbance regimes and carbon dynamics. The Pacific Northwest has experienced an increase in average annual temperature, and a decrease in total snowfall and proportion of precipitation falling as snow. Large wildfires, occurring over longer durations and longer fire seasons, have increased in the Pacific Northwest, a function of warmer summer temperatures and decreasing summer precipitation (Holden et al. 2018, Littell et al. 2009). Over the past few decades, bark beetle outbreaks have caused tree mortality in parts of the Pacific Northwest (Bentz et al. 2010), which can have a significant effect on carbon sequestration (Kurz et al. 2008).

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 Western United States will be affected by direct physiological effects (e.g., lower productivity in response to lower soil moisture), and indirect climate-mediated effects (e.g., increased disturbances and shifts in species or age composition) (Vose et al. 2012). More detailed carbon stock and flux estimates can inform land management planning at the forest or unit scale.

Pollinator Services

Pollination by animals is essential to the reproduction of many crops and many wild plants (Klein et al 2007). Although pollination services are 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 (Klein et al 2007, Wratten et al 2012). In the United States, honeybee (*Apis mellifera* L.) pollination alone adds more than $15 billion in value annually to agricultural crops (Pollinator Health Task Force 2015). In addition, wild insects can potentially pollinate crops more efficiently than managed

Box 8.2

Excerpts From the 2014 Presidential Memorandum on Pollinators

Section 3A: Federal agencies will enhance pollinator habitat on managed lands and facilities through increased native vegetation (integrated vegetation and pest management) with application of pollinator-friendly best management practices and pollinator-friendly seed mixes.

Section 3B: Federal agencies will evaluate permit and management practices on power line, pipeline, utility, and other rights-of-way and easements, and consistent with applicable law, make necessary and appropriate changes to enhance pollinator habitat on federal lands through the use of integrated vegetation and pest management and pollinator-friendly best management practices, and by supplementing existing agreements and memoranda of understanding with rights-of-way holders, where appropriate, to establish and improve pollinator habitat.

Section 3C: Federal agencies will incorporate pollinator health as a component of all future restoration and reclamation projects as appropriate, including all annual restoration plans.

Section 3F: Federal agencies will establish a reserve of native seed mixes, including pollinator-friendly plants, for use on postfire rehabilitation projects and other restoration activities.

Section 3G: The U.S. Department of Agriculture will substantially increase both the area and forage value of pollinator habitat in the department’s conservation programs, including the Conservation Reserve Program, and provide technical assistance, through collaboration with the land-grant university-based cooperative extension services, to executive departments and agencies; state, local and tribal governments; and other entities and individuals, including farmers and ranchers, in planting the most suitable pollinator-friendly habitats.

Box 8.3

The 2015 National Strategy to Promote the Health of Honeybees and Other Pollinators

From Pollinator Health Task Force (2015)

Goals:

- Reduce honeybee colony losses to economically sustainable levels.
- Increase monarch butterfly numbers to protect the annual migration.
- Restore or enhance 2.8 million ha of land for pollinators over the next 5 years through federal actions and public/private partnerships.

The strategy addresses four themes central to the June 2014 Presidential Memorandum, “Creating a federal strategy to promote the health of honeybees and other pollinators”:

- Conduct research to understand, prevent, and recover from pollinator losses.
- Expand public education programs and outreach.
- Increase and improve pollinator habitat.
- Develop public-private partnerships across all these activities.

Box 8.4

Building Organizational Capacity to Improve Pollinator Habitat

Management of pollinator decline is based on avoiding or reducing the spread of new and existing diseases and pathogens, reducing pesticide use, and improving the resistance and resilience of native plant communities by encouraging or planting a wider variety of regionally appropriate pollinator-friendly plant species. The following action items are encouraged:

- Assign a point of contact for pollinators and native plant materials development in each unit.
- Plant pollinator gardens to raise awareness about pollinator decline for the public, decisionmakers, and resource specialists.
- Interpret and improve best management practices for pollinators.
- Assess pollinator issues of greatest need for different locations.
- Develop revegetation guidelines, including seed mixes by habitat type and seed transfer zones; include this document in updated plans.
- Assess the need for increased seed supply by species.
- Focus seed collection and material development on areas anticipated to have the greatest need.
- Actively engage in outreach and education about pollinator declines and climate change.
- Identify appropriate areas for apiary (honeybee colony) permits.
- Improve and maintain pollinator habitat through appropriate grazing management.

ones (e.g., honeybees), and diverse pollinator assemblages typically provide better pollination services than a single species (Garibaldi et al 2013, Ricketts 2004).

Pollination services also have significant ecological and cultural value. Virtually all of the world’s seeded plants need to be pollinated. Wildflowers, in particular, benefit from pollinators, which help these plant species reproduce and maintain genetic diversity. Culturally, pollinators help sustain native nontimber forest products, such as traditional or first foods and medicinal plants. Spurred by the “critical importance of pollinators to the economy, including to agricultural production and general ecosystem services,” a presidential memorandum on pollinator health was released in 2014, leading to creation of the Pollinator Health Task Force led by the U.S. Environmental Protection Agency and U.S. Forest Service (Pollinator Health Task Force 2015). One goal of this task force was to restore or enhance 2.8 million ha of land for pollinators through federal actions and public-private partnerships. A critical component of pollinator habitat enhancement involves increasing native vegetation through application of pollinator-friendly seed mixes in revegetation, rehabilitation, and restoration of aquatic and terrestrial ecosystems (boxes 8.2 through 8.4).

