Climate Change Vulnerability and Adaptation in Coastal Oregon

Editors

Jessica E. Halofsky is the director of the Northwest Climate Hub and Western Wildland Environmental Threat Assessment Center, Pacific Northwest Research Station, 3625 93rd Avenue SW, Olympia, WA 98512; **David L. Peterson** research biological scientist (emeritus), U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 400 N 34th Street, Suite 201, Seattle, WA 98103; **Rebecca A. Gravenmier** (retired) was a science coordinator and regional climate change coordinator, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station and Pacific Northwest Region, 1220 SW 3rd Avenue, Portland, OR 97204.

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Abstract

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The Oregon Coast Adaptation Partnership (OCAP) was developed to identify climate change issues relevant for resource management on federal lands (U.S. Forest Service, Bureau of Land Management) in coastal Oregon. 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 climate, water resources, fisheries, vegetation, wildlife, recreation, and ecosystem services.

The vulnerability assessment shows that the effects of climate change on hydrology in coastal 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 if the frequency of extreme climate events (heat waves, drought) and ecological disturbances (wildfire, insect outbreaks) increases. Roads and other infrastructure will experience major impacts if flooding increases.

The distribution and abundance of coldwater fish species are expected to decrease in response to higher water temperature and to shifts in watershed condition, stream hydrology and function, and estuarine conditions that could degrade aquatic habitat. Effects will vary as a function of local habitat and competition with nonnative fish. Spring Chinook salmon has the highest vulnerability to climate change of all fish species in the assessment area. Highly vulnerable species are western brook lamprey (long residence time in freshwater), Pacific lamprey (long time in the larval stage), green sturgeon (long life and slow growth), eulachon (limited presence in coastal Oregon), coho salmon (cumulative effects throughout its life cycle), and fall Chinook salmon (affected by high stream temperature and summer low-flows). Moderately vulnerable species are winter steelhead (requires cold, connected habitats throughout the year), coastal cutthroat trout (has multiple life-history strategies), and chum salmon (spawning and egg life stages in freshwater, rearing in the estuarine and near-shore environment).

The direct effects of higher temperature, altered precipitation, and increasing carbon dioxide will potentially alter forest mortality, growth, and reproductive processes (seed production, regeneration), all of which may be sensitive to altered phenology and biotic interactions within and among species. 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. The indirect effects of climate change are expected to be expressed through increased frequency and extent of disturbances (drought, wildfire, insects, pathogens), with invasive plant species being an additional stressor. These disturbances may cause rapid ecological changes at broad spatial scales, resulting in more forest area in younger age classes, although the relative importance of different disturbances will differ geographically and among species and seral stages.

Climate change can affect wildlife populations directly and indirectly, with the magnitude of effects across the assessment area differing by habitat type and species. Primary climate sensitivities include regional temperature and precipitation shifts; subsequent effects on vegetation distribution and productivity, phenology, and physiological tolerances for temperature-sensitive species; and the frequency and extent of future disturbances that alter habitat structure and connectivity. These climate change stressors will interact with increasing human-related conflicts such as continued development and habitat fragmentation, introduction of invasive species, and more frequent human-wildlife interactions. Animal species with a narrow range of preferred habitats (e.g., riparian, old forest) will be the most vulnerable to disturbance and large-scale shifts in flora, whereas species that are generalists and tolerate frequent disturbances may experience positive outcomes.

The direct effects of altered temperature and precipitation patterns are likely to affect most outdoor recreation activities and are especially important for warm-weather activities (hiking, camping, etc.), which are expected to increase in a warmer climate. Indirect effects are important for recreation activities and opportunities that depend on ecosystem components such as wildlife, vegetation, and landscapes. Recreation visits to sites with highly valued natural characteristics (e.g., tide pools, coastal dunes) with wildlife species popular for fishing and viewing may decrease if the quality of those characteristics is degraded. Increased flooding near streams and higher wildfire frequency may indirectly reduce recreation participation by restricting access to recreational areas. Recreationists modify their activities according to current conditions, but recreation management has generally not been so flexible.

Climate change and socioeconomic stressors are expected to negatively affect or cause fluctuations in most ecosystem services in the assessment area. Timber supply and carbon sequestration will decrease if the frequency and extent of disturbances increase. The availability of non-timber forest products, including traditional food sources, may become less reliable because of a warmer climate and increasing human demand. Native pollinators may be affected by altered vegetation distribution and phenological mismatches between insects and plants. Water supplies may decrease in quantity, quality, and reliability because of an altered hydrologic cycle and higher demands associated with development and higher human populations.

Resource managers who participated in OCAP 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 aquatic systems, a dominant theme is restoration of the structure and function of streams to retain cold water for fish and other aquatic organisms. In terrestrial systems, a dominant theme of adaptation is management that increases resilience to drought and disturbances by maintaining appropriate stand densities, increasing species and structural diversity, and removing invasive species. Many adaptation options can accomplish multiple outcomes; for example, improving the resilience of hydrologic systems and infrastructure to increased frequency of flooding will provide benefits for coldwater fish habitat as well as recreation activities. 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, coastal Oregon, ecosystem services, fisheries, hydrology, infrastructure, recreation, science-management partnership, terrestrial ecosystems, vegetation, wildlife.

Summary

The Oregon Coast Adaptation Partnership (OCAP) is a science-management partnership consisting of the U.S. Forest Service (Siuslaw National Forest, Oregon Dunes National Recreation Area, Cascade Head Experimental Forest, Pacific Northwest Region, Pacific Northwest Research Station, Northwest Climate Hub), Bureau of Land Management (Northwest Oregon District, Cascade Head Biosphere Reserve), and the University of Washington. These organizations worked together over a period of two years to identify climate change issues relevant to resource management in coastal 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 1.2 to 1.5 °C 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 (RCP 8.5; comparable to current emissions) project that warming will continue throughout the 21st century. Compared to observed historical temperature, average warming is projected to increase 2.0 to 3.9 °C by the end of the 21st century (2070–2099). Precipitation may increase slightly in the winter, although the magnitude is uncertain.

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

Climate

- Changes in regional climate have already been observed within the OCAP assessment area, including a mean annual temperature increase of 1.5 °C since 1895. Annual precipitation has not changed over the past century, but there is some indication of wetter spring conditions in recent decades. With the warming temperatures, days with snow cover decreased by over a month at high-elevation locations in the Coast Range. The assessment area will have a significantly warmer future with a projected mean annual temperature increase of around 4.0 °C for a high greenhouse gas emission scenario (RCP 8.5). This means that temperatures may more closely resemble those currently observed in central to northern California by the mid to late 21st century. Future droughts are likely to occur more frequently and persist longer. Precipitation is expected to increase in the winter and decrease during the growing season, but interannual variability will remain high. These changes will lead to increased growing degree-days but a higher climatic water deficit. Snow will decline throughout the assessment area, including at high elevations. The El Niño Southern Oscillation and Pacific Decadal Oscillation will continue to create climatic variability at annual to decadal scales.

Water and Infrastructure

- Effects: If the timing and intensity of rainfall in the Oregon Coast Range change as expected, low flows in summer will be lower, and peak flows in winter will be higher. Altered low flows will affect water supplies, aquatic habitat, vegetation, and soil moisture. Depending on the amount and duration of the summer marine fog layer, drying and increased fire risk may occur. Higher peak flows may put communities and transportation infrastructure at seasonal risk and may affect municipal infrastructure such as water treatment facilities located at low elevations. Water supplies for human use and for terrestrial and aquatic ecosystems may be more strained in the future. Reservoir storage provides adaptive capacity for water supplies exists, but financial and ecological costs of reservoir construction and operation may impose constraints. Transportation facilities and stream crossings may be challenged by flooding and increased wet-weather traffic, requiring decisions about closure and risk reduction. Local changes in the hydrologic regime will likely lead to more small streams drying earlier or being subject to flooding, with consequences for sediment yields, fisheries, and water quality. At the same time, reduced summer precipitation may facilitate more wildfires while further reducing low flows, potentially contributing to degraded water quality in small streams. The fractured and diverse geology of this area also leads to fine-scale changes in geologic storage of water.

- Adaptation options: Most adaptation options for water resources focus on improving the functionality of existing water bodies and associated infrastructure. A primary adaptation strategy is to increase the resilience of depositional floodplains by increasing the connectivity of streams. Increasing the resilience of transportation systems (roads, bridges, etc.) to peak flows will be critical to accommodate more frequent flooding. Protecting and improving water quality for aquatic and human systems is a near-term need in anticipation of future challenges with both quantity and quality of water. Specific adaptation tactics include reintroduction of American beavers for water retention, increasing shade adjacent to streams to maintain cooler water, upsizing culverts to handle larger volumes of water, and decommissioning roads that are failing or will be subject to repeated damage and erosion in the future.

Fish

- Effects: Rapid shifts in temperature and precipitation regimes may alter the timing of environmental conditions, potentially disconnecting alignment among seasonal habitats to which native fishes are adapted in freshwater streams, rivers, and coastal lakes, or alter transition times in estuary and marine areas. Temperature modeling and downscaled projections to 100-m reaches were used to develop a fine-scale understanding of climate influences on stream habitats. *Winter steelhead* has moderate vulnerability to climate change owing to their presence across watersheds and their requirement for cold, connected habitats throughout all seasons of the year. *Coastal cutthroat trout* has moderate vulnerability because they have multiple life-history strategies, possibly offering flexibility in their response to future conditions. *Pacific lamprey* is considered highly vulnerable owing to the long time they spend in the larval stage in freshwater. *Western brook lamprey* is considered highly vulnerable owing to their long residence time in freshwater. *Green sturgeon* is considered highly vulnerable owing to their long life and slow growth. *Eulachon* is considered highly vulnerable owing to their limited known presence in coastal Oregon and the lack of information about their distribution or life-stage needs. *Coho salmon* is considered highly vulnerable because they face cumulative acute effects during many stages of their life cycle. *Spring Chinook salmon* is considered to have very high vulnerability, similar to other spring runs in the Willamette River and California, and *fall Chinook salmon* has high vulnerability, similar to the Snake River fall run of Chinook salmon. *Chum salmon* is considered moderately vulnerable owing to effects on adult spawning and egg life stages in freshwater, and in the estuarine and near-shore environment for rearing.

- Adaptation options: Most adaptation strategies are focused on increasing or maintaining resilience of fish species and habitat to a warmer climate. Improving and expanding fish habitat while increasing connectivity will improve fish movement across the aquatic landscape. Habitat resilience and access to upstream habitat refugia (summer thermal refugia and winter flow refugia) can be restored by ensuring stream and floodplain structure and processes are intact. Increasing habitat connectivity for fishes using estuaries will allow more habitat while they transition between life stages. Sedimentation associated with erosion, wildfire, and trails needs to be reduced while increasing connectivity to allow fish movement. Specific adaptation tactics include removing barriers to fish passage, reintroducing beavers, restoring stream function, removing tide gates, maintaining access to coastal lakes, and developing natural fire breaks.

Vegetation

- Effects: Projected increases in temperature, soil moisture deficits, and wildfire will affect species composition and structure of vegetation in the Oregon Coast Range and adjacent locations. Additional stressors, including nonnative species, may drive vegetation shifts by competitively excluding native species or altering disturbance regimes. Many special habitats, especially those exposed to sea-level rise (e.g., tidal marshes and estuaries) are particularly vulnerable. Improving and expanding fish habitat while increasing connectivity will improve fish movement across the aquatic landscape. Douglas-fir will likely remain the dominant species throughout the region and potentially shift its range, replacing noble fir at high elevations as well as Sitka spruce in lower-elevation coastal areas. Warmer, drier summers with less fog will likely favor. Western hemlock and western redcedar may become more restricted to locations that buffer projected temperature increases. Moist coniferous forests may transition to warm and subtropical mixed forests that currently do not exist in the assessment area. Dry forests will likely expand in inland areas. Disturbances and interacting stressors will be prominent agents of change in a warmer climate. Insects and disease may decrease productivity as summer drought stress increases with higher temperature and less coastal fog. Although wildfires have been rare and small in recent decades, large stand-replacing fires are possible during dry east-wind events. Non-forest transitions or protracted periods of early-seral development following short-interval reburns will be more likely if drought frequency increases.

- Adaptation options: Adaptation strategies focus on maintaining good forest vigor across different spatial scales and on managing for resilience to disturbances. Managing for high diversity across the landscape will increase adaptive capacity to climate change; this includes species diversity, structural diversity, and genetic diversity (e.g., through assisted migration). Limiting introductions of nonnative invasive species, and preventing establishment and spread, will reduce risks to establishment and growth of native tree species. Reducing fire risk is critical, while considering fire-severity regime, ignition sources, and resources and values at risk. A better understanding of wind events (especially rare east winds) will facilitate improved management of fire, including whether interventions are feasible. Coordination among adjacent jurisdictions (federal agencies, state agencies, tribes, NGOs) will improve the effectiveness of responses to wildfire and other disturbances at large spatial scales. Specific adaptation tactics include using Maximum Stand Density models (including climate, soils, and other factors) to establish and manage for stand densities that support tree vigor. Promoting Firewise practices, home hardening, and defensible space in the wildland-urban interface around communities will reduce structural losses. Early detection and rapid response will efficiently target and remove nonnative species that threaten high-value resources.

Wildlife

- Effects: Sensitivity to climate change was assessed for eight focal habitats:

Mixed conifer forest—
Effects: Significant shifts in species dominance from moist temperate needleleaf forest to a mix of sub-tropical and temperate warm forest similar to the northern California coast. Species affected: Humboldt's flying squirrel, North American porcupine, red tree vole, Roosevelt elk, Anna's hummingbird, marbled murrelet, red-breasted sapsucker, spotted owl, Vaux's swift.

Coastal Sitka spruce forest—
Effects: Expansion of coastal mixed forest and an increase in hardwoods.
Species affected: Humboldt's marten, red tree vole, Marbled murrelet, and many amphibian species.

Oak savanna woodlands—
Effects: Increased woodland area along the Willamette Valley margins.

Species affected: western gray squirrel, acorn woodpecker, California scrub-jay, mountain quail, wild turkey.

Montane forests and meadows—
Effects: More winter flooding, reduced snowpack duration, and drought stress in summer.
Species affected: Humboldt's flying squirrel, Roosevelt elk, gray-crowned rosy finch, rufous hummingbird, snow bunting, and many amphibian species.

Coastal meadows and grasslands—
Effects: More extreme weather events and warmer winters will potentially convert meadows and grasslands to other dominant vegetation, so less area may be covered by meadows and grasslands in the future.
Species affected: Roosevelt elk, rufous hummingbird, several reptile species, Oregon silverspot butterfly, coastal greenish-blue butterfly.

Aquatic and wetland ecosystems—
Effects: Increased temperature and increased frequency, duration, and intensity of drought will alter the timing and volume of runoff (particularly in unregulated basins), decrease groundwater recharge, increase evapotranspiration, and increase water temperatures.
Species affected: American beaver, mountain beaver, bald eagle, purple martin, rufous hummingbird, and many amphibian species.

Marine and estuarine—
Effects: Higher sea level, stronger storm events in winter, and warmer and drier conditions in summer will influence the spatial extent of marine and estuarine habitats, as well as interactions with coastal terrestrial habitats.
Species affected: Bald eagle, black oystercatcher, peregrine falcon, purple martin, red knot, Western snowy plover, northern red-legged frog, Pacific tree frog, hairy-necked tiger beetle, hoary elfin butterfly.

Dune shrub forest—
Higher sea level and warmer and drier conditions in summer will influence the spatial extent and vigor of dune shrub forest.
Species affected: Humboldt's marten, white-footed vole, porcupine, Anna's hummingbird, varied thrush, and several reptile and amphibian species.

- Adaptation options: A region-wide plan is needed to ensure a mosaic of landscape conditions that include refugia, areas managed for diverse and resilient forests and grassland landscapes supported under current climatic conditions, and transition areas where plants and wildlife are allowed to adapt to new ecological conditions. Developing structural and biological complexity in managed forest stands is a critical adaptation strategy. Habitat connectivity will help ensure a mosaic of conditions at multiple scales, including forested corridors for aquatic, terrestrial and arboreal species, passage structures to facilitate safe crossing of major highways, and effects of management activities on individual species. Conservation translocation (including assisted migration) can also be considered where appropriate. Specific adaptation tactics include reintroducing beavers to improve water-holding capacity of aquatic systems, focusing on vegetation composition and wildlife dispersal in edge habitats, protecting old forests while increasing the resilience of younger forests, and developing collaborations with private landowners to promote habitat connectivity.

Recreation

- Effects: Higher temperature, more wildfire, and other climate change effects, combined with changes within the larger region (e.g., inland areas with large population centers), will alter the landscape and seasonality of outdoor recreation in the assessment area. Higher temperatures in the spring and fall will provide favorable conditions for warm-weather recreation (hiking, camping, nature viewing, etc.), which will encourage increased recreation use, potentially creating stress for facilities and management systems. Higher temperatures will also encourage more water-based recreation. More wildfire in both the assessment area and other locations in Oregon and the Pacific Northwest in general will result in closures of recreation sites, fire restrictions, and altered use patterns (e.g., recreationists coming from inland areas where fire and smoke are prevalent). Sea-level rise, higher high-tide lines, shifts in precipitation, and storm surges will make some coastal areas unusable, possibly damaging recreation infrastructure and access roads. Snow-based recreation will be limited by less snowpack, but this is a small portion of activities in the area. Effects of climate change on wildlife activities and forest product gathering are uncertain and may cause minimal disruption.

- Adaptation options: Considering climate-related changes in outdoor recreation supply and demand is critical in planning new recreation infrastructure and proactively managing for expected shifts in recreation. The most important adaptation strategy is to incorporate climate change vulnerability as a component of sustainable recreation planning. From an organizational perspective, increased management flexibility and capacity for managing recreation resources are needed to increase to meet shifting demands. In addition, agencies will need to increase resilience to wildfire through infrastructure modifications and assertive communication with recreationists during fire events. Specific adaptation tactics include considering climate change vulnerability in project designs and strategic investment, managing expectations when notifying the public about sites that become unavailable, coordinating with other recreation providers about which opportunities are offered, and considering the potential for increased summer demand and interactions with other climatic vulnerabilities during recreation planning.

Ecosystem Services

- Effects: A broad range of ecosystem services may be affected by climate change, as described below.

Forest-based ecosystem services: timber, non-timber forest products, and carbon—
Forests in the assessment area are expected to remain productive in the future, although increased frequency of summer drought and wildfire could affect productivity in some locations. Douglas-fir is expected to remain dominant, although some shifts in species composition may occur over time in response to drought, insects, and pathogens. Disturbances will affect timber availability, although local and regional socioeconomic conditions may have greater effects on industries and communities that participate in the timber economy. Climate-driven shifts in vegetation abundance and distribution, as well as increased competition among harvester groups are key vulnerabilities for non-timber forest products (NTFPs). Higher harvest levels can in turn increase risks to some harvested species. The current young age of most forests in the assessment area means that carbon uptake will remain high and carbon storage will increase for the next few decades. If the frequency and extent of wildfire and other disturbances increase later in the century, then carbon storage may level off or decline.

Pollinator services—
Climate change is expected to affect pollinator populations both directly and indirectly. Higher temperatures may alter insect physiology and behavior, as well as seasonal phenology of flowering plants, resulting in potential mismatches in timing of flower and pollinator emergence, thus affecting both plant reproduction and vigor of insect populations. Altered abundance and distribution of vegetation would also affect resources for pollinators, both positively and negatively.

Cultural values—
Climate change effects on ecological processes and plant and animal community structure may affect culturally important natural resources, places, and traditions, including how people and landscapes are connected. Altered hydrologic regimes, increased vulnerability of vegetation to insects and disease, shifts in species composition, and changes in pollinator patterns may affect related habitats, products, and cultural uses of forests. Native Americans may be particularly vulnerable to climate shifts because of cultural connections with ecosystems and specific plant and animal species.

Recreation, fish and wildlife, and water resources—
See the appropriate sections above.

- Adaptation options: Two general strategies are relevant to all ecosystem services: (1) protecting areas that provide key ecosystem services and values, and (2) planning, cross-jurisdictional coordination, and communication in preparation for climate-influenced acute (e.g., extreme events) and chronic (e.g., development, sedimentation in water) stresses. Enhancing pollinator habitat on federal lands and near federal facilities is a priority in most locations. Ensuring equitable access and sustainable supply of NTFPs for resource users while maintaining ecological function may strike a fine balance in a warmer climate. Managing for ecosystem function and resilience is an overarching strategy focused on sustainability. Specific adaptation tactics include (1) supporting a diversity of approaches for managing timber and storing carbon in the long term, (2) identifying and mapping critical areas for culturally sensitive species, (3) developing a checklist that includes pollinator services in planning, project analysis, and decision making, (4) providing education on NTFP ecology, harvest dynamics, stewardship practices, and market dynamics, and (5) communicate more effectively with resource users on federal lands, so they have realistic expectations for access and use.

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Chapter 1: Introduction and Biogeographic, Cultural, and Historical Setting

Alexia Prosperi[1]

Introduction

The Oregon Coast Adaptation Partnership (OCAP) (fig. 1) is a science-management partnership between Siuslaw National Forest, U.S. Forest Service (USFS) Pacific Northwest Region, USFS Pacific Northwest Research Station, U.S. Department of Agriculture (USDA) Northwest Climate Hub, Bureau of Land Management (BLM) Northwest Oregon District, and the University of Washington School of Environmental and Forest Sciences. The OCAP was initiated in 2019 to assess the vulnerability of natural resources and ecosystems to climate change and develop adaptation options that address climate change effects collaboratively. It was developed with the goals of increasing climate change awareness, assessing climate change vulnerability of ecosystems and natural resources, 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/ocap). Developed in response to proactive climate change strategies of the USFS (USDA FS 2008, 2010a,c), and building on previous efforts in national forests (Halofsky and Peterson 2017; Halofsky et al. 2011, 2018a, 2018b, 2019, 2022a, 2022b; Littell et al. 2012; Raymond et al. 2013, 2014; Rice et al. 2012; Swanston et al. 2011, 2016), the partnership brings together resource managers, research scientists, and stakeholders to plan for climate change in coastal Oregon.

The OCAP assessment area is comprised of federal, state, and private land, resulting in a variety of management practices, objectives, and goals. With climate change, the region will experience effects on ecosystems and natural resources that will vary spatially and temporally. Collaboratively developing management actions that can be implemented across landscape boundaries can help address the expected effects of climate change in a manner that will be beneficial for regional ecosystems and natural resources, regardless of ownership.

Biogeography of Coastal Oregon

The OCAP assessment area (2.2 million ha) is located along the coast of Oregon, from the Pacific Coast to the western margins of the Willamette Valley. This area includes the Coast Range and is home to many rivers, streams, and coastal lakes. The major rivers in the assessment area are the Nestucca, Alsea, Siuslaw, Umpqua, Yaquina, and Siletz, all of which drain into the Pacific Ocean. The rivers and streams provide habitat for numerous fish species (chapter 4). Diverse and dynamic estuaries are also found in the region and provide habitat for a variety of species. Headlands, which are coastal areas located above sea level, are also common. The assessment area spans across Coos, Douglas, Lincoln, Benton, Polk, Yamhill, Tillamook, Washington, Columbia, and Clatsop counties. This includes the South Coast, Mid Coast, and North Coast/Lower Columbia basins, in addition to parts of the Willamette and Umpqua basins.

Generally, mild winters and abundant rainfall result in favorable growing conditions and a variety of ecosystems within the OCAP assessment area. Western hemlock (*Tsuga heterophylla* [Raf.] Sarg) and Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) dominate most of the landscape, especially at lower elevations, with the western hemlock vegetation zone accounting for approximately 70 percent of the assessment area. In wet coastal areas where coastal fog is frequent, Sitka spruce (*Picea sitchensis* [Bong.] Carr.) is dominant, although Douglas-fir, western hemlock, and western redcedar (*Thuja plicata* Donn ex. D. Don) also occur. Parts of the region report some of the highest growth rates and greatest volumes per hectare for any temperate forest in the world. The assessment area contains numerous habitats specific to coastal region, such as tidal and coastal estuaries and large expanses of sand dunes. Climate change effects on sea-level rise, severe storm frequency, and air and water temperature may alter disturbance in these habitats, potentially altering their ecological function.

The OCAP assessment area ranges in elevation from just above sea level to over 1,200 meters at its highest point. Geological composition in the region varies based on proximity to the coast. Along the coast, younger deposits of sediment and volcanics are common, whereas the Oregon Coast Range is composed of accreted oceanic sediments and sedimentary rock from 25 to 60 million years ago.

During the Holocene, the OCAP assessment area had differing periods of fire and climate, alternating between frequent wildfire and wet, cool periods with longer periods between fire. This affected species composition and influenced which species currently dominate the landscape (chapter 5). Fire was and continues to be important to landscape dynamics throughout time, although the Coast Range has experienced little fire activity over the past century. Other disturbance, such as native and nonnative pathogens and insects, windstorms, and landslides have affected tree mortality and species composition. Timber harvests started in the late 1800s, influencing subsequent forest age, structure, and dynamics; old-growth forests are currently rare.

There are numerous outdoor recreation opportunities within the OCAP assessment area, from whale watching to snowmobiling (chapter 7). The most popular recreation activities occur during warm weather (hiking, camping, etc.), but the wide variety of recreational opportunities available throughout the year leads to visitation during all months. Recreation contributes heavily to the economy in the assessment area; over $55 million is spent annually on visits to the Siuslaw National Forest alone.

Climate Change Response in the Forest Service

Climate change is an agency-wide priority for the USFS, which has issued direction to administrative units for responding to climate change (USDA FS 2008). In 2010, the USFS provided specific direction to the National Forest System in the form of the National Roadmap for Responding to Climate Change (USDA FS 2010a) and the Performance Scorecard (2011–2016) for Implementing the Forest Service Climate Change Strategy (USDA FS 2010a). The overarching goal of the USFS 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 4 dimensions: (1) increasing organizational capacity; (2) partnerships, engagement, and education; (3) adaptation; and (4) mitigation and sustainable consumption. Progress towards accomplishing elements of the scorecard was reported annually from 2011 to 2016 by each national forest and national grassland; all units were expected to accomplish 7 of 10 criteria by 2015, with at least one “yes” in each dimension. More recently (in 2022), a Climate Action Tracker was implemented to track the progress of climate-based management and planning in the USFS.

The OCAP builds on previous efforts in ecosystem-based management to address climate change in the western United States. Other efforts have also demonstrated the success of science-management partnerships to increase climate change awareness among resource managers within and across jurisdictional boundaries. Developing and maintaining partnerships is a critical first step towards developing collaborative, all-lands approaches to climate change adaptation.

Representatives from federal and state management agencies, research groups, non-governmental organizations, and tribes participate in the assessment development, adaptation workshops, and assessment review. By prioritizing collaboration at the beginning of the assessment process, the OCAP and similar partnerships can provide a consistent, detailed overview of locally relevant climate change information to a large group of managers so assessments can inform adaptation actions. This interdisciplinary approach enables the OCAP assessment area to better prepare for climate change as a whole region, not just on federal lands.

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 OCAP is focused on implementation of the principles and practices discussed in the guidebook.

Oregon Coast Adaptation Partnership Process

The USFS climate change strategy identifies the need to build partnerships and work across jurisdictional boundaries when planning for adaptation. One of the first steps in the OCAP process was to establish an effective, long-term science management partnership between multiple agencies and stakeholders to assess climate change science and its implications for biophysical and social resources. This partnership was developed between the USFS, BLM, and University of Washington.

The OCAP process had multiple objectives. The first was to synthesize the best available scientific information to assess climate change vulnerability and develop adaptation strategies in the Oregon Coast Range to understand and mitigate potentially adverse effects of climate change on natural resources and ecosystem services. 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 influences of climate.

Model output, scientific literature, and expert knowledge were evaluated to assess exposure, sensitivity, and adaptive capacity, and to identify key vulnerabilities for the identified resource areas of concern. The vulnerability assessment focuses on priority resources within the OCAP area, including water resources and infrastructure, fisheries, wildlife, vegetation and disturbance, recreation, and ecosystem services. The vulnerability to climate change was discussed on monthly calls for each of these resources. This provides the scientific foundation for operationalizing climate change in planning, ecological restoration, and project management (Peterson et al. 2011; Raymond et al. 2013, 2014; Swanston et al. 2016).

The second main objective was to develop a framework and tools for resources managers to incorporate the synthesized scientific information into assessments, resource management plans, resource monitoring, project design, National Environmental Policy Act analysis, conservation strategies, restoration plans, and State Wildlife Action Plan updates. This occurred through educating and engaging partners, stakeholders, decision makers, planners, and research scientists, building an enduring partnership to facilitate the application of climate-smart management.

Although partners were involved throughout the OCAP process, a science-management workshop helped to focus dialogue on climate change. During the workshop, the vulnerability assessment was presented for feedback from the group, and adaptation strategies (general approaches) and tactics (on-the-ground actions) for each resource were developed by resource experts. Participants generally focused on adaptation options that could be implemented given the 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. This process identified and prioritized the most significant vulnerabilities to climate change for each resource. Adaptation options are intended to reduce resource vulnerability and correspond to management operation levels at different spatial and temporal scales. The various scales will contribute to planning for climate change on federal, state, and private lands, and across jurisdictional boundaries.

This publication contains a chapter on climate in the Oregon Coast assessment area, and one chapter for each of the resource sectors addressed in the vulnerability assessment: hydrology and infrastructure, fish and aquatic habitat, forest vegetation and disturbance, wildlife habitats, recreation, and ecosystem services. It also contains a chapter on adapting natural resource management to climate change, and a concluding chapter.

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Chapter 2: Historical and Future Climate on the Oregon Coast

James Miller, John B. Kim, Alexia Prosperi, Alex Dye[1]

Regional Climate Overview

The Oregon Coast Adaptation Partnership (OCAP) assessment area extends from the coast to the edge of the Willamette Valley and spans about 4 degrees of latitude from the Klamath Mountains in the south to the Columbia River in the north. About 10 percent of the region is managed by the Siuslaw National Forest, with a similar area managed as state forests, including the Clatsop, Tillamook, and Elliot State Forests. Although much of the region is mountainous, Coast Range elevations are low compared to the near-coastal terrain in California and Washington. Nearly 75 percent of the region is under 400 m elevation, and less than 1 percent rises above 900 m. The highest point is Marys Peak (1249 m), 20 km west-southwest of Corvallis, although Coast Range crest heights are generally between 400 and 700 m above sea level (fig 2.1). The largest population centers are generally along or near the coast and are below 100 m in elevation.

Despite its relatively high latitude, the OCAP assessment area has a mild, maritime climate with a wet winter-dry summer mediterranean precipitation pattern (fig. 2.2B). Over 70 percent of annual precipitation occurs between November and March, with the wettest Coast Range locations receiving 4,000 mm during this five-month period. However, in mid-summer, dry spells can last for weeks at a time, with less than 10 percent of annual precipitation occurring between June and September.

Although the Coast Range is not a high-mountain barrier compared to the Cascade Range, it nevertheless creates a strong climate gradient between the coast and inland valleys by enhancing precipitation on the upwind side (west slopes of the Coast Range) through orographic uplift. The windward slopes (west slopes) of the Coast Range are among the wettest locations in Oregon, with mean annual precipitation totals between 4,000 and 5,000 cm (Taylor and Hannan 1999). Downwind (on the east slopes) of the coastal mountains, near the Willamette Valley, precipitation amounts are considerably lower, with mean annual totals ranging between 100 and 1,500 cm. Precipitation also varies according to latitude, with the highest totals observed in the northern reaches of the assessment area, where the winter rain season starts earlier and ends later than in the south. This is illustrated in fig. 2.1B, which shows that the highest annual precipitation totals in the southern portion of the assessment area are around half of those observed in the northern Coast Range.

Annual precipitation within the OCAP assessment area is among the highest in the Pacific Northwest, but precipitation is generally light to moderate intensity, with heavy rain and thunderstorms relatively uncommon. This is illustrated by comparing precipitation-days and total precipitation for a representative location like Astoria to those located in northern California. Mean November to January precipitation in Astoria is approximately 800 mm, distributed among 65 days with precipitation, whereas Crescent City (northern California coast) receives a similar amount in about 40 days. Climatologically, about half of the annual precipitation in Astoria falls on the wettest 30 days out of the nearly 190 days per year with measurable precipitation (WRCC 2020).

Relatively infrequent, heavy winter rains associated with moisture-rich atmospheric-river episodes can account for 30 to 50 percent of the annual precipitation along the West Coast

(Dettinger et al. 2013, Guan et al. 2010); the majority of heavy precipitation events in the coastal Pacific Northwest from 1950 to 2009 were associated with atmospheric rivers (Warner et al. 2012). Not surprisingly, precipitation totals are strongly tied to the position of the Pacific storm track, which varies on decadal to centennial timescales (Wise and Dannerberg 2017).

Most precipitation in the OCAP assessment area falls as rain due to prevailing mild temperatures. Coastal and lowland snow is generally infrequent and usually melts within a couple of days if it does occur. Snow cover can blanket the highest terrain within the OCAP region for more than four months during some winters (e.g., 1981–82, 1984–85, 1992–93, 1998–99, 2007–08, 2010–11), whereas milder or drier winters (e.g., 1991–92, 2013–14, 2014–15) have little snow cover within the Coast Range.

Winter (December, January, February) mean monthly temperatures range from around freezing at the highest locations in the OCAP assessment area, to 8 °C along the southern coast. Summer mean monthly temperature varies from 14 °C to 20 °C (fig. 2.2). Relatively mild temperatures prevail near the ocean, with low diurnal, daily, and seasonal temperature change. Winter maximum temperatures range from 8 to 10 °C along the north coast to 12 °C at southern coast locations. Winter minimum temperatures average about 3 °C in the north to 5 °C along the southern coast. The mildness of the assessment area can be illustrated by comparing the average winter temperature at Astoria (46 degrees north) to Atlanta, Georgia (34 degrees north). Despite a location 12 degrees poleward of Atlanta, winter mean temperatures in Astoria and Atlanta both average around 6 °C due to the strong moderating influence of the Pacific Ocean on Astoria climate.

Although mean winter minimum temperatures are generally above freezing, subfreezing temperatures occur at many locations during winter, especially higher elevation and inland sites. For example, minimum temperatures drop below 0 °C in coastal locations such as Newport and Lincoln City on about 20 nights per year, whereas nearby Laurel Mountain, located over 1,000 m above sea-level, typically experiences 120 nights below freezing each year (WRCC 2020). Most inland OCAP assessment area locations experience 30 to 90 nights per year below freezing, depending on elevation and local topography. Mean summer maximum and minimum temperature at coastal locations average around 17 °C and 11 °C, respectively, with little latitudinal variation observed.

Orography also affects maritime temperature influence, with the strongest maritime effect along the immediate coastline to the base of the mountains. However, due to low Coast Range elevations, the temperature contrast between windward and lee side locations is less than that created by higher mountain ranges like the Cascades. Thus, inland mean winter temperatures are only 1–3 °C lower than those along the Pacific Coast. In summer, the continental effect is much larger (fig. 2.1C). Mean summer daytime temperature in the coastal town of Reedsport is about 19–20 °C, whereas daytime temperatures in Cottage Grove, just 90 km inland, are typically 5–8 °C warmer. The moderating influence of the Pacific Ocean on temperature is likewise evident in diurnal temperature range. Along the immediate coast, diurnal temperature change varies by about 8 °C during summer, whereas farther inland, day-night temperatures can vary by more than 15 °C.

Frequent cloud cover and fog are a key characteristic of the regional climate, with significant variation found within small distances. From November through March, cloud cover and fog frequency are similar in Astoria and Portland. However, from April to September, Portland averages just 4 days with heavy fog compared to 17 in Astoria. Portland also has more clear sky days during this period. By reducing surface shortwave radiation flux, frequent low clouds along the immediate coast moderate summer temperatures and reduce evaporation.

There is evidence that low cloud cover decreased significantly along the northern California coast during the 20th century (Johnstone and Dawson 2010). Mass et al. (1986) quantified the moderating influence of marine air pushes in the Pacific Northwest, but longer-term trends in regional cloud cover have not been evaluated. Climate change effects along the coast are sensitive to projections of future cloud cover, an issue heightened by the challenge of accurately modeling clouds, especially at finer spatial resolution (see box 2.1 for further discussion on fog). In general, climate change effects are expected to be moderated by coastal proximity in the Pacific Northwest, with bigger effects farther inland (Rupp et al. 2017)

Atmospheric and oceanic conditions in the tropical and extratropical Pacific Ocean play a crucial role in Pacific Northwest weather and climatic variability on time scales from days to decades. Several teleconnection indices, such as the Pacific Decadal Oscillation (PDO), El-Niño Southern Oscillation (ENSO), and Pacific North American (PNA) pattern, are commonly used to evaluate climatic variability and inform seasonal forecasts.

On decadal time scales, the PDO is a distinguishable pattern that relates to the weather of the Pacific Northwest (Newman et al. 2016). Warm phases of the PDO are associated with cooling in the central and western North Pacific and warmer ocean temperatures along the west coast of North America (Mantua et al. 1997, Mantua and Hare 2002, Newman et al. 2016). Warm phases are associated with warmer and drier conditions to the Pacific Northwest, whereas cold phases are characterized by more frequent cold air masses, enhanced precipitation, and higher snow accumulation (Mote et al. 2003). Phase shifts are associated with major changes in global climate, with concomitant ecosystem and societal impacts (Mantua 2002). In particular, the 1976–77 phase shift led to many significant environmental changes across the Pacific Basin (Ebbesmeyer et al. 1991). Global climate model (GCM) projections suggest that future states of the PDO and other climate modes of variability may be less predictable (Li et al. 2020).

The ENSO characterizes the fluctuation between cold and warm ocean temperatures in the central and eastern Pacific. Each phase persists for about 8–15 months with irregular return intervals and occasional neutral periods (McPhaden et al. 1998). Cold phases of ENSO (La-Niña) tend to produce cold and wet conditions in the Pacific Northwest and favor drought in California and the southwestern United States, and warm phases (El-Niño) normally have the opposite pattern (Cayan 1996, Redmond and Koch 1991).

Although the ENSO provides seasonal forecast utility, it explains only a modest fraction of interannual climatic variability in the northwestern United States (e.g., Abatzoglou et al. 2014, Beebee and Manga 2004, Kennedy et al. 2009, McCabe and Dettinger 1999, Miller and Goodrich 2007, Redmond and Koch 1991). For example, Redmond and Koch (1991) observed that the June-to-November Southern Oscillation Index explained less than 10 percent of interannual variability in October-to-March precipitation and temperature along the Oregon coast. Oregon's location near the transition zone of the ENSO north-south dipole pattern reduces ENSO-related seasonal prediction skill (Wise 2010). Nonetheless, streamflow in three major Oregon rivers, including the Wilson River in the OCAP assessment area, is strongly linked to ENSO variability (Redmond and Koch 1991).