Climate Change Effects

Human actions and climate-induced stressors, including introduction of nonnative species, inappropriate livestock grazing, altered wildfire regimes, habitat modification, and land use, affect native plant communities and species that depend on them, including both native and managed pollinators. The geographic distribution and extent of contemporary ecosystems are shifting, and novel ecosystems may develop in a warmer climate. These changes result in the loss, degradation, or fragmentation of basic habitat requirements, such as floral resources (nectar, pollen) and other basic needs like nesting sites and materials (GBNPP 2017).

Climate change is expected to affect pollinator populations both directly and indirectly (Vanbergen and Insect Pollinators Initiative 2013). Temperature shifts could alter insect physiology (e.g., altered body size and lifespan) and behavior (e.g., altered foraging behavior) (Scaven and Rafferty 2013). The timing and amount of precipitation will interact with temperature thresholds to potentially alter the structure and function of plant communities and ecosystems. The ability of pollinators to track these changes will have implications for plant-pollinator mutualisms.

Climate change is expected to affect the phenology of some plant species (Miller-Rushing and Primack 2008, Panchen et al. 2012). Potential mismatches in timing of flower and pollinator emergence can potentially affect plant reproduction, especially when either the flowers or pollinators are short lived (Fagan et al. 2014). Specifically, critical nectar resources may become unavailable at key times during pollinator life stages. Pollinators will be most sensitive to altered plant phenology at the beginning and end of their flight seasons.

However, native bees, as opposed to nonnative (and managed) honeybees, may be more capable of shifting their phenology to compensate for warming temperatures, thus 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 and Insect Pollinators Initiative 2013).

Ecological Restoration and Pollinators

Landscapes that retain functionality in a warmer climate will have greater capacity to survive natural disturbances and extreme events. Ecological restoration addresses composition, structure, pattern, and ecological processes in terrestrial and aquatic ecosystems, typically with a focus on long-term sustainability relative to desired social, economic, and ecological conditions. Including pollinators as a consideration in climate change adaptation will assist other restoration goals related to genetic conservation, biological diversity, and production of habitat for endemic species. Increasing the capacity of federal agencies to mitigate current damage to pollinator populations and facilitate improvement of habitat will contribute to both restoration and climate change adaptation (fig. 8.12).

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Figure 8.12—Green metallic sweat bee (*Agapostemon* sp.) rests on a woolly sunflower (*Eriophyllum lanatum* (Pursh) Forbes) (left), and a female rufous hummingbird (*Selasphorus rufus* Gmelin) visits a scarlet gilia (*Ipomopsis aggregata* (Pursh) V.E. Grant) (right).

Strategies for sustaining pollinator habitat in the face of climate change and other stressors include habitat creation, enhancement and restoration of open areas such as meadows and connectivity routes (roadside, right-of-ways, and riparian habitat) using diverse pollinator-friendly seed mixes. There is also a need to incorporate mitigations specific to pollinators in land management projects, such as timing, duration, and scale of activities, as well as application methods and ingredients for herbicide use. The U.S. Forest Service is currently planting native vegetation following wildfire and timber sales to help ensure sufficient habitat for native pollinators. Expanding these efforts to other projects involving ground disturbance would be beneficial.

Partnerships are critical to sustaining pollinator habitat in the region. The Southwest Oregon Pollinator Collaborative, which includes the U.S. Forest Service, BLM, Fish and Wildlife Service, Lomakatsi Restoration Project, Seaburg Institute, Southern Oregon Monarch Advocates, The Nature Conservancy, Natural Resources Conservation Service, and Jackson County Soil and Water Conservation District, is actively engaged in restoration projects. One of its most significant efforts is implementation of a National Fish and Wildlife Foundation grant to restore 121 ha of monarch butterfly (*Danaus plexippus* L.) habitat from the coast to the Cascade Range (fig. 8.13).


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Figure 8.13—Monarch butterfly (*Danaus plexippus* L.) nectaring on showy milkweed (*Asclepias speciosa* Torr.), a host plant for the species.

The Rogue Native Plant Partnership plays an integral role in pollinator habitat restoration. The partnership is focused on developing a large-scale native plant industry in the Rogue Basin that will help meet the needs of pollinator species and restoration efforts. Seed from several species of native flowering plants is being collected by partners and used in a wide range of projects, including outplanting of more than 30,000 containerized native forbs. The U.S. Forest Service and partners have also been planting pollinator gardens on national forests and assisting local communities to create these gardens as part of a larger education and outreach campaign.

Increasing survey efforts for pollinator species and local habitat assessments can better inform management objectives. Through a partnership with the Xerces Society, the Forest Service and BLM have been involved in ongoing surveys for the western bumble bee (*Bombus occidentalis* Greene), Franklin's bumble bee (*B. franklini* Frison), and mardon skipper (*Polites mardon* W.H. Edwards). This helps the agencies track the functionality of pollinator habitats and viability of populations.