The relationship between surface climate variables and ENSO fluctuates over decadal periods, with stronger correlations observed in recent decades compared to the early 20th century (Diaz et al. 2001, McCabe and Dettinger 1999). Moreover, each ENSO phase is unique, with precipitation anomalies differing from expectation, such as the 2015–16 El-Niño, which was exceptionally dry in California and relatively wet in the Pacific Northwest (counter to seasonal outlooks) (Cash and Burls 2019). Chiodi and Harrison (2015) suggested that there is stronger statistical predictability for some ENSO years than others. It is also suggested that ENSO and PDO tend to reinforce one another, with moderated effects when they are out of phase (e.g., Miller and Goodrich 2007, Mote et al. 2003, Praskievicz and Chang 2009, Wang et al. 2015), but such analyses are limited by the few occurrences of distinct PDO phases in the instrumental period. Climate change may modify ENSO effects on global and regional climate variability, although some studies suggest no distinguishable change (Stevenson et al. 2012, Zhou et al. 2014). Overall, there is considerable variability in projected ENSO changes and associated teleconnection relationships (Yeh et al. 2018).

The PNA pattern is another prominent mode of planetary-scale atmospheric variability linked to Pacific Northwest climate (Leathers et al. 1991). Anomalously warm temperatures in the Pacific Northwest nearly always accompany positive PNA phases due to enhanced ridging over western North America (Leathers et al. 1991). However, increased radiational cooling from reduced cloud cover during positive phases can lead to cold nighttime winter temperatures in deep valley locations. The PNA also affects April 1 snowpack and spring and summer streamflow throughout the western United States, with positive phases generally associated with dry conditions across the region (Redmond and Koch 1991). Higher freezing levels leading to a significant reduction in low-elevation snowpack across the western United States have been linked to a greater frequency of positive PNA episodes in the last half century (Abatzoglou 2011). In addition, higher summer wildfire risk in Oregon occurs following positive winter PNA conditions (Trouet et al. 2008). Climate model projections point to amplification of the PNA pattern, particularly in its positive phase (Chen et al. 2018). For the Pacific Northwest, this could potentially lead to drier and warmer winter conditions during positive PNA episodes.

In recent years, ocean temperatures in the northeastern Pacific Ocean garnered widespread general and scientific interest. In late 2013, ocean temperatures 1–4 °C above average developed south of the Gulf of Alaska and persisted into spring 2014, at which time the anomalously warm waters spread eastward towards the coastal Pacific Northwest, expanding along the California coast by 2015 (Kintisch 2016). The area of elevated ocean temperatures became known as “the blob,” causing extensive effects on climate and marine ecosystems (Bond et al. 2015). Throughout the Pacific Northwest, a major “snow drought” (unusually low snowpack) and the hottest summer on record coincided with the anomalous conditions (Cooper et al. 2016, Sproles et al. 2017). Although scientists disagree whether this unusual event was the result of climate change, it may offer a preview of future conditions under climate change (Kintisch 2016).

Recent Climate Trends

To assess regional climate trends and patterns from 1895 to 2019, we analyzed monthly precipitation and temperature data from: (1) 10 U.S. Historical Climate Network (USHCN) stations within or proximate to the region (Menne et al. 2009), and (2) Oregon Climate Division 1 from the National Oceanic and Atmospheric Administration, National Climatic Data Center Climate Division network (Guttman and Quayle 1996, Vose et al. 2014). In addition, snow-water equivalent (SWE) data from Seine Creek (628 m) and Saddle Mountain (948 m) in the snow telemetry (SNOTEL) network (Serreze et al. 1999) were analyzed to assess trends in Coast

Range snow cover. To evaluate regional drought trends, we examined the summer (June–August) Palmer Drought Severity Index (PDSI) from Oregon Climate Division 1.

A Theil-Sen's regression analysis (Sen 1968) suggests that annual mean temperature in the OCAP assessment area increased by 1.2 °C and 1.5 °C in the climate division and USHCN datasets, respectively (fig. 2.3). Because the climate division and USHCN datasets generally indicate the same trends, we selected the USHCN data for most of the climate analysis because it provides more site-specific information for the region. An 11-year moving average filter applied to the USHCN time series revealed two distinct periods of warming, with a roughly 30-year hiatus between the mid-1940s and mid-1970s (fig. 2.3). From approximately 1910 to 1945, the mean annual temperature increased by about 0.4 °C. In the recent warming period that began in the mid to late 1970s, temperatures increased more rapidly, with nearly 1 °C of warming observed. Both temperature datasets indicate that the most recent 10-year period, 2010–2019, was the warmest on record. Overall, the last 20 years were approximately 0.7 °C warmer than the mean temperature from 1900 to 1999.

Although temperature increased at each USHCN station, warming has varied throughout the OCAP assessment area (table 2.1). Mean annual temperature generally increased more in the southern part of the region, with the largest changes observed at Drain (+ 2.2 °C), North Bend (+2.1 °C), Roseburg (+2 °C), and Newport (+1.9 °C). The least amount of warming occurred at Astoria (+0.8 °C) and Tillamook (+0.9 °C). In general, maximum temperature warmed more than minimum temperature, although three locations (Forest Grove, North Bend, and Roseburg) were exceptions.

Asymmetrical maximum and minimum temperature trends have produced changes to global and regional diurnal (day-night) temperature range (DTR) (Davy et al. 2017). Globally, DTR has decreased due to minimum temperature increasing more than maximum temperature (Davy et al. 2017). An increase in regional DTR resulting from decreased cloud coverage was noted by Elliot and Angell (1997), although their study covers a shorter and different period of record (1973–1993) than our USHCN analysis. The climate data for the OCAP assessment area generally indicate increasing regional DTR, though with contrasting trends among the USHCN stations. A greater DTR change was observed in Oregon Climate Division 1, but this is due to a large increase in the early period of record. From 1895 to 1940, DTR in Oregon Climate Division 1 increased by almost 2 °C, but no trend was observed from 1940 to 2019. Although less pronounced, a similar pattern was noted in the USHCN DTR data. Land-use change, station relocations, instrument changes, and local cloud changes affect temperature trend estimates, either amplifying or dampening the regional signal (Hart and Sailor 2009, Quayle et al. 1991). This likely explains the inconsistent DTR trends, from more than a 1 °C decrease in Forest Grove and North Bend to more than a 1 °C increase in Cottage Grove and Drain.

There is also variability in temperature trends by season, with the most warming observed in summer (+1.8 °C), particularly for minimum temperatures (fig. 2.4). This matches results from Abatzoglou et al. (2014) for the broader Pacific Northwest region, although seasonal differences within the assessment area are modest, with less than a 0.5 °C range in total warming. While the average USHCN summer maximum temperature warmed by 1.5 °C since 1895, individual stations vary from no change at Astoria to a 3.4 °C increase at Drain.

Evaluating differences between coastal and inland locations provides clarity to the disparate USHCN station trends. The annual maximum temperature trend is similar for inland and coastal locations. Average maximum temperatures warmed more at inland sites than at coastal locations during summer and fall. However, during winter, the coastal stations observed more daytime warming than inland locations. Annual minimum temperature trends were also similar for coastal and inland locations; evaluated by season, coastal stations had more nighttime warming during winter and spring, whereas inland minimum temperatures increased more during summer. As noted previously, annual DTR increased modestly, but during summer, DTR range decreased by 0.8 °C and 0.4 °C at the coastal and inland stations, respectively. Conversely, in fall and winter, coastal and inland stations each had a 0.6 °C to 0.9 °C increase in DTR. Changes in seasonal cloud coverage may explain some of the observed DTR trends.

Because the SNOTEL data span only the period from 1979 to the present, we also carefully examined temperature changes in the past 40 years to assess more recent temperature trends. The USHCN temperature data show that warm-season (April–September) mean temperatures increased by 0.25 °C per decade since 1980, whereas no statistically significant trend in cold-season (October–March) temperature was observed.

There is concern that climate change will produce longer, more frequent, and more intense heat waves (Wuebbles 2014). Global climate models suggest an increase in heat wave frequency, with inland locations projected to be affected more than humid, maritime locations such as the OCAP assessment area (Brewer and Mass 2016). Although we did not specifically evaluate extreme temperature events within the assessment area, previous research suggests that regional cold spells have moderated more than heat waves have intensified in magnitude (winter temperatures have increased more than summer), which matches climate change projections (Wuebbles 2014). For example, Vose et al. (2017) noted that the coldest day of the year increased by 2.7 °C in the Pacific Northwest, while the warmest day of the year decreased slightly. Extreme overnight temperatures between June and September increased in frequency, but with no change in the frequency of extreme daytime temperatures (Bumbaco et al. 2013). Nevertheless, given the likelihood of drier conditions during summer, even a modest increase in heat waves could be a significant driver of increased fire activity.

There is abundant evidence that climate change is occurring differentially by elevation (Diaz and Eischeid 2007, Pepin and Lundquist 2008, Rangwala et al. 2013). Unfortunately, there is insufficient direct measurement of long-term temperature trends at high-elevation locations within the OCAP assessment area to evaluate possible elevation-dependent trends. High-elevation locations are thought to be warming more than lowland locations, especially during the summer and shoulder (spring and autumn) seasons due to snow-albedo feedback changes (Minder et al. 2018). Overall, climate models suggest elevation-dependent warming will occur, with anticipated snowpack losses lowering surface albedo, resulting in increased shortwave radiation gain (Rangwala et al. 2013). Climate change model simulations suggest this could enhance warming by up to 2 °C (more than baseline climate warming) (Minder et al. 2018).

Assessing contemporary and historical changes in the climate of mountainous regions is complicated by poor spatial coverage of measurements, inconsistent data quality, and short periods of record (Pepin et al. 2015). For example, Oyler et al. (2015) identified a significant warm bias leading to artificially amplified temperature trends in the SNOTEL network, which serves as a primary source of higher elevation climate data within the western United States. The remote automated weather station (RAWS) network provides weather information to assist with fire management across the United States (Zachariassen et al. 2003), but its use in long-term climate studies is limited due to its relatively short period of record and quality control issues. Moreover, stations within the RAWS network are typically located on dry ridgetops and southwest-facing slopes, which may not be representative of other locations. Daly et al. (2009) observed that temperature trends at hilltop/ridgeline locations are strongly correlated with free-atmosphere temperature trends, whereas valley locations are considerably less so. During periods of lower atmospheric pressure, valley and ridge trends tend to be similar. Conversely, during periods of stable, high-pressure conditions, temperature trends are disparate.

Decadal variability in annual precipitation driven by ENSO, PDO, and other sources of natural climatic variability exceeds any longer term trend in the period of record evaluated (1895 to 2019) (fig. 2.5). Although there may have been a minor decrease in annual precipitation, particularly at coastal locations, the trend rests on an observed decrease from the late 1890s through about 1930. There is no trend in annual precipitation over the past 90 years. However, recent years have been dry compared to the 20th century average. Annual precipitation totals during the previous 20 years (1999 to 2019) are roughly 5 to 10 percent below the 20th century average, with more anomalously dry conditions observed at the coast than inland sites. Central coast locations, including Newport and North Bend, received 12 to 15 percent less annual precipitation during the last 20 years compared to the 20th century mean. Three distinct dry periods are evident in the annual precipitation record, two from the previous 30 years (1989 to 2019). The recent trend towards dry conditions is also exemplified by 2013 being the driest calendar year for the 10 USHCN stations. Moreover, fig. 2.5 shows that the wettest years during the last two decades were not particularly wet compared to those in the previous century.

The trend towards slightly lower annual precipitation within the OCAP assessment area in recent decades is more evident in seasonal amounts, although there is no clear indication of a significant seasonal trend since 1895. In recent decades, spring precipitation has been 5 to 10 percent above the 20th century mean (Abatzoglou et al. 2014). Conversely, summer, fall, and winter have had below-average precipitation, with summer the most anomalously dry at just 79 percent of normal 20th century amounts. Notably, Holden et al. (2018) observed that recent (1979 to 2016) increases in wildfire activity were associated with a significant decrease in summer precipitation and rain days across the western United States.

Long-term moisture trends can also be evaluated through drought indices, with advantages and disadvantages for each index (Eslamian et al. 2017, Zargar et al. 2011). We used the Palmer Drought Severity Index (PDSI), a standardized index that utilizes precipitation and temperature data (but not snowpack information) to estimate water availability (Alley 1984). The index ranges from -10 (dry) to 10 (wet), with values less than -3 indicating severe drought. The summer mean PDSI for Oregon Climate Division 1 reveals considerable interannual and interdecadal variability, with no long-term trend towards wetter or drier conditions (fig. 2.6).

The PDSI data indicate that the region's most prolonged and severe drought conditions persisted for almost two decades, overlapping with the period known as the "Dust Bowl" years. However, more severe regional droughts occurred throughout the 14th, 15th, and 16th centuries (Stahle et al. 2007). Two of the four Tillamook Burns occurred in northwest Oregon during the Dust Bowl years, including the largest event in August 1933. The blaze left millions of fire-prone dead trees standing that, combined with continued drought, helped fuel another major wildfire in summer 1939. The two subsequent Tillamook Burns in 1945 and 1951 also occurred during drought conditions. Following the severe drought conditions of the Dust Bowl era, the region experienced about 30 years of alternating moderate pluvial and drought episodes. The wettest period in the past 125 years as measured by the summer PDSI began in the mid-1970s and lasted for approximately 10 years. The 21st century has been anomalously dry across the region due partly to above-average temperatures and increased evapotranspiration. However, Cook et al. (2004) noted that in the context of the past 1200 years, the 20th century was a relatively wet period for western North America. Climate change may increase the probability of more extreme droughts than those observed in the past century (Lehner et al. 2017).

Approximately half of the runoff in the western United States derives from mountain snowpack, which typically peaks on or near April 1 (Li et al. 2017, Mote et al. 2018). Snow course data indicate that April 1 snowpack has decreased by 15–30 percent over much of the western United States since 1950 (Mote et al. 2018). In recent decades, covering the entire SNOTEL era, western United States snowpack (April 1st SWE) has been stable despite a 1 °C increase in average winter temperature (Siler et al. 2018).

Although snow cover in the Coast Range is limited, and the majority of the OCAP assessment area runoff originates from rainfall, the highest terrain can have several months of continuous snow cover. We analyzed snow trends in the OCAP assessment area using maximum SWE accumulation and days with snow cover data, evaluating two stations from the SNOTEL network. Maximum SWE accumulation at the higher location, Saddle Mountain (948 m) averages about 300 mm of snow, and snow depth peaks in mid-February. However, at the lower elevation site, Seine Creek (628 m), average maximum SWE accumulation is only 100 mm, and there is often no snow cover during mid-winter. As shown in fig. 2.7a, there is no statistically significant trend in maximum SWE accumulation at Saddle Mountain. However, maximum SWE accumulation at Seine Creek decreased by about 30 percent in the previous 40 years. The number of days with snow cover at both locations decreased by 10 to 12 days per decade in the same time frame (fig. 2.7b). The trend towards fewer snow cover days is consistent with evidence that snow accumulation is beginning later in autumn, while snowmelt season is occurring one to three weeks earlier across the western United States (Siler et al. 2018, Stewart et al. 2005). Future regional warming is expected to accelerate this trend (Mote et al. 2003, Gergel et al. 2017).

Projected Future Climate

To explore possible future climate in the OCAP assessment area, we utilized the NASA NEX-DCP30 downscaled climate dataset (Nemani et al. 2011), which contains climate projections produced by 30 GCMs from the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al. 2012) for two common climate change scenarios: Representative Concentration Pathway (RCP) 4.5 and 8.5 (van Vuuren et al. 2011). NEX-DCP30 uses a statistical downscaling method called Bias Correction-Spatial Disaggregation (BCSD) to downscale GCM output to 30 arc-second resolution (approximately 800 m) for the conterminous U.S., using Parameter-elevation Regressions on Independent Slopes Model (PRISM) as a reference climate dataset (Thrasher et al. 2013).

In CMIP5, climate models were run under several different greenhouse gas (GHG) concentration scenarios, or Representative Concentration Pathways (RCPs), of which there are four: RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 (van Vuuren et al. 2011). These each represent specific global development and energy futures, with the numbers representing change to Earth's atmosphere in radiative forcing, ending with +2.6, +4.5, +6, and +8.5 $W\ m^{-2}$, respectively, by the year 2100.

RCP 2.6 represents a future in which global GHGs peak by 2020, which would likely limit global warming to 1.5–2 °C above pre-industrial temperatures (Moss et al. 2010). Despite modest reductions in carbon emissions in both the European Union and United States since 2005, global carbon emissions increased by over 20 percent in that time frame due to increases from China and other developing nations (Figueres et al. 2018). Thus, it is unlikely GHG emissions peaked in 2020. RCP 4.5 represents a future in which global GHG emissions peak by 2040, followed by significant reductions, leading to climate stabilization by year 2100. This would result in global warming of 2–2.5 °C above pre-industrial levels (IPCC 2014). RCP 6.0 is also termed a stabilization scenario, with global GHG emissions peaking by 2080 leading to a 3 °C temperature increase above pre-industrial levels. RCP 8.5 represents a future with little mitigation, high population growth, and an increase in coal extraction and burning, leading to increasing GHG emissions throughout the 21st century. By the end of the century, RCP 8.5 would result in atmospheric CO_2 concentrations above 1200 ppm, over four times higher than pre-industrial levels. GCMs suggest that global warming under RCP 8.5 would result in more than a 4 °C increase above pre-industrial conditions. Although there is debate on the plausibility of RCP 8.5 (e.g., Ritchie and Dowlatabadi 2017, Wang et al. 2017), it remains the benchmark that the IPCC and climate research community use to assess climate change scenarios. Therefore, we focus primarily on the RCP 8.5 scenario as a high-emissions benchmark, and the RCP 4.5 scenario as a moderate emissions benchmark.

All of the GCMs under any of the RCP scenarios suggest temperatures will increase during the 21st century, especially in the latter half (fig. 2.8). The projected temperature increase by the year 2100 for the OCAP assessment area differs considerably between RCP 4.5 and RCP 8.5. Although temperature projections under RCP 4.5 initially track closely to RCP 8.5, they diverge after 2050, with significantly more warming under the RCP 8.5 scenario by the end of the century. Mean annual regional temperature is projected to increase by about 3.9 °C under RCP 8.5, whereas GCMs run under RCP 4.5 suggest regional warming of about 2 °C.

In general, the GCMs simulate future seasonal warming that matches observed seasonal patterns over the past 125 years (1895 to 2019). The GCMs consistently show the largest temperature increase during summer, with a median 4.3 °C increase projected by the year 2100 (fig. 2.9). During fall, the projected temperature increase is 4.1 °C. Of the 30 GCMs evaluated, 26 indicate the most warming will occur in summer; four GCMs simulate the largest temperature increase during fall. Projected warming during winter and spring is only slightly less, with projected increases of 3.6 °C and 3.3 °C, respectively. A 4 °C temperature increase at high-elevation locations like the Saddle Mountain SNOTEL site or Marys Peak, the highest point in the Oregon Coast Range, would increase mountain temperatures to levels comparable with current temperatures in lowland areas of the Willamette Valley. The same temperature increases at the warmest OCAP assessment area locations, such as Corvallis, would shift temperatures closer to those currently experienced in Sacramento, California. Such large temperature increases would make days below freezing, which are already relatively infrequent, much rarer. A 4 °C temperature increase would substantially decrease snow in the Coast Range, and the magnitude of heat waves in the assessment area would increase significantly.

Compared with temperature, precipitation projections from GCMs are more uncertain, variable, and smaller in magnitude. Overall, annual precipitation is projected to increase by 2 percent (ensemble mean). GCMs generally project either no change in annual precipitation or a negligible increase; only seven of the evaluated GCMs indicate more than a 5 percent increase. The models generally suggest that winter precipitation will increase 8–10 percent, with 13 models indicating greater than 10 percent increase. However, there are both increases and decreases in precipitation depending on the season. Summer precipitation is projected to decrease by an average of 28 percent, with about a quarter of the models simulating greater than a 40 percent decrease. Only one model shows an increase in summer precipitation. During spring and fall, most models project a small decrease or no change in precipitation. The projected precipitation changes point to an amplified seasonal cycle featuring wetter winters and drier summers.

The GCMs analyzed were evaluated by Rupp et al. (2013) to assess their performance in simulating Pacific Northwest climate. We analyzed whether models ranked higher by Rupp et al. (2013) simulate a different temperature increase for the OCAP assessment area than the lower ranked models. However, the analysis did not reveal any clear patterns (fig. 2.10). Notably, the highest and the lowest temperature increases are indicated by GCMs that performed poorly in the Rupp et al. (2013) analysis. In general, the models do not suggest a large change in annual precipitation, but increased winter precipitation and decreased summer precipitation are a consistent finding.

To examine a range of possible climatic changes within the OCAP assessment area, we selected projections from five GCMs as case studies (fig. 2.11a, b). The case studies cover a variety of future climates, while giving preference to GCMs ranked better in their ability to simulate past climate of the Pacific Northwest (Rupp et al. 2013). All five case-study models (i.e., CESM1(CAM5), BNU-ESM, CanESM2, MIROC-ESM-CHEM, and MRI-CGCM3) project significantly higher temperatures in all seasons (fig. 2.11a).

The CESM1(CAM5) model projects a future climate nearest the mean of the 31 GCMs, with an annual temperature increase of about 4 °C and no statistically significant change in mean annual precipitation. Accordingly, this model is referred to as the “near-mean” model. The BNU-ESM model shows no change in mean annual precipitation, but it projects the greatest increases in future temperature; thus, it is labeled the “hot” model. Interpretation of projections based on BNU-ESM model may require some caution, as the BNU-ESM dataset may contain some inadvertent errors related to snow.[2] The CanESM2 model is the “hot-wet” model with a 7-percent increase in annual precipitation and a 5.3 °C increase in annual temperature. The MIROC-ESM-CHEM model projects a 5 °C temperature increase and a 6 percent decrease in mean annual precipitation, making it the “hot-dry” model. The “cool” case-study model is the MRI-CGCM3 model, with a 2.7 °C increase in annual temperature and a 4 percent decrease in annual precipitation.

All models project that winter precipitation will increase, although projections are variable (fig. 2.11b). Decreased precipitation is anticipated in spring and summer, which would likely increase fire risk. There is no agreement among the models in simulated fall precipitation. There is a clear trend towards amplification of the seasonal precipitation cycle, with increased precipitation during the cooler half of the year.

Although there are significant differences among the models in simulated temperature and precipitation, elevation-dependent changes are less pronounced (fig. 2.12). Each of the five models analyzed showed a similar change in temperature by elevation (fig. 2.12b). Likewise, there were no statistically significant differences in simulated precipitation based on elevation among the five case-study models. Because both PRISM and NEX-DCP30 datasets provide monthly average temperatures, and because we used 0 °C as a threshold for counting months of the growing season, growing season length was 12 months at all elevation bands. The use of daily temperature values and a higher threshold may produce shorter growing season estimates for higher elevation locations.

Growing degree-days (GDD) and wet growing degree-days (WGDD) are projected to increase substantially under the RCP 8.5 scenario (fig. 2.13). GDD is a general index of energy available for plant growth, calculated as the product of the temperature above 0 °C and the number of days (McMaster and Wilhelm 1997). WGDD is an index of energy available for plant growth while there is moisture available. The warmest model simulations indicate the largest increase in GDD. Annually, GDD is projected to increase by 25 to 50 percent, with the largest increase during summer, though in percentage, the largest change in all models occurs in winter. In winter, GDD increases by about 40 percent with the MRI-CGCM3 (“cool” model), whereas the warmest GCMs indicate a doubling of winter GDD. During summer, the GCMs that simulate hotter futures suggest GDD will increase by around 40 percent, with the cool model suggesting increases of half that amount.

Data from all five GCMs suggest increases in annual total WGDD, with projections varying from an 18 percent increase with the “cool” MRI-CGCM3 model, to just over 50 percent with the “hot” BNU-ESM model. Seasonally, the largest absolute and percentage change in WGDD occurs in winter. During summer, projections vary from a 10 to 20 percent decrease in WGDD with the “hot-wet,” “hot-dry,” and “cool” model simulations, to a 40 percent increase with the “hot” and “average” model outputs. Overall, the model output indicates more favorable growing conditions.

Although the RCP 8.5 climate change scenarios suggest more favorable conditions for plant growth by the end of the century with respect to GDD and WGDD, warmer summer temperatures may produce increased drought stress. Therefore, 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 OCAP assessment areas 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. Under RCP 8.5, the models each simulate at least a doubling of the historical (1970–1999) CWD values by the end of the century. In the hottest models, CWD increases almost threefold.

Summary

Major changes in regional climate have already been observed within the OCAP assessment area, including large temperature increases throughout the year. Annual precipitation has not changed markedly over the past century, but there is some indication of wetter spring conditions in recent decades. With the warming temperatures, days with snow cover decreased by over a month at the two SNOTEL locations, although maximum SWE accumulation was stable at the highest elevation site. Overall, the assessment area is projected to have a significantly warmer future with modeled temperatures far outside the range of recent historic conditions. Precipitation is expected to increase in the winter and decrease during the growing season, but interannual variability will remain high. These changes lead to increased GDD and WGDD in general, but a greater CWD. Collectively, these variables suggest that future conditions will be more suitable for vegetative growth overall, but drought stress may limit this growth. If anticipated changes under RCP 8.5 occur, temperatures in the assessment area may more closely resemble those currently observed in central to northern California by the mid to late 21st century.

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Chapter 3: Effects of Climate Change on Hydrology and Sea-Level Rise in Coastal Oregon

Kami Ellingson, Rebecca L. Flitcroft, Paris B. Edwards, Charles H. Luce, Benjamin S. Soderquist

Introduction

Climate change is expected to alter the physical and hydrologic processes of coastal regions of Oregon and the ecosystem processes provided by ecosystems along the Oregon Coast. The projected effects include increased flooding and erosion of low-lying areas, loss or alteration of freshwater wetlands, and altered seasonal salinity patterns caused by more frequent tidal inundation from sea-level rise (SLR) and storm surges (Ruggiero et al. 2013). Riparian and floodplain vegetation and aquatic habitats for fish and wildlife species will likely be modified by altered storm frequency and intensity and associated flooding. In addition, climate change is likely to increase the frequency and duration of drought and alter the amount and timing of precipitation (Holden et al. 2018, Luce et al. 2013, chapter 2). These changes will modify the annual hydrologic regime, causing reduced summer streamflow (Kormos et al. 2016), and increased stream temperatures (Isaak et al. 2012, 2016; Luce et al. 2014) with changes in peak flow events in the fall and winter (Hamlet and Lettenmaier 2007, McCabe et al. 2007, Safeeq et al. 2015). These changes may also affect geomorphic processes (e.g., Goode et al. 2012, 2013), with consequences for aquatic habitats and native fish (Wenger et al. 2011). Finally, changes in the amount and timing of precipitation will affect soil moisture, evapotranspiration, and the distribution and abundance of plant species (Vose et al. 2016a), which will in turn affect water resources (Adams et al. 2012, Vose et al. 2016b).

In this chapter, we describe the projected effects of climate change on hydrologic parameters, including peak streamflow and low streamflow. We also describe projections for SLR and storm surges, and effects on estuaries and shoreline processes along the Oregon Coast. These projections are used to assess vulnerability of water uses and infrastructure to climate change in the Oregon Coast Adaptation Partnership (OCAP) assessment area.

Hydrogeological Setting

The OCAP assessment area encompasses the Oregon Coast Range, spanning 480 km along the Pacific Ocean, defined by a 50- to 65-km-wide swath of moderately high mountains (600–1,070 m). The interplay between climatic processes expressed along topographic and elevational gradients and the underlying structure and hydrologic properties of the terrain determines current streamflow regimes and likely future changes. Many of the hydrologic processes in the assessment area will be affected by altered timing and amount of rainfall, snow, and the marine fog layer. If the period of rainfall is shortened and intensified, flood impacts may be intensified; if the period without rain is lengthened, the vegetation and soils will dry, resulting in increased fire risk and decreased streamflow.

The geologic setting reflects the ongoing collision of the Earth's tectonic plates directly off the coastline and the subduction of the oceanic plates beneath the continent (Ruggiero et al. 2013). Understanding how future climate regimes could change streamflow requires an appreciation of how geology interacts with precipitation patterns to determine the rate and timing of the transformation of water from rain into streamflow, as well as how the tidal signature interacts with streams. SLR will interact with streams in low-lying areas along the Coast Range, typically where roads, cities, recreation sites, and housing exist (Plane et al. 2019).

Geologic Setting

The Oregon Coast Range is composed of accreted oceanic sediments. The oldest rocks, the Siletz River volcanics, are oceanic crust formed during the Paleocene to middle Eocene (60 to 45 million years BP). Deposited synchronously with these volcanics are regionally extensive marine sandstone and siltstone. Commonly referred to as the Tyee formation, this unit is mostly formed by repeated deposition of dense currents of sediment (turbidity currents) derived from uplifted terrestrial sources. Successively younger deposits of sediments and volcanics are found both to the east of the Coast Range and along the coast. Overall, the rocks are gently folded and have a slight westward dip (Kelsey et al. 1994). During the Oligocene (25 million years ago), uplift of sedimentary basins in Oregon resulted in the westward migration of the coastline from as far east as Idaho towards the present position.

Synchronous with uplift, giant fissures in northern Oregon brought lava flows up from the subducting plate. Dikes and sills also intruded into the Eocene and Miocene sedimentary rocks that comprise most of the Coast Range today. These isolated volcanics tend to resist weathering and erosion more than the surrounding sedimentary rocks and constitute some of the prominent peaks in the Coast Range. Different lithologies have variable groundwater storage capacity, thereby affecting groundwater residence time, summer low-flow quantity, and stream temperature. Although most Oregon Coast Range lithology has limited aquifer permeability, volcanic lithology has higher infiltration rates than sedimentary lithologies, affecting water storage and summer low-flow conditions in streams.

Hydrologic setting

Several rivers flow west across the assessment area and empty directly into the Pacific Ocean. These rivers generally flow across sedimentary or volcanic bedrock, with differential groundwater storage associated with lithology (Hale and McDonnell 2016). Coastal fog and low cloud cover are a regular climatological feature of the Coast Range, contributing to the cool water available for discharge to streams in late summer. Fog drip contributes to the water available to become streamflow and reduce plant water demand, and indirectly decreases air temperature and evapotranspiration by reducing solar energy input (box 2.1).

The rain-dominant hydrology, steep topographic relief, and relative dominance of porous volcanic subsurface facilitate rapid infiltration and "flashy" pulses of water inputs and limited freshwater storage in much of the assessment area. Considered together, these factors encourage reduced summer low flows (Luce and Holden 2009, Safeeq et al. 2013) and higher water temperature (Arismendi et al. 2012, Isaak et al. 2012).

Future Streamflow Changes

Simulating Hydrologic Processes

Precipitation in the OCAP assessment area will remain rain dominated as air temperature continues to increase with climate change (chapter 2). Therefore, shifts in precipitation phase (i.e., rain versus snow) are a minor consideration when assessing future hydrologic shifts of the Oregon Coast Range. Despite the insensitivity of precipitation type to warming in the assessment area, watersheds can still experience shifts in the timing and magnitude of seasonal maximum and minimum streamflows driven by increasing temperatures, and changes in altered amount, timing, and intensity of precipitation.

We used the Variable Infiltration Capacity (VIC) model (Liang et al. 1994) to estimate future shifts in maximum (peak) and minimum (low) streamflows across the OCAP assessment area. VIC is a process-based and spatially distributed simulation model that uses physically based algorithms to simulate key hydrologic processes, including snow accumulation and melt, subsurface infiltration, streamflow, and evapotranspiration. Elevation, topography, and vegetation characteristics, meteorological variables, and other parameters are key inputs to the VIC modelling framework. We chose VIC because it is the only hydrological model that considers climate change from which simulation output is readily available for the OCAP assessment area. It has also been used in all other previous climate change vulnerability assessments for national forests in the Pacific Northwest (e.g., Halofsky et al. 2011, Clifton et al. 2017).

The simulation results presented in this chapter follow the approach of Wenger et al. (2010), in which VIC was used to simulate hydrologic processes for individual streams at 1/16th degree resolution under historical conditions (1975–2005) and future scenarios projected through the mid (2040s) and late 21st century (2080s) under the A1B emission scenario (a moderate greenhouse gas emission scenario). For our discussion of projected changes in peak streamflows (highest streamflow of the water year [October 1–September 30]), we also consider results from regression models developed by Safeeq et al. (2015) to estimate changes in streamflow magnitude and flood risk across the assessment area.

Geologic and soil water storage characteristics also influence the discharge of groundwater from a watershed. Therefore, streamflow simulations can be particularly sensitive to the calibration of several of the model parameters that describe stream baseflow and subsurface infiltration rates (Mattheusen et al. 2000). To account for the effects of local geologic and subsurface characteristics on annual peak and low streamflows, we incorporated watershed-scale geology and drainage characteristics into VIC simulations by integrating watershed recession constants (k) calculated following the methods of Safeeq et al. (2013, 2014). Specifically, 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 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.

Coastal stream and watershed hydrology can be further influenced by higher sea levels, shifts in tidal processes, and other changes in the timing or intensity of coastal weather and climatological patterns. As a result of numerous interacting factors, watershed responses to changing climatic conditions remain uncertain and are not yet fully represented by current process-based hydrologic modeling approaches run at broad scales (such as the OCAP assessment area). Given the complexity of coastal hydrology, VIC simulation results presented in this chapter provide only a partial overview of the range of potential changes to streamflow and the responses of coastal and estuarine hydrology to warming temperatures. Despite the limitations inherent with any modeling approach, the VIC model has been successfully calibrated to assess future hydrologic conditions in coastal systems similar to that of the OCAP assessment area (Chegwidden et al. 2019). Findings from these analyses and the results presented in this chapter provide ecologically and socially relevant information that managers can use to make informed decisions in preparation for changes in seasonal water availability, flood regimes, and extreme weather events.

Our discussion of climate change effects on watershed hydrology and simulated streamflows across the OCAP assessment area focuses on watershed recession constants (k), shifts in future watershed sensitivity to shifts in peak flows, and changes in the magnitude of peak flows and summer low flows (where summer low flows for a given year are defined as the period starting from the first day after June 1 when flows fall below mean annual flow rates through September 30). Shifts in these hydrologic conditions are some of the most important to consider when: (1) planning for altered flood regimes, (2) identifying critical infrastructure or ecosystems that are vulnerable to changing streamflows, and (3) implementing watershed management strategies that account for altered water availability and demand (Clifton et al. 2017, 2018).

Watershed Drainage Efficiency and Recession Constants

Groundwater storage and drainage capacities of a watershed are key controls on the timing and magnitude of peak and low streamflows (Safeeq et al. 2013, 2014). Factors controlling watershed drainage, such as watershed topography and geology, can be represented using the watershed recession constant (k), an empirical metric describing the time it takes for water introduced as recharge to become discharge (measured in units of fraction per day). In watersheds with low k values, groundwater is retained for longer periods of time, whereas watersheds with higher k constants have shorter periods of groundwater retention and release water more rapidly as streamflow.

The OCAP assessment area falls under a relatively rapidly draining hydrogeologic regime compared to more interior areas of Oregon, where porous geology and deep groundwater storage result in lower k values and longer recession times (Safeeq et al. 2014). Using the Safeeq et al. (2013) threshold, k values in the OCAP assessment area are frequently the largest in coastal watersheds, often falling into the “high-k” stream class, indicating these watersheds are characterized by shallow subsurface storage capacities and rapidly draining hydrogeologic conditions. In some of the interior watersheds of the assessment area, k values are lower, with some falling below the “low-k” threshold (fig. 3.1), which suggests that these watersheds are increasingly groundwater dominated, characterized by deeper subsurface water storage capacities.

In general, k values for the OCAP area are not particularly variable and fall under a medium range of values compared to those seen in fast-draining surface water-dominated (high k-values) and groundwater-dominated, volcanic landscapes (low k values). Any attenuation effects driven by future shifts in precipitation will likely be modest because large basalt flows that can absorb winter runoff are uncommon in the Oregon Coast Range.

Projected Changes in the Sensitivity and Magnitude of Peak Flows

Following the analysis of Safeeq et al. (2015), peak flow sensitivity is expressed as the ratio of historical and projected flood magnitudes, calculated with a combination of climatic and physiographic variables describing watershed conditions: topographic wetness, forest cover, soil conductivity, drainage area, and the number of rain-on-snow days. When considering changing temperature and precipitation regimes, small increases in the peak flow sensitivity ratio indicate watersheds with low sensitivity to changes in peak flows, whereas large increases in the sensitivity ratio indicate an increased capacity for watersheds to experience shifts in peak streamflows.

For this assessment, changes in peak flow sensitivity were projected through the 2040s and 2080s. Although the precipitation regime of the OCAP assessment area will remain rain dominated through the 21st century, the sensitivity of peak flows is projected to increase for many interior watersheds (fig. 3.2). Increased peak flow sensitivities are also accompanied by increases in the magnitude of average peak flows (Safeeq et al. 2015). Across the assessment area, slight increases in the size of average peak flows are expected during the 21st century (fig. 3.3). In these watersheds, average peak flows projected for the 2080's may increase as much as 24 percent relative to historical conditions (fig. 3.3). The magnitude of those potential changes is lower than would be seen in many snow-dominated systems across the Pacific Northwest that are projected to experience more frequent winter rain-on-snow events and accelerated melt timing with climate change (Nolin and Daly 2006, Wenger et al. 2011). The more subtle increases in peak flows projected for the assessment area, particularly in coastal watersheds (fig. 3.3), are the result of the current rain-dominated precipitation regime combined with fast-draining watersheds with shallow soils that quickly release groundwater following precipitation.

Despite modest streamflow responses to changing climatic conditions relative to other regions in the Pacific Northwest, flooding in the coastal regions of Oregon will continue to be a concern for resource managers (Safeeq et al. 2015). Historically, flooding in the OCAP assessment area has occurred during the fall and winter months when precipitation events are typically the most frequent and intense (chapter 2). In rapidly draining watersheds like those found across the Oregon Coast Range, future flood events can be locally exacerbated by extreme tidal fluctuations and SLR (Cheng et al. 2015). Further, there may be effects on native fish habitat (Goode et al. 2013, Tonina et al. 2008, chapter 4). However, the hydrologic simulations in this analysis consider only changes in streamflow and do not account for additional factors such as tidal fluctuations and higher sea level; future flood risk in tidally affected stream segments (and those just upstream) are underestimated without additional data on projected shifts in tidal surges and sea level.

Projected Changes in Low Flows

As mentioned earlier, snowpack currently plays a minimal role supporting streamflows in the OCAP assessment area. Therefore, the timing, intensity, and amount of incoming precipitation, increased evapotranspiration, and landscape drainage characteristics will influence the magnitude and duration of summer low flows in a warming climate. In recent decades, summer precipitation has decreased in many regions of the western United States (Holden et al. 2018). Declining summer precipitation in the region is a general expectation based on CMIP5 model projections (USGCRP 2017) along with longer periods between summer rainfall events, driven by weaker summer circulation (e.g., Coumou 2018). Continued decreases in the amount and timing of summer precipitation may further decrease seasonal low flows in areas where streamflow regimes are not controlled by melting snowpacks (Chang et al. 2012).

Across most of the OCAP assessment area, average VIC-simulated summer streamflows are projected to decrease during the 21st century, with flows in some watersheds in the southern and northern assessment area declining 20–28 percent from historical conditions by the 2080s (fig. 3.4). Because watershed drainage is relatively efficient and not supported by water stored in seasonal snowpack, future reductions in average summer streamflows are modest for most of the assessment area compared to those projected for other parts of the Pacific Northwest (e.g., the Cascade and Olympic mountain ranges) where streamflows are largely controlled by the amount of snow-water storage and timing of snowmelt, both of which are sensitive to increasing temperatures (Safeeq et al. 2014). However, increased duration of low-flow events may stress native fishes that require cool water in deeper pools to survive summer conditions (chapter 4).

Projecting Hydrologic Changes in Rain-Dominated Coastal Systems

The effects of climate change on hydrologic and streamflow processes in coastal areas of the Pacific Northwest remain understudied relative to the snow-dominated systems of the Cascade Range and Intermountain West (Burke and Ficklin 2017). Although the Oregon Coast Range will maintain a rain-dominated precipitation regime, interactions between freshwater and marine environments make it difficult to project hydrologic shifts in coastal watersheds. The VIC simulations in this chapter are derived from a well-established hydrologic modeling approach based on physical processes and relationships. Nevertheless, the results are not able to fully address the complex processes linking freshwater and marine hydrological systems, such as SLR, tidal fluctuations, and changing oceanic weather patterns.

Despite knowledge gaps and the heterogeneous coastal conditions found across the Oregon Coast Range, the VIC results agree with other studies that have analyzed the effects of warming temperatures and shifting precipitation regimes on streamflows in Pacific Coast watersheds. Burke and Ficklin (2017) analyzed shifts in streamflow timing and magnitude in five coastal watersheds spanning the Pacific coast of the United States, including the Siletz River watershed south of Lincoln City, Oregon (fig. 3.3). Using a different hydrological model, they concluded that streamflows will increase 18 percent during winter (peak streamflow season) by the late 21st century; this is similar to but slightly higher than projections in figure 3.3. Chegwidden et al. (2019) found widespread model agreement that winter streamflows will increase across coastal regions of the Pacific Northwest, although the largest changes are attributed to decreased snow-water equivalent, which is not important for the OCAP assessment area. As described above, there will also likely be decreases in summer low flows in the region, although these decreases will likely be smaller in magnitude compared to other parts of the Pacific Northwest that are more affected by snowpack loss.

Climate Influences on Tides and Near-Shore Areas

Estuaries are the point of intersection between inland watersheds and the sea. Ten estuaries draining from the Oregon Coast Range into the Pacific Ocean are included in the OCAP assessment area (fig. 3.5). In this area, estuaries and the lower floodplains of their rivers are often a nexus for human infrastructure and community development (Flitcroft and Giannico 2013, OCMP 2017). These areas also provide habitat for commercially and culturally important marine, freshwater, and anadromous fish, and shellfish species (i.e., O'Higgins et al. 2010). Sediment supplied from headwater areas in the Oregon Coast Range is delivered to coastal estuaries and wetlands, allowing these systems to expand or contract in vertical and horizontal directions (Peck et al. 2020) in response to changes in marine sea-level or precipitation regimes (Ruggiero et al. 2013).

Decadal-scale climate patterns associated with the OCAP assessment area (described in chapter 2) demonstrate strong linkages between marine conditions and patterns of precipitation. Precipitation patterns are predictable in the area, with most rain currently falling in the winter months. This predictability is important for adaptations in life histories of native fishes (chapter 4), and in management of water supplies for coastal communities (see below). River discharge intersects with tidal height in estuarine areas to determine the amount of inundation of adjacent wetlands and lowland areas (Huang et al. 2011). Changes in precipitation amount or delivery will affect river discharge, altering the interaction between tidal height and lowland inundation. In addition, storms surges can contribute additional marine water to estuary and coastal systems, particularly when storms coincide with high-tide events (Allan et al. 2011).

Tectonic activity results in uplift at varying rates along a latitudinal gradient in the OCAP assessment area. The active Cascadia subduction zone (Hyndman and Wang 1993, 1995) exists offshore, resulting in predictable and intense earthquakes and accompanying tsunamis (Kelsey et al. 2005). The most significant events have occurred once every 500 years, but the time between events varies (Kelsey et al. 2005). The last significant earthquake and tsunami occurred off the Oregon Coast around 1700 (NRC 2012). Between events, vertical land-surface adjustment continues to occur. In the OCAP assessment area, land surface is rising at a rate of approximately 2.3 mm per year at Coos Bay, Oregon and 1.7 mm per year at Pacific City, Oregon (NRC 2012 with CAS3D-2 model data rates from He et al. 2003; Wang 2007). This increase in land-surface elevation may provide a buffer against some of the projected increases in sea level for this area.

In the OCAP assessment area, climate change projections include: (1) landward vegetation migration zones influenced by sea-level height, (2) tidal inundation that combines changes in precipitation patterns, resulting in more intense storm events with sea-level height, and (3) modifications in sand deposition and coastal erosion. These anticipated changes will likely intersect, with consequences for coastal communities and the habitats of native aquatic and terrestrial species. In this section, we focus on projected changes in sea level and flooding associated with intense storms and tides. We also review projected modifications in wave power that may affect patterns of erosion and deposition of coastal cliffs, bluffs, and beaches.

Changes in Sea Level and Estuaries

Projections of sea level are driven by changes in the thermal mass of the ocean from global heating, and changes in ice and land dynamics in polar regions (NRC 2012). Warmer water takes up more space, resulting in expansion of the existing volume of marine waters. Melting of continental glaciers in polar regions will result in more water in marine environments and will lead to glacial isostatic adjustment; land masses currently covered by glaciers will uplift as the weight of the glaciers are removed. Existing glaciers have massive density that exerts gravitational force on adjacent marine waters, drawing sea water towards them. As glaciers retreat, reduced gravitational forces from mainland areas will likely result in the lowering of sea level in areas of the far northern and southern latitudes (NRC 2012).

Uncertainty regarding the amount and rate of glacial melting, ocean thermal conditions, and changes in land elevation combine to make projections of future sea level challenging. This uncertainty is often addressed with different potential scenarios of future SLR that can be used for planning and management. Comprehensive estimates of SLR and the mechanisms that drive those changes were developed for coastal Washington, Oregon, and Northern California (NRC 2012). These projections include estimates and variance reflecting the uncertainty associated with SLR projections for different scenarios on short- and long-term time steps.

Areas of vulnerability to SLR for estuary and lowland wetlands have also been identified within the OCAP assessment area. Scenarios presented here were developed by Brophy and Ewald (2017) and represent comprehensive projections of specific SLR effects on coastal wetlands in the assessment area to date. The projections focus on identifying “landward migration zones” (LMZs) for salt-water tolerant wetland plant species.

The LMZs identified by Brophy and Ewald (2017) inform areas of projected vegetation migration in response to higher sea level. Vegetation is highly responsive to inundation and salt water accumulation (e.g., Buffington et al. 2020). As sea level rises, the amount of time upslope areas are inundated increases. For areas currently inundated, this may result in changes from existing wetland to mudflat (Brophy and Ewald 2017). Areas not currently part of the areas of tidal inundation would experience increased water and salt exposure. Such exposure will convert existing non-tidal areas into tidal wetland communities that can survive exposure to water and salt.

Brophy and Ewald (2017) modeled six scenarios of SLR. They used Lidar imagery to capture coastal elevation and mapped different elevation heights onto this base dataset. Although Lidar imagery in coastal Oregon can be problematic due to its collection regardless of tidal height (Flitcroft et al. 2018, Santelmann et al. 2019), it still provides the most accurate base elevation dataset. We display and summarize the Brophy and Ewald (2017) projections of sea level at the current elevation (0.0 m) and at three additional elevations of 0.48 m, 1.42 m, and 2.50 m. These three elevations are similar to other regional projections of potential SLR for the OCAP assessment area (i.e., NRC 2012). However, in Brophy and Ewald (2017), no assumptions of time were made for when projected sea-level elevations might be realized.

The Brophy and Ewald (2017) maps of current and future sea-level elevation indicate varying amounts of vegetation change among coastal estuaries in the OCAP assessment area (fig. 3.6). Seven of the ten estuaries in the OCAP assessment area are projected to see initial increases in LMZ area with modest rises in sea level (0.48-m SLR scenario), including Alsea Bay, Nestucca Bay, Salmon River, Sand Lake, Siletz Bay, Tillamook Bay, and the Umpqua River (tables 3.1, 3.2). For example, at Alsea Bay, LMZ area increases initially from an area of 380 hectares to 425 hectares (at 0.48 m SLR), but then drops to 274 hectares (at 1.42 m SLR) and 134 hectares (at 2.50 m SLR). Increases in LMZ area under the 1.42-m SLR scenario are projected to occur only at Salmon River and Siletz Bay (tables 3.1, 3.2). Decreases in LMZ are projected for all estuaries under the 2.50m SLR scenario (tables 3.1, 3.2).

Inundation from Storm Surges

Inundation of estuary and lowland areas due to SLR may be increased by river discharge associated with intense storm events (Huang et al. 2011). In the OCAP assessment area, the amount of future precipitation is projected to remain similar to current conditions. Rather than the lower intensity storm events that have historically occurred throughout the wet season (late autumn through spring), intense but less frequent storm events are expected to occur (NRC 2012). The high-gradient Oregon Coast Range is composed primarily of volcanic and sedimentary rocks with limited water storage capacity, making runoff rapid and river discharge highly responsive to precipitation events (see above).

The combination of SLR and discharge from intense storm events may increase coastal flooding beyond that described by the LMZ projections discussed above. In 2017, the Oregon Coastal Management Program (OCMP), working in collaboration with the U.S. National Oceanic and Atmospheric Administration (NOAA) Coastal Management Program, developed tidal inundation maps and analysis that combined projected future SLR with river hydrology estimates (OCMP 2017). They identified coastal infrastructure that may be at risk from flood events that combine SLR and river flow events. We present the year 2030 and year 2100 scenarios of SLR and river flow from this comprehensive assessment to describe estuary and lowland conditions in the assessment area in the future.

In the OCMP (2017) work, the year 2030 and year 2100 estimates of tidal water surface are meant to capture short-term and longer-term projections of tidal inundation. SLR estimates included the upper end of projections for 2030 and 2100 (NRC 2012). These projections of 22.86 cm and 142.24 cm, respectively, were then combined with modeled water levels taken from the NOAA extreme water-level dataset from several tide measurement stations on the Oregon Coast. Water surface models (developed using NOAA's VDatum tool http://vdatum.noaa.gov) and land-surface elevation information (from Lidar elevation measurements) allowed for the determination of frequency and height of surface-water events. Although variability in these tools has been documented (Flitcroft et al. 2018), they are the most comprehensive and consistent data sources available for the Oregon Coast. We used OCMP (2017) scenarios of tidal flood-event heights with a 50 percent chance of occurrence in the maps projecting future tidal water surface for the 10 estuaries in the OCAP assessment area. Such an event would be expected to occur at least once every two years. Modeled flood height varied by estuary (table 3.3).

Maps of tidal water surface for each OCAP estuary that combined SLR estimates for 2030 and 2100 and a flood event with a 50 percent chance of occurrence indicate patterns of inundation similar to the LMZ work discussed above (fig. 3.6). Differences in area of tidal inundation vary between 2030 and 2100 among estuaries, with the most expected in Coos Bay and the least in Salmon River (table 3.4). In terms of percent differences in area of tidal water surface, the largest increase in inundation as a percent of 2030 area is expected in Nestucca River estuary and the lowest percent at Alsea Bay estuary (table 3.4).

Vulnerability Assessment for Water Uses

National Forest Contributions to Water Resources

Siuslaw National Forest lands provide a critical source of municipal water supply in the OCAP assessment area and play a key role in mediating the quality and quantity of surface and groundwater resources. According to data from the USFS National Forest Contributions to Streamflow dataset (Luce et al. 2017), Siuslaw National Forest lands provide 50–100 percent of total mean annual flow to half (772) of the 1,559 rivers and streams within national forest boundaries (Luce et al. 2017). The rivers receiving the largest contributions to mean annual flow include the Alsea (10.4 billion m^3), Siuslaw (8.1 billion m^3), and Siltcoos Rivers (141 million m^3), which are valuable sources of drinking water, recreation, and fish habitat.

Data are available for 164 subwatersheds (HUC12) within the OCAP assessment area (F2F2 2018). OCAP subwatershed lands average more than 60 percent national forest and serve about 150,000 residents. The watersheds with the highest proportion of national forest lands (24 percent or more) provide water to 75,000 people, or 50 percent of the total population served by municipalities. The subwatersheds with the highest proportion of Siuslaw National Forest lands include Cummins Creek (87 percent), Lower Drift Creek (86 percent), Tenmile Creek (84 percent), Cap Creek (83 percent), and Upper Five Rivers (83 percent) (table 3.5).

Water Uses in the Assessment Area

Dominant water uses in the OCAP assessment area, in order of withdrawal rate, include domestic, agriculture and irrigation, industrial, and environmental (Achterman et al. 2005). According to the Oregon Water Resources Department (OWRD 2015) data on point-of-diversion water rights, domestic uses make up 38 percent of total water rights uses, environmental uses 27 percent, agricultural uses 22 percent, and industrial uses 3 percent (10 percent other uses).

Municipal use drives demand in the OCAP assessment area, which is mostly rural and serves 150,000 municipal users and numerous private users who draw from surface (8,900) and groundwater (330) points of diversion. These community drinking water sources originate in or are adjacent to watersheds that are mostly within Siuslaw National Forest (ODEQ 2019, F2F2 2018) (table 3.6, fig. 3.7). There are an additional 598 documented private, domestic surface wells (defined as serving no more than three households) and an unknown number of undocumented exempt[2] private groundwater wells affected by forest watershed conditions that provide drinking water to those not connected to city systems (Achterman et al 2005, ODEQ 2005).

Municipal Water Supply Vulnerabilities

Municipal water supply sources—

Municipal water supply in the OCAP assessment area is rain dependent with little to no seasonal snowpack storage. Projections of the effects of climate change on precipitation are uncertain, although regional estimates suggest a decrease in average summer precipitation (Dalton et al. 2017). Human and ecological demands are highest in the summer when precipitation and streamflow are lowest (Mote et al. 2019). This seasonal asynchrony of water supply and demand is already stressing many municipal supplies each summer when demand from tourism is high.

Modeled projections for low streamflow in summer indicate the potential for decreases of 20–28 percent from historical conditions by the 2080's (fig. 3.4) in some watersheds. Adapting to the expected decreases in summer water availability will require watershed management approaches that consider likely increases in human and biophysical demand (OWRD 2015). Higher seasonal peak flows are also a concern for water supply and are projected to increase by as much as 24 percent by 2100 (fig 3.3). Potential consequences of higher peak flows, including increased turbidity from erosion and flooding impacts to aging infrastructure, are currently top concerns of municipal water managers (Brown 2012).

Land use change and development—
Rising demand for water resources from population growth and associated development (housing development and associated infrastructure) reduces in-stream flows and decreases resilience to sediment, bacteria, and other inputs from increases in wastewater and stormwater. According to the Forest 2 Faucets 2.0 Development Threat Index, a combination of development and climate change effects on water inputs pose a risk to watersheds in the OCAP assessment area (fig. 3.8).

Development causes loss of forested lands that filter and store water and reduce erosion and sedimentation. Increased development, particularly in headwater areas, has implications on water quality and quantity, with cascading consequences across human and ecological systems. OCAP subwatersheds with high development pressure commonly coincide with partial national forest ownership (table 3.7). Subwatersheds that are likely to face development pressure over the next several decades and are near national forest lands (particularly headwaters) provide an opportunity to inform targeted land protection, partnerships for ecosystem service markets, and forest management practices that mitigate negative consequences on forests and drinking water systems (Mockrin et al. 2014).

Infrastructure—
The American Society of Civil Engineers (ASCE) gives Oregon drinking water infrastructure a C- grade in its Report Card for American Infrastructure (ASCE 2019). The U.S. Environmental Protection Agency (EPA) estimates that community water infrastructure in Oregon serving populations of 10,000 or fewer (a large portion of OCAP systems) require more than $2 billion in upgrades and repairs (EPA 2018a). Water storage potential is limited because of steep topography in headwater areas (Achterman et al. 2005). This contributes to vulnerability to climate change by limiting the ability of municipalities to set aside water for times when water availability is low.

Infrastructure for drinking water, wastewater, and stormwater is vulnerable to several climate change effects. Underground water pipelines may be increasingly susceptible to damage from hillslope movement or failure because of soil supersaturation and instability from increased magnitude and frequency of precipitation events (see fig. 3.9). Storage, treatment, and delivery systems in low-lying areas (below 1.2 m) face increasing susceptibility to flood events, storm surges, and higher tides, coupled with SLR in some areas. Expected increases in the frequency and intensity of flooding events is likely to affect private wells, septic systems, and infrastructure for drinking water and wastewater (CDC 2018).

Groundwater—
Hydrogeology and rapid infiltration rates in the OCAP assessment area, coupled with increasing frequency and intensity of large storm events, amplify existing challenges around flooding, stormwater, and control of surface contaminants that contribute to groundwater vulnerability (ODEQ 2015, Safeeq et al. 2014). There are approximately 550 municipal wells and 460 groundwater points of diversion in the study area. Watersheds with high infiltration rates may be more vulnerable to surface contamination and pollution from increased flooding potential.

The number of private, domestic groundwater wells in the study area is unknown, although 35 percent of the state's population depends on private groundwater; this number is probably higher in rural areas in the OCAP assessment area. Well contamination may be a public safety issue because private and exempt wells are not regulated by the federal Safe Drinking Water Act or monitored for quality outside of private testing. These well users may be especially vulnerable to water quantity changes, health implications of quality degradation, and lack of information that would aid conservation and other adaptive management (ASCE 2019).

Dunal aquifers in the southern portion of the OCAP assessment area and a system of hydrologically connected lakes supply water to municipal, industrial, and private consumers and are vulnerable to altered rainfall and private, municipal, and commercial development (City of Florence 2011) (figs. 3.10, 3.11). Dunal aquifers are susceptible to water quality challenges because of high infiltration rates and a shallow water table vulnerable to contamination from septic tank effluent, storm runoff, chemical fertilizers, and recreational all-terrain vehicle use (Doliber 2012). Reduced summer inputs to lakes and aquifers, coupled with higher evaporation rates and user demand, could lead to altered timing and lower availability of water, with impacts on human uses and aquatic ecosystems (Mote et al. 2019). Coos Bay, North Bend, Florence (figs. 3.10, 3.11), and an unknown number of private wells depend on water from dunal aquifers.

Water Quality for Municipal Uses and Ecosystems

Turbidity and pollutants—
Turbidity (suspended particles that decrease clarity) and pollutants have the potential to affect municipal water intake and aquatic ecosystem health. Communities served by surface-water diversions are already experiencing the consequences of more frequent severe storms and intense rainfall events in the form of increased turbidity in drinking water systems (Abatzoglou et al. 2014, Dalton et al. 2013, ODEQ 2019). Greater potential for streambank erosion and sedimentation from increased peak streamflow and wildfire add to water quality concerns. For municipal water supplies, these changes will likely result in higher costs related to infrastructure maintenance, filtration (clogging), and reliance on disinfectants (Emelko et al. 2011).

Landslides also contribute to turbidity and water quality degradation. OCAP landslide risk analyses from the Aquatic Riparian Effectiveness Monitoring Program, aggregated to the subwatershed scale, indicate that 15 percent of OCAP subwatersheds rank in the "moderate" to "highest" risk categories (fig. 3.9). Clusters or "hotspots" of moderate to high landslide risk are in the northern and southern portions of the assessment area, including subwatersheds important for surface drinking water (table 3.8). Higher turbidity from increased streamflow and landslides could lead to more frequent system shutdowns, particularly for watersheds located in erosion-sensitive areas and those with higher modeled recession constants and sensitivity to peak flow increases (ODEQ 2010). Small rural municipal systems typically have low capacity to respond to events and adapt to changes, and the communities they serve typically have fewer financial resources to shoulder higher rates for upgrades or recovery.

Susceptibility of municipal drinking water to turbidity and associated water quality problems is also related to filtration technology (ODEQ 2010). Approximately one-third (32) of community water treatment systems, serving about 11,850 people in the study area, utilize slow sand, cartridge, diatomaceous earth, or natural filtration water treatment systems (ODEQ 2017)[3]. Other than unfiltered treatment systems (Reedsport), these treatment systems are considered most vulnerable to particulate matter and turbidity, serving small rural communities (4,000 or fewer people) that are more likely to have low capacity to respond or adapt (ODEQ 2017).

Stream temperature—

With increasing temperatures and lower summer streamflows, average surface-water temperatures are expected to increase during summer months (Isaak et al. 2017, chapter 4) (fig. 3.4). Many rivers and streams in the OCAP assessment area do not currently meet state OAR 340-041-0028 (3c) or federal Clean Water Act section 303 (d) water quality temperature criteria during summer months (7-day average maximum of at least 17.8 °C) (fig. 3.12). These rivers and streams provide salmon and trout habitat and are “threatened or impaired,” which requires the state to develop an improvement plan (total maximum daily load, TMDL).

Establishment of TMDLs is still underway for the Alsea, Yaquina, and Siuslaw Rivers (among others in the assessment area), and the plans do not presently account for projected stream temperature in the future. Figure 3.12 shows 2080 projections for rivers and streams designated as water-quality impaired and having a TMDL, and those that are 303(d) listed and needing a TMDL. Since late 2017, “implementation-ready” TMDL development has focused on only dissolved oxygen, data analysis, and model development. Water quality challenges related to bacteria, temperature, and sediment impairments have been temporarily or indefinitely suspended pending ongoing litigation (ODEQ 2020). Projected temperature change in the rain-dominant (as opposed to snow-dominant) assessment area is challenging for regulators and managers of forest and riparian areas.

Harmful algal blooms—

Water temperature increases with climate change are expected to increase the frequency and duration of harmful algal blooms (HABs) in lakes, ponds, and reservoirs that support drinking-water systems and recreation. HABs are also an issue for human health with respect to harvest of fish and shellfish from estuarine areas, an important food source for Indigenous communities and others in the region (May et al. 2018, chapter 8).

The Oregon Health Authority oversees HABs in drinking water throughout the state (Oregon Health Authority 2018). As of April 2020, the Newport drinking water system is the sole system in the assessment area listed as “susceptible” to cyanobacteria and therefore subject to state regulation for monitoring and testing. Cyanobacteria in surface water can negatively affect wildlife and fishes (Briand et al. 2003). Existing and future challenges related to water temperature are likely to increase the risk of cyanobacteria outbreaks in surface water. Lessons learned from ongoing challenges for recreational water bodies may prove helpful for responding to this risk.

Since 2007, there have been 13 official advisories for cyanobacteria blooms in water bodies in the OCAP assessment area (table 3.9) that lasted from 4 to 114 days throughout summer, fall, and winter. To date, Devils Lake in Lincoln County and the Tenmile Lakes region in Coos County have had a high frequency and duration of freshwater cyanobacteria outbreaks (Oregon Health Authority 2018).

According to data from the ODEQ, multiple private surface wells and springs draw drinking water from water bodies with recreational advisories (table 3.9). These private wells may be particularly vulnerable to an increased frequency of exposure over time (Paerl et al. 2011). Because private, domestic surface well water is not regulated or tested by public entities, safety precautions depend on well-user knowledge of cyanobacteria outbreaks and potential harm. Beyond households, locations vulnerable to contaminated well water could include campgrounds, churches, rural schools, and parks (Achterman et al. 2005).

Wildfire—

Wildfires in the Oregon Coast Range typically occur on a centennial frequency, and when wildfires occur, they are generally large and intense (Spies et al. 2018). Wildfire will likely occur more frequently in a warmer climate (chapter 5), so fire may become a greater risk for watersheds and water supplies. The effects of high-intensity wildfire on drinking water include short-term interruptions in service, damage to storage and delivery infrastructure, and short-term contamination from ash and debris. Following fire, additional treatment may be required for sediment, source-water may decrease, and stored water or secondary systems may be needed (Emelko et al. 2011, Sham et al. 2013, Smith et al. 2011).

Long-term challenges stem from vegetation loss and soil changes that contribute to slope and bank destabilization, higher peak flows, water temperature increases, reduced storage capacity in reservoirs, and flooding in estuaries (Hallema et al. 2018, Istanbulluoglu et al. 2004, Moody and Martin 2009, Murphy et al. 2015). However, a positive long-term outcome of wildfires in the Oregon Coast Range includes contributions of sediment to stream channels, improving fish habitat and creating a mosaic of habitats (Gresswell 1999, Penaluna et al. 2018).

Vulnerability Assessment for Roads, Infrastructure, and Access

Roads, trails, bridges, and other transportation infrastructure in the OCAP assessment area connect people to National Forest System and Bureau of Land Management lands for recreation, resource management and extraction, local travel, and emergency response. Access to public lands promotes use, stewardship, and appreciation, and contributes to quality of life (Louter 2006). Access management balances these benefits with ecosystem services. The following section describes road conditions and infrastructure management and maintenance constraints to provide context for identifying climate change vulnerabilities and adaptation options.

Siuslaw National Forest jurisdiction in the OCAP assessment area contains 3,463 km of system roads, only 10 percent of which are considered suitable for passenger vehicles. Most of the passenger-vehicle roads are on non-federal jurisdictions serving small communities bordering National Forest lands. Many of the roads (and trails) cross streams, rivers, wetlands, and estuaries. Siuslaw National Forest contains over 2,100 road-water crossings; 71 are bridges, and most of the rest are culverts. Approximately 190 km (6 percent) of roads in the assessment area are within 90 m of a stream and may be vulnerable to increased peak flows with climate change.

Roads can have negative effects on aquatic ecosystems. Roads intercept precipitation, surface runoff, and shallow groundwater; reduce the infiltration capacity of the watershed; 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). These processes tend to increase peak flows within the stream network (Jones and Grant 1996). Roads aligned along or across rivers, streams, wetlands, and estuaries generally have a greater direct impact on the fluvial system (Luce and Black 1999). Roads in the uplands also affect these processes and can affect slope stability and sediment delivery (Trombulak and Frissell 2000).

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

State Highways 18, 20, 22, 34, and 126, and federal highway US 101 are major travel corridors in the OCAP assessment area. Recreational use in Siuslaw National Forest is concentrated along river corridors and the Oregon Dunes National Recreation Area (ODNRA). Campgrounds and trailheads are concentrated in the ODNRA, although many developed areas and dispersed sites are found inland. Summer is the primary season for recreation, but salmon fishing, hunting, hiking, camping, firewood collection, birding, and boating draw visitors at various times throughout the year.

In Siuslaw National Forest, arterials (maintenance level 3 and 4 roads) are used to reach most recreation sites, boat launches, and campgrounds. Use typically peaks around July 4 and decreases sharply after Labor Day. High-use areas are typically centered along the coastal strip and developed sites. Secondary focal points for recreational use include access points and trailheads for wilderness areas, Marys Peak, and major campgrounds. Use in areas remote from urban population centers occurs year-round and peaks during bow- and rifle-hunting seasons.

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).

Road Management and Maintenance

Road designs and conditions, which affect water runoff and erosion, differ widely across the OCAP assessment area. Roads on federal lands range from closed roads (stabilized to address resource concerns) to open paved passenger roads. On private industrial forest land within the assessment area, roads support timber harvest. On federal ownership, a minimum road network is managed to balance variable-use access with potential risks to resources, such as water, fisheries, and terrestrial habitat. Some roads are paved and designed to provide travel in passenger cars, but much of the road system was designed with lower standards to facilitate timber extraction, resource management, and recreational access for high-clearance vehicles. Forest Service roads were largely built and maintained by a formerly large timber program. Road construction began in the late 1930s, with construction peaking in the 1980s. By 1990, 90 percent of the total road system had been constructed.

Most roads were developed when engineering standards for road-stream crossings were required to withstand a 25-year flood event (pre-1990), rather than the current standard to withstand a 100-year flood event. Construction techniques during the early road-building period often do not meet 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 10–15 percent of the existing road system. Many roads, bridges, and culverts are deteriorating, having exceeded their design life.

National forests develop annual road maintenance plans based on road operational maintenance level and category. Maintenance of forest roads subject to Highway Safety Act standards or high recreational use receive priority for available funding. 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 and terrestrial habitat. Appropriated funding is typically used to maintain level 3 and 4 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 watershed restoration and protection are also targeted for road maintenance for the purpose of reducing sediment input to streams and improving fish passage.

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 enables 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 financial sustainability and flexibility.

A forest-wide travel analysis was completed for Siuslaw National Forest in 2014. Part of this analysis included ranking road segments according to their importance for public and administrative use, as well as their environmental risks. Impacts to aquatic resources were weighted heavily in determining environmental risk, but climate change was not considered. The climate change information in this assessment can supplement information currently used in travel analysis.

Roads near rivers and streams often have a direct impact on fluvial systems, although roads in the uplands can increase slope instability in some locations, causing landslides that affect infrastructure, water quality, and aquatic habitat (Trombulak and Frissell 2000). A valley confinement algorithm, developed by the USFS Rocky Mountain Research Station, was used to assess the road network and position in depositional valleys across the OCAP assessment area (fig. 3.13).

Process-driven spatial and terrain analysis tools that assess road risks—the Geomorphic Road Analysis and Inventory Package (GRAIP) (Black et al. 2012) and NetMap (Benda et al. 2007)—are often used to identify hydrologic impacts and guide management decisions on projects. In 2012, the GRAIP was used to monitor 241 km of roads in the North Fork Siuslaw River watershed. This analysis determined that 2 percent of the road network in Siuslaw National Forest ownership within the watershed delivered 90 percent of the sediment to streams (Cissel et al. 2012). This inventory allowed Siuslaw National Forest to target problem areas, address resource concerns, and maintain a minimum road system necessary for management and recreation access. Since 1994, Siuslaw National Forest has invested funding in roads with high resource risks, implementing road stabilization and decommissioning where long-term access was not feasible or necessary.

Climate Change Effects on Transportation Systems

Direct effects of climate change on transportation systems are those that physically alter the operation or integrity of transportation facilities, including effects related to floods, snow, landslides, extreme temperatures, and wind. Hydrologic extremes (e.g., flooding) may exceed the historical range of intensity and frequency, as well as the current design standards for infrastructure. Many county and state connector roads are routed along streams, rivers, and wetlands, which are at greatest risk of flooding.

Roads and trails constructed decades ago have high sensitivity because of declining condition. Many infrastructure components are at or near the end of their design lifespan. Culverts, the most common infrastructure component of the transportation system, were 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, making them vulnerable and often resulting in damage or loss of roads during storm events.

In the face of 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 ability of bridges to withstand high flow and debris. Problems stemming from poor road locations, outdated standards, and lack of maintenance are likely to grow worse if hydrologic regimes change as anticipated in a warmer climate. New or replaced infrastructure is expected to have increased resilience to climate change. New culverts and bridges are typically larger than the original structures to meet agency regulations and current design standards that accommodate larger floods.

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 western Oregon that are built to a higher traffic standard and regularly maintained will be more resilient to climate change than unpaved roads built to a lower design standard. Lack of funding for repairing and improving infrastructure also contributes to the vulnerability of roads and trails.

Current and Near-Term Climate Change Effects

Higher streamflow in winter and higher peak flows and tidal storm surges increase the risk of flooding and impacts to structures, roads, and trails. In the short term, flooding of roads in valley bottoms or adjacent locations will likely increase, threatening the structural stability of stream crossing infrastructure and subgrade material. Roads under all jurisdictions near streams are especially vulnerable, and many of these roads are used for recreation access. Flooding and inundation are 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; floods also 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.

Landslides also contribute to flooding by diverting water, blocking drainages, and filling channels with debris (Chatwin et al. 1994, Crozier 1986, Schuster and Highland 2003). 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 debris 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 comprised of undersized culverts for stream crossings. The number of landslides is directly correlated with total kilometers of roads in an area (Chatwin et al. 1994, Montgomery 1994). Consequently, areas with high road or trail density that already experience frequent landslides may be especially vulnerable to increased landslides.

Short-term exposures to changes in climate may affect safety and access in the OCAP 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 coastal communities and river recreation, and reduce access to emergency evacuation routes. Road locations across low-lying coastal areas are prone to flooding and subject to sea-level rise. These impacts are likely to increase in frequency and will affect travel. The steep terrain and erodible soils of the Coast Range increase the risk of road failure in mid-slope roads and the risk of impacts by debris flows from landslides. Infrastructure, roads, and housing are often positioned where erosional processes and depositional processes interact.

Emerging and Intensifying 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 (10–30 years) and long term (greater than 30 years). 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, storm surge, and flooding (MacArthur et al. 2012).

Flooding in fall and early winter is projected to intensify in the medium and long term. By the 2080s, peak flows are expected 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. 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.

Projected increases in flooding in fall 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 flooding and landslides, challenging crews to complete necessary repairs. 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. Meeting road design standards for aquatic habitat will be especially important for maintaining viable populations of coldwater fish species, although some streams may be buffered by inputs from groundwater in the medium term.

Over the long term, higher winter soil moisture may increase the risk of landslides in fall and winter. Landslide risk may increase more in areas with tree mortality from fire and insect outbreaks, facilitated by reduced root cohesion in the soil and by decreased interception and evaporation of water (Martin 2006, Montgomery et al. 2000, Neary et al. 2005, Schmidt et al. 2001). Although floods and landslides will continue to occur near known hazard areas, they may also occur in new areas (MacArthur et al. 2012). Coinciding exposures in space and time may be particularly detrimental to access.

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 for recreation. Extreme weather and flooding will pose challenges for river recreation, especially in the winter. Early-season recreation may also increase use of unpaved roads in the wet season, which can increase damage and associated maintenance costs.

Conclusions

A primary effect of climate change in the Oregon Coast Range will be altered intensity and timing of rainfall, resulting in lower low-flows in summer and higher peak flows in winter. Altered low flows will affect water supplies, aquatic habitat, vegetation, and soil conditions. Depending on the amount and duration of the summer marine fog layer, drying and increased fire risk may occur. Higher peak flows may put communities and transportation infrastructure at seasonal risk, and may affect municipal infrastructure such as water treatment facilities located at low elevations.

Water supplies for human use and for terrestrial and aquatic ecosystems may be more strained in the future. Reservoir storage that provides adaptive capacity for water supplies exists, but financial and ecological costs of reservoir construction and operation may impose constraints. Transportation facilities may be challenged by flooding and increased wet-weather traffic, requiring decisions about closure and risk reduction. Stream crossings will be a focus for evaluating if infrastructure (culverts, dams) will withstand projected increases in peak flows.

Interpreting climate change effects for the OCAP assessment area requires thinking about processes with a fine-grained approach. Local changes in the hydrologic regime will likely lead to more small streams drying earlier or being subject to flooding, with consequences for sediment yields, fisheries, and water quality. At the same time, reduced summer precipitation will likely facilitate more wildfires and other disturbances while further reducing low flows. Such disturbances would add to water quality declines in smaller streams. The fractured and diverse geology of this area also leads to fine-scale changes in geologic storage of water, with consequences for understanding climate change effects on flora and fauna.

The OCAP assessment area will require thought and observation by local professionals to understand the full scope of potential climate change effects on water resources. Output from coarsely gridded climate and hydrology models will need to be accompanied by information on variability in topography and geology at small spatial scales to generate improved projections of climate change effects across the landscape.

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Chapter 4: Effects of Climate Change on Fishes of Concern in the Riverscapes of Coastal Oregon

Brooke E. Penaluna, Rebecca Flitcroft, Dona Horan, Dan Isaak, John C. Chatel, Julian D. Olden, Kelly Christiansen, and Gordon H. Reeves

Introduction

USDA Forest Service (USFS) and Bureau of Land Management (BLM) resource managers are responsible for maintaining the productivity of aquatic and riparian ecosystems on federal lands, helping partners to protect the associated biota, and ensuring ecosystem services they provide. Federal lands are important sources of water, recreation opportunities, and habitat for animals and plants, including many that are afforded protection under the U.S. Endangered Species Act (ESA). However, growing demands by human society have increased global consumption of natural resources, and driven precipitous declines in biodiversity and ecosystem services (Millenium Ecosystem Assessment 2005, Tickner et al. 2020). In addition, the interactive effects of multiple long-standing and emerging threats on streams and rivers have become increasingly apparent in recent years (Craig et al. 2017, Reid et al. 2019, Sabater et al. 2018).

Climate change is associated with significant effects on thermal and flow regimes of streams, posing significant challenges on the manner in which riverine systems are managed (Tonkin et al. 2019). This is particularly apparent in the Pacific Northwest region of North America where changes in river hydrographs are likely most pronounced in systems that are currently snow dominated, but that will become rain dominated as precipitation regimes change (Reidy-Liermann et al. 2012), and more extreme air temperatures will differentially modify thermal regimes (Arismendi et al. 2012, Steel et al. 2019). Terrestrial disturbance processes such as wildfires will likely change both in response to modifications to vegetation structure, climate change (Jentsch et al. 2007), and fire suppression and management, leading to habitat and thermal alterations (Isaak et al. 2010, Koontz et al. 2018). Marine effects on freshwater habitats include sea-level rise and storm surges that will affect low-elevation river systems. There is mounting evidence for reductions in flow (Luce and Holden 2009, Papadaki et al. 2016, Safeeq et al. 2013) and increases in water temperature (Arismendi et al. 2012, Isaak et al. 2012).