Increasing awareness about the critical role that pollinators play in increasing the resilience of forested systems is an important adaptation strategy. Collaborating with partners to spread the word about ecosystem services provided by pollinators on federal and other lands can strengthen support for restoration by diverse stakeholders. Expanding education, survey data, and pollinator-friendly restoration practices will help sustain pollinator habitats in the face of a changing climate.

Cultural Values

Cultural ecosystem services include connections between people and the land that may be intangible, such as spiritual enrichment, heritage, identity, and aesthetic values. Cultural ecosystem services also include practices like harvesting of first foods by American Indian tribes, rituals in sacred places, recreation activities, and sense of place. People and communities can develop connections to specific locations, features, or landscapes. Memories, interactions, and history play a role in the attachment of visitors and residents to the land (Eisenhauer et al. 2000, Kruger and Jakes 2003). The attraction of these 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 landscapes (Hess et al. 2008, Lynn et al. 2011). Disruptions to hydrologic processes, increased vulnerability to insects and disease, shifts in species composition, and changes in pollinator patterns may affect related habitats, products, and cultural uses of forests.

Some human populations may be more deeply affected by climate change than others owing to geographic location, 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 cultural connections with ecosystems and specific plant and animal species, as well as use of resources for subsistence (Cordalis and Suagee 2008, Lynn et al. 2011).

The Cow Creek Band of the Umpqua Tribe of Indians (Cow Creek Tribe) and the Confederated Tribes of Siletz Indians (Siletz Indians) both have rich histories in southwest Oregon. The Cow Creek Tribe historically lived between the Cascade Range and coastal ranges, along the South Umpqua River and Cow Creek. Their mobile way of living covered a domicile that extended north into the Willamette Valley, east toward Crater Lake and the Klamath Marsh area, as far west as the coastal ranges, and south through the Rogue River watershed and into the Siskiyou Mountains. The Siletz Indians comprise many tribes and bands that historically maintained 8 million ha of aboriginal territory in the Rogue and Umpqua valleys, coastal areas, and other parts of southwest Oregon. Modern practices of Siletz Indians continue to maintain a strong relationship with these places and resources.

Historically, the Cow Creek people made use of abundant natural resources, including Columbian black-tailed deer (*Odocoileus hemionus columbianus* Richardson), elk (*Cervus elaphus* L.), summer runs of coho salmon (*Oncorhynchus* *kisutch* Walbaum), and winter runs of steelhead trout (*O. mykiss* Walbaum). Huckleberries (*Vaccinium* spp.) along the Rogue-Umpqua Divide have been a historical resource for the tribe, as are the hunting areas and "medicine trees" near Jackson Creek. South Umpqua Falls and Big Rocks also provided for subsistence fishing. Other resources of cultural importance include red fox (*Vulpes vulpes* L.) and river otter (*Lontra canadensis* Schreber) as sources of food and hides; beaked hazelnut (*Corylus cornuta* ssp. *californica* Marshall) bark, common beargrass (*Xerophyllum tenax* (Pursh) Nutt.), and northern maidenhair fern (*Adiantum pedatum* L.) for basket weaving; and huckleberries, blackberries (*Rubus* spp.), western raspberries (*R. leucodermis* Douglas ex Torr. & A. Gray), tarweed (*Madia* spp.), beaked hazelnut and giant chinquapin (*Chrysolepis chrysophylla* (Douglas ex Hook.) Hjelmq.) nuts, wild onions (*Allium* spp.), wild lettuce (*Lactuca* spp.), acorns, common camas (*Camassia quamash* (Pursh) Greene), and mushrooms. Wild plants that serve medicinal purposes include broom snakeweed (*Gutierrezia sarothae* (Pursh) Britton & Rusby), common mullein (*Verbascum thapsus* L.), and wild ginger (*Asarum caudatum* Lindl.).

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 shift. For example, salmon have spiritual, physical, and economic significance for many Pacific Northwest tribes. Climate change may alter the timing and magnitude of streamflow, increase stream temperatures, and cause higher levels of sediment as a result of disturbance (chapters 3 and 4). 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 common camas, which has culinary significance to the Cow Creek Tribe. Camas bulbs are roasted in an earth oven and eaten fresh or sun-dried and mashed to be stored for winter use. Decreased summer flows and groundwater could reduce camas persistence.

Invasive plants and plant diseases also may threaten the abundance of cultural resources. Swiss needle cast (caused by *Phaeocryptopus gaeumannii* [Rohde] Petrak), sudden oak death (*Phytophthora ramorum* Werres et al.), various fungal diseases, and other direct climate change effects are likely to create additional stress to already threatened cultural resources. Historically, tribal ancestors used burning at appropriate times, seasons, and locations depending on the purpose of the use of fire as a management action. A well-developed overstory hinders the productivity of berry plants as well as flowering and fruiting plants. Furthermore, pollinator viability influences tribal resources, because of the importance of pollinators for vegetation health and resilience.

Increased drought and shifts in plant 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 output as well as access to first-food sites. Hazardous fuel treatments, for example, reduce shading on huckleberries and competition with trees. Interconnected forest and meadow restoration treatments also increase the vigor of camas, (Lynn et al. 2013). These strategies could be applied in the Huckleberry Patch Special Interest Area located on Tiller Ranger District in Umpqua National Forest and Prospect Ranger District in Rogue River-Siskiyou National Forest. This 3843-ha area is managed with tribal consultation to serve and recognize cultural, historical, and traditional values, as well as encourage huckleberry production.