Past and projected responses to climate change in terms of flow and temperature are highly variable and, in some cases, uncertain depending on stream gradient, lithology composition, precipitation regime, and upland vegetation composition. In low-elevation rain-dominated watersheds of the Pacific Northwest, water temperature is predominantly influenced by groundwater and shading from riparian forests (Arismendi et al. 2012). However, in streams and rivers along coastal Oregon, groundwater is not a major factor. Because solar radiation is the dominant driver of stream temperature in most forested headwater and mid-order stream systems (Johnson 2004, Sinokrot and Stefan 1993), shading by riparian forests can decrease water temperatures (Arismendi et al. 2012, Johnson 2004, Wondzell et al. 2018), possibly mediating the predicted increase in air temperature from climate change (Lawrence et al. 2014). However, alterations in the seasonal availability of water from altered precipitation regimes combined with changes in thermal regimes will likely result in changes in seasonal habitat conditions for aquatic biota, but uncertainty remains about precipitation and temperature projections. Altered habitat conditions have direct and indirect effects on fish survival, abundance, distribution, fecundity, and reproductive success, which in turn can influence species interactions and the timing of key life events, distributions, and abundance (Closs et al. 2016).

Fish are ectothermic organisms and consequently thermal conditions dictate their metabolic rates and most aspects of their life cycles. This includes 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). Climate change has been implicated in shifts in fish species distributions (Parmesan and Yohe 2003, Comte and Grenouillet 2015), changes in timing of key fish life events (Crozier et al 2011), and decreasing body sizes for fishes around the globe (Daufresne et al. 2009). Some fishes have physiological requirements requiring cold environments making them especially vulnerable to the thermal variation associated with climate change (Comte and Olden 2017a).

Climate change affects fishes, especially these coldwater species, through changes in distributions (Wenger et al. 2011, Comte and Olden 2017b), phenology (Crozier et al 2011, Kovach et al. 2013), demography (Al-Chokhachy et al. 2013), recruitment (Ward et al. 2015), and genetic diversity (Muhlfeld et al. 2014). For example, climate change simulations have shown changes in trout phenology and shrinking body sizes (Penaluna et al. 2015). Possible acceleration of climate change during the 21st century (chapter 2) is likely to have important implications for coldwater fishes, complicating conservation and management efforts.

Here, we present a climate change vulnerability assessment for specific fish species and their associated aquatic habitats for the Oregon Coast on federal lands managed by Siuslaw National Forest and the BLM. We describe the status and potential climate vulnerabilities for fishes of concern in the assessment area (fig. 4.1). Fish species considered were identified during discussions with land managers, USFS regional staff, and biologists from several agencies at the outset of the project. Spring-spawning fishes in this assessment include:

- Coastal winter steelhead species management unit (SMU)/Oregon Coast ecological significant unit (ESU) winter run (*Oncorhynchus mykiss* Walbaum)
- Oregon Coast coastal cutthroat trout SMU/Oregon Coast ESU (*O. clarkii clarkii* Richardson)
- Pacific lamprey (*Entosphenus tridentatus* Richardson)
- Western brook lamprey (*Lampetra richardsoni* Vladykov and Follett)
- Green sturgeon (*Acipenser medirostris* Ayres), including the southern distinct population segment (DPS)
- Eulachon southern DPS (*Thaleichthys pacificus* [Richardson])

Fall-spawning fishes included in this assessment are:

- Oregon Coast ESU coho salmon (*O. kisutch* Walbaum)*;*
- Spring and fall runs of coastal Chinook salmon SMUs (*O. tshawytscha* Walbaum in Artedi),
- Coastal chum salmon SMU/Pacific Coast ESU (*O. keta* Walbaum in Artedi)

We discuss results from two analyses: (1) temperature modeling using the NorWeST Regional Database and Modeled Stream Temperatures (Isaak et al. 2017b) to understand climate influences on stream habitats for focal fishes in the assessment area at the scale of 1 km, and (2) downscaled projections to 100-m reaches using Netmap that allow for a finer-scale understanding of climate influences on stream habitats. For salmonids in the assessment area, we use their current climate vulnerability assessment status, described by Crozier at al. (2019), which incorporates the elements of biological sensitivity, climate exposure, and adaptive capacity.

Study Area

The Oregon Coast Adaptation Partnership (OCAP) assessment area spans portions of major Oregon Coast Range rivers that drain into the Pacific Ocean, including the Umpqua, Siuslaw, Alsea, Yaquina, Siletz, and Nestucca Rivers (fig. 4.2). The Oregon Coast Range and Pacific continental shelf are on the edge of an active subduction zone resulting in large tectonic-driven earthquakes on a 300- to 500-year return interval (chapter 3). These events have resulted in flooding of estuary areas, tsunamis, and large earth-movement events, all of which alter the character, composition, and distribution of aquatic habitats in coastal rivers and streams. The underlying geology of the Oregon Coast Range includes fine-grained sedimentary and older volcanic deposits, and younger sedimentary and crystalline lithologies (Comeleo et al. 2014). Different lithologies have variable groundwater storage capacity, thereby affecting groundwater residence time, summer low-flow quantity, and stream temperature. Although most Oregon Coast Range lithology has limited aquifer permeability, volcanic lithology is known to have higher infiltration rates than sedimentary lithologies, possibly affecting water storage and summer low-flow conditions in streams.

In the OCAP assessment area, the Siuslaw National Forest encompass vast areas of land reaching from the headwaters to the ocean in some locations, and BLM lands are most often located in headwater areas. Almost a third of the land in the Oregon Coast Range is in state or federal ownership with the remaining lands predominantly classified as private industrial forest land or private nonindustrial forest land (Spies et al. 2007). Management goals in Siuslaw National Forest lands include timber harvest, old-growth conservation, wildlife habitat, fish habitat, water quality, and recreation. BLM land is also managed for a variety of uses, including energy development, livestock grazing, timber harvest, recreation, and protection of natural, cultural, and historic resources.

Stream habitats throughout the OCAP assessment area have been modified by human actions, particularly occurring over the past 150 years following Euro-American colonization. Continued eradication of American beaver (*Castor canadensis* Kuhl), historical forest harvest practices such as splash-damming and log drives (e.g., Miller 2010), contemporary forestry, and diking and draining of river floodplains contributed to degraded stream conditions. In addition, management of forests on public and private lands in the OCAP assessment area diverged almost 30 years ago (FEMAT 1993) after the implementation of the Northwest Forest Plan, leading to differences in forest stand age by ownership (Steel et al. 2017). For example, in Oregon, 30 percent of federal lands versus ≤5 percent of private lands have forest stand age >120 years based on basal stand weighted area (Steel et al. 2017).

Climate Change Effects on the Coastal Oregon Riverscape

Along the margin of the Pacific Ocean, the physiography and climate of coastal rivers are strongly influenced by marine processes. The high-gradient Oregon Coast Range closely abuts the ocean due to a combination of tectonic mountain-building action, and past sea-level rise, resulting in the fjorded river mouths characteristic of the Oregon Coast (Cortright et al. 1987). The diversity of connected environments from the ocean to river headwaters offers diverse habitats ideal for fishes with evolved and complex sea-run or migratory life histories (Flitcroft et al. 2014). However, predictability in transitions among habitats between seasons is necessary for the timing of life stage events for individuals that must traverse vast marine or freshwater distances during their lifetimes.

Climate change projections in the rain-dominated hydrology of coastal Oregon indicate rapid shifts in temperature and precipitation regimes (Burke and Ficklin 2017, Mote et al. 2019, Sawaske and Freyberg 2014). These changes may alter the timing of environmental conditions in ways that could disconnect alignment among seasonal habitats that native fishes are adapted to or alter transition times in estuary and marine areas. Effects of climate change will be particularly acute in watersheds with low aquifer permeability (Leibowitz et al. 2014). Here, we synthesize climate change information across the assessment area based on the current state of science, recognizing that uncertainty exists in how climate change will play out locally and regionally.

Freshwater Streams and Rivers

In the OCAP assessment area, lotic systems transition from small, forested, and generally high-gradient headwater streams, often with seasonally intermittent flow, to larger mainstem rivers with floodplain forests and prairies. Projected effects of climate change associated with altered precipitation and thermal regimes will modify freshwater habitats differently depending on where they are located within the continuum of habitats that comprise a river network (Fausch et al. 2002). Precipitation amount is projected to remain similar into the future, but to be delivered in more intense storm events through the fall and winter (chapter 2). Rain-dominated hydrologies of streams in the assessment area are underlain with geology that has limited permeability and water storage, although volcanic lithologies offer more infiltration capacity than sedimentary rock. Limited storage results in freshets (high-runoff events) during and immediately after storm events, with relatively low-flow conditions between storms in winter, and longer low-flow conditions in summer resulting from limited storage capacity.

Air temperature is expected to increase in the OCAP assessment area, and increased water temperature is projected in streams that are surface-water fed or lack riparian cover to intercept solar radiation (Arismendi et al. 2012; table 4.1). Headwater streams benefiting from riparian shading may be more buffered from increasing thermal conditions than downstream reaches (Lawrence et al. 2014). However, increasing water temperatures may become apparent in lower-gradient and larger rivers that have less canopy cover from riparian trees and through thermal inertia of higher water volume. As with high-gradient areas, alterations in storm events and precipitation will likely result in increased scour potential in lower-gradient rivers where floodplains are no longer connected or intact (e.g., Sloat et al. 2017). This may result in scour of spawning habitats for some fishes, likely affecting eggs or alevin of fall-spawning fishes that are overwintering in the gravel (Battin et al. 2007, Goode et al. 2013). However, depositional areas may accumulate more sediment and wood flushed down from upstream areas, possibly enhancing habitat complexity for aquatic biota. Habitat enhancement may provide additional winter refuge areas or deeper pools that provide thermal refuge in summer for coldwater fishes.

In headwater streams, summer low flow may become more pronounced (table 4.2) with a shrinking of perennial streams and an increase in intermittent streams during summer low flow

(Olson and Burton 2019). Higher-intensity precipitation events in the fall and winter may cause scour events and increase transport of large wood and sediments out of headwater areas into lower-gradient floodplains, and/or larger rivers. Slow-water winter-refuge areas are considered to be a limiting habitat for survival of rearing salmonids (Nickelson et al. 1992). Projected higher-intensity storm events may exacerbate issues of over-winter survival for juvenile fishes.

Large mainstem rivers are often characterized by floodplain habitats. However, large intact floodplains in the lower reaches of rivers are relatively uncommon in the OCAP assessment area owing to the close proximity between the Oregon Coast Range and the sea and extensive development in coastal areas (Cortright et al. 1987). Also, historical sea-level rise following the Little Ice Age resulted in the inundation of the lowland areas that fringed the Oregon Coast (NRC 2012). Many of the current floodplains have been drained and streams have been downcut, thereby reducing the availabiltiy of the floodplains for use by fishes and other aquatic organisms.

Movement of rearing fishes into estuaries might increase overlap with predatory fishes, especially invasive warmwater fishes such as bass (*Micropterus* spp.). Projected increases in storm intensity may result in enhanced flooding of these lowland areas during winter months. Further, the inability of riparian trees to fully shade large rivers will also result in increased exposure to solar radiation that, in turn, increases water temperature. Increased thermal conditions may push coldwater fishes upstream into cooler habitats, or farther downstream into estuaries. Large mainstem rivers that are close to estuaries may experience greater tidal inundation and flooding in the winter in response to higher sea-level water intersecting with high flow from intense winter storms. In places with floodplains not modified by tide gates or levees, tidal inundation may increase over winter habitats in lowland areas, particularly for Chinook and/or coho salmon (Jones et al. 2014; Reimers 1971, 1973).

Coastal Lakes

Freshwater lakes occupy portions of the OCAP assessment area (fig. 4.2). Some of these lakes are naturally formed in dunal areas and provide dunal aquifer recharge. Although disconnected from rivers, many of these dunal lakes have populations of native freshwater mussels (e.g., *Anodonta* spp.), native fishes (especially coho salmon), and nonnative fishes, many of which are tolerant of warmer water temperatures. Other coastal lakes are enhanced, impounded waterbodies created by relatively small dams. Impoundments were generally created for municipal and industrial water supply storage, rather than for hydropower.

The effects of altered timing and amount of precipitation and of higher summer air temperatures on coastal lake systems are unclear. Impounded lakes associated with the mid-coast area provide critical over-winter habitat, particularly for endangered Oregon Coastal coho salmon and are considered key to their recovery (Wainwright et al. 2008). In these areas, juvenile coho salmon that were spawned in the small freshwater streams connected to the coastal lakes use the lakes for a portion of their rearing, resulting in large smolts (Gunnarsdóttir 1992). This is noteworthy considering the presence of invasive warmwater fishes such as largemouth bass that also occupy these lakes and support a trophy warm-water fishery. Thermal stratification in a few of the deeper lakes, as well as seasonal thermal conditions, likely contribute to habitat partitioning between juvenile coho salmon and warmwater largemouth bass. Potential changes in the coastal thermal regime (fig. 4.3) may alter thermal conditions in lakes, possibly changing the ability of coho salmon to survive alongside nonnative predatory fishes.

Estuaries

Estuaries occur at the intersection between saline marine waters and coastal freshwater rivers. Estuaries in the OCAP assessment area respond to daily fluctuations in marine water height associated with tides, and to seasonal variation in freshwater river flow associated with inland precipitation events. During the winter, large freshwater inputs from storm runoff result in reduced estuary salinity. Reduced salinity and cold marine water make estuary areas productive for rearing salmonids. Diversity in rearing strategies of juveniles have been documented in estuary areas for coho salmon, Chinook salmon, and cutthroat trout (Jones et al. 2014; Krentz 2007; Miller and Sadro 2003; Reimers 1971, 1973).

Climate change is projected to affect Oregon coastal estuaries through sea-level rise and storm surges that drive increased flooding. Isostatic adjustment on the Oregon Coast is the cause of gradual land rise north of Cape Arago. However, coastal uplift is not expected to keep up with sea-level rise in future decades (NRC 2012). Sea-level rise has the potential to increase tidal inundation time on lowland marshes, altering vegetation composition, and leading to a transition to mudflat or open-water environments (chapter 2). Tidally active channels in lowland marshes are often the areas occupied by rearing juvenile fishes due to inputs of terrestrial insects and invertebrates representing high-quality food sources. A shift to a mudflat environment would reduce the habitat available for salmonids (Flitcroft et al. 2013).

Storm surges are projected to increase flooding of lowland areas in and around coastal estuaries. Storm surges occur when storms offshore push more marine water landward at the same time as precipitation from the storm is increasing discharge from coastal rivers. During high tides, storm surge and high discharge events can cause extensive flooding of lowland areas (chapter 2). Levees and tide gates enclose many estuaries on the Oregon coast, with the goal of minimizing influx of marine waters. However, storm surges that occur during high-tide events have the potential to damage human infrastructure. In contrast, storm surges and flooding of lowland areas may enhance habitat for rearing fishes by providing access to slow-water refugia.

Ocean

Most fishes considered in this assessment are sea run, relying on multiple habitats across the freshwater-marine interface in their lifetime. Many sea-run fishes spend more time in ocean environments than in freshwater, making marine environments critical to their population sustainability (fig. 4.1). Most of these sea-run fishes move into estuaries and the ocean as juveniles or smolts, and their timing and size at ocean entry influence survival in their first year at sea (Van Doornik et al. 2007). In the Pacific Ocean, climate change will increase sea-surface temperature and possibly El Niño Southern Oscillation (ENSO) strength, leading to changes in the Pacific Ocean’s net primary production, and consequently the availability of food for focal fishes (Behrenfeld et al. 2006).

The timing of seasonal high productivity events in the North Pacific Ocean is influenced by a combination of marine winds and weather patterns. Outmigration of juvenile fishes or smolts for many populations of sea-run fishes in the OCAP assessment area coincide with seasonal upwelling events that create a highly productive environment on the continental shelf offshore. Upwelling generally occurs during spring and summer, driven by northerly winds along the Oregon coast from April through September. These winds push surface water to the south, simultaneously pulling cool, high-salinity, and nutrient-rich subsurface water to the surface. This cold water stimulates primary productivity, enhancing survival of juvenile fish outmigrants from coastal watersheds. The amount of upwelling is related to growth and survival of Chinook salmon and other salmonids (Nickelson 2011) in the California current (Hassrick et al. 2016; Wells et al. 2016). Projected changes in upwelling and other marine conditions are variable, depending on the climate models used. Some sources identify relatively small changes in upwelling (Mote and Salathé 2010), while other sources indicate larger changes (Scheuerell and Williams 2005) that will lead to reduced survivorship of Chinook salmon outmigrants from the Columbia River.

Methods: Modeled Stream Climate Temperature using NorWeST (1-km resolution) and Flows Using VIC

We described stream climate trends and the extent of habitat available to the species of concern by delineating an 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 predicted by the Variable Infiltration Capacity hydrologic model (VIC; Wenger et al. 2010) were obtained from the Western U.S. Flow Metrics website (https://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 0.0057 m^3s^{-1}, which approximates a low-flow wetted width of 1 m (based on an empirical relationship developed in Peterson et al. [2013]). This was done because fish occurrences are rare in small 1st order headwater streams (Isaak et al. 2017a).

The network was further filtered to exclude reaches with >15 percent slope. Especially steep headwater reaches often have geological barriers that are insurmountable to fish and are prone to frequent disturbances (e.g., post-wildfire 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 7,911 km network that served as the basis for subsequent analyses and summaries. Overall, 19 percent of the network flowed through USFS lands, 11 percent flowed through BLM lands, and 70 percent flowed through private lands (fig. 4.2).

Scenarios representing mean August stream temperature were downloaded from the NorWeST website (https://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html; Isaak et al. 2016a) and linked to reaches in the analysis network. NorWeST scenarios for other months of the year are also available (e.g., June, July, September, and annual maximum) but generally show the same spatial patterns as mean August scenarios. 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 assessment area at 1,837 unique stream sites (Isaak et al. 2017b). 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 streams across the project area. To depict temperatures during a baseline period, we used a scenario that represented average conditions for 1993–2011 (hereafter 2000s). The mean August stream temperature during this period was 14.9 °C, and ranged from 7.64 to 22.58 °C throughout the network (table 4.1, fig. 4.3).

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 greenhouse gas emission scenario (A1B, a middle-of-the-road scenario for future emissions) as those used for the VIC streamflow analysis in the OCAP water and infrastructure assessment (chapter 3). The future NorWeST scenarios for 2040s and 2080s accounts for differential sensitivity and slower warming rates of the coldest streams that are often buffered by groundwater (Isaak et al. 2016b, Luce et al. 2014). Future mean August stream temperature increases relative to the baseline period of 2000 were projected to average 1.37°C by the 2040s and 2.36 °C by the 2080s, which imply summer warming rates of ~0.30 °C/decade (table 4.1, fig. 4.3) and is similar to historical warming rates observed during summer months at long-term monitoring sites along the Oregon coast and the region (Isaak et al. 2018).

Potential changes in streamflow characteristics are described in detail in the water and infrastructure assessment (chapter 3), so are only briefly summarized here. Because most basins in the assessment area occur at relatively low elevations, hydrographs of most streams are typical of rainfall runoff patterns, and their form is not anticipated to change appreciably with future warming. For example, the frequency of high winter flows is projected to change little in the assessment area (fig 4.4; table 4.2). The most significant change in hydrologic patterns will be a decrease in summer flows, which are projected to decline on average by 5.6–18.4 percent in the 2040s and 9.4–27.6 percent in the 2080s (fig. 4.5). For additional spatial resolution, Appendix A provides a tabular summary of conditions during the historical and future climate periods by 6th code hydrologic units for flow and stream temperature characteristics. Geospatial shapefiles summarizing the data by 6th code units are available on the USFS shared T drive in the OCAP project directory.

Methods: Downscaling stream climate projections to 100-m reaches using NetMap

We used geospatial tools developed by NetMap (Benda et al. 2007) to model the effects of climate change on stream temperature and stream flow. We also modeled the importance of riparian shading to mitigate climate change effects by taking into account local land features, including digital elevation models (DEMs), roads, and distributions of fish in streams. The delineated stream layer in these analyses is synthetic, with approximately 100-m-long reaches, and is based on 10-m digital elevation models. We used the NHD to guide channel locations where channel gradients were less than 4 percent; the NHD was applied where flow accumulation and direction are insufficient to accurately delineate the low-relief portions of river networks using 10-m DEMs.

All virtual watersheds contain attributes of habitat intrinsic potential for coho salmon, Chinook salmon, coastal cutthroat trout, and steelhead (e.g., Burnett et al. 2007). The habitat intrinsic potential modeling requires channel gradient, valley confinement (valley width divided by channel width), and mean annual flow. To describe shade and its effects on thermal loading, a few analyses use the metric "Soldifmax", which is the difference between the current shade thermal energy and estimated thermal energy under maximum shade. Essentially, it provides an index of where increasing shade would have the greatest benefit to help managers make more informed decisions about riparian management. Landslides occur throughout the assessment area; NetMap defines landslide density number (landslides km^{-2}) based on empirical data from the Oregon Coast Range. To describe beaver habitat, we used the beaver habitat tool, which computes habitat using gradient and drainage area, based on an empirical model of beaver dams based on data from the Stillaguamish River, Washington (Pollock et al. 2004).

For climate change scenarios under NetMap, we include climate change projections developed by the Climate Impacts Group at the University of Washington. The approximate 7-km by 7-km gridded climate change data (rasters) included air temperature, precipitation, snowmelt, snow-water equivalent, and summer and winter runoff (streamflows). The climate projections represent a composite average of ten global climate models (GCMs) for the western US under one greenhouse gas scenario (A1B). Projected summer and winter runoff were developed using the VIC model. Climate change projections were transferred to individual channel segments (entire network including headwaters) based on the local contributing area of each channel on both sides of the stream (these local contributing areas are referred to as "drainage wings" in NetMap). Climate change projections of stream temperature and flow were also aggregated downstream. Projections in NetMap are reported in percent change from historical (1993–2011) to the 2040s (includes years 2030–2059) and 2080s (includes years 2070–2099), which can be positive or negative values (but air temperature projections are in absolute change in degrees C). In addition to incorporating future projections of stream temperatures based on climate change projections, stream temperature values for the fish-bearing network were used from the NorWeST regional database on modeled stream temperatures in August. Geospatial shapefiles of NetMap data are available on the USFS shared T drive in the OCAP project directory.

Focal Species Status and Vulnerability with Reference to the Riverscape

In this assessment, we focus on spring-spawning and fall-spawning fishes, many of which are listed as threatened under the U.S. Endangered Species Act (table 4.3). The temporal scales at which climate change may affect different species vary based on life history. For some species, immediate negative effects resulting from shifts in stream conditions may alter survival and life stage completion. Other species may experience benefits from the changes in stream conditions as they achieve optimal survival conditions. Vulnerabilities and benefits are discussed and contextualized in this section using: (1) species-specific distribution maps provided by the USFS Pacific Northwest Region and Oregon Department of Fish and Wildlife, with NorWeST modeled peak August stream temperature and Variable Infiltration Capacity (VIC) flow modeling; and (2) a fine-scale analysis using NetMap tools. The fish distribution data were the best available information at the time.

Spring-Spawning Fishes

Spring-spawning fish have been coping with climatic variability for decades, although there is still much uncertainty about how future climate change effects will affect different life stages, as well as specific effects on watershed-scale and reach-scale stream characteristics (see details for each species below). In general, after laying their eggs, emerging fry and developing juveniles of spring-spawning fishes stay in the gravel during spring and early summer. Consequently, the egg and early emergence stages of these fishes are vulnerable to changes in freshwater and riparian conditions during the spring and early summer months. Changes in flow and temperature during this timeframe can affect outmigration timing, survival, and habitat for spawning and rearing fishes. In addition, resident fishes (e.g., western brook lamprey) and some sea-run fishes may rear for an extended period in freshwater (e.g., steelhead, coastal cutthroat trout, and Pacific lamprey) and are consistently affected by habitat conditions.

If the anticipated high winter flows persist into spring under climate change, then upon emergence, smaller fish may be more susceptible to displacement due to higher flows. Increasing flows in winter (fig. 4.4) may destabilize redds for fish that spawn early. Decreasing flows in summer, which are anticipated for many streams in the assessment area by 2080 (fig. 4.5), may dewater redds, compromise critical rearing habitat, push juveniles into main channels with adults and larger fish, and increase disease transmission and development. Changes to stream temperature and flow may cause adult fish that are migrating or holding in streams on their way to spawning sites to stop, delay, or prematurely alter the timing of their upstream or downstream movements (Battin et al. 2007).

Winter steelhead trout—

The native distribution of *O. mykiss* spans the entire west coast of North America from Alaska to Baja California, Mexico, and portions of Asia. They express multiple life histories, including sea-run (steelhead), adfluvial, fluvial, and resident, that all spawn during the spring. Although various populations of steelhead in the Columbia River basin have elevated levels of protection at the federal level, coastal Oregon steelhead do not. In coastal Oregon, steelhead are predominantly categorized as winter-run (name coincides with timing of adult return to freshwater) or ocean-maturing (where they return from the ocean ready to spawn), There are two small populations of summer-run or stream-maturing (where they do not return ready to spawn, but must spent time to mature in freshwater) steelhead in the Umpqua and Siletz Rivers in the OCAP assessment area. The distribution of winter steelhead or rainbow trout in the assessment area comprises 6,634 km of stream habitat (table 4.4, fig. 4.6).

Winter steelhead in Oregon are classified as vulnerable by the state of Oregon, are a special status species according to the BLM, and are classified as "sensitive" by the USFS. The 2005 Oregon Native Fish Status Report developed by the Oregon Department of Fish and Wildlife (ODFW) used six biological characteristics (abundance, productivity, habitat use distribution, etc.) to assess species viability, persistence, and conservation risks. Within the Coastal Winter steelhead SMU, most populations meet all status criteria, whereas the Siletz, Yaquina, Alsea, and Coos populations meet 4–5 criteria (fig. 4.7). The 2014 Coastal Multi-Species Conservation and Management Plan concluded that all populations within the coastal SMU are viable but strong-guarded (meaning they are widely distributed with no immediate threats, however there is a lack of robust data for considered parameters) based on the lack of data for spatial structure and diversity assessments (ODFW 2014).

The expression of steelhead versus rainbow trout life history of *O. mykiss* is in response to the combination of absolute water temperature and variation in water temperature, with warmer thermal regimes fostering residency via earlier maturation (Kendall et al. 2015; but see

Rosenberger et al. 2015). Consequently, steelhead are vulnerable to warming temperatures under climate change, potentially leading to a change in life history expression for *O. mykiss*, with a loss of steelhead life history forms and an increase in inland rainbow trout forms because of a faster growth rate (Benjamin et al. 2013). Steelhead have persisted in the past, at least in part, because there is a fitness advantage associated with migrating to the ocean to feed and returning to freshwater to spawn (Quinn and Myers 2004). If this advantage is reduced or lost, freshwater residency could increase in populations, assuming that changes in the freshwater environment are suitable for the persistence of the freshwater life history. Other Pacific Coast populations of *O. mykiss* maintain primarily resident populations in locations where the stream temperatures are warming, such as in southern California and Mexico.

Winter runs of steelhead migrate into rivers in late fall, early winter, and spring and spawn shortly after entering freshwater, which potentially helps them to be less vulnerable against the warm freshwater conditions that summer-holding fish face. Juvenile steelhead are expected to rear for one or more years in streams of more low flows and higher stream temperature in summer. However, if riparian areas can be maintained (including vegetation that provides shading), then stream temperatures can be buffered through the late 21st century (table 4.4). Steelhead adults likely face barriers to migration as steelhead populations stop moving when water temperature exceeds 21 °C (Siegel et al. 2021). Headwater rearing locations for steelhead are also susceptible to debris flows and scour at a higher frequency than other places in the river network in streams of the Oregon Coast Range (Goode et al. 2012). In the Nestucca River basin, there is habitat potential for steelhead in upper Elk Creek that coincides with beaver habitat potential (fig. 4.8). Overall, winter steelhead in the OCAP assessment area have a moderate climate vulnerability owing to their presence across watersheds and their requirement for cold, connected habitats throughout all seasons of the year (table 4.3).

Coastal cutthroat trout—

Coastal cutthroat trout extend from Prince William Sound, Alaska, south to the Eel River in northern California, and inland up to several hundred kilometers from the Pacific coast. Since 1999, there have been a series of petitions for listing of coastal cutthroat trout under the ESA because of declines in some populations. However, they have been precluded from listing owing largely to their broad distribution from headwater streams to river mouths, and the lack of recognition of different life-history forms that contribute to each population. They have a State of Oregon species status of vulnerable and a USFS species status of sensitive.

In the OCAP assessment area, coastal cutthroat trout distribution comprises 6,634 km of stream habitat (table 4.5, fig. 4.9). The 2014 Coastal Multi-Species Conservation and Management Plan from ODFW concluded that coastal cutthroat trout are widely distributed and all populations are viable. However, the watersheds comprising SMUs were given a strong-guarded status due to the lack of data for abundance and productivity (ODFW 2014).

Coastal cutthroat trout have diverse life histories, including sea-run, lake, fluvial, and resident freshwater populations, although in the study area the lake forms appear to be supported by a few reservoirs. Several life history expressions often co-occur, leading to the synchronous use of a wide variety of habitats, including rivers, tributaries, headwater streams, lakes, estuaries, and the nearshore ocean within a single watershed. Depending on local conditions, coastal cutthroat trout spawn from late winter through spring, with peak activity in February. Fry emerge between March and June. Upstream movements of adults occur year round, probably owing to various forms using the river, but peak in July and August on the Umpqua River (Flitcroft et al.

2016). They are generally the salmonid found furthest upstream in a network, and hence are often the fish used to determine the upper distribution boundary of fish throughout their range. Cutthroat trout are not usually found in water temperatures higher than 22 °C; juveniles prefer water temperatures around 15 °C, although they can tolerate temperatures as high as 26 °C for brief periods (Behnke 1992).

Coastal cutthroat trout have moderate climate vulnerability in the assessment area because they have multiple life-history strategies, possibly offering flexibility in their response to future conditions (table 4.3). Mean August stream temperature in the OCAP assessment area is projected to increase in all areas occupied by coastal cutthroat trout, with over 40 percent of the streams exceeding 17 °C (table 4.5). Projected mean August stream temperatures by 2080 are 17 to 20 °C for 47 percent of the coastal cutthroat trout streams circa 1980s, four times greater than current conditions (12 percent).

Similar to Pacific salmon and steelhead, sea-going forms of cutthroat will experience changes in marine and freshwater environments in the future. However, unlike other Pacific salmon, cutthroat tend to use nearshore habitats. Due to their narrow marine distribution and shorter migration distances (compared with other interior populations of Pacific salmon), their response to climate change has been shown to be affected primarily by *O. mykiss* nearshore coastal conditions (Di Lorenzo and Mantua 2016).

In a warming climate, returning adults of the sea-run form and juveniles located farther down the river network may be subject to increased temperatures in river mainstems. For freshwater forms using stream reaches further up the stream network, climate change may increase susceptibility to wildfire and lower summer flows owing to changing precipitation regimes, and higher water temperature. Although wildfire can have long-term benefits to aquatic habitat in the Oregon Coast Range from inputs of sediment and wood from post-wildfire landslides, short-term effects may include risks of fine-sediment inundation and reduced riparian shading (Koontz et al. 2018).

Changes in coastal precipitation regimes could result in reduced water volumes during low-flow periods of the year in headwater streams that could push resident coastal cutthroat trout downstream, thereby reducing their water network of connected, perennially flowing habitats (Battin et al. 2007). Within the assessment area, mean summer flows are projected to decrease 15.6–19.8 percent on BLM and USFS lands (table 4.2). The downstream displacement of headwater-rearing fish will expose them to warmer stream temperatures than those to which they are adapted, and may intensify biological interactions with native and nonnative species found lower in the watershed ion (Lawrence et al. 2012, Steel et al. 2019). Conservation plans for coastal cutthroat trout include restoration to maintain cold water in smaller tributaries and main river channels, and enhancement of the abundance of pools and instream cover throughout the network by allowing large wood to recruit to streams.

Pacific lamprey—

Pacific lamprey are distributed from Mexico north into Alaska and eastern Asia, and into the interior west of the Rocky Mountains in North America. They are sea run, requiring connectivity among ocean, estuarine, and freshwater habitats to complete their life cycle, similar to Pacific salmon and trout (fig. 4.3). Pacific lamprey are a USFS Regional Forester sensitive species, BLM special status species, and a State of Oregon sensitive species due to their apparent range-wide declines. The 2017 Pacific Lamprey Assessment of the North Coast sub-region by the U.S. Fish and Wildlife Service concluded that the distribution was reduced from 2011 in all hydrologic unit codes except the Necanicum River (USFWS 2018). In response to this decline and the cultural significance of the fish to tribal communities, Pacific lamprey has become a focus for research and management. However, while work to date has increased our understanding of Pacific lamprey, the species remains largely understudied, thus precluding more robust climate change vulnerability assessments. Pacific lamprey inhabit 2,130 km of stream habitat in the assessment area (table 4.6; fig. 4.10), but a better understanding of their status and distribution is needed.

Adult lamprey spend 1–3 years in the ocean and have a jawless, sucker-like mouth, allowing them to be parasitic on other fish during their oceanic phase. They return to freshwater in the spring, with upstream migrations occurring from May to July, resulting in spawning in freshwater the following March through July. Spawning usually occurs in wider, low-gradient rivers (<2 percent slope). After emergence, juveniles (called ammocetes) experience a lengthy larval stage that lasts 3–7 years, during which time they burrow into sandy substrates (Gunckel et al. 2009). At broad spatial extents, studies show that Pacific lamprey larvae are positively associated with water depth and open riparian canopy. Patchiness in larval occurrence is observed at fine spatial extents and is associated with low-water velocity, channel unit morphology (pool habitats), and the availability of fine-grained sandy habitats suitable for burrowing (Torgersen et al. 2004).

Altered hydrologic regimes and stream temperatures in freshwater caused by climate change could severely affect Pacific lamprey in the assessment area. For example, in a study focused on the survival of embryonic and newly-hatched Pacific lamprey, survival was the highest at 18 °C and lowest at 22 °C, suggesting that temperature above 20 °C can cause severe stress (Meeuwig et al. 2005). These thermal thresholds are relevant because populations in the OCAP area are projected to experience more stream miles over 20 °C in mean August temperatures by 2080 than they do now accounting for 28 percent of their stream habitats (964 stream km; table 4.6).

Streams inhabited by Pacific lamprey populations in coastal Oregon are projected to have decreases in summer low flows that have the potential to affect the larval ammocetes. Projected increases in mean August stream temperature by the turn of the century (table 4.6) may affect survival of larval rearing fishes and the timing or number of individuals as they metamorphose into their ocean-going life stage. Increases in water temperature could cause premature migration of juvenile lamprey as they metamorphose to their ocean life stage. Such early migration downstream toward estuary and ocean environments could expose them to salt water in estuarine and marine areas before they have made the physiological changes needed to accommodate their osmoregulatory function. Owing to the long residence time that larval Pacific lamprey spend in freshwater, they are considered highly vulnerable to climate change in the assessment area (table 4.3).

Western brook lamprey—

Western brook lamprey are a non-parasitic fish that is eel-like in form and distributed from California to Alaska along the Pacific coast. Western brook lamprey are a small fish (<18 cm) that occupies freshwater and coastal nearshore habitats exhibiting resident and migrant life histories (fig. 4.1). Populations appear to be declining, based on local extirpations from habitat loss and passage limitations. However, comprehensive data on their distribution and population status do not exist. They are not protected at the state or federal level even though they have been petitioned for listing under the ESA. In the OCAP assessment area, western book lamprey inhabit 350 km of stream habitat (table 4.7, fig. 4.11).

Western brook lamprey are concentrated in headwater and low-order streams throughout coastal Oregon catchments (Gunckel et al. 2009). Spawning occurs from March to July. Ammocetes generally emerge a few weeks after spawning and live in freshwater as filter feeders for 2–7 years. A study focused on the survival of embryonic and newly-hatched fish found that western brook lamprey survival was the highest at 18 °C and lowest at 22 °C, similar to Pacific lamprey, suggesting that temperatures above 20 °C cause stress (Meeuwig et al. 2005). More than a third of the streams in western brook lamprey habitat are projected to have mean August temperature above 20 °C by 2080, which may make it difficult for western brook lamprey to persist in those streams without adequate access to coldwater refugia (table 4.7). They are considered highly vulnerable to climate change in the assessment area owing to their residence time in freshwater (table 4.3).

Green sturgeon—

Green sturgeon are a large, sea-run fish that is long lived, and slow growing. They are found in western North America from Mexico to Alaska, one of the two sturgeon species found in coastal Oregon. They are olive-green colored and occupy freshwater, estuarine, and ocean habitats with most time spent in saltwater (fig. 4.1). Although little is known about the current or historical abundance of green sturgeon, they are thought to have experienced substantial population declines during the past century from overharvest and habitat destruction. There are two distinct populations of green sturgeon in Oregon. The northern population, which spawns in the Rogue River, Klamath, and Trinity Rivers, can be found off the Oregon coast in coastal rivers and estuaries, and in the Columbia River estuary and Washington estuaries. The southern population, which spawns in the Sacramento River, is ESA-listed as threatened, and are also found off the Oregon coast in coastal rivers and estuaries, and in the Columbia River estuary and Washington estuaries. The northern population of green sturgeon has no special status in Oregon at the state or federal level, although both populations mix off of coastal Oregon. In the assessment area, green sturgeon inhabit 197 km of stream habitat of coastal Oregon (table 4.8, fig. 4.12).

Information about green sturgeon distribution and life history is largely associated with capture as bycatch in commercial salmon, white sturgeon, and bottomfish fisheries. They are occasionally found in all coastal Oregon estuaries and in the lower reaches of rivers. Green sturgeon from the Columbia River have been captured in the Sacramento River and as far north as Vancouver Island, British Columbia. Green sturgeon reach sexual maturity around 15 years of age and can live to be 70 years old. They can spawn in freshwater several times in their lives, returning to their natal rivers every 3–5 years. Over half of green sturgeon habitat is projected to exceed 23 °C by 2080, and although their specific temperature tolerances are not known, they are a coldwater fish and will need access to coldwater refugia to persist (table 4.8). They are considered highly vulnerable to climate change in the assessment area owing to their long life and slow growth (table 4.3).

Eulachon—

Eulachon (also spelled oolichan, ooligan, hooligan, olachen, olachan, oolachan, oolichan, and oulachan in different native languages), is also called the candlefish (owing to its high oil content) or the salvation fish (owing to their presence when First Nations people were starving or low on winter food supplies). Eulachon is a small, sea-run smelt ranging from northern California to the southern Bering Sea. Eulachon return to streams in early spring to spawn (beginning in February for coastal Oregon populations, in March or April in British Columbia, and in April or May in Alaska). Many populations throughout their range have declined, and some appear extirpated, although the extent of decline is unknown. Historical information about eulachon runs on the Columbia River is anecdotal or based on tribal, commercial, or recreation information. The southern DPS of eulachon was listed as threatened under the ESA on March 18, 2010 (75 FR 13012). The National Marine Fisheries Service 2016 ESA five-year review concluded that the threatened designation remained appropriate. Although eulachon abundance in monitored rivers improved in 2013–2015, recent conditions in the northeast Pacific Ocean may have caused the sharp declines in eulachon abundance in monitored rivers in 2016 and 2017 (Lee et al. 2016).