Some culturally important plants may thrive in projected future climate conditions. For example, gray pine (*Pinus sabiniana* Douglas ex Douglas) in the Rogue Valley may be well suited to drier sites. There may be opportunities to manage for gray pine habitat and establish nursery stock for planting.

Climate change adaptation can be informed by tribal connections with the land and experience with harvesting first foods under a variety of conditions. This history forms the basis of traditional ecological knowledge, a cumulative body of experience, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings with one another and their environment (Lynn et al. 2011). Tribes have responded adaptively to past climate stressors, including conducting sustainable harvests during regional reductions in salmon populations and habitat quality (Lynn et al. 2013). This knowledge and resilience to change can inform successful adaptation strategies.

Comparison Among Units

Table 8.2 provides an overview of selected ecosystem services for the SWOAP assessment area. This broad-level summary includes only services that have quantified numerical values. The comparison illustrates the ecosystem service portfolio for each unit, which is influenced by land area, distribution of ecosystem types, and accessibility to human populations. Given the importance of recreation as a cultural value, forest visits are included here. See chapter 7 for more detail about recreation uses and vulnerability.

Table 8.2—Summary of metrics describing selected ecosystem services in the four largest Southwest Oregon Adaptation Partnership units

		Ecosystem service								
				Forest products[c] permits sold						
Unit	**Area**	**Grazing[a]**	**Timber volume[b]**	**Christmas trees**	**Mushrooms**	**Specialty wood/ firewood**	**Other (foliage, cones, berries, etc.)**	**Carbon stock[d]**	**Recreation**	**Water supply**
	Thousand hectares	*AUMs*	*Million board feet sold*	- - - - - -	- - - - - *Number*	- - - - -	- - - - - -	*Metric tons per hectare*	*Thousand visits*	*Million cubic meters*
Rogue River-Siskiyou National Forest	696	14,944	32.5	6,543	1,192	1,094	308	47	1,174	11 551
Umpqua National Forest	399	1,249	34.5	1,807	811	804	377	61	1,239	4 037
BLM Medford District	355	9,197	39.8	1,123	88	419	208	49	984	NA
BLM Roseburg District	172	None	23.9	212	401	309	565	63	988	NA

AUM = animal unit month, BLM = Bureau of Land Management, NA = not available.

[a] From U.S. Forest Service INFRA inventory data for fiscal year 2016; BLM 2016.

[b] For Forest Service, timber volume is 2011–2015 annual average reported in Huber-Stearns et al. (2016); timber volume for BLM is 2016 and 2017 annual average, Wheeler, A. 2018. Personal communication. Oregon State Lead O&C Forester, 1220 SW 3rd Avenue, Portland, OR 97204.

[c] For Forest Service units, forest product permit figures are 2012–1016 annual averages from local Rogue River-Siskiyou National Forest and Umpqua National Forest offices; Medford BLM figure is annual average of 2008–2010 contracts, and Roseburg BLM figure is annual average for 2012–2016 contracts from both local district offices.

[d] For Forest Service units, carbon stocks are for 2013, as reported in USDA FS (2015); BLM estimates are also from 2013, as reported in BLM (2016).

Adapting Ecosystem Services Management to Climate Change in Southwest Oregon

Warming temperatures (chapter 2) and changes in hydrology (chapter 3) are the two primary climate change drivers that will alter ecosystem function and related benefits for people. These changes may affect the timing and availability of timber and nontimber forest products, livestock forage, carbon stocks, and critical habitats. Climate shifts may also affect access to recreation opportunities and vital cultural resources. Adaptation strategies described in previous chapters increase the resilience of forests to stressors and thus the ability of landscapes to provide ecosystem services. Adaptation strategies and tactics in table 8.3 build upon these recommendations.

Table 8.3—Ecosystem services adaptation options for southwest Oregon

Sensitivity to climate change	Adaptation strategy	Adaptation tactic
Shifting precipitation and temperature trends (drought conditions, changes in hydrology) could affect cultural resources.	Apply traditional ecological knowledge to increase resilience.	• For plant-based resources such as huckleberry, camas, oaks, walnut, and mushrooms, adjust timing of actions such as road and trail openings and closures and special-use permits based on resource concerns. • For native fishes such as spring and fall Chinook salmon, coho salmon, summer and winter steelhead, coastal/resident cutthroat trout, rainbow trout, Pacific lamprey, freshwater mussels, crayfish, and endemics, manage special-use permits to honor treaty rights. • For hunting and game, adjust hunting seasons based on changing ungulate movement and migration routes to honor treaty rights.
Shifts in phenology may lead to changes in timing and availability of special forest products, potentially leading to conflicting uses between subsistence, heritage, and commercial uses.	Manage product harvest timing, location, and user types.	• Monitor and adaptively manage products and related vegetation types (e.g., salal, bear grass). Track changes over time to inform permitting for sustainable harvest levels.[a] • Assess shifting use patterns for cross-resource impacts (wildlife, etc.).[a] • Redirect use away from highly vulnerable areas.[a] • Determine impacts from increased access.[a]
Increased wildfire will threaten archaeological and sacred sites.	Encourage pre- and post-disturbance strategies to protect high-value sites and resources.	• Inventory, map, and rate fire risk for archaeological resources and sacred sites.[a] • Develop a plan to address postfire effects on sites that have been exposed.[a]