In the assessment area, eulachon inhabit 37 km of stream habitat in the Umpqua River (table 4.9, fig. 4.13), but a better understanding of their coastal distribution is needed to determine their presence in other coastal streams. For example, there have been sightings of eulachon in Tenmile Creek and Big Creek. The mean August water temperatures of mainstem Umpqua River is projected to exceed 23 °C by 2080 (table 4.9), thus challenging the persistence of eulachon in that basin without coldwater refugia. They are considered highly vulnerable to climate change in the assessment area, owing to their limited known presence in coastal Oregon and the lack of information about their distribution or life stage needs (table 4.3).

Fall-Spawning Fishes

Fall-spawning fishes along coastal Oregon are expected to be vulnerable to seasonal changes in temperature and flow patterns manifested at different times of the year. Low flow and higher temperatures in the summer may make freshwater refugia more difficult to find. For example, species with long-term freshwater residency, such as coho salmon and spring Chinook salmon, may be affected by long-term increases in temperature and summer low flows. Projected declines in flow by the end of this century could reduce potential population sizes by intensifying competition for food and space (Luce and Holden 2009).

The entire assessment area inhabited by fall-spawning fish is projected to regularly experience high-flow conditions (10 or more days of 95th percentile flows per year (tables 4.10–4.12), reflecting the hydrologic flashiness of coastal Oregon streams. In fall, delayed rain events coupled with lower flows may affect access to stream reaches and delay spawning, possibly increasing adult mortality and reducing spawning success. Anticipated changes in rain-snow hydrologies or shifts in storm patterns and delivery of precipitation can scour incubating eggs and newly emergent fishes (Goode et al. 2013). Scour effects differ depending on species and life history and are buffered by local variations in channel confinement and geomorphology (Goode et al. 2013, Sloat et al. 2017).

Coho salmon—
Coho salmon are a sea-run Pacific salmon whose distribution ranges from central California to northern Korea in Asia. Although most coastal coho salmon are considered wild in origin, there are hatchery stocks present in many coastal watersheds. In 2015, coho salmon returns across the region were far below returns from previous years, likely owing to ocean conditions from El Niño and negative impacts from “the blob,” a high-temperature/low-oxygen marine event in the region. Because major declines in coho salmon populations have been noted since the 1970s, they are listed as a threatened species under the federal ESA. The Oregon Coast coho salmon

ESU is an ESA-listed unit, ranging from coastal rivers south of the Columbia River to north of Cape Blanco. Coho salmon are also listed as critical by the State of Oregon.

The 2016 Oregon Coastal Coho Salmon Recovery Plan indicated that native coho salmon returns to the Oregon Coast have improved since the species was listed. Recent native coho salmon returns hit modern-era highs of over 350,000 spawners in 2011 and 2014, but declined to 99,000 spawners in 2012 and 57,000 spawners in 2015 (ODFW 2016). These fluctuations indicate that coho salmon abundance along the Oregon coast is tied largely to marine conditions, which can change quickly, creating uncertainty about whether recent levels of abundance can be sustained. In the OCAP assessment area, coho salmon habitat is represented by 5,200 km of the stream network (table 4.10; fig. 4.14).

Oregon coastal coho salmon juveniles rear in freshwater, and less commonly in estuarine habitats, for approximately a year before juveniles smolt and migrate to sea. Adults generally spawn in small, unconfined, low-gradient tributaries to larger rivers (Burnett et al. 2007) or coastal lakes. Some populations of coho salmon occupy coastal dune lakes while in freshwater, including Siltcoos, Tahkenitch, and Tenmile Lakes. Juvenile coho salmon have a general preference for pools, alcoves, and beaver ponds rather than habitats with higher flow velocities (Gonzalez et al. 2017, Nickelson et al. 1992). Growth and winter survival of juvenile coho salmon is higher in intermittent streams compared to perennial mainstem streams (Ebersole et al. 2006, 2009). Oregon coastal coho salmon smolts migrate downstream to the ocean from late March through July and often spend 1–2 years in the ocean before returning as adults to spawn in freshwater, migrating upstream from October through January.

There is little variation in return timing of adults within populations, leading to tight run timing that varies by local temperature and flow patterns (Flitcroft et al. 2019). For example, coho salmon in the Columbia River migrate upstream at Ice Harbor Dam in summer/early fall (September and October) and at Bonneville Dam in summer (July to September); Oregon coastal coho salmon on the Umpqua River at Winchester Dam migrate in autumn and winter (September to December). Migration distances to spawning areas are often short, so migration can be completed in a few days or weeks, and spawning usually occurs within one or two weeks of reaching the spawning grounds.

Coho salmon are affected by both temperature and discharge, reflecting the hydrology and water management of their upstream watersheds (Flitcroft et al. 2019). In the OCAP assessment area, mean August temperature of coho salmon stream habitat is projected to increase for all populations, with over 65 percent of the streams exceeding 17 °C (table 4.10). Approximately 40 percent of streams in the Oregon coast coho ESU are already considered temperature impaired (ODEQ 2007), and rising water temperatures could cause further habitat degradation. Temperature increases can: (1) accelerate egg incubation rates in winter or spring, (2) accelerate growth in spring, and (3) potentially desynchronize the developmental phenology of juveniles from the temporal availability of seasonal habitats (Wainwright and Weitkamp 2013).

Sand Creek (a small coastal tributary) and Andy Creek (a tributary to Sand Creek) support medium and high intrinsic potential habitat, respectively, above where coho are currently found, which also coincides with modeled beaver habitat (fig. 4.15). These upstream areas may provide future coho salmon habitat if access to these locations is enhanced. Three Rivers, a tributary of Nestucca River, and Bear and Maple Creeks, tributaries of Siltcoos Lake, have higher-elevation coho salmon habitats overlapping with mainstem reaches that may benefit from intact riparian corridors (figs. 4.16, 4.17). Stream segments could be restored or managed for coho salmon in all of these locations to encourage expansion of their distribution. Our different examples (figs. 4.15–4.17) corroborate results from Flitcroft et al. (2019), which indicate that under climate change, there will not be a single change that will be experienced equally across coho salmon; rather, each population will need to be evaluated separately. Coho salmon are considered highly vulnerable, but are also highly vulnerable for southern Oregon coast coho populations, to climate change in the assessment area because they face cumulative acute effects during many stages of their life cycle (Crozier et al. 2019) (table 4.3).

Chinook salmon—
Chinook salmon are the largest-bodied species of Pacific salmon in the genus *Oncorhynchus*, ranging from southern California to Kotzebue Sound in Alaska. Their common name refers to the Chinook native peoples of the Pacific Northwest. Chinook salmon spend their developmental stages of egg, fry, and juveniles lower in watersheds, generally in rivers, but also in estuarine habitats, before smolting and moving to the estuaries and then ocean, where they spend 1–6 years before returning to freshwater to spawn and die. Of all Pacific salmon, they have the greatest variability in their life stages (Crozier et al. 2019), with variation even within a single ecotype (Reimers 1971, 1973). Early-migrating stream-type (or spring) Chinook salmon migrate upriver from May through July, and late-migrating ocean-type (or fall) Chinook salmon migrate from September through December. Both spring and fall Chinook salmon spawn at similar times between September and December. Spring Chinook are found in a few coastal rivers, including Tillamook, Nestucca, Siletz, Alsea, Coquille, Umpqua, and Rogue Rivers. Chinook salmon of the Oregon coast are not ESA listed.

Chinook salmon occupy 2,979 km of stream habitat in the OCAP assessment area (table 4.11, fig. 4.18) encompassing 11 coastal population groups. Spring Chinook population assessments in the Oregon Native Fish Status Report (ODFW 2005) conclude that the Nestucca and Tillamook River populations meet less than four criteria, while spring Chinook in the Alsea River, and fall Chinook in the Salmon and Coos Rivers, meet four to five criteria in the Oregon Native Fish Status Report (ODFW 2005) (fig. 4.19). The 2014 Coastal Multi-Species Conservation and Management Plan by ODFW concluded that most Chinook populations are viable, with only one population (Elk River) considered non-viable. However, seven populations had recent declining abundance trends, resulting in an overall strong-guarded status.

Chinook salmon populations in the assessment area are projected to have over 75 percent of streams experiencing mean August temperatures >17 °C by 2080 (table 4.11). This could especially affect the Tillamook, Nestucca and Alsea River populations where abundance is already low as evidenced by declining hatchery and wild-fish returns. Stream habitats where there is intrinsic potential for Chinook salmon beyond where they currently are distributed could be prioritized for restoration to encourage distribution extension (figs. 4.20, 4.21).

Juvenile Chinook generally undergo smoltification by April or May of each year, which under climate change, is a time period projected to have highly variable flow and temperature regimes. High in-river flows and high water temperature have adverse effects on smolt migration (Sykes et al. 2009) by creating inhospitable conditions that narrow the window for smolt migration. In contrast, cool water temperatures and minimal flows can also delay migration. Spring Chinook return to freshwater in spring or early summer and hold in rivers and streams for several months before spawning, making them vulnerable to thermal stresses that may accumulate through the summer. Adults rest in large pools with cool water, which are naturally less abundant in late summer and early fall. Holding and migrating adults may become increasingly stressed and susceptible to disease, which will diminish reproductive potential and increase pre-spawning mortality (Bowerman et al. 2018). Coolwater refuges are likely to become even less available at those times as the climate warms.

Warmer water temperatures lead to changes in behavior, physiology, and growth, with negative implications for long-term persistence of Chinook salmon (Kuehne et al. 2012), especially for spring Chinook. Returns of adult spring Chinook on the Umpqua River were the lowest in 2018 (28 adults returning), which is attributed to stream temperatures near lethal limits and to poor ocean conditions. For example, Beechie et al. (2006) found that the loss of summer pre-spawn staging habitats in rivers entering Puget Sound, Washington could result in the replacement of spring Chinook salmon by fall Chinook, whose fall run-timing avoids exposure of adults to warm, low-flow summer conditions. However, recent research shows that spring and fall Chinook may be genetically different (Thompson et al. 2019).

Spring Chinook salmon may have more vulnerability to freshwater conditions than fall Chinook salmon, owing to them spending more time in freshwater habitats. Fall-migrating fish return one to three cohorts of fish, which may make them more vulnerable to ocean conditions, or good years may be able to compensate for bad years. Chinook salmon will experience increasing strength of ENSO and decreasing net primary productivity, leading to a potential lack of food sources. Overall, spring Chinook salmon in the OCAP assessment area are considered to have very high vulnerability to climate change, similar to other spring runs in the Willamette River and California, and fall Chinook have high vulnerability similar to the Snake River fall run of Chinook salmon (fig. 4.3; Crozier et al. 2019).

Chum salmon—

Chum salmon are distributed from North America along the mid-Oregon coast into Asia, and may historically have been the most abundant of all Pacific salmon. Coastal Oregon populations are at the southern-most extent of their range. Chum salmon numbers plummeted in the early 1950s and have yet to recover, causing their populations to be considered extinct south of the Umpqua River and presumed extinct in the Alsea and Siuslaw Rivers. However, chum fry have been captured in coastal streams, including in the Knowles Creek smolt trap in the last 10 years. Major spawning populations of chum salmon are found only as far south as the Yaquina River on the mid-Oregon coast.

Adult salmon monitoring by the ODFW indicates that chum salmon are present in only a few coastal basins on a consistent basis. The Nestucca River population along the coast meets the fewest status criteria in the Oregon Native Fish Status Report (ODFW 2005) owing to low production, abundance, and limited distribution. By comparison, the Yaquina River and Tillamook River populations meet the most criteria (fig. 4.22). The status of chum salmon for the State of Oregon is considered critical, and they are also a USFS Regional Forester sensitive and BLM special-status species. A better understanding of their status and distribution is needed throughout the assessment area, as well as an understanding of the connection among coastal Oregon populations.

Historically, chum salmon spawned from October through March in a variety of stream types ranging from small tributaries to large mainstem rivers and side-channels. Now they spawn from October through December in small tributaries close to mainstem rivers in lower river segments. Chum salmon emerge in February to April, and generally migrate directly to the estuary or near-shore environment by April for rearing. They need to find high-quality habitat quickly, including good water quality, abundant food resources, and refuges from predators, as they lack energy reserves and the ability to swim well. Because they migrate downstream as emergent fry, they can be especially vulnerable to predation by pinnipeds, birds, and other fishes. The estuary provides critical rearing grounds for chum salmon, making connectivity between freshwater spawning and estuary rearing habitats critical for the survival of early life stages (fig. 4.1). In the assessment area, chum salmon inhabit 460 km of stream habitat of coastal Oregon (table 4.12, fig. 4.23).

Climate change is expected to affect the adult spawning and egg life stages of chum salmon in freshwater, in the estuarine and near-shore environment for rearing, and in the ocean where they grow to full size and mature as adults before returning to freshwater. Climate change may already be affecting chum return timing and adult body size. For example, in the Skagit River, chum salmon adults are returning to streams up to two weeks earlier than in the past, and fish are spawning before the first fall rains, which they did not do historically (Rubenstein et al. 2019). Adult chum salmon in Japan decreased in body size from the 1970s to the 1990s, which may have been caused by temperature increases and reduced marine food resources (Kishi et al. 2010).

Although chum salmon spend less time in freshwater than other Pacific salmon, they depend heavily on freshwater spawning habitats, and rearing habitats in tidally influenced and estuarine settings, making them sensitive to degraded estuarine conditions. While in freshwater, populations of chum salmon are projected to experience increasing temperatures by 2080 when temperatures in more than a quarter of the streams will be greater than 20 °C (table 4.12). Coastal Oregon chum salmon are considered moderately vulnerable to climate change, similar to the Columbia River run (table 4.3; Crozier et al. 2019).

Research Needs

Habitat conditions and regional climates in the OCAP assessment area have been variable through time, thus providing a template upon which adaptive capacity of native fishes has evolved. Therefore, aquatic ecosystems and fishes may already possess some resilience to climate change (Comte and Olden 2017b). However, species- and habitat-specific responses are uncertain and will be complex and potentially divergent. Consequently, understanding how individual species respond to climate change, and their interactions with other stressors, is essential (Reid et al. 2019). Part of understanding climate change will be capturing both the uncertainty and variability in environmental conditions, which will account for the range of possible dynamics and responses.

Baseline monitoring data of fish distributions, aquatic ecosystem complexity, and habitat components contribute to assessments of the effectiveness of aquatic conservation plans. These plans and associated monitoring will be most effective in partnership with local stakeholders and implemented across land ownerships. Fish distribution, seasonal habitat needs, and life-stage occupancy information is incomplete for several fish species in this assessment, especially Pacific lamprey, western brook lamprey, green sturgeon, and eulachon. In addition, more information is needed on habitats such as coastal lakes and back channels. Distribution information can be combined with existing datasets describing fish barriers, roads, and habitat quality to identify areas of special conservation concern or focus. Comprehensive information about the amount, pattern, and type of restoration activities across land ownerships that have already been implemented in streams and forests is also incomplete (Reeves et al. 2018).

The potential effects of wildfire, both stand replacing and low intensity, on fishes and aquatic habitats in the OCAP assessment area may be increasingly important in the future. Climate change models that can more accurately project changes at finer spatial and temporal scales will be especially valuable for fisheries management. Ultimately, the conservation of freshwater habitats and their associated fishes depends on our ability to implement solutions that allow these habitats and species to coexist with a growing scope of human influences.

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Chapter 5: Climate, Disturbance, and Vegetation Change in the Oregon Coast

Matthew J. Reilly, Doug A. Glavich, Steve A. Acker, Holly S.J. Kearns, Elizabeth A. Willhite, Becky K. Kerns, John B. Kim, Chelsea S. Monks, Chris Donaldson, and Jessica E. Halofsky

Introduction

Climate change is expected to have profound effects on the structure, composition, and function of ecosystems across the United States over the next century (Clark et al. 2016, Peterson et al. 2014, Vose et al. 2012). However, interactions among climate, disturbance, and vegetation change are often complex. The Oregon Coast Adaptation Partnership (OCAP) assessment area is located in the Oregon Coast Range and covers approximately 2.2 million ha, from the shores of the Pacific Ocean to the western margins of the Willamette Valley (fig. 5.1). Understanding the geographic variability in projected changes is essential to anticipating the implications of these changes and developing strategies to adapt to them.

The goals of this chapter are to provide a biogeographic assessment of the projected effects of climate change on vegetation. We first provide some historical perspective, extending back the last 12,000 years during the Holocene. Knowledge of how vegetation responded to changes in the climate in the past provides important insights into how vegetation may change in the future. These historical studies document widespread and often rapid changes in broad patterns of vegetation prior to Euro-American colonization. Next, we discuss the role of disturbance on stand and landscape dynamics to provide context for understanding the historical range of variability in forest conditions in the assessment area. We then describe the results of a computer simulation model that projects changes in the geographic distribution of vegetation types and biomes with climate change. Finally, we synthesize existing knowledge to identify current and future vulnerabilities to climate and disturbance on vegetation.

We define vulnerability as “the extent to which a species or population is threatened with decline, reduced fitness, genetic loss, or extinction owing to climate change” (Dawson et al. 2011). Collectively, climate change vulnerability is a function of three main components: sensitivity, exposure, and adaptive capacity, all of which we assessed based on current scientific knowledge. Sensitivity refers to the degree to which change in climate will affect the persistence or fitness of a species or population. Exposure refers to potential for climate change to affect an organism, species, or landscape. Adaptive capacity refers to the potential of a species or population to survive and persist by migrating or adjusting *in situ* to changes in climate. Our assessment of climate change vulnerability in this chapter is derived primarily from empirical observations on past and current changes in forests of the region. Despite a wealth of scientific knowledge about climate change in the assessment area, uncertainties remain because the depth of knowledge differs among components of vulnerability.

Environmental Setting and Current Vegetation

The Oregon Coast Range is a rugged mountainous region characterized by a mild climate with abundant precipitation and highly productive forests. We divide the assessment area into different vegetation types (table 5.1, fig. 5.1, fig. 5.2) with different geographic distributions related to climatic factors that vary with distance from the coast and topography. At the broadest level, we distinguish among vegetation zones (fig. 5.1) (McCain and Diaz 2002). Vegetation zones represent biophysical settings that are referred to by the most common shade tolerant species occurring within a particular setting in the absence of disturbance. Therefore, existing or current vegetation often varies within zones depending on seral stage (i.e., successional stage or stage of structural development) and time since disturbance. For example, the most abundant vegetation zone in the Coast Range, western hemlock, is currently dominated by Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) but would be dominated by western hemlock (*Tsuga heterophylla* [Raf.] Sarg) in the absence of disturbance. Within each of these zones, multiple plant association types are distributed across a broad range of environmental and climatic conditions within the assessment area (fig. 5.2) (McCain and Diaz 2002).

Vegetation zones and plant association groups provide an ecological framework for discussing climate and vegetation change across broad geographic extents. Vegetation zones have overlapping species pools but consist of distinct plant community assemblages, as well as similar but internally variable biophysical conditions and historical disturbance regimes that vary geographically (Spies et al. 2018, Winthers et al. 2005). Individual vegetation zones also have characteristic pathways of structural development that differ in complexity and reflect regional gradients in productivity and disturbance regimes (Reilly and Spies 2015). We provide a broad overview of the composition and geographic distribution of the major vegetation zones and plant association groups (McCain and Diaz 2002, Simpson 2020). A more detailed and comprehensive characterization of plant communities including patterns of structural development and successional change is found in Franklin and Dyrness (1973).

Sitka spruce (*Picea sitchensis* [Bong.] Carr.) is the dominant vegetation zone in wet coastal areas and comprises approximately 16 percent of the assessment area. The distribution of this zone is mostly limited to the coast and closely related to the occurrence of summer fog, extending inland only along major river valleys. Other common tree species include Douglas-fir, western redcedar (*Thuja plicata* Donn ex. D. Don), and western hemlock. Red alder (*Alnus rubra* Bong.) is a major hardwood species and bigleaf maple (*Acer macrophyllum* Pursh) may be present.

The Sitka spruce zone is composed of three forested plant association groups distributed along a precipitation gradient. Sitka spruce and salmonberry (*Rubus spectabilis* Pursh), a common shrub, occur as a plant association group on wet sites with low slopes and near streams. On moist sites, Sitka spruce is often found with understories dominated by Oregon oxalis (*Oxalis oregana* Nutt.) and western swordfern (*Polystichum munitum* [Kaulf.] C. Presl). The driest Sitka spruce sites are occupied by a mesic salal (*Gaultheria shallon* Pursh) community. Devil's club (*Oplopanax horridus* [Sm.] Miq.) is an important species at intermediate levels of precipitation, as are red huckleberry (*Vaccinium parvifolium* Sm.) and fool's huckleberry (*Menziesia ferruginea* Sm.). Common herbaceous species in the understory include miner's lettuce (*Claytonia sibirica* L.), deer fern (*Blechnum spicant* [L.] Sm.), and sweet-scented bedstraw (*Galium triflorum* Michx.).

The western hemlock zone comprises approximately 70 percent of the OCAP assessment area. This zone covers much of the lower elevations and is primarily dominated by Douglas-fir with increasing levels of shade tolerant western hemlock in mature and late-seral stands. Western redcedar is also present, primarily at lower elevations in wetter sites. Hardwoods are also an important component of forest communities in the assessment area. Red alder is common following disturbance and in riparian areas. Bigleaf maple may be found on a range of sites but occurs mostly in the interior and eastern slopes of the Coast Range where colder winter temperatures improve germination. Giant chinkapin (*Chrysolepis chrysophylla* [Douglas ex Hook.] Hjelmq.) and Pacific madrone (*Arbutus menziesii* Pursh) are evergreen hardwoods that are often present on dry, warm sites.

The western hemlock zone is broken into five different plant association groups that are distributed along a precipitation gradient. The understories of the wettest sites are dominated by Alaska huckleberry (*Vaccinium ovaifolium* Sm.) and Oregon oxalis. A plant association group dominated by salmonberry occurs on wet sites throughout the southern, western, and central portions of the assessment area. Mesic sites often include western sword fern, Cascade barberry (*Berberis nervosa* Pursh), and salal. Moist site plant associations are characterized by swordfern. Warm sites at intermediate levels of precipitation include Pacific rhododendron (*Rhododendron macrophyllum* D. Don). Several species of shrubs including California hazel (*Corylus cornuta* Marshall), vine maple (*Acer circinatum* Pursh) may also be present. Devils club also occurs on sites that are relatively wet and cool.

The Pacific silver fir zone makes up only 1 percent of the OCAP assessment area and occurs mostly in areas where elevation exceeds 900 m. This zone is located on several peaks including Mary's Peak, Saddlebag Mountain, Laurel Mountain, Stott Mountain, Saddle Mountain, and Mt. Hebo and is dominated by noble fir (*Abies procera* Redher). Summer frosts are common, and snow may persist well into the spring, particularly in openings such as meadows. This zone is represented by a single plant association group characterized by noble fir in the overstory and Oregon oxalis in the understory. Western hemlock and Douglas-fir may also be present in the overstory with several shrub species including salmonberry, prickly currant (*Ribes lacustre* [Pers.] Poir.), big huckleberry (*Vaccinium membranaceum* Douglas ex Torr.), red huckleberry (*Vaccinium parvifolium* Sm.), and trailing blackberry (*Rubus ursinus* Cham. & Schltdl.) in the understory. Common understory herbaceous species include western swordfern, northern inside-out flower (*Vancouveria hexandra* [Hook.] C. Morren & Decne.), starry false Solomon's seal (*Maianthemum stellatum* [L.] Link), false lily of the valley (*Maianthemum dilatatum* [Alph. Wood] A. Nelson & J.F. Macbr.), and vanilla leaf (*Achlys triphylla* [Sm.] DC.).

Dry vegetation zones including Douglas-fir and grand fir comprise 6.5 percent and 5 percent of the OCAP assessment area, respectively. These vegetation zones are found mostly in the southern Coast Range on lands managed by the Bureau of Land Management. The Douglas-fir zone is represented by a single plant association group that is often characterized by poison oak (*Toxicodendron diversilobium* [Torr. & A. Gray] Greene) and may include California black oak (*Quercus kelloggii* Newberry) to the south. The grand fir zone (*Abies grandis* [Douglas ex D. Don] Lindl.) is found mostly around the margin of the Willamette Valley in the southeastern part of the assessment area.

Special Habitats

A variety of special habitats associated with unique environmental settings also occur across the assessment area. Riparian areas occur along rivers and usually have a large component of shrubs and hardwoods (Pabst and Spies 1999). Along the coast, these include tidal and coastal estuaries, Sitka spruce swamps, and coastal dunes. Meadows occur on coastal headlands and in the inland mountains. These habitats are relatively rare, but they provide important components of biodiversity and ecosystem services.

The structure and composition of riparian areas vary with stream order, distance from stream and broad-scale factors including valley floor width and climate (Pabst and Spies 1999). Conifer dominance increases with distance from stream, and hardwoods and shrubs become more important at greater distances and in higher-order streams. Bigleaf maple and red alder are the most important hardwood species, and salmonberry is usually the dominant shrub (Hibbs and Giordano 1996, Pabst and Spies 1999).

Tidal estuaries occur along the coast where tides deliver salt water to low areas. Closer to the ocean where water is more brackish, these communities are commonly dominated by tufted hairgrass (*Deschampsi cespitosa* (L.) P. Beauv.) with other less common species including Baltic rush (*Juncus balticus* Willd.) and silver beachweed (*Potentilla anserina* L.). As waters become less brackish, estuarine communities grade into those dominated by slough sedge (*Carex obnupta* L.H. Bailey) and Hooker’s willow (*Salix hookeri* Barratt ex Hook.) along the margins.

In coastal estuaries, marsh plant communities occur across a salinity gradient related to relatively fine scale changes in surface elevation and salinity (Santelmann et al. 2019). Pickleweed (*Salicornia* spp.), swampfire (*Sarcocornia perennis* [Mill.] A.J. Scott), and saltgrass (*Distichlis spicata* [L.] Greene) are common in low marshes at the saltier end of the salinity gradient. Mid Marshes are commonly dominated by Lyngbye’s sedge (*Carex lyngbyei* Hornem.). High marshes dominated by tufted hairgrass, silver beachweed, and Baltic rush grade into small-flowered bulrush (*Scirpus microcarpus* J. Presl & C. Presl) and waterparsley (*Oenanthe sarmentosa* C. Presl ex DC.) at the fresh end of the salinity gradient. Hooker’s willow fills less saturated areas and transition zones to forest. Slough sedge fills freshwater channels.

Swamps dominated by Sitka spruce may also occur intermixed with tidal estuaries in coastal fens. Common species of Sitka spruce swamps include slough sedge and skunk cabbage (*Lysichiton americanus* Hultén & H. St. John).

Coastal dune communities range from open sand communities composed of forbs and graminoids to stable mat communities dominated by dwarf shore pine (*Pinus contorta* var. *contorta* Douglas ex Loudon) forests mixed with shrubs (Christy et al. 1998). Open dune communities are dominated by sand fescue (*Festuca ammobia* Pavlick) and seashore bluegrass (*Poa macrantha* Vasey). The Pacific coast endemics, yellow sand verbena (*Abronia latifolia* Eschsch.), pink sand verbena (*Abronia umbellata* ssp. *Brevifolia* [Standl.] LA Galloway), and grey beach pea (*Lathyrus littoralis* (Nutt.) Endl. ex Walp.) are also found in the open dune communities. If these communities remain stable, they eventually succeed to shore pine mat communities that are dominated by bearberry (*Arctostaphylos uva-ursi* [L.] Spreng.). Dune systems have gone through profound changes due to multiple invasive species, particularly two species of European beachgrass (*Ammophila arenaria* [L.] Link and *A. breviligulata* Fernald). Other invasive species, including Scotch broom (*Cytisus scoparius* [L.] Link), gorse (*Ulex europaeus* L.), and Portuguese broom (*Cytisus striatus* [Hill] Rothm.), have significant impacts on dune communities.

Several special habitats exist on coastal headlands and inland mountains including meadows, wetlands, and topo-edaphic positions with soils that are too shallow to support trees. Mesic to dry meadows occur primarily on inland gabbro intrusions of mountain summits at greater than 900 m elevation and at lower elevation on east- and west-flank extrusive basalt flows.

The higher elevation meadow plant communities are dominated by Roemer's fescue (*Festuca roemeri* [Pavlick] E.B. Alexeev), blue wild rye (*Elymus glaucus* [Buckley] Nevski), and California oatgrass (*Danthonia californica* Bol.), with California sedge (*Carex californica* L.H. Bailey), broadleaf lupine (*Lupinus latifolius* Lindl. ex J. Agardh), early blue violet (*Viola adunca* Sm.), and meadow chickweed (*Cerastium arvense* L.).

Lower elevation basalt-associated meadows on the western side of the Coast Range typically have steep slopes and shallow soils. Summer soil moisture is maintained by fog. Roemer's fescue dominates these sites with lesser amounts of herbs tolerant of low soil moisture, American carrot (*Daucus pusillus* Michx.), farewell-to-spring (*Clarkia amoena* (Lehm.) A. Nelson & J.F. Macbr.), and coastal tarweed (*Madia sativa* Molina). Lower elevation, basalt-associated meadows on the eastern side of the Coast Range also occur on steep slopes and shallow soils but are xeric with the warm summer climate and no summer fog. These sites are forb dominated with xeric-adapted species including Oregon sunshine (*Eriophyllum lanatum* [Pursh] Forbes), arrowleaf buckwheat (*Eriogonum compositum* Douglas ex Benth.), and deltoid leaf balsam root (*Balsamorhiza deltoidei* Nutt.).

Paleoecological History and Holocene Dynamics

Looking back on how the vegetation of the OCAP assessment area responded to climatic variability in the past provides a context for understanding the potential ecological effects of climate change in the future. Paleoecological studies examine temporal patterns of charcoal and pollen in lake sediment cores, which serve as proxies for past environmental conditions and for reconstructing changes in vegetation composition over time (Whitlock et al. 2003).

Paleoecological studies are limited in terms of their spatial and temporal precision, but when multiple studies are compared across the region, they provide a biogeographic retrospective of vegetation change over the last ~12,000 years during the Holocene. In some cases, it is possible to identify individual species from pollen, while in others the taxonomic resolution may be limited to genus. Collectively, these studies indicate that the vegetation of the Pacific Northwest experienced major ecological changes during the Holocene. Multiple periods of quasi-stability were punctuated by distinctive periods of transition and rapid change often catalyzed by fire.

Knowledge of vegetation changes during the Holocene is particularly rich in the greater Pacific Northwest. In addition to studies from three lakes in the Oregon Coast Range, there are several studies from the western Cascade Range of Oregon and Washington, the Olympic Peninsula of Washington, and the Klamath Mountains in southwestern Oregon and Northern California. Although the climatic and environmental settings of these studies differ from that of the OCAP assessment area, they share many of the same species and exhibit similar patterns of long-term change.

Complex interactions between a fluctuating climate and fire drove vegetation change during the Holocene (Bartlein et al. 1998, Crausbay et al. 2017, Marlon et al. 2009, Walsh et al. 2015, Whitlock 1992, Whitlock et al. 2008). Species responded individually to changes in climate, sometimes forming species assemblages that lack contemporary analogs (Whitlock et al. 2003). Species ranges expanded and contracted over time, with some species persisting in refugia where local conditions allowed persistence in regions where climate was generally inhospitable (Gavin et al. 2014). Refugia likely played an important role in the persistence of populations through the numerous climatic transitions that occurred since the last glacial maximum (Bennett and Provan 2008, Hampe and Jump 2011).

The early Holocene—approximately 12,000 to 8,000 years before present (BP)—was a time of rapid vegetation change with species assemblages that lack modern analogs (Whitlock 1992). Following glacial retreat, increased summer insolation led to higher summer temperatures and drier conditions than the present, while lower winter insolation led to cooler and wetter winters, likely amplifying seasonality and summer drought compared to present day climate (Bartlein et al. 1998). Fire activity was relatively low at the beginning of the early Holocene but increased and remained high until approximately 8,000 BP (Briles et al. 2005, Walsh et al. 2015). As summers warmed and glaciers receded, forests replaced non-forested areas and open woodlands, and xerophytic species increased at many low elevation sites across western Oregon and Washington (Walsh et al. 2015).

As the climate warmed during the early Holocene, species responded individually and became distributed along elevational and latitudinal gradients (Whitlock et al. 2003). Douglas-fir, red alder, and oak (*Quercus* spp.) replaced spruce and pine at lower elevations in the Coast Range and western Cascades (Cwynar 1987, Grigg and Whitlock 1998, Long et al. 2007, Sea and Whitlock 1995, Walsh et al. 2008). The fire-return interval in the Coast Range was approximately 110 years during this period (Long et al. 1998), and high levels of bracken fern (*Pteridium aquilinum* [L.] Kuhn) suggest forests were more open (Long et al. 2007). On the Olympic Peninsula, herbaceous tundra was replaced by subalpine fir (Gavin et al. 2001). Mid-elevations of the Klamath Mountains in Oregon and California were dominated by open woodlands composed of pine and oak species and incense cedar (*Calocedrus decurrens* Torr.) (Briles et al. 2005, Daniels et al. 2005, Mohr et al. 2000).

Climate shifted towards cooler, wetter conditions with decreasing summer insolation during the middle of the Holocene (~8,000 to 4,000 BP) (Bartlein et al. 1998). Fire activity decreased during this time (Briles et al. 2005, Walsh et al. 2015), and modern species assemblages formed in some parts of the Pacific Northwest (Whitlock et al. 1992). In the Coast Range, species composition shifted to more fire-sensitive species, including western redcedar, western hemlock, and Sitka spruce, around 6850 years BP (Long et al. 1998). Western redcedar and western hemlock increased during this period across low- and middle-elevation forests of the Coast Range, the Cascade Mountains, and the Puget Trough (Cwynar 1987, Prichard et al. 2009, Walsh et al. 2008). Likewise, Pacific silver fir, mountain hemlock (*Tsuga mertensiana* [Bong.] Carrière), and Alaska cedar (*Callitropsis nootkatensis* [D. Don] D.P. Little) increased on the Olympic Peninsula (Gavin et al. 2001). In the Klamath Mountains, expansion of pine, fir, and *Cupressaceae* species also indicated cooler, wetter conditions during this period (Briles et al. 2005, Daniels et al. 2005, Mohr et al. 2000). With the exception of lower elevations, fire activity started increasing again around 5,500 yr BP (Walsh et al. 2015).

Fire activity continued to increase in the Pacific Northwest during most of the late Holocene (~4,000 yr BP to present) despite evidence that this period remained cool and moist (Bartlein et al. 1998, Walsh et al. 2015). Paleoecological studies indicate that fire activity was high in the Coast Range, and intervals between fire episodes are estimated at approximately 140 years (Long and Whitlock 2002). Around 2700 years BP, current climate was established (Long et al. 2007), fire activity began decreasing, and the interval between fire episodes recorded in the paleoecological record almost doubled to approximately 240 years (Long and Whitlock 2002). As fire activity decreased, western hemlock and Sitka spruce replaced red alder (Long and Whitlock 2002). In the Klamath Mountains to the south, fire activity increased during this time despite cool and moist conditions, and modern forests in the current Douglas-fir and white fir (*Abies concolor* [Gordon & Glend.] Lindl. ex Hildebr.) zones established approximately 2,000 years ago in the Klamath Mountains (Briles et al. 2005, 2008; Daniels et al. 2005; Mohr et al. 2000).

Climate and fire fluctuated considerably during the last 1,000 years (Long and Whitlock 2002). The warmest temperatures occurred during the Medieval Climate Anomaly (MCA; 900–1250 AD), and the coldest temperatures occurred during the Little Ice Age (LIA; 1450–1850 AD, Steinman et al. 2012). Precipitation also varied during this time, but there is less consensus about this in the literature. Cook et al. (2004) argue that a period of drought occurred during the MCA, but more recent evidence suggests a wet MCA and dry LIA (Steinman et al. 2014). Fire frequency increased during the MCA in the Oregon Coast Range (Long et al. 2007) and Klamath Mountains (Daniels et al. 2005, Mohr et al. 2000), as well as in the rest of Oregon and Washington (Walsh et al. 2015). Fire activity decreased during the LIA then increased in the 1800s when several large wildfires affected the Oregon Coast Range starting around 1850 (Teensma et al. 1991).

Disturbance Regimes

Multiple agents of natural disturbance operated at different spatial and temporal scales and drove forest stand and landscape dynamics over the last several centuries (Spies and Franklin 1989). Disturbance agents can be characterized as biotic (e.g., pathogens, insects) or abiotic (e.g., fire, wind, volcanoes), and differ considerably among vegetation types in terms of their prevalence and severity (i.e., tree mortality) (Reilly and Spies 2016). Biotic disturbances include several species of pathogens and insects (table 5.2) that are native to the area and played an important role in background mortality. Abiotic disturbances, including wildfire and wind, played a more variable role. Fires occasionally affected large areas, but the historical fire regime varied along an east-west gradient (fig. 5.3), and there is evidence that smaller, non-stand-replacing fires were common (Impara 1997, Weisberg and Swanson 2003). Physical disturbances and mass-wasting events such as landslides and floods affected smaller patches in specific topographic settings, creating habitat heterogeneity in topographically complex landscapes.

Biotic Disturbance

Biotic disturbances are common (table 5.2) and played an important role in forest development and landscape dynamics across the assessment area. Biotic disturbances such as insects and pathogens contribute to “background mortality rates,” which are also associated with competition and stand development. However, insect and pathogen infestations also have the potential to erupt into epidemic outbreaks that result in high levels of tree mortality (e.g., Raffa et al. 2008). Pathogen and insect activity do not always result in immediate tree mortality. However, the resulting decline in tree growth and vigor (Hansen and Goheen 2000, Marias et al. 2014) may initiate a long process of decline that eventually leads to mortality (Franklin et al. 1987, Manion 1981). Pathogens may also make trees less resistant and increase sensitivity to wind disturbance by predisposing them to stem breakage (Larson and Franklin 2010). Native pathogens and insects play a prominent but variable role in the disturbance regimes of both moist and dry vegetation zones of the assessment area (Hansen and Goheen 2000, Shaw et al. 2009).

Although some biotic disturbance agents are specific to a single host, many have the potential to affect multiple tree species (table 5.2). Tree mortality rates associated with insects are generally much lower than those associated with wildfire in the Pacific Northwest (Reilly and Spies 2016), but insects have the potential to cause greater loss of live carbon and canopy mortality than fire at large spatial scales (Berner et al. 2017, Hicke et al. 2016). They can also increase stand heterogeneity and accelerate successional dynamics.