Pollinator habitat may be diminished by multiple climate change effects (shifts in hydrology, vegetation, disturbance).	Increase agency and public awareness of the importance of native pollinators. Enhance pollinator habitat on federal lands and federal facilities.	• Establish a pollinator coordinator to communicate with district- and forest-level teams, as well as the regional office and the public.[a] • Develop a checklist to consider pollinator services in planning, project analysis, and decisionmaking.[a] • Establish pollinator gardens.[a]
	Enhance pollinator habitat on federal lands and federal facilities.	• Direct federal management units to improve pollinator habitat by increasing native vegetation (via integrated pest management) and by applying pollinator-friendly best management practices.[a] • Establish a reserve of native seed mixes, including pollinator-friendly plants that are adapted, available, affordable, and effective.[a] • Develop revegetation guidelines that incorporate menu-based seed mixes by habitat type (e.g., species that are good for pollinators, sage-grouse, umbrella species) and by empirical or provisional seed zones.[a]
Climate change will lead to shifts in grazing patterns across BLM, Forest Service, state, and private lands.	Develop adaptive grazing strategies and systems to respond to changing conditions and mitigate the effects of fire, invasive species, and drought.	• Enhance flexibility in timing, duration, and intensity of authorized grazing to coincide with range readiness and plant phenology. • Seed with native grasses and forbs to reduce spread of invasive plants and benefit forage as well as pollinator habitat. • Inform selection of seed mix with traditional ecological knowledge and cultural uses. • Use grazing as a tool to achieve desired conditions (e.g., identify strategic fire breaks and apply grazing as a way to control fuels). • Target grazing on noxious weeds to limit competition with natives.[a]
Climate variability and warming will affect water availability for livestock.	Understand ranchers' business approach, lands used, water management practices, and competing demands from other resource areas.	• Identify and monitor where water is limited and potentially vulnerable. • Enhance water storage during the wet season (use tanks, guzzlers). • Implement education programs for managers and the public about climate change effects and sustainable grazing practices (highlight both positive and negative effects).[a]

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[a] Indicates adaptation strategies and tactics from the Climate Change Adaptation Library for the Western United States (http://adaptationpartners.org/library.php) identified as relevant to southwest Oregon by workshop participants.

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Chapter 9: Conclusions

Joanne J. Ho[1]

The Southwest Oregon Adaptation Partnership (SWOAP)—encompassing Rogue River-Siskiyou National Forest, Umpqua National Forest, the Bureau of Land Management (BLM) Medford and Roseburg Districts, and Oregon Caves National Monument and Preserve—contributed to our understanding of climate change vulnerabilities and responses to potential climate change effects in southwest Oregon. The effort synthesized the best available scientific information to assess climate change vulnerability for key resources of concern, develop recommendations for adaptation options, and catalyze a collaboration of land management agencies and stakeholders seeking to address climate change issues. Furthermore, the vulnerability assessment and corresponding adaptation options provided information to support national forests in implementing agency climate change objectives described in the National Roadmap for Responding to Climate Change (USDA FS 2010a) (chapter 1).

Relevance to U.S. Forest Service Climate Change Response Strategies

The SWOAP process is directly relevant to the climate change strategy of the U.S. Department of Agriculture, Forest Service (U.S. Forest Service). Information presented in this report is also relevant for other land management entities and stakeholders in the SWOAP assessment area. This process can be replicated and implemented by any organization, and the adaptation options are applicable beyond Forest Service lands. As in previous assessment and adaptation efforts (e.g., Halofsky and Peterson 2017; Halofsky et al. 2011, 2018a, 2018b, 2019; Raymond et al. 2014), a science-management partnership was critical to the success of the SWOAP. Those interested in following this approach are encouraged to pursue a partnership as the foundation for increasing climate change awareness, assessing vulnerability, and developing adaptation plans.

Communication, Education, and Organizational Capacity

Organizational capacity to address climate change, as outlined in the U.S. Forest Service Climate Change Performance Scorecard (2011–2016) (USDA FS 2010b), required building institutional capacity in management units through information exchange and training for employees. Information sharing and education were built into the SWOAP process through a 2-day workshop. On the first day of the

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workshop, resource managers and scientists presented results of the vulnerability assessment, including the effects of climate change on water resources and infrastructure, fish and aquatic habitat, vegetation, wildlife, recreation, and ecosystem services. On the second day, resource managers and stakeholders developed adaptation options in response to climate sensitivities identified in the assessment. This hands-on approach allowed resource managers to both participate in the process and contribute directly to information and outcomes, thus increasing organizational capacity to address climate change in the future.

Partnerships and Engagement

Relationships developed through the SWOAP process were as important as the products that were developed because these relationships build the partnerships that are the cornerstone for successful agency responses to climate change. We built a partnership across federal agencies, tribes, special interest groups, collaborative groups, and the University of Washington. This partnership will remain relevant for future forest planning efforts and restoration conducted by federal agencies in collaboration with other partners and stakeholders. By working with partners, the capability to respond effectively to climate change increases, especially through the use of an all-lands approach, which was an important context for the assessment.