Most native pathogens operate at decadal time scales, affecting relatively small areas, and cause low levels of tree mortality. However, native pathogens are persistent and generally widespread across the region (Reilly and Spies 2016) and may kill more volume than fire or insects in a year at regional scales (Lockman and Kearns 2016). Over 8 percent of Douglas-fir forests in western Oregon are occupied by laminated root rot centers in which half the Douglas-fir are dead (Hansen and Goheen 2000). Such root rot centers may initiate forest canopy gaps that can expand over time from increased exposure to wind.

Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) preferentially attacks larger Douglas-fir trees and typically operates on relatively small patches of trees, particularly after blowdown from wind events (Powers et al. 1999). In 1954, Douglas-fir beetle affected 1.8 million ha following successive large blowdown events in 1950 and 1951 (fig. 5.4). Three other years of exceptional Douglas-fir beetle activity occurred prior to 1970 following other wind events. Severe winter storm events can create large amounts of fresh Douglas-fir down trees and slash that are colonized by Douglas-fir beetle during the spring. Rapid beetle population increases in the fresh down material typically result in associated beetle attacks on standing green trees the following year, with beetle-killed trees turning a reddish color that can be visually detected by airborne sensors the second year following the initiating winter-storm event (Shaw et al. 2009).

The fir engraver (*Scolytus ventralis* LeConte) affects true firs and is positively associated with drought and root disease. Sitka spruce in warmer, drier habitats outside the heavy fog zone along the coast are highly susceptible to white pine weevil (*Pissodes strobi* Peck) which can cause severe terminal leader damage, stem deformation and growth reduction (Reeb and Shaw 2015). Frequent, repeated attacks can significantly impede height growth and in mixed stands make it difficult for Sitka spruce to successfully compete with other species during early stand development. Defoliating insects are also common. Since the early 1900's several western hemlock looper (*Lambdina fiscellaria lugubrosa* Hulst) outbreaks have been recorded in the north Oregon Coast Range. Although most defoliators rarely cause mortality, insect defoliation may reduce growth and make trees more sensitive to other insect infestations and root disease (e.g., *Armillaria* spp).

Pathogens, particularly root diseases, are prevalent in all vegetation zones. Laminated root rot (*Coniferiporia sulphurascens* [Pilat] L.W. Zhou & Y.C. Dai, formerly *Phellinus weirii*, *P. sulphurascens* Pilát) primarily affects Douglas-fir and true firs. Armillaria root disease (*Armillaria ostoyae* [Romagnesi] Herink) affects Douglas-fir, true firs, hemlocks (*Tsuga* spp.), pines, and Sitka spruce. Heterobasidion root disease (*Heterobasidion occidentale* Otrosina & Garbel, formerly *H. annosum* s-type) affects true firs and hemlocks. Heartwood decays, such as those caused by the velvet top fungus (*Phaeolus schweinitzii* [Fr.] Pat.) and the ring-scale fungus (*Porodaedalea pini* [Brot.] Bondartsev & Singer), cause decay in the butts and stems of mature trees. These decay organisms are weak pathogens that do not directly kill trees, although heartwood decay in the butt or stem can increase sensitivity to tree failure or breakage and subsequent mortality. Black stain root disease (*Leptographium wageneri* var. *pseudotsugae* T.C. Harr. & F.W. Cobb) affects Douglas-fir. Other important pathogens include stem rusts (*Cronartium* spp.) and dwarf mistletoe (*Arceuthobium tsugense* subsp. *tsugense* [Rosend.] G.N. Jones). Other biotic disturbance agents include foliage diseases, which are a serious concern when planting trees in locations where they are not currently found. These pathogens rarely result in the mortality of trees but may decrease individual tree growth and stand productivity over time and predispose trees to attack by insects and other pathogens.

Swiss needle cast (*Nothophaeocryptopus gaeumannii* [T. Rohde] Videira, C. Nakash., U. Braun & Crous) is a disease specific to Douglas-fir that has been increasing since the early 1990s (Hansen et al. 2000). Ritokova et al. (2016) found that damage to Douglas-fir from Swiss needle cast in the Oregon Coast Range more than tripled between 1996 and 2015, causing growth reductions of 23 percent. High-density Douglas-fir plantations near the coast where Sitka spruce and western hemlock were historically dominant are thought to be particularly vulnerable to Swiss needle cast (Black et al. 2010, Hansen et al. 2010, Manter et al. 2005, Rosso and Hansen 2003). An extensive list of research on Swiss needle cast is available at: http://sncc.forestry.oregonstate.edu/publications.

Several species of hardwoods are also subject to insects and pathogens. Tent caterpillars (*Malacosoma spp.)* are defoliators that feed on red alder and other riparian hardwoods including willows (*Salix* spp.) and cottonwood (*Populus trichocarpa* Torr. & Gray ex Hook.). Decline of Pacific madrone related to multiple fungal diseases has been reported over the past 30 years, with larger, older trees experiencing the most mortality (Elliott et al. 2002). Although not currently present in the assessment area, sudden oak death (*Phytophthora ramorum* Werres et al.) may be a threat to multiple species of trees and shrubs in the future, particularly if tanoak expands its northern distribution. This invasive pathogen has the potential to spread through air, water, and infected plant material (Peterson et al. 2014, Rizzo and Garbelloto 2003). Although it does not affect Oregon white oak, other hardwood species (e.g., madrone, bigleaf maple), and several species of shrubs (e.g., *Rhododendron* spp.) are susceptible.

Several nonnative pathogens and insects are of particular concern in the OCAP assessment area. White pine blister rust (*Cronartium ribicola* A. Dietr.) has contributed to the virtual elimination of western white pine (*Pinus monticola* Dougl. ex D. Don) in the Oregon Coast Range. Balsam woolly adelgid (*Adelges piceae* Ratzeburg) is widely established and has affected Pacific silver fir, and especially grand fir growing at lower elevations west of the Cascades (Mitchell and Buffam 2001). Sporadic outbreaks of the spruce aphid, *Elatobium abietinum*, are associated with warm winters coupled with mild early spring weather in the coastal areas and have caused varying levels of decline and occasional mortality in Sitka spruce (USDA FS and ODF 2020). Port Orford cedar (*Chamaecyparis lawsoniana* [A. Murray] Parl.) is susceptible to a lethal, nonnative root pathogen (*Phytophthora lateralis* Tucker and Milbrath) that may spread over long distances via organic matter carried on boots, vehicles, water, and animal hooves (Hansen et al. 2000, Jules et al. 2002).

Abiotic Disturbances

Abiotic agents of disturbance in the assessment area include windstorms, mass wasting, and wildfire. Abiotic agents cause higher rates of tree mortality than biotic disturbance and are the primary natural agents of stand-replacing disturbance in the Pacific Northwest. However, most abiotic disturbances operate mostly at intermediate levels of mortality, leaving substantial live legacies and altering pathways of structural and successional development (Reilly and Spies 2016). Abiotic disturbances create forest gaps and patches of mortality that range in size depending on the disturbance agent (Spies and Franklin 1989). Smaller gaps created by abiotic disturbances may increase stand and landscape heterogeneity, whereas large, infrequent disturbances also have effects on landscape composition and structure that are qualitatively different from smaller disturbances (Romme et al. 1998) and often persist for centuries (Foster et al. 1998).

Wind is a common agent of disturbance and is especially important near the coast. In close proximity to the Pacific Ocean, chronic wind (e.g., persistent winds not associated with individual storms) may limit tree growth and shape forest structure in exposed sites or other topographic settings with little shelter from prevailing winds (Kramer et al. 2001). A long-term study of wind mortality at the Cascade Head Experimental Forest found that wind accounted for 16–59 percent of total mortality since 1935 (Harmon and Pabst 2019). Individual gaps created from blowdowns often increase in size, as openings create edges where trees are more susceptible to windthrow (Greene et al. 1992, Harcombe et al. 2004). Such gaps are important for the persistence of Sitka spruce as this species may not reproduce in small gaps (less than 0.1 ha; Taylor 1990). Gaps are also important for recruitment of western hemlock (Harmon and Pabst 2019).

Acute windstorms arising from extratropical cyclones off the Pacific Ocean are also an important driver of stand dynamics. These less frequent windstorms have the potential to produce hurricane-force winds and extensive damage to forested ecosystems. Large storms affected parts of the Oregon Coast Range several times in recorded history (Harmon and Pabst 2019, Mass and Dotson 2010). The most intense of these events, the Columbus Day Storm of 1962, killed approximately 11 billion board feet of timber in Oregon and Washington (Lynott and Cramer 1966). High-wind events are positively associated with neutral to warm Pacific Decadal Oscillation (PDO) conditions and their influence has shifted northward over the last 120 years (Knapp and Hadley 2012). These events are generally characterized by southwesterly winds and occur during the winter when soils are saturated (Sharp and Mass 2004), thus increasing the potential for mass-wasting events.

Mass-wasting events (e.g., landslides) and floods also occur in the Coast Range. These disturbances may cause significant damage or mortality through physical damage (e.g., abrasion, snapping, uprooting), but are generally limited to specific landforms in steep or mountainous terrain (Miles and Swanson 1986). Floods are a chronic agent of mortality in floodplains and riparian areas, and occasionally reach higher levels of mortality in large events where trees are tipped up or swept away (Acker et al. 2003). Mass-wasting events are most commonly associated with intense rain and storm events and can cause significant erosion. Swanson and Dyrness (1975) found that landslide area was 2.8 times greater in clearcuts and 30 times greater along road rights-of-ways than in forested areas in unstable zones below 1,000 m in the central western Cascades.

Wildfire is one of the primary drivers of historical landscape dynamics across the assessment area, although its role differs in different locations (Agee 1993) (fig. 5.3). Much of the current understanding of the historical fire regime in the Coast Range is focused on relatively infrequent and severe fires associated with strong east winds and drought. Large (>100,000 ha) high-severity fires occurred in the Coast Range in the 1800s and most recently in the 1933

Tillamook Fire. However, the historical fire regime varied along an east-west gradient (fig. 5.3) and there is abundant evidence of smaller, non-stand-replacing fires, particularly on the eastside of the Coast Range where fire was more frequent (Impara 1997, Weisberg and Swanson 2003).

Native American populations played an important role in fire ignition, especially along the valley margins and major rivers (Boyd 1999). Lightning in the Coast Range is relatively rare compared to much of the rest of the Pacific Northwest (Rorig and Ferguson 1999), though individual storms may result in multiple lighting ignitions during some years (fig. 5.6). Regional drought, driven by teleconnections with sea-surface temperature anomalies (e.g., PDO, El Niño Southern Oscillation), may have resulted in synchronous occurrence of fires in the assessment area as was the case elsewhere in the Pacific Northwest, and other regions of the western United States (Weisberg and Swanson 2003, Hessl et al. 2004, Wright and Agee 2004, Trouet et al. 2006, Heyerdahl et al. 2008, Kitzberger et al. 2007, Schoennegal et al. 2005). However, a lack of annually precise, cross-dated information currently limits our understanding of fire and climate relations over the last several centuries.

Knowledge of the fire regime in the Coast Range prior to Euro-American colonization is based primarily on forest age structure derived from ring counts on stumps in the field, and few studies based on cross-dated fire scars exist from the OCAP assessment area. Although Douglas-fir will scar, most scars are eventually overgrown by bark as soon as 20 years after fire in these highly productive forests (Weisberg 2004). This makes estimates of historical fire frequency extremely difficult compared to forest dominated by ponderosa pine. Due to the lack of precision without cross-dating, available fire history studies likely underestimate fire frequency and the occurrence of non-stand-replacing fire (Weisberg and Swanson 2001).

Available reconstructions of fire activity report two major periods of wildfire in the Oregon Coast Range from 1400 to 1650, and more recently from 1800 to 1900 (Weisberg and Swanson 2003). A period of lower fire activity from 1650 to 1800 was potentially related to cool climatic conditions during the Little Ice Age. Impara (1997) reported a historical mean fire return interval of 85 years since the 1600s based on reconstructions from stumps counted in the field, with fire activity peaking following Euro-American colonization around 1850, then declining with fire suppression in the early 1900s. Teensma et al. (1991) reconstructed fire and forest dynamics from 1850 to 1940 based on age structure of unlogged stands and document multiple large fires in the late 1800s and early to mid-1900s. These results are consistent with other accounts of extremely large, high-severity fires prior to and during early European settlement (Morris 1934) and early 1900s maps of stand-replacing fire (Spies et al. 2018).

Synoptic east-wind events during the dry season typically drive large fire events (Agee 1993). These events occur primarily from late August until early October (Cramer 1957). The potential for these dry east-wind events to drive large, high-severity fires was demonstrated in the 1933 Tillamook Fire. On Aug 25th and 26th, 1933, dry east winds (minimum relative humidity less than 25 percent) and warm temperatures drove a fire ignited by logging activities across most of the total 140,000 ha that burned. Early seral conditions created by these large, high-severity fires likely facilitated a series of five reburns, including fires in 1939 and 1945 that burned almost 80,000 ha each (Reilly et al. 2022).

Late Twentieth-Century and Contemporary Forest Dynamics

Timber Harvest

Extensive timber harvest in the Coast Range by Euro-American colonizers began in the late 1800s. Logging started along the coast, as well as along streams and rivers, which were used to transport logs. Splash dams were commonly used to help transport logs along streams and rivers. Following World War II, heavy equipment became more available, and extensive new road networks allowed heavy equipment to access forests in areas that were previously inaccessible.

About 27 percent of the OCAP assessment area has been clearcut at least once in the last 30 years (fig. 5.5; Cohen et al. 2002). Forests less than 80 years old currently cover the majority of the landscape, scattered in patches throughout the assessment area (fig. 5.5). Land ownership is a major driver of forest structure patterns across the landscape (Griffey et al. 2020, Ohmann and Gregory 2002). Large, old conifer forests are currently rare, with the few remaining large tracts on federal and state lands (Ohmann and Gregory 2002). Although old-growth forests are rare, forests that established after mid-19th century fires with mature and late-successional characteristics have increased over the last 25 years in the absence of logging and fire on federal lands (Davis et al. 2022).

Tree Mortality and Disturbance

Recent changes in climate raise significant concern regarding increased rates of tree mortality and consequent forest decline in the western United States. Forest decline detected with remote sensing peaked in the mid-2000s (Cohen et al. 2016) during the warmest decade in the past 100 years (Abatzoglou et al. 2014). Of particular concern are increasing tree mortality rates in old-growth forests across the western United States related to regional warming and increasing water deficits (van Mantgem et al. 2009). There is less evidence of increased drought occurrence in the Pacific Northwest than in other regions of western North America (1960–2013) (Peters et al. 2014), and recent work suggests that forests of the Pacific Northwest are less vulnerable to future drought and wildfire than the rest of the western United States (Buotte et al. 2019). However, field-based studies in the Pacific Northwest substantiate the occurrence of higher levels of mortality in old-growth forests caused by pathogens and insects than in previous decades, although mortality rates differ by vegetation zone and seral stage (Reilly and Spies 2016).

Mortality rates in old-growth forests in the Pacific Northwest have increased above most published rates (greater than 1 percent/yr) prior to 2000 (van Mantgem et al. 2009, Reilly and Spies 2016). A regional study on mortality rates on USDA Forest Service (USFS) lands in Oregon and Washington corroborated the occurrence of high mortality rates in old-growth forests across all vegetation zones from the mid-1990s to mid-2000s during region-wide drought (Reilly and Spies 2016). However, Acker et al. (2015) found that mortality rates were less than 1 percent per year in wet forests of Lewis and Clark National Historic Park, Olympic National Park, Mount Rainier National Park, and North Cascades National Park, suggesting that moister forests may be more buffered from drought. There is generally poor understanding of the effects of recent mortality on stand structure and composition. However, Bell and Gray (2016) found that biomass accumulation in old-growth forests dominated by Douglas-fir was higher in warm, moist environments than in dry environments during the same time period.

Harmon and Pabst (2019) examined long-term trends in tree mortality in maturing stands (85–163 years old) and found a 5- to 8-fold increase in wind-related mortality since 1940 in old-growth forests at Cascade Head. Most plots had the highest mortality rates between 1995 and

2015. Despite losses of live biomass in most plots, live tree density increased due primarily to recruitment of western hemlock. Although wind favored recruitment of western hemlock, this species was also more prone to wind-related mortality than Sitka spruce and Douglas-fir. In all species, smaller trees generally had the lowest rates of mortality from wind, but intermediate sized trees often had higher rates of mortality than the largest trees.

Increasing tree mortality rates have been documented in young stands of other regions, and some studies suggest that young stands may be more sensitive to changes in climate than old-growth stands (Luo and Chen 2013). However, mortality rates in early and mid-seral stages were lower than expected across the Pacific Northwest (Reilly and Spies 2016) in comparison to other studies in young forests of the western hemlock and Pacific silver fir zones in the western Cascades (Larson et al. 2015, Lutz and Halpern 2006). Higher tree mortality rates in previously published studies are likely due to the inclusion of smaller trees (less than 2.5 cm diameter) that are more sensitive to density-dependent mortality and competitive exclusion during early-seral development.

Wildfire

Increased extent of wildfire across the western United States since the mid-1980s has been attributed to drought (Littell et al. 2009), longer fire seasons associated with earlier snowmelt, warmer spring and summer temperatures (Jolly et al. 2015, Westerling et al. 2006), increasing fuel aridity (Abatzoglou and Williams 2016), and declines in summer precipitation (Holden et al. 2018). Shifts in human populations are also important in increasing fire activity in some regions (Balch et al. 2017, Syphard et al. 2017). The Pacific Northwest has experienced recent increases in area burned, but recent fire activity differs substantially depending on spatial scale and geographic location across the region (Davis et al. 2015, Reilly et al. 2017).

Despite increases in fire activity across much of the Pacific Northwest, the Oregon Coast range has experienced very little fire since the Tillamook burn in the early to middle 20th century (fig. 5.6). Most of the fires that occurred between 1970 and 2022 were anthropogenic ignitions, and less than 5 percent were ignited by lightning strikes. Most fires occurred between July and September and very few were greater than 40 ha. The 2020 fires in the Coast Range were relatively small compared to historical fires and primarily mixed severity (fig 5.7). These fires occurred during a regional wind event and had major impacts on local communities, but winds were not as strong and did not persist as long as in the western Cascades where fires burned much larger areas (Reilly et al. 2022).

Given the lack of fire activity in the Coast Range over the last several decades, there is little known about vegetation response and tree regeneration following fire. However, a few studies from the Tillamook Fires provide some insight into post-fire recovery in the Coast Range. Neiland (1958) compared vegetation between adjacent burned and unburned forests between 750 and 900 m in elevation, 15 years after the last of the burns. This study found that most common species of shrubs and herbs in the unburned upland forest were present in the burned area but with lower frequency. Isaak (1938) studied natural conifer regeneration following the 1933 fire and found several large patches (greater than 2,500 ha) of non-stocked areas (seedlings present on less than18% of eight adjacent subplots in 4-m^2 plots) as well as one extremely large non-stocked patch (greater than 50,000 ha) where repeated high-severity fire occurred. Most fully stocked areas were located adjacent to patches of surviving trees. In 1937, four years after the fire, 53 percent of the burned area was non-stocked, 28 percent was partially stocked (seedlings present on 18–82% of eight adjacent subplots in 4-m^2 plots), and 19 percent was fully stocked (seedlings present on greater than 82% of eight adjacent subplots in 4-m^2 plots). Given the short intervals between successive fires and large areas lacking conifer regeneration, massive replanting efforts were necessary to reestablish seedlings after the series of fires.

Although there are no studies on post-fire regeneration following recent fires in the Coast Range, a few studies from the western Cascades provide insights into post-fire dynamics. Brown et al. (2013) found that Douglas-fir regeneration 14 years following the 1991 Warner Creek fire was abundant and ranged from ~1,500 to >300,000 seedlings per hectare. Regeneration occurred across several years despite the abundant growth of shrubs. Following the Warner Creek fire, regeneration of Douglas-fir, western hemlock, and western redcedar was abundant in areas burned at low or moderate severity (Larson and Franklin 2005). Although available studies indicate that moist forests in the western Cascades of Oregon have been relatively resilient to fires during the 1990s, recent work from dry forests in other regions suggests regeneration and resilience to high-severity fire is decreasing (Stevens-Rumann et al. 2018, Tepley et al. 2017). However, little is known about regeneration patterns in more recent fires in moist forests (after 2003), or how post-fire drought might influence future regeneration patterns in the assessment area.

Current Terrestrial Conditions and Forest Vulnerability to Drought

A national assessment of terrestrial condition class characterized most of the assessment area as very good condition (fig. 5.8). This assessment was based on observed insect and pathogen mortality, critical loads of atmospheric nutrient deposition (e.g., nitrogen, sulfur) in soils, departures from long-term temperature and precipitation trends, road density, patterns of current fire, and departure from the natural range of variability (Cleland et al. 2017).

Mildrexler et al. (2016) calculated a forest vulnerability index (FVI) using drought and high temperatures across Oregon and Washington from 2003 to 2012. The results of this study suggest that parts of the western hemlock zone may be vulnerable to drought, specifically in the central and southeastern portion of the assessment area (fig. 5.9).

Soil drought-stress maps (Ringo et al. 2018) (fig. 5.10) may help resource managers identify where drought effects will be most severe in the future, although the existence of "droughty soils" does not necessarily imply vulnerability, because species occurring on these soils may be drought resistant. Nevertheless, the map may be useful for identifying where seedling survival and establishment will likely not be deterred by future drought. The highest soil drought probabilities occur inland towards the southern part of the assessment area.

Potential Climate Change Effects on Vegetation

Climate change is expected to alter vegetation through a variety of mechanisms that may be characterized as *direct effects* (e.g., effects of carbon dioxide [CO_2] and climate on physiological processes) or *indirect effects* (e.g., disturbance processes). The direct effects of climate change and increasing CO_2 on vegetation are expected to be expressed through changes in mortality, growth, and reproductive processes (i.e., seed production, regeneration), all of which may be sensitive to altered phenology and biotic interactions within and among species (Peterson et al. 2014). The indirect effects of climate change are expected to be expressed through increases in the frequency and extent of disturbances, particularly drought, fire, insects, and pathogens. Direct and indirect effects may also be related and interact, and thus they represent endpoints along a continuum. These disturbances have the potential to cause rapid ecological change at broad spatial scales and are expected to be a greater driver of ecological change than direct effects (Dale et al. 2001, Littell et al. 2010). However, the relative importance of these drivers is likely to vary geographically and among species and seral stages.

Direct Effects of Climate Change: Demographic Responses

Tree mortality from higher temperatures and drought stress has already occurred in some forests of the western United States and is expected to increase in future decades (Allen et al. 2010, 2015). Warmer temperatures and increased frequency and duration of droughts projected for the assessment area are likely to increase exposure to climate-induced physiological stress on plants (Adams et al. 2009).

Drought-related stress can lead to two separate, but non-mutually exclusive mechanisms of tree mortality—hydraulic failure (irreversible desiccation and collapse of water transport structures) and carbon starvation (McDowell et al. 2008). Trees are able to survive within a range of conditions but may ultimately cross a threshold after which they are unable to recover (Hartmann et al. 2018). However, interactions among risk factors are complex and limit our ability to predict where and when thresholds are likely to be crossed. Despite recent work on physiological mechanisms associated with tree mortality, a better understanding of these mechanisms is needed to assess vulnerability and enhance our ability to predict mortality (Hartmann et al. 2015). Furthermore, a better understanding of the ecological consequences of mortality in terms of composition, structure, and ecosystem function is needed (Anderegg et al. 2012).

The potential response of tree growth to climate change varies substantially among species and depends on the factors that limit growth, such as water and length of growing season (Littell et al. 2010, Peterson and Peterson 2001). Growth in Douglas-fir is projected to decrease in a warmer climate in locations where it is currently water limited (Restaino et al. 2016). However, growth may increase where the species is currently limited by growing-season length or lower than optimal temperature, provided these sites do not become drought limited (Albright and Peterson 2013; Littell et al. 2008, 2010).

For species in higher-elevation forests where growth is limited by temperature and growing season length (e.g., subalpine fir, mountain hemlock), growth has increased during the 20th century with warmer winter temperatures and longer growing seasons (McKenzie et al. 2001, Nakawatase and Peterson 2006, Peterson et al. 2002). Warmer winters and earlier snowmelt may also increase potential for drought stress in higher-elevation forests, especially towards the southern portion and lower-elevation extent of their distribution. However, these effects are not well documented or understood, and the potential for increased growth is expected to persist in the near term (Albright and Peterson 2013).

Increased atmospheric CO_2 concentration is also likely to directly affect vegetation change, especially in moist forests where growth is less limited by water availability. The patterns that emerged from elevated-CO_2 research from 1984 to 2007 in moist forests and semi-arid grassland systems suggest that elevated CO_2 reduces stress during drier periods and enhances net annual productivity (McMurtie et al. 2008). Seasonal variations in atmospheric CO_2 concentrations can affect photosynthesis by increasing water use efficiency at moist sites (Jiang et al. 2019). These results apply broadly to groundwater-dependent ecosystems that are distinct from the surrounding upland plant communities. In addition, forested and grassland systems usually have higher soil moisture under elevated CO_2, arising from effects such as greater litter production in conifer forests (Schäefer et al. 2002) or through mechanisms such as increased water use efficiency in forests (Jiang et al. 2019, Keenan et al. 2013) and grasslands (Morgan et al. 2011).

Although notable increases in water use efficiency have been reported within and across forest biomes, equivalent increases in growth rates have not been consistently documented (Hararuk et al. 2019, Silva and Anand 2013). Although distinct growth responses have been detected (positive and negative), there is no clear evidence of a prevailing CO_2 stimulation based on changes in growth rates alone. Responses in tree growth, when described in relation to changes in water use efficiency, are latitude dependent. Silva and Anand (2013) identified net positive relationships between water use efficiency and tree growth in boreal and Mediterranean forests located in latitudes greater than 40° N. However, this pattern was more negative in temperate, subtropical, and tropical forests. These results agree with the discussion above regarding limitations (i.e., water versus growing season length) on Douglas-fir growth.

It is unclear if the CO_2 fertilization effect will outpace drought stress brought on by warming temperatures (Sperry et al. 2019). Broadly speaking, climate change is likely to bring chronic hydraulic stress to the region with possible increases in mortality. There is some evidence that any benefits of CO_2 fertilization will be outweighed in the future as the climate warms and water becomes more limiting (Gedalof and Berg 2010, Restaino et al. 2016). Increased levels of CO_2 also have the potential to accelerate maturation and increase seed production (LaDeau and Clark 2001, 2006), but little information is available within the assessment area on the effects of climate change on reproduction.

The ability of a species to respond to changes in climate (e.g., earlier warming and drying) with shifts in phenology will be an important factor in determining responses to climate change. Altered seasonality may affect growth and reproduction in some plant species. For example, California hazelnut (*Corylus cornuta* ssp. *californica* [A. DC.] A.E. Murray), salal, and Oregon grape are all expected to shift towards earlier flowering and ripening of fruits and nuts with future warming (Prevéy et al. 2020).

A major concern associated with warmer winters and earlier springs is the requirement for many species (e.g., Douglas-fir, western hemlock, pines and firs) to experience chilling for the emergence of new leaves or budburst (Harrington and Gould 2015). Douglas-fir may experience earlier budburst in some portions of its range due to warming in early spring, but reduced chilling may cause later budburst in the southern portion of its range (Harrington and Gould 2015), leading to delayed growth initiation (Ford et al. 2016).

Climate change may also affect interactions among and within species in complex ways. These effects are poorly understood, although studies from higher-elevation moist forests in the Pacific silver fir vegetation zone of Washington provide some insights. For example, the negative effect of competition on growth is likely to be greater for saplings than for adults, and climate change may have less effect on closed-canopy forests at lower elevations than higher elevations (Ettinger and HillesRisLambers 2013). Similarly, Dobrowski et al. (2015) found that forest canopies can mitigate climate effects for younger trees in the understory that are more sensitive to climate in open conditions. Consistent with theory (i.e., density-dependence), individual growth is likely to increase most in lower density stands, as trees may show little response to climate at higher density where room for growth and expansion is more limited (Ford et al. 2017).

There is little known about the effects of climate change on positive species interactions (e.g., facilitation), which are important in stressful subalpine environments (Callaway et al. 2002) and play a role in early stand development in dry and cold vegetation zones (Reilly and Spies 2015). However, facilitation is likely to become more important in the future, especially as climatic conditions necessary for establishment become less common (Kitzberger et al. 2000, Brooker et al. 2008). Resprouting broadleaf species and shrubs may grow more quickly and outcompete conifers for light and water following fire, but mycorrhizal connections formed between hardwoods, *Arctostaphylos* species, and conifer seedlings after disturbance may facilitate seedling establishment (Borchers and Perry 1990, Horton et al. 1999, Simard 2009). *Ceanothus* species fix nitrogen, which could contribute this important macronutrient to the soil and facilitate forest recovery after fire (Busse et al. 1996, Busse 2000).

Indirect Effects of Climate Change: Disturbance

The indirect effects of climate change will likely be expressed through an increase in the frequency and severity of disturbance and will likely be the primary mechanisms of ecological change in the future (Dale et al. 2001, Littell et al. 2010). Disturbances include discrete events that alter the structure and function of ecosystems (Pickett and White 1985) but may also include prolonged droughts or multi-year epidemics of pathogens and insects that have direct effects on tree growth. Interactions among climate change, forests, and disturbance regimes may result in disturbance effects outside the natural range of variation (Dale et al. 2000).

Biotic disturbances—

The effects of native insects and pathogens on mortality are expected to increase as trees are exposed to more stress associated with growing-season drought. However, the implications and magnitude of their effects are likely to differ geographically and among species (Agne et al. 2018, Chmura et al. 2011, Kolb et al. 2016, Sturrock et al. 2011). In addition to affecting host species, climate change will affect population dynamics and ranges of pathogens and insect populations.

Pathogen activity is likely to increase in areas where they typically infect drought-stressed host species. However, the effects of climate change on pathogens that cause greater infection under moist conditions may be more variable and difficult to predict (Sturrock et al. 2011). Higher temperature may also allow some forest pathogens to expand their altitudinal and latitudinal ranges (Kliejunas et al. 2007). Swiss needle cast is projected to increase in the Oregon Coast Range in response to warmer and wetter conditions in the future (Stone et al. 2008), although an increase in drought may inhibit spread of the disease (Rosso and Hansen 2003).

Warmer winters and hotter droughts are expected to enable some species of insects (e.g., mountain pine beetle (*Dendroctonus ponderosae* Hopkins) to increase reproductive rates and move into previously unsuitable habitat (Bentz et al. 2010, 2016). Indeed, many regions in western North America have experienced what are considered unprecedented outbreaks of insects in the last few decades (e.g., Raffa et al. 2008). Drought and insects may also interact to further increase sensitivity and exposure to mortality, but these dynamics are complex and are just beginning to be understood (Anderegg et al. 2015). A recent study from an old-growth forest in the western hemlock zone at the Wind River Experimental Forest in Washington found that tree mortality rates were positively related to dwarf mistletoe infection during warm and dry periods, providing evidence that pathogens can amplify the effects of climate change on trees (Bell et al. 2020).

Invasive plant species—

Nonnative plant species have the potential to alter vegetation dynamics, soil properties (Caldwell 2006, Slesak et al. 2016), and disturbance regimes (Brooks et al. 2004). Most nonnative plant species were initially introduced for horticultural uses, for erosion control, or in contaminated crop seed (Reichard and White 2001). Gray (2008) used a systematic inventory of forest health monitoring plots and found that over 51 percent of plots in the Coast Range of Oregon and Washington had nonnative species present. Some of the more common species of particular concern in the OCAP assessment area are listed in table 5.3.

Many common nonnative plants are associated with disturbance and management (e.g., clearcuts, thinning, roads), although there is potential for spread of some nonnative, shade-tolerant shrubs in undisturbed forests (Gray 2005). Many nonnative plant species persist in seed banks or are wind dispersed (Halpern et al. 1997, 1999) and thus they are capable of rapid response following disturbance. In an early study of post-fire plant communities following the Tillamook Burn, Isaac (1940) noted the rapid expansion of nonnative plant species, including Scotch broom (*Cytisus scoparius*), gorse *(Ulex europaeus*), purple foxglove (*Digitalis purpurea* L.), Australian fireweed (*Erechtites minima* [Poir.] DC.), goatweed (*Hypericum perforatum* L.), and "a large number of grasses."

Little information is available on temporal trends in the abundance of nonnative plants, but higher temperatures may favor nonnative species (Sandel and Dangermond 2012). Warm, dry sites with increased topographic exposure may be particularly susceptible to nonnative species, especially annual grasses following high-severity fire (Dodson and Root 2014, Reilly et al. 2020). Roads can also facilitate the spread of nonnative plants (Parendes and Jones 2000, Rubenstein and Dechaine 2015). The abundance of nonnative plants increased with lower stand density from clearcutting or thinning (Gray 2005). Likewise, Bailey et al. (1998) found that species richness of nonnative species was greater in thinned stands than in undisturbed, old-growth stands.

Climate change is expected to alter the distribution and spread of nonnative plant species (Hellmann et al. 2008). Some existing nonnative species will likely expand with climate change, because ecosystem disturbance and shifts in native species ranges will provide opportunities for establishment by nonnatives (Ayres et al. 2014). For example, nonnative species may exploit post-fire conditions better than native species (Zouhar et al. 2008). Nonnative species may also alter fire regimes through changes in fire frequency or severity (e.g., D'Antonio and Vitousek 1992). Gorse and scotch broom are of particular concern in the Coast Range. Both species develop persistent seed banks and respond positively to fire. The foliage of these species also contains waxes and resins that make them extremely flammable. Gorse is implicated with rapid fire spread during an east wind event that burned Bandon, Oregon on September 27, 1936.

Gray et al. (2011) provide a field guide and prioritized list of nonnative plants along with range maps that cover the entire assessment area. More information on management of nonnative species is available in Harrington and Reichard (2007).

Abiotic disturbances—
Most research into the effects of climate change on abiotic disturbances has focused on wildfire. Studies from other coastal regions of the world suggest an increase in tropical cyclones and hurricanes (Emmanuel et al. 2005, Webster et al. 2005), but we are currently unaware of any published literature with future projections of the frequency or intensity of windstorms in the assessment area. However, if more precipitation falls and saturates soils during intense winter storms, exposure to large blowdown events and landslides would increase. Areas affected by pathogens that predispose trees to snapping or tip up may be particularly sensitive to blowdown events.

Hessl (2011) outlines a framework proposing three major pathways through which future fire activity may respond to climate change: fuel conditions, fuel amount and structure, and ignition sources. Most studies to date have assumed that the major pathway to change will be through alteration of fuel conditions, as the relationships among weather, fuel moisture, and fire activity are well established. Fewer studies have focused on changes in the second pathway, alteration of fuel amount and structure, though this may be of particular concern given its relationship with severity. The least is known about the third pathway, changes in sources of ignition. This pathway will be subject to changes in lightning frequency as well as changes in human ignitions and fire suppression efforts (Balch et al. 2017, Syphard et al. 2017). Although there is evidence suggesting lightning frequency will increase in the future because of warming at the continental scale (Romps et al. 2014), changes in lightning frequency are uncertain.

A number of studies using different techniques project increases in a variety of metrics of fire activity (i.e., area burned, fire size, severity, fire interval) during the 21st century, but projections vary across the assessment area (table 5.4). Most studies report coarse-scale projections (i.e., individual states), and few include details at finer geographic scales (i.e., ecoregions or forest types). Although projections differ geographically and among studies, most project increased fire activity during the 21st century. Statistical models generally project increases in fire activity, whereas process models project decreasing to neutral changes. While some of the projected increases by statistical models may seem high, it is important to note that the recent extent of fire in moist forests is very low, and a tripling of fire may still be a relatively small amount in absolute terms of total area affected. Even though the ecological effects may be of localized, even a doubling of area affected by fire events like the 2017 Eagle Creek fire (~20,000 hectares) would have significant social and economic impacts.

Davis et al. (2017) projected slight increases in suitability for large wildfires (>200 ha) for the Coast Range during the 21st century (fig. 5.10) using a statistical model based on fire activity from 1971 to 2000. The suitability for large forest fires in the Coast Range is projected to increase across approximately 5 percent of the area under moderate- and high-warming scenarios. Suitability during the century is highest inland and to the south of the Coast Range. The relative lack of change in projected suitability is likely due to a lack of recent fires in the Coast Range to use in the model. Increases in future activity will largely depend on the occurrence of dry east-wind days during the late summer and early fall.

Several studies project increased fire activity in the future. Less work has been done projecting future fire severity, which has not been well studied (Hessl 2011, Parks et al. 2016), because of the complexities of incorporating feedbacks from fire and climate on fuel structure and arrangement at different spatial scales. Previous fires have the potential to inhibit the spread of subsequent fires occurring within a limited time window (Parks et al. 2015), and increased area burned in the future may provide feedback related to decreased fuel availability, though this may not be applicable in a highly productive environment like the Coast Range. Rogers et al. (2011) used the MC1 model to show that increased burn severity of 29–41 percent associated with climate change was related to increased productivity and biomass during non-summer months. However, a recent study incorporating changes in vegetation type, fuel load, and fire frequency projected either no change or potential reductions in fire severity across the entire region for 2040–2069 under the most extreme climate change scenario (Parks et al. 2016). The authors attribute decreased fire severity to higher water deficits, decreased productivity, and less available fuel.

The uncertainty and wide range of projections for future wildfire within the assessment area are related to several factors, including differences in emission scenarios, spatial and temporal scale, model structure (e.g., statistical versus process-based), and variability in how models project precipitation. Differences in projections from empirical models are affected by whether or not they are based on empirical relationships between area burned and climate (e.g., Davis et al 2017), or empirical relationships between vegetation, climate, and area burned (e.g., McKenzie and Littell 2017). Because the former approach does not include vegetation and fuel limitation, projected increases are generally larger than in the latter which incorporate fuel limitations and limiting feedbacks to fire. McKenzie and Littell (2017) also show that differences in climate-fire relationships among physiographic provinces are likely to be substantial, and further analysis is required to put differences in methodological and regional future projections of fire into context. At coarser regional scales, dynamical and statistical approaches to projecting future fire activity may agree, but the mechanisms operating at more local scales require careful interpretation.