Climate change response is a relatively new and evolving aspect of land management, and the SWOAP provided an opportunity for participants to effectively communicate their professional experiences with respect to climate change and resource management in a collaborative and supportive environment. The workshop was especially valuable because it covered a broad range of topics, and multidisciplinary group discussions resulted in conceptual breakthroughs across disciplines.

Assessing Vulnerability and Adaptation

Elements 6 and 7 of the U.S. Forest Service Climate Change Performance Scorecard require units to identify the most vulnerable resources, assess the expected effects of climate change on vulnerable resources, and identify management strategies to improve the adaptive capacity of national forest lands. The SWOAP vulnerability assessment described the climate change sensitivity of multiple resources in southwest Oregon. Adaptation options developed for each resource area can be incorporated into resource-specific management plans.

Dialogue among groups of resource managers and scientists identified management practices that are useful for increasing resilience and reducing stressors to various ecosystem components. Although implementing all adaptation options developed in the SWOAP process may not be feasible, resource managers can draw from the menu of options as needed. Some adaptation options can be implemented now, whereas others may require changes in management plans or policies or become more appropriate as climate change effects become more apparent.

Science and Monitoring

Where applicable, chapters in this publication have identified information gaps and uncertainties important to understanding climate change vulnerabilities and management influences on vulnerabilities. These information gaps can help determine where monitoring and research would reduce uncertainties inherent in management decisions. In addition, current monitoring programs (and additional monitoring needs) that provide information for detecting climate change effects were identified for some resources in the vulnerability assessment. Working across multiple jurisdictions and boundaries will allow SWOAP participants to potentially increase collaborative monitoring on climate change effects and effectiveness of adaptation actions. Scientific documentation in the assessment can also be incorporated into large landscape assessments, such as national forest land management plans, environmental analyses for National Environmental Policy Act (NEPA) projects, and specific project design criteria and mitigations.

Implementation

Although challenging, implementation of adaptation options will gradually occur over time, often motivated by extreme weather and large disturbance events, and facilitated by changes in policies, programs, and land management plan revisions. It will be especially important for ongoing restoration programs to incorporate considerations for climate change adaptation to ensure effectiveness. A focus on thoroughly vetted strategies may increase ecosystem function and resilience while minimizing implementation risk. Land management agencies, American Indian tribes, and private landowners working together will make implementation effective, particularly across boundaries.

Toward a Landscape Approach

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 and Peterson 2017; Halofsky et al. 2011, 2018a, 2018b, 2019; 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. Scenario planning may be a useful next step.

Information in this assessment can (1) be incorporated into everyday work through climate-informed thinking, (2) assist in planning, and (3) influence management priorities such as public safety. Flooding, wildfires, and insect outbreaks may all be exacerbated by climate change, thus increasing the frequency and extent of hazards faced by federal employees and the public. Resource management can help minimize these hazards by restoring hydrologic function, reducing fuels, and modifying forest species composition. These management activities are commonplace, demonstrating that, in many cases, current resource management is already preparing for a warmer climate.

Integration Across Resources

Within this report, climate sensitivities are discussed in separate chapters for each resource. In practice, these resources interact with one another in terms of biophysical function and management applications. For example, water is a resource used by vegetation, terrestrial and aquatic wildlife, and people. Vegetation provides habitat for wildlife as well as a scenic landscape for recreationists. Forests provide shade that cools streams for fish habitat. Figure 9.1 illustrates some of the interactions that exist among different resources within a forest. Forests also provide benefits beyond the borders of the forests themselves. Figure 9.2 illustrates the benefits (ecosystem services) that can be transported from public lands or are simply valued outside of those lands.

Looking across adaptation options for each chapter in this report, many of the resource areas share common climate change sensitivities (table 9.1). For example, water, infrastructure, and recreation are sensitive to winter soil saturation that can lead to erosion and landslides. Higher temperatures and earlier snowmelt are ranked highest in affecting the number of resources. Lower summer streamflow, increased disturbances, and change in timing of events are also prominent effects. The compound influences of multiple stressors leading to larger and more frequent disturbances affects many resources. Identifying common concerns across resource areas may provide opportunities to coordinate adaptation efforts, thus improving effectiveness and efficiency.

Although many resource areas are sensitive to similar climate change effects, adaptation options in each chapter are generally designed to protect individual resources. Reorganizing adaptation strategies and tactics by sensitivity may provide insight on opportunities for coordination. For example, table 9.2 shows how two different chapters have arrived at similar adaptation strategies and tactics for the same concern. Similar and complementary tactics have been highlighted to illustrate shared goals across chapters. Recognizing these shared goals can enhance organizational capacity to respond to climate change.