Disturbance interactions—

Of particular concern are multiple, successive, or compound disturbances (Paine et al. 1998). The interaction of disturbances may result in multiplicative effects on the structure and function of ecosystems that differ from the cumulative effects of individual disturbances. The effects of compound disturbances are difficult to predict but may amplify disturbance severity, cause changes between ecological states (e.g., forest to non-forest transitions), and decrease forest resilience (Buma 2015). However, despite growing recognition and interest in interactions among disturbances, the effects of compound disturbances remain poorly characterized and difficult to predict (Buma 2015, Seidl et al. 2017).

A major concern with increasing fire frequency is the potential for short-interval reburns. Fuels have the potential to recover rapidly in high-productivity environments such as the Coast Range, and there is historical precedent for short-interval, high-severity reburns in moist forests of the Pacific Northwest (e.g. subsequent reburns following the 1933 Tillamook Fire; Reilly et al. 2022).Young conifers with thin bark have low resistance to fire (Agee 1993), and if burned prior to reaching reproductive age, young forests may be subject to shifts from forest to non-forest states or long periods of protracted succession and development (Enright et al. 2015). Reproductive traits such as early development in serotinous conifers (Reilly et al. 2019) and resprouting of hardwood tree species enhance forest resilience to high-severity fire (McCord et al. 2020). Conifer regeneration in large patches of high-severity reburns may depend on long-distance seed dispersal facilitated by wind or animals (Donato et al. 2009) and are likely to favor drought tolerant species (Davis et al. 2018) and resprouting hardwoods. Conditions for conifer regeneration may be too harsh for survival or establishment following short-interval fire, but shrubs may facilitate establishment by promoting mycorrhizal associations and providing shade and mitigating desiccation (Fuchs et al. 2000).

Interactions between wind disturbance and pathogen and insect infestations are well documented in the assessment area. Pathogens and disease may predispose trees to tip-up or snapping in windstorms (Larson and Franklin 2010). Tall, old-growth trees may be particularly sensitive to snapping if weakened by stem and butt decay fungi. Outbreaks of Douglas-fir beetles are common within the first few years following wind events and generally affect small patches of forest consisting of a few to several trees. Larger trees (>36 cm diameter at breast height) in dense stands with a large proportion of Douglas-fir are most susceptible to attack (Shaw et al. 2009).

Invasive plant species may also interact with fire and logging and be a potential threat to dry forest and non-forest vegetation types. Invasive plants pose a competitive threat to native vegetation for early-season soil moisture and increase the frequency of fire (Kerns et al. 2020). Scotch broom and gorse are seed bank-forming shrubs that can facilitate fire spread, and gorse was implicated as a major driver of a fast-moving fire that burned the city of Bandon in the Oregon Coast Range in the 1930s (Isaac 1940). In contrast, false brome (*Brachypodium sylvaticum* [Huds.] P. Beauv.), a prominent invasive grass in moist forests of the Pacific Northwest, may inhibit spread of fire under moderate fire weather conditions (Poulos and Roy 2015). High-intensity prescribed fire may help control false brome, but low-severity fire may increase its cover.

Simulated Vegetation Response to Future Climate Change

Several types of simulation models project vegetation responses to potential future climate scenarios, and each model has its own assumptions, strengths, and weaknesses (see Peterson et al. 2014 for a more in-depth review). Models simplify complex processes by representing them with equations and algorithms based on theory or observations. A key benefit of models is that they allow explorations of complex interactions among the many parts of an ecosystem. However, given the simplifying assumptions in models, the best use of models may be to understand variability in the magnitude of climate change effects, as opposed to predicting specific outcomes (Jackson et al. 2009, Littell et al. 2010). In essence, the model is calibrated to predict a baseline of historical conditions against which future projected changes are compared.

The MC2 dynamic global vegetation model (USDA FS 2022) was run for the OCAP assessment area. MC2 is based on MC1 (Bachelet et al. 2001, Conklin et al. 2016), revised for improved code organization and computational efficiency. It simulates biogeographic patterns of vegetation, biogeochemistry, and fire across broad spatial scales over long time periods, but does not simulate other disturbances such as wind, timber harvest, insects, and pathogens that often create canopy gaps. MC2 represents the landscape as a grid and runs on a monthly time step. The model is driven by long-term climate data output from global climate models (GCMs). Atmospheric CO_2 concentration increases simulated plant productivity in a quasi-linear fashion from a factor of 1.0 at 350 ppm to a factor of 1.25 when CO_2 doubles to 700 ppm. MC2 outputs include vegetation distribution, fire effects, and ecosystem conditions, including various ecosystem carbon pools and water balance information.

MC2 does not simulate individual species growing in a particular region. Instead, vegetation is represented in terms of potential plant function types (table 5.1), which are further grouped in major biomes. However, simulations are calibrated with region-specific data, and MC2 output of plant functional types can be crosswalked with vegetation zones and species distributions during analysis and interpretation.

MC2 output describes long-term patterns in relationships among climate, potential natural vegetation, and fire. In the model, climatic factors determine the biogeography of plant functional types and drive plant productivity, fire occurrence, and fire behavior. Even where the simulated climate-vegetation-fire relationships may not necessarily hold under a future climate, the model still serves as a framework that identifies how climate is likely to change in ways that are most influential for vegetation. Because MC2 represents vegetation in terms of functional types, it may project no change in some areas. However, that does not preclude climate change affecting vegetation, and we can use existing knowledge to assess which potential changes may occur.

Methods

MC2 was used to simulate potential changes in vegetation types in the OCAP assessment area at a 30 arc-second spatial resolution (~800-meter pixels) 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 were driven with the NASA NEX-DCP30 downscaled climate dataset, as described further below. Soils data were synthesized from the best available regional soil surveys and converted to a format required by MC2.

For this assessment, we calibrated MC2 for Oregon and Washington. Simulating a spatial extent larger than the limits of the OCAP assessment area allowed model calibration for a broader range of vegetation types than those that currently exist in the 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 (MODIS) net primary production (NPP) data (Zhao and Running 2010). We adjusted thresholds in its biogeography 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. Once calibration was complete, we ran the simulation at full resolution for 1895–2012 using PRISM climate data.

MC2 simulations of future vegetation dynamics were driven with climate data from the NASA NEX-DCP30 downscaled climate dataset (Thrasher et al. 2013). This is the same dataset used in similar assessments for southcentral and southwest Oregon (Case et al. 2019, Halofsky et al. 2022). The NEX-DCP30 dataset comprises outputs from 31 general circulation models (GCMs) used in the Coupled Model Intercomparison Project Phase 5 (CMIP5; Taylor et al.

2012), downscaled from each GCM's coarse spatial resolution to 30 arc-second (~800 m) resolution for the conterminous United States.

NEX-DCP30 includes climate projections for Representative Concentration Pathways (RCPs) 4.5 and 8.5. RCPs describe scenarios of emissions and land use, based on consistent scenarios representative of current literature (van Vuuren et al. 2011). For this study, we selected RCP 8.5, which represents a rapidly warming scenario without any effective climate change mitigation activities, leading to approximately 1,370 ppm CO_2 (Riahi et al. 2011) and a 3.7 °C increase in global mean surface temperature by the end of the 21st century (Stocker et al. 2013). We selected RCP 8.5 because it represents a "business as usual" or "worst case" scenario, an important benchmark for risk-averse decision making. The likelihood of a particular RCP being realized is unknown, and multiple plausible scenarios could give rise to any single endpoint. However, current global emissions are consistent with the RCP 8.5 trajectory.

MC2 simulations were run from 1950 to 2100 with 28 GCMs for which vapor pressure data were available. 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 simplify display here, we selected simulations driven by five GCMs and focus on their outputs.

The five GCMs were selected to avoid the poorest-performing models for the Pacific Northwest, 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: "mean" CESM1(CAM5; CESM1 hereafter); "hot-wet" CanESM2; "hot" BNU-ESM; "hot-dry" MIROC-ESM-CHEM (MIROC hereafter); and "warm" MRI-CGCM3 (MRI hereafter). BNU-ESM may overestimate winter precipitation because the original GCM data contain processing errors (pers. comm. K. Hegewisch and D. Rupp), although it is not a particularly "wet" outlier GCM in the 28-member ensemble, even with this error (see chapter 2).

MC2 Output

Vegetation—
MC2 consistently projected vegetation-type changes (across all 28 climate projections) with high agreement across most of the Coast Range except along most of the eastern margin of the Willamette Valley where agreement was moderate to high (fig. 5.12). Model agreement was also low to low/moderate in the northeastern part of Coast Range. There was low agreement for changes in plant biomes across the entire Coast Range, suggesting relative stability and persistence of forests into the future as only a few models project change (fig. 5.12).

Almost the entire Coast Range was projected to increase in productivity by the end of the 21st century (fig. 5.13). Projections suggested the largest increases in productivity (40 to 50 percent) will occur along the coast, as well as some inland areas in northwest part of the Coast Range. Predictions vary from 0 to 10 percent increases inland in the hot scenarios, and from 20 to 40 percent in the warm scenarios. Projected increases in productivity are likely driven by warming temperatures and a longer growing season, especially along the coast, but summer drought in the hot scenarios may limit productivity regardless of changes in precipitation. However, MC2 does not model the potential effects of summer drought well. In the model, although productivity shuts down when water is limited, complex plant responses (e.g., branch death, biomass loss, mortality, and vulnerability to insects and disease) are not modeled. Thus, summer drought and climatic water deficits may offset projected gains in productivity and exacerbate growth losses in some species. Overestimation of winter precipitation in the BNU-ESM scenario may lead to overestimation of vegetation productivity by MC2. Increases in productivity were lowest when the simulation was driven with the hot and dry MIROC climate projection.

Projected modal (most often occurring) vegetation types for the historical period, and middle and end of the 21st century, are shown for five different future climate projections in figures 5.14–5.18; the proportion of the landscape in different vegetation types for the historical period and end of the century are shown in figure 5.19. See table 5.1 for approximate crosswalks between potential vegetation types (figs. 5.1–5.2) and MC2 vegetation types.

Changes in MC2 vegetation types indicate that the climate will no longer be suitable for most current potential vegetation zones/types. All models project widespread shifts from moist coniferous forests to warm mixed and subtropical mixed forests. These types are present only in historical simulations along the extreme southern part of the Oregon Coast. Given the extremely limited extent of the mixed types in the historical simulations, it is difficult to say what the composition of these types may look like in the future. Future forests may resemble those of the southern Oregon Coast and Klamath Mountains (see Halofsky et al. 2022), but there is also the potential that mixed types do not have current analogs in terms of structure and composition. Potential changes in composition are discussed in the following section on specific vulnerabilities.

Model results suggest major shifts in species composition likely characterized by a decrease in conifer dominance and an increase in hardwoods. Disturbances, specifically wildfire, will likely be the main mechanisms that initiate major compositional change. Other disturbances that are not modeled by MC2 (e.g., insects, pathogens, wind) will contribute to conifer decline as well. However, there is some uncertainty surrounding the degree of conifer decline as MC2 may insufficiently simulate resistance of mature trees to projected changes in climate. Therefore, changes in species composition and abundance will likely be more gradual than indicated by simulations, because of the longevity of many tree species and high tolerance of mature trees to climatic variation (Lloret et al. 2012), as well as the potential for acclimation of some species though phenotypic plasticity (Kozlowski and Pallardy 2002).

Projections for moist coniferous forests, which historically made up most of the Coast Range, varied among the simulations driven with five selected GCMs. All GCMs project a loss of coniferous forests with gains in subtropical mixed forests and temperate warm mixed forests with exception of the northeastern part of the Coast Range. The warm climate projection (MRI) projects less loss of moist coniferous forest than the others with persistence of this vegetation type in the eastern side of the Coast Range along the Willamette Valley margins (fig. 5.18). Simulations under the other four climate projections suggested losses of moist coniferous forests which primarily transitioned to warm mixed forest with some temperate warm mixed forest (figs. 5.14–5.17).

Four of the five selected simulation results suggest that subtropical mixed forests will expand northward and inland during the century. Much of this area is projected to transition to temperate warm mixed forest by mid-century, then transition to subtropical mixed forests. Subtropical mixed forests are projected for the historical period only along a small portion of the southern coast of Oregon that is currently dominated by the Sitka spruce and moist western hemlock vegetation zones. The simulated shift to the subtropical mixed forest type was 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. 5.18), and highest for the GCMs with the most warming, including BNU-ESM (fig. 5.14), CanESM2 (fig. 5.15), and MIROC (fig. 5.17).

MC2 projected an expansion of warm mixed forest in the lower elevation eastern portion of the assessment area under all but one of future climate projections (MRI), with greater eastward and northward expansion between mid-century and the end of the century. Under historical climate, this type was only projected in a strip along the coast from southern Oregon to northern Washington currently dominated by the Sitka spruce and moist western hemlock vegetation zones. The expansion of the warm mixed forest type replaces the currently dominant moist coniferous forest and often transitions to subtropical mixed forest by the end of the century.

Maritime evergreen needleleaf forests and temperate needleleaf forests, both historically rare, are projected to disappear by the end of the century.

Wildfire—

We examined simulated fire occurrence by computing mean fire-return interval (MFRI) for the assessment area (fig. 5.20). MC2 simulates the occurrence and effects of wildfire for individual grid cells, and fire spread between grid cells is not specifically simulated. Fire occurrence is calculated as a function of fuel moisture indices, and fire effects are calculated as a function of weather and vegetation characteristics. Suppression is simulated after year 1950. The fire simulation module is described in detail in Conklin et al. (2016). Because specific historical fires and vegetation conditions are not simulated, simulated historical MFRIs may not closely match empirical observations, and graphs should be interpreted 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) period (fig. 5.20). Thus, fires are expected to be more frequent in the future, as increased vegetation productivity drives increases in fuels. In most cases, the largest decreases in MFRI occur by mid-century. Simulated MFRIs for warm mixed forest were highly variable, likely due to the limited extent of this vegetation type. In most cases, projections under the hot and wet Cesm1CAM5 GCM had longer MRFIs than the other GCMs. Decreases in MFRI were greatest under the hot and dry MIROC, hot BNU-ESM GCMs, and the hot and wet CanESM2, where increases in vegetation productivity in spring and fall resulted in more fuels, but fuels dried out more intensely in the summer.

We assessed simulated fire severity by examining projections of mass of live carbon lost from fire from MC2. Carbon lost from fire was generally projected to increase compared to the historical time period (fig. 5.21). Increased fire severity was generally greatest under the hot BNU-ESM and the hot and dry MIROC GCMs.

Changes in MFRI and fire severity projected by MC2 can be explained by seasonal changes in temperature and precipitation projected by each of the GCMs. These components of climate change drive fuel moisture content, plant productivity, and aboveground biomass. Fire occurrence is primarily a function of fuel moisture in MC2 (fuels must be dry enough to burn). Fire severity (live carbon killed by fire) is related to standing biomass or productivity. The amount of fuel or biomass may increase for some vegetation types in the future with increases in productivity (fig. 5.13). Given that MC2 does not model the effects of summer drought on productivity, increases in fire severity may be overestimated by MC2. However, more dry fuels could also lead to higher fire severity. In any case, more fuels under a hotter future climate resulted in MC2 simulating longer flame lengths and higher incidence of canopy fires.

Vulnerability Assessment in the OCAP Assessment Area

This section describes potential effects of climate change on three broad vegetation groups in the OCAP assessment area, including moist forests, dry forests, and special habitats (e.g., meadows, shrublands, woodlands). Although forests of the Pacific Northwest are expected to be less sensitive to future drought and fire than other regions in the western United States (Buotte et al. 2018), several key vulnerabilities to projected increases in exposure exist. We discuss the geographic variability in potential vegetation responses and vulnerability to change within each of the vegetation groups to highlight how climate change effects may differ geographically within the assessment area.

Given that our knowledge of effects associated with climate change is limited in many cases, we rely on multiple lines of evidence to assess vulnerability. These include current knowledge of past vegetation response to climate change from paleohistory studies, recent sensitivity and ongoing vegetation response to climatic variability and disturbance, and climate projections as interpreted through simulations of future dynamics with MC2. We base our assessment of vulnerability to change on observations of recent and ongoing responses of vegetation to changing climatic conditions to provide a basis for assessing decline, reduced fitness, and sensitivity, while exposure and extinction can be informed from climate change projections and broad scale changes in vegetation type from MC2.

The cumulative effects of climate change will ultimately manifest in shifts in species distributions and ranges. These effects will also depend on the size and degree of connectivity within populations; thus, species in smaller, more isolated populations will likely be more vulnerable to local extirpation. Range expansion occurs through migration and colonization at the outer limits, or “leading edge,” of a species distribution where climate is becoming more favorable. Range expansion at the leading edge is controlled by fecundity and dispersal (Thuller et al. 2008). Species that produce more seeds or other propagules and have a greater ability to disperse will have greater potential to track climate change than those with poor dispersal ability.

At the lower limits or “trailing edge” of a species distribution, where climate is becoming less favorable, range contraction and progressive isolation will occur through local extirpation. Range contraction is related to the ability of a species to persist in locations that experience less change than the surrounding landscape. Individuals at the trailing edge may thus play an important role in the maintenance of genetic diversity for some species (Hampe and Petit 2005). Although local extirpation may occur throughout the range of species, small, isolated populations at the trailing edge may be particularly vulnerable when the climate changes rapidly (Davis and Shaw 2001).

Moist Forests

Forests in the OCAP assessment area will likely continue to be dominated by Douglas-fir in a changing climate. Paleoecological evidence suggests that during warm, dry periods of the past, Douglas-fir was favored in moist forests, whereas western hemlock decreased in abundance (Long et al. 1998). MC2 projections suggest shifts towards subtropical and mixed hardwood vegetation types which lack current analogs, so interpreting what these changes will mean in terms of species is difficult. Hardwoods are likely to be favored by increasing fire frequency in lower-elevation forests; these areas are projected to shift towards a mixed forest type with more hardwood species. Paleoecological evidence suggests that during warm, dry periods of the past, red alder increased in abundance (Long et al. 1998). The ability of other hardwood species to resprout (e.g., bigleaf maple, madrone, chinkapin) makes them resilient to high-severity fire, even at short intervals (McCord et al. 2020).

MC2 projected increased productivity in moist forest types with a warming climate because of increased growing season length, adequate moisture levels, and increased atmospheric CO_2. However, forest productivity could be sensitive to changes in summer fog which are not modeled by MC2. Dye et al. (2020) found that the frequency of low clouds in coastal Oregon decreased between 1996 and 2017. Decreased cloud frequency was highest in May and June, especially in more northerly locations. Loss of summer fog, particularly in the Sitka spruce zone could have negative effects on growth by increasing vapor pressure deficits and contributing to drier fuel conditions that could facilitate fires.

Fire frequency is projected to increase in moist forests, and fire occurrence could increase as fuels become increasingly drier with higher summer moisture deficits. Nonnative, pyrogenic shrubs (e.g., gorse) could facilitate fire spread and in increase intensity where they are locally abundant in disturbed areas. Although recent fires in moist forests have been relatively small and uncommon, there is historical precedent for extremely large fires in the assessment area (fig. 5.3). Such events are historically associated with dry, east-wind events that occur in the early fall (Cramer 1957). An increase in the frequency of dry, east-wind events and drier fuels could increase exposure to extremely large wildfires. Paleohistorical studies from other moist forest types in the Pacific Northwest provide evidence that extremely large fires have the potential to be a catalyst for rapid and widespread vegetation change (Bartlein et al. 1998, Crausbay et al. 2017, Marlon et al. 2009, Walsh et al. 2015, Whitlock 1992, Whitlock et al. 2008).

Fire- and drought-intolerant species, including western hemlock, noble fir, and western redcedar, are likely to decrease in abundance and may be more sensitive to insects and pathogens on drier sites because of drought stress (Chmura et al. 2011). Shifts towards the cooler portions of the range of these species have already been observed (Monleon and Lintz 2015), and they may become more restricted to climate change refugia (e.g., moist or cool landscape settings; Morelli et al. 2016). Western yew (*Taxus brevifolia* Nutt.), one of the species in the assessment area that has experienced relatively high mortality (Monleon and Lintz 2015), may be particularly sensitive to climate change and dependent on refugia (Germain and Lutz 2020).

Noble fir stands that dominate the highest elevations may also be sensitive to replacement by species from lower elevations, primarily Douglas-fir. Given the shade-intolerant nature of Douglas-fir, fire will most likely catalyze shifts of this species towards higher elevations. Noble fir that currently occupy the higher-elevation moist coniferous forests may not have suitable habitat to migrate upwards to as they already exist at the highest elevations. These species may be especially sensitive to extirpation at the lowest elevations of their distribution in the Coast Range.

Warmer, wetter conditions may promote native and non-native pathogen activity, particularly Swiss needle cast on Douglas-fir near the coast. Warmer or drier conditions during important biological windows may promote increased insect activity and host sensitivity. Grand fir and noble fir growing in the OCAP assessment area are likely to become increasingly susceptible to tree decline and mortality caused by balsam woolly adelgid, which is favored by warmer conditions. Western hemlock looper outbreaks in hemlock-dominated stands may become more frequent and severe (McCloskey et al. 2009). Sitka spruce in the coastal fog belt may also experience increasing spruce weevil activity that detrimentally suppresses growth and competitiveness during early stand development. Spruce aphid outbreaks may become more frequent and severe.

Several species of hardwoods may also be increasingly sensitive and exposed to insects and pathogens in the future. At lower elevations, larger Oregon white oak trees are often infected by a variety of root and butt rots (e.g., *Armillaria* spp., *Inonotus dryadeus* [Pers.: Fr.] Murr.) and may be susceptible to increased defoliation by western oak looper (*Lambdina fiscellaria somniaria* [Hulst]). However, leafy mistletoes, including oak mistletoe (*Phoradendron villosum* [Nutt.] Nutt. ex Engelm.), usually have minimal effects on healthy trees. Recent observations of decline in bigleaf maple are associated with higher temperatures, decreased precipitation, a variety of site factors (Betzen 2018), and feeding damage by a native leafhopper, *Empoasca elongata* (B. Willhite[2], unpublished data). Pacific madrone is susceptible to multiple fungal foliage diseases, twig dieback, and trunk cankers, as well as root diseases (Bennett and Shaw 2008).

Important components of forest understories are likely to experience change in the future. Species distribution models for hazelnut and salal projected less suitable conditions for all three species in the coming century (Prevéy et al. 2020). There is little research on the response of herbaceous species to climate change in the assessment area. However, changes in forest herb communities in the Klamath Mountains of Oregon appeared to respond to a drier climate during the second half of the 20th century (Harrison et al. 2010). Species with northern affinities experienced declines in cover, and species composition shifted towards species that were initially more prevalent on southerly aspects.

Dry Forests

Dry forests will likely experience many of the same changes experienced by moist forests. Douglas-fir and grand fir may be able to maintain dominance as trees of these genotypes of species may already be better suited towards warmer and drier growing season conditions that are projected for the future. Dry forests may also be important sources of genetic variation for shrub species that are expected to experience less suitable conditions in the future (e.g., hazelnut, Cascade barberry, salal) (Prevéy et al. 2020). Sudden oak death has been observed on Douglas-fir and grand fir in southwestern Oregon and a particular aggressive lineage (EU1) is a concern (LeBoldus et al. 2018).

MC2 results suggest that dry forests are likely to have a much larger hardwood component. Deciduous hardwoods that are currently common (e.g., Oregon white oak, bigleaf maple) are likely to increase and be favored by increased wildfire frequency. The hardwood evergreen component, particularly Pacific madrone and other less common species (e.g., giant chinkapin), will also likely be favored by future conditions. Composition may resemble that of mixed-evergreen forests of the Klamath Mountains to the south. Tanoak may extend its range north, but sudden oak death is likely to be an issue if it spreads north as well. Warmer, wetter winters intensify risk of infection and increase exposure (Haas et al. 2015), and the area affected by sudden oak death is projected to increase tenfold by the 2030s under warmer and wetter conditions (Meentemeyer et al. 2011).

Special Habitats

The OCAP assessment area contains multiple special habitats that are geographically restricted but represent an important component of biodiversity and are among the most vulnerable to climate change. Many of these may include threatened, rare, and endangered species of plants and deserve special recognition.

Meadows

Continued loss of meadows across high-elevation landscapes is consistent with projections from MC2 that suggest persistence of forests. Tree canopy cover in major forest biomes outside the tropics has increased over the past 35 years, and temperate continental forests experienced the largest gain (Song et al. 2018). Warming, decreased snowpack, and higher atmospheric CO_2 may facilitate woody vegetation growth and increase sensitivity to meadow loss. Observed losses of meadows during the late 20th century due to fire exclusion and cessation of grazing are likely to continue and may be mediated through changes in snowpack (Zald et al. 2012).

The occurrence of large patches of high-severity fire may restore some aspects of meadow vegetation, depending on the status of native species that may or may not persist following tree encroachment. However, Haugo and Halpern (2007) found that once trees move into meadows, they may alter soil properties and reduce the seed bank of native meadow species, thus impeding conversion back to meadows. Fires may also increase exposure to invasions of nonnative plant species (e.g., *Hieracium* spp.). Meadow flora may persist in places where it has the potential to migrate upwards in elevation prior to establishment of colonizing woody species.

Riparian Areas

The primary effects of climate change on riparian areas in the OCAP assessment area will likely be mediated through disturbance. Increased flooding may occur in some riparian areas because of increased intensity of winter precipitation events (Hamlet et al. 2013). 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 are also likely to cause changes in riparian areas. Fires generally burn with lower severity in riparian areas of southwest Oregon (Halofsky and Hibbs 2008), perhaps providing sources of propagules for adjacent uplands following fire.

Riparian vegetation depends on the presence of flowing and/or standing water. Increasing temperature and evapotranspiration as well as decreasing summer streamflows may lead to drying and increased drought effects in some riparian areas (Dwire and Mellmann-Brown 2017). Drying in riparian areas could decrease the extent of the riparian zone in some locations and/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 associated with riparian areas (e.g., deciduous hardwoods), particularly along smaller streams. However, riparian areas may serve as refugia for species dependent on cooler conditions, as dense vegetation may buffer temperature increases, especially in topographically complex landscapes where cold air drainage may mitigate higher temperature (Morelli et al. 2016).

Nonnative species may also become more competitive in riparian areas with increased opportunities for invasion after disturbance (Catford et al. 2013). Riparian areas in the assessment area are particularly sensitive to invasion from Japanese knotweed (*Fallopia japonica* [Houtt.] Ronse Decr.). This species can grow and expand rapidly once established and form dense, clonal patches that produce copious amounts of seed that may then be transported downstream. Urgenson et al. (2009) found that Japanese knotweed negatively affected the richness and abundance of native plant species and reduced the nutrient quality of litter in a riparian area at low elevation along the Skagit River in Washington. The study also found that Japanese knotweed displaced regenerating trees, suggesting that the species may have long-term effects on the composition and structure of riparian forests.

Altered riparian plant species composition and reduced riparian extent could result in direct losses to the quantity and quality of ecological contributions by 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).

Wetlands and Groundwater-Dependent Ecosystems

Increased exposure to higher temperatures, decreased fog and increased evapotranspiration, and more nonnative species may affect wetlands and groundwater-dependent ecosystems in the assessment area. 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 dependent on groundwater and may shrink or 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 on 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 wetlands at higher elevations are expected to be highly sensitive to a warmer climate; some ephemeral montane wetlands may disappear, and 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).

Tidal Estuaries and Marshes

Rising sea level is a major threat to tidal estuaries and marshes. This is in addition to extensive losses in tidal wetlands caused by diking or conversion to forest (Brophy et al. 2019). Thorne et al. (2018) found the potential for up to 100 percent submergence of marsh habitats in Oregon by 2110 under a high sea-level rise scenario (+142 cm). Under a low sea-level rise scenario (+12 cm), 95 percent of the high marsh and 60 percent of the middle marsh were projected to be lost, with only low marsh remaining. Although some species may be able to migrate as sea level shifts, the historical reduction in habitat caused by land conversion and lack of adjacent upland habitat will limit migration and loss of tidal wetlands.

Dune Systems

Dune systems are likely to be particularly vulnerable to climate change. Invasive plants, especially European beachgrass, have substantially altered dune morphology and reduced native species richness (Hacker et al. 2012). The stabilization of dunes by European beachgrass has decreased longshore heterogeneity and promoted the development of coastal scrub vegetation and wetlands by reducing sand delivery to foredunes (Wiedemann and Pickart 2004). The potential response of European beachgrass to changes in temperature are unknown, but one experimental study on American beachgrass from Sleeping Bear Dunes in Michigan found that survivorship decreased by 46 percent with an increase in temperature of 5°C. European beachgrass may decline if it has a similar response to projected increases in temperature, but it is unknown how other dune species may respond to climate change or decreased dominance of European beachgrass.

Summary and Conclusions

Projected increases in temperature, soil moisture deficits, and wildfire will affect species composition and structure of vegetation in the Oregon Coast Range and adjacent locations. However, the effects are expected to differ geographically, and considerable uncertainty exists about the ecological implications and timing of change. Additional stressors, including nonnative species, may drive vegetation shifts by competitively excluding native species or altering disturbance regimes. Many special habitats, especially those exposed to sea-level rise (e.g., tidal marshes and estuaries) are particularly vulnerable.

Douglas-fir will likely remain the dominant species throughout the region and potentially shift its range, replacing noble fir at high elevations as well as Sitka spruce in lower-elevation coastal areas. Warmer, drier summers with less fog will likely favor hardwoods and result in shifts away from shade tolerant conifers. Western hemlock and western redcedar may become more restricted to topographically sheltered refugia in old-growth forests that buffer projected increases in temperature. MC2 projects widespread shifts from moist coniferous forests to warm and subtropical mixed forests that currently do not exist in the assessment area. Dry forests will likely expand in inland areas and potentially resemble mixed-evergreen forests of southern Oregon and northwestern California.

Disturbances and invasive species are expected to be prominent mechanisms of change. Insects and disease have the potential to decrease productivity as summer drought stress increases with higher temperature and less coastal fog. Although wildfires have been rare and small in recent decades, historical fires demonstrated the potential for extremely large stand-replacing fires during dry east-wind events. High-severity fire will also favor hardwoods and promote the invasion and expansion of nonnative plant species that are already widespread throughout the Coast Range. Non-forest transitions or protracted periods of early-seral development following short-interval reburns such as the Tillamook fires will be more likely under more frequent drought conditions.

A long-term paleoecological perspective provides a context for some of the mechanisms and resulting changes projected by MC2 for the Oregon Coast Range. However, there is still considerable uncertainty surrounding some ecological outcomes. Considering this uncertainty in the light of the degree of agreement among paleoecological studies, empirical observations on contemporary forest change and model projections for the future will be essential for developing strategies to adapt to future changes in climate.

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Chapter 6: Climate Change, Wildlife, and Wildlife Habitats in the Oregon Coast Range

Todd M. Wilson, Lindsey Thurman, Erik A. Beever, Peter Singleton, Deanna H. Olson, Deanna Williams, and Douglas A. Glavich

Summary

Climate change is likely to have profound effects on wildlife species within the Oregon Coast Adaptation Partnership (OCAP) assessment area, although the direction and magnitude of effects are likely to vary across species. Increased mean and extreme temperatures, especially during summer, may cause shifts in plant and animal species ranges, reduce habitat for some temperature-sensitive wildlife, alter plant phenology and the timing of available food resources, and affect species interactions (e.g., predation, competition). Altered timing of precipitation, summer drought, loss of fog, increased flooding events, earlier snowmelt, and rising sea level may reduce plant productivity, increase tree mortality, shift plant species composition, and lead to reduced wildlife habitat and habitat quality for some forests, riparian areas, wetlands, meadows, estuaries, and beaches. In addition, increasing frequency and extent of wildfire and insect outbreaks may reduce the extent of late-successional forest, reduce habitat connectivity, and increase the spread of invasive species. The biggest change expected for the assessment area is an increase in area where climatic conditions favor coastal mixed forest and a large reduction in area favoring montane conifer forest. Although actual changes in forest types may not necessarily occur by the end of the 21st century, climate change may add physiological and behavioral stress to wildlife. Some wildlife species will be able to persist in place and adapt to new conditions; some may be able to migrate to find suitable habitat; and some may be greatly reduced or extirpated from the assessment area or even go extinct. Shifts in major tree and shrub species will play a major role in food, den, and cover availability for wildlife. Rising sea level will reduce low-elevation habitats along the coast. An increase in the frequency of high-severity weather events will increase frequency and magnitude of flooding, including debris flow events. Coupled with increased temperatures during summer, this may reduce or fragment important ecosystems for aquatic and semi-aquatic species. Evaluation of the vulnerabilities of nine wildlife species based on literature reviews suggests that each species has life-history attributes that can lead to resilience or vulnerability to climate change effects. Depending on long-term objectives, several broad adaptation strategies focus on protecting refugia, establishing redundant wildlife strongholds with large-scale connectivity, and promoting structural and biological complexity.

Introduction

Climate change will affect the abundance and distribution of wildlife, from local to global scales. As a result, vulnerability assessments are being conducted to: (1) project how wildlife will respond to the effects of climate change on ecosystems and habitat, and (2) inform management strategies that can help reduce negative outcomes of these changes over time (Case et al. 2015, Chapman et al. 2014, Halofsky et al. 2011, Hixon et al. 2010, Marcot et al. 2015, Pacifici et al. 2015, Raymond et al. 2014, Vié et al. 2009). Projections of the effects of climate change on wildlife range from positive effects, to minimal negative effects, to species extinction, to trophic web collapse (Helono et al. 2020).

Climate change may have direct physiological effects for some animal species and is also likely to affect wildlife habitat, including resources that provide food, water, shelter, protective cover, and breeding and dispersal life functions (Cahill et al. 2012). One of the most important resources for providing wildlife habitat is vegetation, including trees, shrubs, grasses, forbs, and non-vascular plants. The diverse array of resources provided by vegetation includes direct and indirect sources of food, sources of cavity dens, platforms for nests, locations for thermoregulation and hibernation, protection from wind, rain, and sun, substrates for travel, cover from predators, and sources of moisture. Therefore, an understanding of how vegetation is likely to respond to a changing climate (chapter 5) will inform our understanding of how wildlife may respond to climate change.

The distribution of vegetation, water, and geomorphic resources in space and time is also important. For example, food resources need to be available year-round for species that do not hibernate or migrate, and down wood, duff, and leaf litter may need to occur in sufficient quantities to permit adequate foraging, denning, or nesting habitat for different species. Overstory tree shading can be essential to moderate temperatures for cold-dependent species. Likewise, the availability of water resources is influenced by the spatial distribution and seasonality of available water through rainfall, snowpack, and both aboveground and belowground water retention. An understanding of geomorphology is especially important for mountain ranges, as elevation, aspect, topography, and surface (soil, rock) substrates can exacerbate or mitigate effects of temperature and moisture (e.g., rainfall, solar radiation, moisture retention, duration of snowpack). This occurs at a range of spatial scales, including: (1) topographic hill shading which contributes to cool, moist surface microhabitats (Suzuki et al. 2008, Dobrowski 2011), (2) substrate types that provide interstitial spaces for rock-dwelling species (Nauman 2008, Olson 2008), and (3) stream-reach characteristics that provide potential fish habitat (Burnett et al. 2007).

The ability of wildlife to persist in the face of climate change will also depend on the adaptive capacity of each species. Some animal species will have the capacity to reside in place. For example, generalists like deer mice (see Table 6.1 for a list of common and scientific names used throughout this chapter) are broadly distributed across North America, occupy diverse ecosystems, can rapidly colonize disturbed sites, and can take advantage of diverse microclimatic conditions and food resources. Likewise, human-commensal species like coyotes, raccoons, and American crows may continue to thrive in climate-disturbed landscapes. In contrast, some species are highly specialized in their habitat needs or endemic to a small geographic area and may go extinct if their habitat is adversely affected. This may be especially true for some of the terrestrial salamanders in the Oregon Coast Adaptation Partnership (OCAP) assessment area that have a narrow tolerance for altered temperature and moisture (Mims et al. 2019).

There may be distribution shifts for some wildlife and habitat types as the climate becomes warmer and more extreme (Freeman et al. 2018, Monleon and Lintz 2015, Rumpf et al. 2018). The pattern of such shifts may be upward, asymmetric, or even idiosyncratic (Moritz et al. 2008, Rapacciuolo et al. 2014, Rowe et al. 2015). Different populations within the same species may respond quite differently (Smith et al. 2019). Some wildlife species have the mobility to track shifting vegetation, and others may not, at least not without conservation introductions. In the OCAP assessment area, there may be limited opportunity for upslope migration owing to limited elevation extent in the Coast Range (Marys Peak is the highest peak in the Coast Range at 1,249 m). Shifts in animal distributions are not exclusively upslope. For example, recent changes in the migratory patterns of rufous hummingbirds have been attributed to higher spring temperatures, including delays in arrival and bypassing the Oregon Coast completely in favor of more stable and predictable conditions inland and further north (Courter 2017).

Some species may be at increased risk of local population losses or extinctions. Even common amphibians like the Pacific chorus frog may encounter thermal extremes that reduce reproductive rates and survival (Gerick et al. 2014), which could have ramifications for the larger food web in which the species is critical as both predator and prey. Altered community composition and local losses may result from altered predator-prey dynamics. For example, model simulations suggest climate change could lead to earlier egg production by long-toed salamanders, leading to increased predation of Pacific chorus frog eggs (Jara et al. 2019). Habitat specialists and species with dispersal limitations may be especially prone to local extirpation if new habitat is not formed because of climate change. The factors that mediate the processes of persistence versus extirpation (as well as controls on abundance) have recently been observed to shift rapidly (less than 10 years) for some species across the same sites using the same group of models (Beever et al. 2011, 2013).

Climate change is just one of many factors that influence ecosystem dynamics and habitat in the OCAP assessment area. These factors include forest harvest practices, urban and rural development, roads and highways, agriculture, recreation, diking of estuaries, pollution, nonnative invasive plant and animal species, insect and disease outbreaks, and fire exclusion (e.g., Betts et al. 2018, Ceballos et al. 2017, Diaz et al. 2019, Emel et al. 2019, Wilcove et al. 1998, Young et al. 2016). The overall effect of some of these factors has been extensive habitat fragmentation, as well as removal of apex predators and keystone species. Many of these stressors are addressed in more detail in other chapters. In addition, there is a growing body of literature around general guidance for managing wildlife for climate change effects (e.g., Cross et al. 2012, Foden et al. 2018, Glick et al. 2011, LeDee et. al. 2021, Wilsey et al. 2013).

Assessment Approach

About 595 species of terrestrial vertebrates occur within the Oregon Coast Range, including 388 species of birds, 148 mammals, 36 amphibians, and 23 reptiles (Oregon Explorer 2020). Vegetation in the OCAP assessment area is dominated by forest, interspersed with grasslands and meadows. Climate on the west side of the assessment area is heavily influenced by the Pacific Ocean, which has a moderating effect on winter and summer temperatures, providing moisture driven by more rainfall and fog compared to the eastern portion of the assessment area.