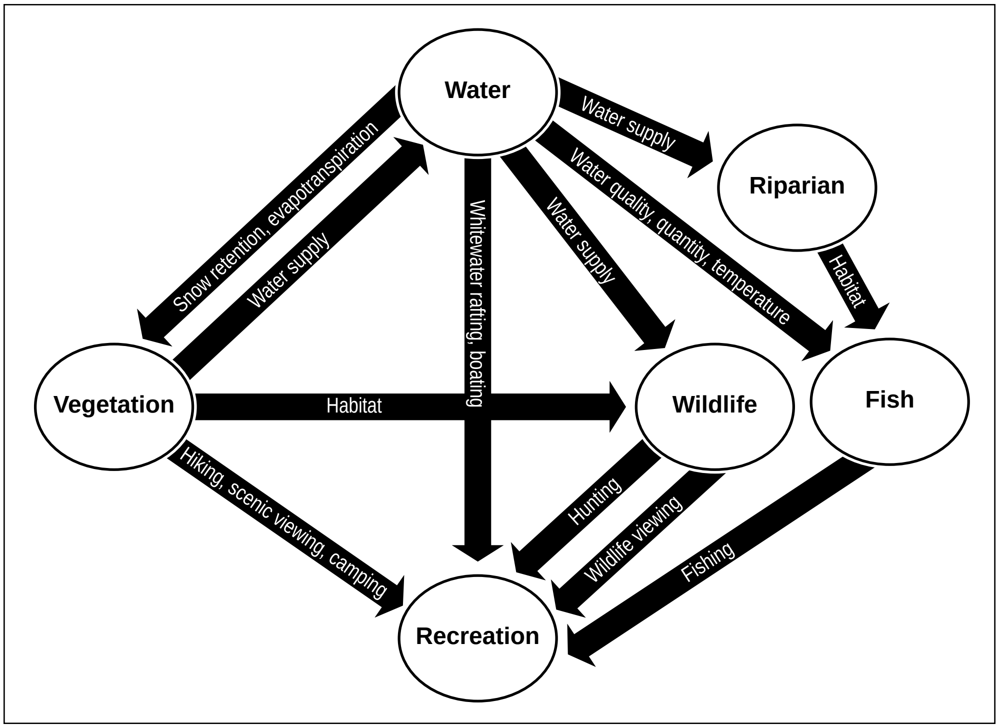

Figure 9.1—Conceptual depiction of interactions among resources.

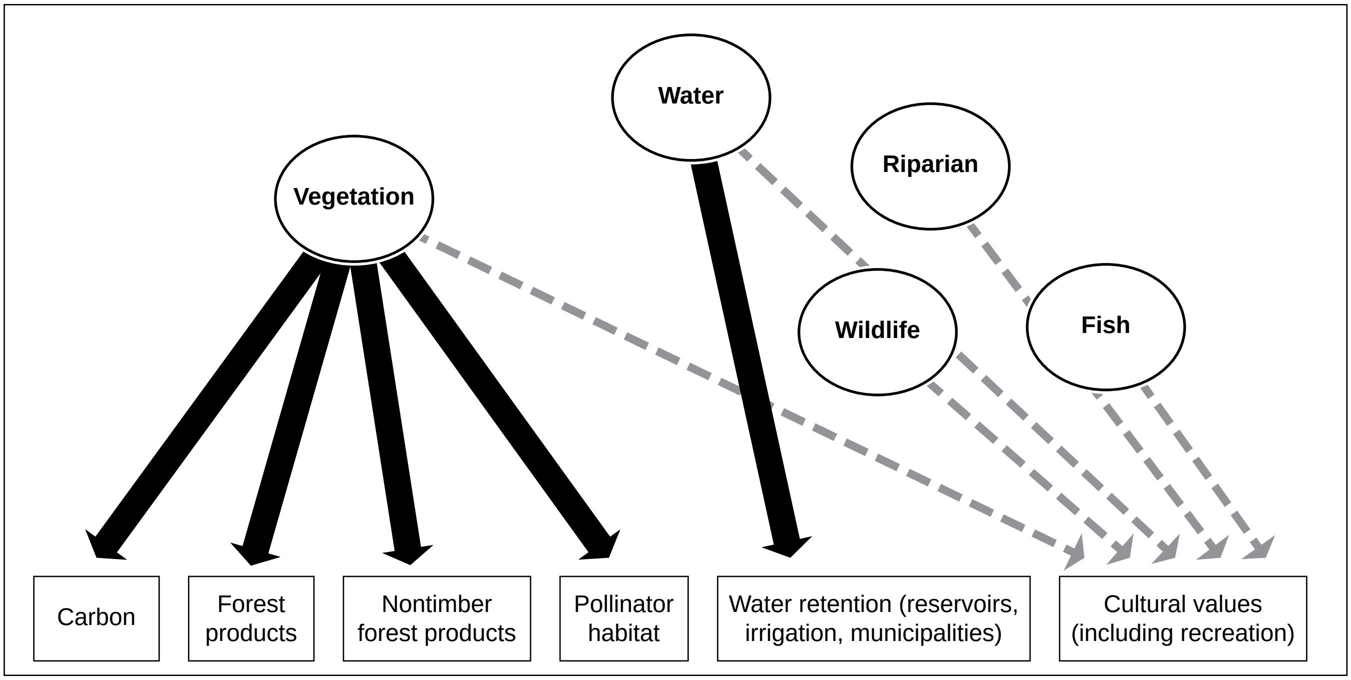

Figure 9.2—Conceptual depiction of ecosystem service benefits beyond the boundaries of a forest. Ecosystem services are listed along the bottom; recreation is considered a subset of cultural activities. Solid arrows represent quantifiable benefits, and dotted arrows represent social values that are not quantifiable.

Table 9.1—Climate change effects identified as high priority by resource area

	Resources affected					
Climate change effect (in descending order of importance)	**Water**	**Fish**	**Vegetation**	**Wildlife**	**Recreation**	**Ecosystem services**
Higher temperatures		✓	✓	✓	✓	✓
Earlier snowmelt	✓		✓	✓	✓	
Lower summer streamflow	✓	✓			✓	
Increased disturbances	✓		✓	✓	✓	✓
Altered timing of disturbances				✓	✓	✓
Increased drought			✓			✓
Altered species composition and distribution		✓		✓		
Altered hydrologic regime	✓					✓
Increased peak streamflow	✓					
Increased invasive species		✓	✓			

Table 9.2—Similar adaptation options identified in the water and infrastructure chapter and recreation chapter for responding to erosion and landslides caused by winter soil saturation

Resource	Water and infrastructure	Recreation
Chapter	3	7
Sensitivity to climate change	Increased winter soil saturation leads to higher risk of landslides, affecting road systems, access, water quantity, water quality, human safety, and maintenance costs.	Increased erosion and landslides will lead to more trail failures and increased risk to public safety. Increased soil saturation will increase the need for trail maintenance.
Adaptation strategy	Increase resilience of existing infrastructure within landslide-prone zones.	Increase resilience of trail systems to saturated soils and erosion. Minimize risks to public safety.
Adaptation tactic	Stabilize slopes with vegetation or by mechanical means.	Increase restoration and erosion control with revegetation projects.
Adaptation tactic	Map landslide-prone areas with LiDAR and use mapping to apply mitigation measures.	Identify, inventory, and monitor vulnerable trails, and include assessment of wildfire risk.
Adaptation tactic	Install early-warning systems to notify visitors of danger.	Manage timing of visitor use relative to hydrologic dynamics.

Operations

Implementation of adaptation actions may be limited by insufficient human resources, insufficient funding, and conflicting priorities. However, climate-influenced effects are already apparent for some resource areas, such as altered hydrologic regimes. Some adaptation options may be precluded and resources may be compromised if actions are not implemented soon. This creates an imperative for timely inclusion of climate change considerations as a component of resource management and agency operations.

The climate change vulnerability assessment and adaptation approach developed by the SWOAP can be used by the U.S. Forest Service and other organizations in many ways. From the perspective of federal land management, this information can contribute to the following aspects of agency operations:

- **Landscape and resource assessments**: The vulnerability assessment provides information on departure from desired conditions and best available science on climate change effects on resources. The adaptation options describe desired conditions and management objectives for inclusion in planning documents.
- **Resource management strategies**: The vulnerability assessment and adaptation options can be used in forest resilience and restoration plans, conservation strategies, fire management plans, infrastructure planning, and state wildlife action plans.
- **Project NEPA analysis**: The vulnerability assessment provides best available science for documentation of resource conditions, climate change effects analysis, and development of alternatives. Adaptation options provide mitigations and project design recommendations for specific locations.
- **Monitoring plans**: The vulnerability assessment can help identify knowledge gaps that can be addressed by monitoring.
- **National forest land management plan revision process**: The vulnerability assessment provides a foundation for understanding key resource vulnerabilities caused by climate change for the assessment phase of forest plan revision. Information from vulnerability assessments can be applied in assessments as required under the U.S. Forest Service 2012 Planning Rule, describe potential climatic conditions and effects on key resources, and 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, and guidelines.
- **Project design/implementation**: The vulnerability assessment and adaptation options provide recommendations for mitigation and project design at specific locations.

We are optimistic that climate change awareness, climate-informed management and planning, and implementation of climate change adaptation options in the SWOAP assessment area will continue to evolve. We anticipate the following within a few years:

- Climate change will become an integral component of federal agency operations.
- The effects of climate change on natural and human systems will be continually assessed.

- Monitoring activities will include indicators to detect the effects of climate change on species and ecosystems.
- Agency planning processes will provide more 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.
- Organizational capacity to manage for climate change will increase within federal agencies and with local stakeholders.
- Resource managers will implement climate-informed practices in long-term planning and management.

This assessment provides a foundation for understanding potential climate change effects and implementing adaptation options that help reduce the negative impacts of climate change and transition resources to a warmer climate. We hope that by building on existing partnerships, the assessment will foster collaboration in climate change adaptation and resource management planning throughout the SWOAP assessment area.

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Appendix A: U.S. Equivalents

When you know:	Multiply by:	To find:
Millimeters (mm)	0.0394	Inches
Meters (m)	3.28	Feet
Meters per second ($m\ s^{-1}$)	2.24	Miles
Kilometers (km)	.621	Miles
Hectares (ha)	2.47	Acres
Square kilometers (km^2)	.386	Square miles
Cubic meters (m^3)	35.3	Cubic feet
Cubic meters per second ($m^3\ s^{-1)}$	35.3	Cubic feet
Kilograms (kg)	2.205	Pounds
Grams per second ($g\ m^{-2)}$	.0352	Ounces
Degrees Celsius (°C)	1.8 °C + 32	Degrees Fahrenheit

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