This chapter highlights wildlife issues to facilitate discussions among resource managers and scientists when developing strategies that may help species adapt to climate change in the assessment area. First, we modeled projected changes in broad vegetation types over the next century based on modeling conducted for previous assessments (i.e., MC2 projections; Halofsky et al. 2022). Four vegetation types were modeled:

- Coastal Mixed Forest Type

- Montane Forest Type
- Interior Mixed Conifer Forest Type
- Grass, Shrubs, and Woodlands Type

Second, we delineated ecosystems within vegetation types to describe the potential effects of climate change on dominant tree and shrub species important to wildlife, following approaches similar to those used in vulnerability assessments conducted elsewhere in the Pacific Northwest (e.g., Singleton et al. 2019, 2022). We chose eight ecosystems based on their likelihood to have a unique response to climate change because of their plant species compositions, elevation, topography, water availability, and proximity to the ocean:

- Mixed conifer forest
- Sitka spruce forest (and associated fog zone)
- Oak-savanna woodlands
- Montane forest and meadows
- Coastal meadows and grasslands
- Aquatic and wetland habitats (including lacustrine, palustrine, riverine, and dune wetlands)
- Marine and estuarine habitats
- Dune shrub forest

For each ecosystem, we provide: (1) a brief description of its distribution and key features of that habitat, (2) projected climate change exposure for that habitat, (3) sensitivity of the ecosystem to the projected climate change, (4) adaptive capacity of ecosystems within the habitat to be resilient to climatic factors, and (5) adaptation measures and management strategies that may help offset negative effects owing to climate change (table 6.2). A full list of adaptation options is presented in Chapter 9.

Finally, we conducted adaptive capacity assessments for nine animal species distributed across these ecosystems (boxes 6.1 to 6.9):

- American beaver
- Humboldt's flying squirrel
- North American porcupine
- Acorn woodpecker
- Marbled murrelet
- Rufous hummingbird
- Western snowy plover
- Rubber boa
- Oregon silverspot butterfly

We use these species to highlight: (1) the diverse and often distinct challenges and opportunities that wildlife species will face as climate change progresses, and (2) the breadth of wildlife considerations that may be needed when determining specific adaptation actions that managers may wish to use within the assessment area.

Vulnerability to climate change is often applied at the individual species level. Since the early 20th century (e.g., Gleason 1926), species have been known in most cases to respond individualistically to ecological disturbance, rather than as a kind of "super organism" (akin to Clements 1916). However, it is possible to manage for the adaptive capacity of species at an ecosystem level and context (Beever et al. 2016). Therefore, we assessed vulnerability for both the eight ecosystems and nine example wildlife species. Vulnerability typically consists of three subcomponents: exposure, sensitivity, and adaptive capacity (Dawson et al. 2011; Foden et al. 2013; Nicotra et al. 2015; Thurman et al. 2020, 2022). Here we use similar terminology as Singleton et al. (2022) to incorporate both species and ecosystems:

- Exposure—The magnitude of environmental change owing to one or more aspects of climatic conditions, especially those that are biologically relevant for the target species or ecosystem.
- Sensitivity—Potential effects of climate change on the ecology or physiology of individuals or habitat components that might affect wildlife. It reflects how dependent or tightly linked a species, population, or ecosystem is to changes in current conditions.
- Adaptive capacity—The capacity of individuals and ecosystems to adapt to shifting and potentially novel environmental conditions associated with climate change (e.g., behavioral changes, evolutionary adaptation, dispersal ability, and range shifts).

Information for this assessment includes: (1) U.S. Department of Agriculture, Forest Service (USFS) potential vegetation maps (Simpson 2013), (2) Oregon GAP/LANDFIRE National Terrestrial Ecosystems maps derived from 2011 remote sensing imagery (USGS 2016), (3) Oregon Explorer Wildlife Viewer (Oregon Explorer 2020), (4) Johnson and O'Neil (2001), and (5) Verts and Carraway (1998). We also used scientific literature searches (e.g., via online and library-based search engines) and ongoing research (unpublished), along with the expertise of the author team, outside experts, and resource managers.

Projected Climate Change

We used projections for the same global climate models and emission scenarios that were emphasized in the vegetation chapter of the Southwest Oregon Adaptation Partnership assessment: BNU-ESM, CanESM2, CESM1(CAM5), MIROC-ESM-CHEM, and MRI-GCM3 (Halofsky et al. 2022). The historic, mid-century (i.e., 2050), and end-century (i.e., 2099) MC2 projections in the OCAP assessment area were clipped for each of the five change scenarios (fig. 6.1). Both historic and projected MC2 vegetation types were reclassified to produce a binary (0,1) map for each vegetation type and then summed to identify areas where one or more scenario projected contraction (values 10–14), expansion (1–5), or persistence (15) for each vegetation type.

MC2 model output projects: (1) higher temperature, especially in winter, including few below-freezing nights at higher elevations, (2) more growing degree days, especially in summer, and (3) climatically driven water deficit (drought stress) that is projected to double by the end of the century. MC2 modeling does not project a big transition in biomes (e.g., forest to woodland or woodland to grassland), but it does suggest that substantial changes in forest type will occur. The largest projected change is an increase in coastal mixed forest (primarily consisting of temperate warm mixed forest and subtropical mixed forest) (fig 6.2). These forests are associated with Sitka spruce and coast redwood forest types, comprising 11 percent of the historical landscape along the coast and south of the OCAP assessment area. This type is projected to increase to about 77 percent of the assessment area by the end of the century (averaged across the five scenarios).

Montane conifer forest (consisting of the moist temperate needleleaf forest MC2 vegetation type) composed 86 percent of the historical assessment area landscape and is projected to decrease to 15 percent of the assessment area by the end of the century (averaged across the five scenarios) (fig 6.3). Interior mixed-conifer forest (consisting of the temperate needleleaf forest MC2 vegetation type) composed 1.7 percent of the historical assessment area landscape and is projected to decrease to <0.01 percent of the assessment area by the end of the century (averaged across the five scenarios) (fig. 6.4). The combined area of shrubland, grassland, and woodland types composed 1.5 percent of the historical assessment area landscape and is projected to increase to 9 percent of the assessment area by the end of the century (averaged across the five scenarios). Around 5 percent of the assessment area is projected to convert to novel vegetation types not currently found in the assessment area. Relationships between MC2 vegetation types and the eight ecosystems are presented in table 6.2.

Climate change is expected to affect hydrologic regimes and freshwater habitat quantity, quality, and distribution (e.g., Olson and Burton 2019). These effects are largely mediated through changes in the amount and timing of precipitation and snowpack conditions that determine water supply and discharge (Wu et al. 2012), with summer heat load influencing small watersheds (Olson and Burton 2019). Climate change is not expected to alter the annual amount of annual precipitation. However, the timing and intensity of precipitation is projected to change, with precipitation projected to decrease in summer.

Coupled with warmer temperatures, summer drought would also lead to drier conditions that can increase the frequency and extent of wildfires (Abatzoglou and Williams 2016). Although historic fire-return intervals have been relatively long within much of the OCAP assessment area compared to other areas of Oregon, when fires have occurred, they had a big influence on forest structure (e.g., the Tillamook burns of 1933, 1939, and 1945). Increased frequency and extent of fires could greatly affect the structural trajectories of forests, further reducing the amount of mid- and late-seral habitat and increasing early-seral habitat. A higher frequency of extreme storms in winter could cause increased landslides and flooding.

Other Stressors

Insects and diseases—
Climate change will likely increase insect outbreaks and perhaps some plant diseases in the OCAP assessment area. For example, Douglas-fir beetle and black stain root disease are likely to become more prevalent with higher temperatures and drier summers. Warmer winters could intensify the effects of Swiss needle cast (Agne et al. 2018). Increased mortality from diseases would create more snags, more coarse woody debris, and less canopy cover.

Some diseases may also directly affect wildlife. A warming climate has been associated with the northward spread of vector-borne diseases in Europe and North America, including Epizootic Hemorrhagic Disease Virus, West Nile virus, chikungunya, and the amphibian chytrid fungus *Batrachochytrium dendrobatidis* ("Bd"; Xie et al. 2016). There is also concern over additional emerging amphibian and reptile fungal and viral diseases that could survive over winter (e.g., Bsal [*Batrachochytrium salamandrivorans*], ranavirus) in a warmer climate.

Invasive species—

Many invasive species are present in Pacific Northwest forests (Seybold et al. 2021). Invasive plant species of particular concern in the assessment area include European beachgrass, gorse, and Himalayan blackberry. Climate change is also expected to facilitate the range expansion of non-native invasive animal species, with some evidence this is already underway (Gervais et al. 2020). For example, species adapted to warmer water (e.g., large-mouth bass, white and black crappie, bluegill, yellow perch, bullhead, Asian carp, American bullfrogs) can compete with, prey on, or hybridize with native fish (e.g., steelhead) and amphibians. Species such as the bullfrog can be disease-causing pathogen reservoirs (becoming infected but not showing disease symptoms) and potentially be disease superspreaders under some conditions (Bd: Ribeiro et al. 2019).

Invasive terrestrial, warm-blooded species are also spreading. For example, black rats and Virginia opossums have been detected in both camera surveys and live-trapping studies within upland forests of OCAP assessment area (T. Wilson, personal communication[2]). In addition, the combination of climate change and increasing land-use change will generally favor human-commensal and eurytopic (tolerant of a wide range of habitats and conditions) species, typically at the expense of stenotopic (tolerant of a restricted range of habitats and conditions, often endemic) species. The current expansion of barred owls (a species with a diverse diet) into habitat previously occupied by northern spotted owls (a specialist with a more restricted diet) is one example.

Human infrastructure and land-use change—

Cessation of burning by humans, stabilization of friable slopes where wind erosion created different plant communities, agricultural development, urban development, clearcut logging, and single-story plantations have greatly altered habitats in the OCAP assessment area. Water flow and hydrology have been modified by barriers (e.g., roads, dams, culverts) and irrigation diversions that can reduce water flow and interfere with fish and wildlife migration. Channelization and development can restrict the natural ability of streams to meander, limiting the quality and availability of these habitats, as well as affecting floodplain function. Restoration projects have addressed these effects in some locations (Cluer et al. 2014, Hoffman et al. 2012, Powers et al. 2019).

Recreation—

Warm-weather recreation is expected to increase across all ecosystems in the OCAP assessment area. Forest use by campers, mountain bikers, hikers, and users of special forest products is increasing, especially in proximity to population centers (chapter 7). In addition, changes in weather patterns could affect seasonal changes in public use of these lands, which could harm sensitive species, especially during breeding periods. Increased road use in spring and early summer could affect breeding migrations, causing more roadkill as animals leave overwintering habitats (Andrews et al. 2015).

Mixed Conifer Forest

Mixed conifer forest habitat occupies the largest extent of the OCAP assessment area. Structurally complex old-growth forest is an important habitat feature in this focal area. The extent of complex old forest has been greatly reduced by widespread logging over the last century. Under the Northwest Forest Plan, late-seral characteristics are promoted in young, managed forest through thinning, promotion of shade-tolerant conifers in the mid-story, and diverse and patchy understories. Several dominant tree species contribute to the structural complexity of late-seral forest and provide food, shelter, and cover for numerous animal species.

Douglas-fir

Douglas-fir is the most common tree species in this habitat, providing many ecological components important to wildlife (fig. 6.7). Resistance to fire, long lifespan, and ability to overtop most other species when grown in open conditions allow Douglas-fir trees to become dominant structures in many locations. Their large size facilitates development of large lateral branches, forks, multiple leaders, dead tops, and baskets creating platforms for nests used by species such as marbled murrelets and red tree voles (Hamer and Nelson 1995, Swingle and Forsman 2009). Cavities in these structures are used by many species, from small songbirds to black bears. The thick, rough bark of mature trees also provides crevices for roosting bats.

Douglas-fir is associated with several hundred mycorrhizal fungi species, and perhaps thousands more across its full geographic distribution (Amaranthus et al. 1994). This fungal diversity helps maintain wildlife communities that feed on fungal fruiting bodies (truffles and mushrooms) such as flying squirrels and voles, which in turn can help maintain healthy predator populations (Maser et al. 1986). Mature Douglas-fir cones are eaten by squirrels and several bird species (Smith and Balda 1979). Douglas squirrels specialize in caching Douglas-fir seeds that provide a rich source of food during the winter when other food sources may be scarce (Smith 1970). Birds such as red crossbills have specialized beaks designed for breaking apart fir cones. Mice consume large amounts of seeds that fall to the forest floor. Other important food sources from Douglas-fir include terminal buds, needles, pollen, and cambium.

Bigleaf Maple

Bigleaf maple is a widely distributed deciduous tree throughout the OCAP assessment area (fig. 6.8). This species has the potential for providing more wildlife-related resources than most other tree species in the region. In spring, the buds, flowers, and pollen are favored by squirrels, birds, and insects. The winged seeds (samaras) of bigleaf maple are sought by squirrels, chipmunks, mice, voles, shrews, jays, and crows. The seeds are frequently cached, providing a food source for some animals well into the winter. Their branches support mosses, lichens, liverworts, ferns, and other epiphytes. Young maple seedlings and saplings, along with green leaves of mature trees, are browsed by deer and elk. Large cavities formed or created in the heartwood are used by squirrels and larger terrestrial vertebrates as denning structures.

Western Hemlock

Most of the Coast Range is in the western hemlock zone; in the absence of disturbance (e.g., fire or wind) western hemlock typically becomes the dominant or co-dominant (with Douglas-fir) in the overstory (fig. 6.9). Western hemlock cones are produced annually, providing a reliable food supply for seed-eating wildlife. In addition, cones can stay on a tree from August through March, providing a winter source of food for seed-eating species that do not cache cones. Low, thick foliage is used as winter cover by grouse, wild turkeys, and many resident songbirds. The dense branches provide suitable cover for nesting birds such as Swainson's thrushes. Mature western hemlocks provide many of the same structural attributes as other dominant conifers, such as large lateral branches and cavities.

Because it is shade tolerant, western hemlock can fill gaps between canopy dominants like Douglas-fir and the understory layer of a forest. This helps provide protective cover from predators for canopy-dwelling species like flying squirrels and red tree voles (Wilson and Forsman 2013). It can also promote a patchy understory that supports diverse and abundant species in late-seral forest (Carey et al. 1999). Low, thick foliage is used as winter cover by grouse and many resident songbirds. The dense branches provide suitable cover for nesting birds such as Swainson's thrushes. The dense foliage can also reduce snowpack under the branches, providing access to food on the forest floor for birds, small mammals, and black-tailed deer during winter.

Grand Fir

Grand fir is prevalent on the eastern edge of the mixed conifer forest (fig. 6.10). Although no wildlife species are dependent on grand fir, this tree provides similar food, den, and cover resources as other conifers. Needles and seeds from grand fir cones provide food for seed-eating birds like black-capped chickadees, crossbills, and Clark's nutcrackers. Squirrels cache cones for a winter food supply. In some places, grand fir needles make up a major part of blue grouse diets. Black-tailed deer and Roosevelt elk may eat grand fir needles in winter if other food becomes scarce. When decay occurs in large trees, it can provide cavities for denning by large vertebrates like black bears and nesting by large owls. Grand fir boughs can be dense, providing protected nest sites for many species including songbirds. When low branches remain green and intact, they provide hiding cover for deer, elk, grouse, and small mammals.

Western Redcedar

Western redcedar is a long-lived, shade-tolerant tree found throughout mixed conifer forest habitat, more commonly lower elevation than Douglas-fir and western hemlock (fig. 6.11). They make excellent cavity trees because they compartmentalize decay and can continue growing for several hundred years. As a result, their cavities provide dens that persist much longer than dens of other live conifers. The tall crowns of western redcedar, which connect the understory and upper canopy layers, reduce visual and aural detection of small mammals by predators (Wilson and Forsman 2013). Redcedar bark is used by squirrels and birds to line their nests. The high oil content of cedar leaves and cones makes them unpalatable to most wildlife, although deer sometimes browse young trees.

Pacific Madrone

Pacific madrone is typically found in well-drained soils in the eastern portion of the OCAP assessment area, associated with Douglas-fir forests in dune shrub habitat (fig. 6.12). Madrone can produce prolific numbers of berries that are consumed by numerous birds and mammals including varied thrushes, fox sparrows, band-tailed pigeons, mourning doves, blue and ruffed grouse, dark-eyed juncos, and squirrels. The berries ripen in September, and heavy crops of berries occur annually. Madrone has several mycorrhizal associates and may be important in adding fungal diversity to a stand (Amaranthus and Perry 1989). Madrone can support small and medium-sized cavities that are used by tree squirrels, woodpeckers, chickadees, house wrens, and bluebirds. The canopy architecture of mature madrone promotes forks and horizontal surfaces for nesting platforms that can support nests of all sizes.

Incense Cedar

Incense cedar is restricted to the southeast edge of the OCAP assessment area in dry Douglas-fir and grand fir forest associations (fig. 6.13). The value of this species to wildlife is similar to that of western redcedar but mostly in drier sites. Use of incense cedar seeds by wildlife is limited, probably because oils in the seeds make them unpalatable. Incense cedar has low palatability as browse, although deer forage on young trees to some extent. Like western redcedar, these trees are long lived and very resistant to decay, thus facilitating the development of cavities for nesting.

Berry-producing Shrubs

Several berry-producing shrubs exist within this ecosystem. They provide highly nutritious browse during the fall, winter, and early spring that are readily consumed by deer, elk, mountain goats, rabbits, and mountain beavers. Berries, especially huckleberries (*Vaccinium* species), are an important summer and early-fall food consumed by a variety of birds and mammals including black bear, Townsend’s chipmunks, pigeons, squirrels, mountain beaver, grouse, thrushes, and other songbirds. Hummingbirds and pollinating insects use nectar in the flowers throughout early and mid-summer.

Assessment of Climate Change Effects

Exposure—
MC2 projects a broad transition from climate favoring moist temperate needleleaf forest to climate favoring a mix of sub-tropical and temperate warm forest similar to the northern California coast. This biome shift is influenced by a relatively warm winter regime, but possibly drier conditions due to a rain-shadow effect on the east side. There is a small portion of interior mixed conifer (grand fir types) in the southwest portion of the assessment area that is projected to disappear by end-century (see Singleton et al. [2022] for a more detailed discussion of this vegetation type).

Sensitivity—

Douglas-fir, which is relatively common throughout the OCAP assessment area, is likely to persist across much of the assessment area for the foreseeable future (fig. 6.7). However, drier conditions (hotter summers, less moisture) could decrease growth and increase mortality especially along areas of the Oregon Coast where Douglas-fir relies on groundwater in shallow soils (Littke et al. 2018).

Bigleaf maple seeds require cold stratification for germination (Zasada and Strong 2008). A warming trend during winter might reduce the capacity of maple to establish in areas where it currently does not exist. This projection is supported by the observation that moderating weather effects of the Pacific Ocean may be associated with maple not currently being found along the coastal edge of the assessment area.

As temperature increases, western hemlock abundance may decrease, especially along the western edge of the assessment area where temperature is expected to increase the most. Douglas-fir may gradually replace western hemlock and western redcedar, which grow more slowly than Douglas-fir and have low resistance to wildfire. Drying conditions could increase the frequency of stand-replacing fires (Keyser and Westerling 2017; Westerling et al. 2006). Coupled with insect outbreaks, this would shift more forests dominated by Douglas-fir into early-seral conditions, resulting in loss of habitat for wildlife dependent on late-seral conditions. For example, species like northern spotted owls and marbled murrelets that are associated with old, complex forests would experience reductions in high-quality habitat. However, this would benefit species such as deer, elk, and some songbird species that use early-seral habitat.

Altered timing of winter and spring frosts, altered abundance of pollinators during flowering, increased frequency of summer drought, and heavy rain events expected with climate change can negatively influence berry production. For example, model projections suggest extirpation of the locally rare black huckleberry and possibly other species such as evergreen huckleberry within the assessment area (Prevey et al. 2020). Production of other berry-producing shrubs such as black currant may also decrease owing to warmer winters (Preedy et al. 2020). Species such as the coastal marten and their prey are dependent on heavy berry crops.

Adaptive capacity—

- Older, structurally complex stands may be more resilient to a warmer climate.
- Opportunities for some species (e.g., grand fir) to move to higher elevations may be limited.
- Bigleaf maple may persist in current locations for the foreseeable future because of its capacity for basal sprouting after fire and timber harvest.

Adaptation strategies—

- Continue development of late-seral conditions in managed forests.
- Promote shade-tolerant tree species following thinning, including grand fir, western redcedar, and incense cedar.

Coastal Sitka Spruce Forest (Fog Zone)

Many of the same conifers and hardwoods (except bigleaf maple and grand fir) that occur in mixed conifer forest also occur in coastal Sitka spruce forest. Sitka spruce is common in this ecosystem but rare elsewhere within the OCAP assessment area (fig. 6.14). The structural complexity of natural forests within this zone provides critical habitat to threatened and endangered species, including northern spotted owls, marbled murrelets, and red tree voles.

Sitka Spruce

The small, winged seeds of Sitka spruce are eaten by squirrels, chipmunks, and other small mammals and seed-eating birds. Needles and twigs are browsed by deer and rabbits in winter. Grouse consume spruce needles extensively. Spruce is a long-lived (>800 yr) species that has the potential for forming large cavities, perches for avian predators, and large lateral branches for platform nesting.

Fungi

This ecosystem is especially diverse and productive because of the coastal fog that modulates temperature, providing moisture favorable for many fungal species. The Pacific Northwest supports some of the most diverse and abundant fungi found anywhere in the world (Trappe et al. 2009). Both epigeous (above-ground) and hypogeous (below-ground) fruiting bodies of fungi are consumed by many animal species, including squirrels, voles, mice, ungulates, and invertebrates.

Assessment of Climate Change Effects

Exposure—
MC2 projects expansion of coastal mixed forest which includes this ecosystem as well as spruce and redwood forests south of the assessment area. This will result in a longer growing season and fewer below-freezing nights. It will also result in conditions more favorable to hardwoods. A 4 °C increase in temperature is projected over the next 100 years for inland habitats, but some projections suggest less than a 4 °C increase along the coast.

Sensitivity—
Decreased fog would increase stress on Sitka spruce, the most drought-intolerant conifer in the assessment area. Cold, wet springs would result in lower reproductive fitness and increased susceptibility to pathogens. More canopy kill may reduce the extent of thermal refugia and availability of habitat components such as moss, which is essential to nesting murrelets. The marine influence on moderating temperature, moisture, and fog is unclear.

Adaptive capacity—

- Older stands may be more resilient.
- An increase in pathogens would increase the number of snags, which would benefit cavity excavators (e.g., woodpeckers) and animals that use snags for dens.

Adaptation strategies—

- Continue to promote development of healthy and resilient late-seral conditions in managed forests.

Oak Savanna/Woodlands

Oak woodlands, which occurs along the eastern fringes of the OCAP assessment area (fig. 6.15), has been an important habitat for wildlife for millennia. Indigenous peoples promoted oak habitat through repeated burnings of grasslands within the Willamette Valley, preventing the spread of Douglas-fir and other conifers.

Oregon White Oak

Over 170 mammals and birds use oaks, including pocket gophers, black-tailed deer, mice, squirrels, band-tailed pigeons, woodpeckers, doves, jays, wood ducks, mice, chipmunks, squirrels, woodrats, deer and bear (Barrett 1980). Western gray squirrels and acorn woodpeckers require oak as part of their habitat needs. Other species take advantage of resources that oaks provide, including acorns, platform branching, and long-lived cavities in both live and dead trees (Gumtow-Farrior 1991). Oaks can bear large crops of nutritious acorns in good years, which can occur every 2 to 5 years (Coblentz 1980, Goodrum et al. 1971).

Oak woodlands are interspersed with grassland communities that are used by several species, including snakes, mice, voles, and deer. Important prairie and savannah species include native grasses, California oatgrass, blue wild rye, Roemer’s fescue, and California fescue. The endangered forb Kincaid’s lupine is an important host plant for the threatened Fender’s blue butterfly. Many plant and animal species found in this habitat cannot compete with more aggressive species found in the adjacent mixed conifer woodlands.

Assessment of Climate Change Effects

Exposure—
MC2 projects increased area for this habitat type along the Willamette Valley margins.

Sensitivity—
Increased susceptibility to sudden oak death, increased frequency and severity of summer drought events, and increased fire frequency and extent could increase oak mortality.

Adaptive capacity—

- Oregon oak-dominated habitat may expand due to the resilience of oak to drought and potential for upslope range shift, especially along the eastern edge of the assessment area.

- As the viable range for oak expands, small mammals and other wildlife will be needed to spread fungal spores to promote oak seeding establishment away from well-established mycorrhizal networks (Frank et al. 2009).

Adaptation strategies—
Little effort has been expended to protect and expand connectivity between areas where oak is present, which could hamper potential expansion of oak woodlands (Pellat et al. 2012). Adaptation strategies include:

- Develop plans to maintain oak woodlands and reduce drought stress. This could include prescribed fire, control of conifer encroachment, and plantings of oak seedlings.
- Control invasive plants.
- Maintain landscape permeability in a way that can assist with upward migration and facilitate connectivity.
- Establish landowner partnerships to conserve and promote this habitat type.

Montane Forests and Meadows

Montane meadows and forests are a small but important ecosystem in the OCAP assessment area. Montane meadows in the Coast Range are limited to relatively shallow Mulkey medial loam soils on gabbro silt-capped summits. These meadows are restricted to habitats at or above 1,000 meters. Plant communities are dominated by grasses, including Roemer's fescue, California sedge, California oatgrass, and native bentgrasses (*Agrostis* spp.). Important native forbs include wild strawberry, early blue violet, tough leaf iris, and Tolmei star tulip (Glavich 2021, Hays et al 2012). Montane meadows provide important habitat for pollinators. Marys Peak is considered a butterfly hotspot with 70 documented species (NABA 2021). Mount Hebo provides habitat for the largest wild population of the federally threatened Oregon silverspot butterfly.

Noble Fir

Noble fir occurs in isolated pockets throughout this ecosystem (Fig. 6.16). Noble fir provides a food source of seeds and pollen, as well as hiding and thermal cover for a wide range of wildlife (Franklin 1990). Douglas' squirrels harvest green cones and cache them in cavities or bury them underground to provide a food through the winter. Many other small mammals use these caches for their own winter survival. Noble fir can provide hiding cover and thermal protection for wildlife, especially when live branches remain low to the ground.

Assessment of Climate Change Effects

Exposure—
MC2 projects more extreme precipitation events in winter, more winter flooding, and possible reduction in snowpack duration. Increased summer temperature will increase evapotranspiration, soil drying, and drought stress.

Sensitivity—

Remnant patches of noble fir may be further restricted or eliminated. Drying conditions may make this species more susceptible to several diseases including annosus root disease and laminated root rot (Filip and Schmitt 1990). Snowpack may decrease on the higher peaks in the Coast Range. Loss of snowpack, combined with summer drought conditions and well-drained rocky soils could negatively affect some of the high-elevation forbs and shrubs associated with these meadows, including spreading phlox and oval-leaf blueberry. This, in turn, could result in loss of specialists like western bumblebees, Oregon silverspot butterfly, coastal greenish blue butterfly, and rosy finches. Forest encroachment into meadows may also continue to increase, reducing overall meadow habitat. Some plant and animal species that are unique to Coast Range meadows may be extirpated over time.

Adaptive capacity—

- Adaptive capacity for noble fir is limited to its ability to survive in refugia, including deep valleys and north-facing slopes.
- Adaptive capacity for montane meadows will be greater in areas where trees are not currently encroaching.

Adaptation strategies—

- Restore meadows through active management of forest encroachment.
- Delineate refugia that will be protected.
- Seed disturbed restoration areas with a diversity of appropriate species that are expected to be resilient to warmer, drier conditions.

Coastal Meadows and Grasslands

Coastal meadow environments are usually more driven by topography and soils than montane meadows, and are found on mostly south-facing, steep slopes with shallow soils and sometimes salt spray. They are limited to basalt headlands and where basalt flows outcrop on coastal mountain slopes. Coastal meadows have no snowpack and are often exposed to high winds. Temperatures are moderate compared to montane meadows, and summer fog helps maintain plant communities.

Plant communities in coastal meadows have been altered at many sites by a history of human management and invasion by non-native plants. Remnant and reference meadow sites suggest plant species such as sand fescue, Roemer’s fescue, coast strawberry, early blue violet, and coast tarweed are important (Glavich 2021, Ripley 1983). Oregon silverspot butterfly populations are completely reliant on zoo propagation for persistence in this ecosystem. Roosevelt elk and domestic cattle are the dominant grazers in these systems. Small mammals are relatively diverse and moderately abundant where native forbs and grasses are diverse, but vagrant shrews are more common than other small mammals in areas dominated by nonnative grasses (T. Wilson, unpublished data[3]).

Assessment of Climate Change Effects

Exposure—
MC2 projects more extreme weather events and warmer winters. There are some scattered pixels of grassland, shrubland, and woodland that show up in mid-elevations of the assessment area by end-century, but no broad-scale biome shifts are expected.

Sensitivity—
One of the primary negative effects of climate change on this ecosystem is loss of habitat owing to sea-level rise. Another concern is whether or not the amount of fog will be reduced. If moisture increases, forest encroachment into meadows and grasslands is likely. If fog is reduced, then some native grasses and forbs may be lost.

Adaptive capacity—
Adaptive capacity is limited. Maintenance of this habitat will depend on management actions that facilitate long-term persistence of the dominant plant species.

Adaptation strategies—
- Restore native grasses and forbs in meadows.
- Manage forest and woody shrub encroachment into meadows.

Aquatic and Wetland Ecosystems

Freshwater ecosystems support high biodiversity, including numerous species of amphibians, reptiles, birds, mammals, and aquatic invertebrates. Freshwater ecosystems consist of a diversity of lotic and lentic habitat types. Lotic (flowing water) systems are a key feature of the Oregon Coast landscape, including streams, rivers, springs, seeps, and intermittent streams. Lentic (non-flowing water) systems include lakes, ponds, and wetlands. Permanently wet habitats include backwater sloughs, oxbow lakes, and marshes, whereas seasonally wet habitats include ephemeral ponds, vernal pools, and wet prairies. Natural lakes are less common in this region than in the rest of Oregon. The Oregon Conservation Strategy (2016) further specifies sub-categories of wetland habitats prevalent in the Oregon Coast Range:

- Deciduous swamps—Located in depressions, around lakes or ponds, or on river terraces that generally flood seasonally with nutrient-rich waters and are dominated by woody vegetation, including willows (*Salix* spp.), hardhack, red alder, red osier dogwood, Pacific crabapple, and Oregon ash.
- Marshes—Located in depressions (ponds), fringes around lakes, and along slow-flowing streams, especially in valley bottoms. Marshes are seasonally or continually flooded and have water-adapted plants, such as sedges, bulrushes, spikesedges, rushes, Common cattails, and floating vegetation. Marshes can have mucky soils, resulting in water with high mineral content and vegetation dominated by herbaceous species, often including wildflowers.
- Off-channel habitat—Oxbow lakes, stable backwater sloughs, and flooded marshes, created as rivers change course. These areas provide rearing habitats for young fish as well as refuge from high-flow events, especially during the migration of young salmon to the ocean.

- Seasonal ponds and vernal pools—These water bodies hold water during the winter and spring but typically dry up during the summer months. Vernal pools occur in complexes of networked depressions that are seasonally filled with rainwater. These habitats can be important for native invertebrate species (e.g., vernal pool fairy shrimp), plants (e.g., big-flowered woolly meadowfoam), and amphibians.
- Wet meadows (including montane wet meadows and poor fens)—These meadows are located on gentle slopes near stream headwaters, in mountain valleys, bordering lakes and streams, near seeps, in large river valley bottoms, and in open wet depressions among montane forests. They are dominated by tufted hairgrass, sedges, reedgrass, spikesedge, rushes, sphagnum, carnivorous sundews, and wildflowers. Montane wet meadows may have shallow surface water for part of the year, are associated with snowmelt, and are not typically subjected to disturbance events such as flooding.
- Wet prairies—These prairies are in lowlands, especially floodplains, whereas wet meadows occur in depressions surrounded by forests and are associated with snowmelt. Wet prairies are dominated by grasses, sedges, and wildflowers.

Wetlands will play a key role in managing risks from climate change. Wetlands are inherently dynamic systems that experience cycles of wet and dry phases on seasonal, annual, and decadal scales. Because of that natural variability, many wetlands may be able to persist with a changing climate and continue to provide ecosystem services including water storage, groundwater recharge, flood control, sediment and nutrient filtering, contaminant sequestration, and nutrient cycling. Undisturbed wetlands also serve as an important carbon sink (but may emit other greenhouse gases such as methane).

Tree species and understory plants associated with aquatic systems are an important component of wildlife habitat:

- Red alder—This deciduous tree is often associated with moist areas, including streams and rivers, but it is also found in upland sites with sufficient moisture (fig. 6.17). Alder is one of the first species to colonize newly disturbed sites. Their catkins are consumed by many small mammals and birds in the spring. Alder seeds are especially important for passerines like pine siskins and American goldfinches. Alder can be an important browse item for deer and elk, especially in fall. Cavities are excavated by woodpeckers in dead trees and are subsequently used by cavity-nesting birds and mammals.
- Black cottonwood—Cottonwood catkins are eaten by squirrels and numerous songbirds; the catkins attract pollinating insects and their prey during the spring. The cotton-like seeds provide an early-summer food source for wildlife. Some birds, especially hummingbirds, use these seeds to line their nests. The seeds are dispersed through wind and water currents and attract birds such as western wood pewees and barn swallows. American beavers favor cottonwood for food and for building structures. The heavy crown of a large cottonwood can support the stick nests of bald eagles and ospreys. Because the heartwood of cottonwood is easily decayed, cavities can form quickly compared to other tree species. Woodpeckers, owls, squirrels, raccoons, and many songbirds use these cavities.

- Oregon ash—This tree is found primarily in moist bottomlands and riparian areas. Oregon ash produces small flowers in April and May that attract pollinating insects, and the winged seeds (samaras) of ash are eaten by several birds and mammals (e.g., evening grosbeaks). When open grown, ash is an abundant seed producer. When grown in competition with other trees, heavy crops occur only every 3 to 5 years. Cavities in ash are used by birds and mammals, including squirrels, raccoons, woodpeckers, and owls.
- Willow species—Several willow species occur in riparian areas and all are highly palatable as browse for deer, elk, beavers, and rabbits. The buds and catkins are consumed by numerous birds and mammals. Dense stands of willow can be used as protective and nesting cover for small mammals and birds. Willow can grow taller than many woody shrubs, providing structural connectivity between the forest understory and overstory.

Assessment of Climate Change Effects

Exposure—
Climate models generally project slightly higher winter precipitation and slightly lower summer precipitation (Mote et al. 2019). Extreme precipitation events are projected to increase by about 10 percent in western Oregon by mid-century. These events can lead to slope instability and landslides. Increases in average winter streamflow (due to precipitation falling as rain rather than snow) corresponds with increases in rapid runoff and flood risk in most basins, paired with reduced summer flows by as much as 50 percent. In addition, decreases in low- and mid-elevation spring snowpack and accompanying decreases in summer streamflow are projected to alter summertime surface and groundwater supply. Summer streamflow will be further affected by higher air temperatures and reduced precipitation in the summer, which is projected to increase evapotranspiration (Olson and Burton 2019). These changes pose a multi-faceted risk to freshwater ecosystems:

- Increased frequency, duration, and intensity of drought.
- Altered timing and volume of runoff (particularly in unregulated basins).
- Decreased groundwater recharge.
- Higher rates of evapotranspiration.
- Increased water temperatures.

Sensitivity—
Increased frequency and duration of flooding (spring) and drought (summer) are possible. Sea-level rise will reduce the extent of dune wetlands.

Adaptive capacity—
Freshwater ecosystems differ in water quantity, water quality, and physical form. This results in a dynamic distribution of habitats across space and time, exerting selective pressures that drive species adaptations, community composition, and ecosystem structure and function. When that variability is lost or altered, the capacity of the system to support biological diversity will generally decline (Grantham et al. 2019). Managing for enhanced adaptive capacity may require

preserving environmental variation (e.g., in flow and temperature) relative to historical conditions.

Maintenance of spatial heterogeneity (Grantham et al. 2019) and structural complexity in freshwater ecosystems influences the diversity, redundancy, and spatial configuration of distinct biophysical elements, including species, biotic assemblages, and habitats. Redundancy, particularly within functional groups, can buffer freshwater ecosystems from large changes. For example, variation in responses to environmental change by species within a functional group (i.e., "response diversity"), along with a diversity of habitat specializations among species, contributes to the overall stability of ecological communities (Angeler and Allen 2016). Managing landscapes for physical processes that support diverse assemblages and life histories can help facilitate adaptive capacity in freshwater ecosystems.

Maintenance of hydrologic connectivity is a key component of adaptive capacity (Boisjolie et al. 2019) for: (1) longitudinal (upstream-downstream linkages), (2) lateral (between freshwater habitat and adjacent riparian areas), (3) vertical (among the hyporheic zone, groundwater, and atmosphere), and (4) temporal (seasonal interactions) (Timpane-Padgham et al. 2017). Connectivity also enhances adaptive capacity by allowing biota to recolonize after disturbance or replenish depleted populations and is essential for facilitating range shifts of organisms to areas of suitable habitat.

Adaptation strategies—

Wetlands can offset changes in precipitation and snowmelt by storing water and reducing the effects of drought and severe storms. The cumulative presence of wetlands and lakes in a watershed can help reduce flood flows during storm events. Wetlands are also a source of surface water and groundwater recharge in drying landscapes. Many adaptation strategies are available for these ecosystems:

- Adjust water management and allocation, including cooperative/voluntary programs for reducing irrigation water diversions.
- Restore and connect aquatic habitats to increase the natural storage capacity of water during the winter season and support native wildlife species.
- Where non-native aquatic species threaten native species, consider appropriate tools (e.g., fire, mechanical or chemical treatment) in locations and during seasons when treatments will not harm native species.
- Continue retention and promotion of late-seral forests that buffer freshwater ecosystems from changes in precipitation and runoff.
- Eliminate passage barriers or improve passage at existing barriers to provide travel corridors for wildlife. For example, remove or replace culverts or other passage barriers with structures that mimic natural conditions as closely as possible (e.g., bridges, open-bottom arch culverts).
- Provide sufficient channel complexity to maintain ecological benefits for wildlife.
    - Restore beavers to aquatic systems to increase water storage capacity (Box 6.7).
- Maintain or create side channels and riparian buffers along rivers and streams to maintain flood control, water storage, shading (i.e., cooling), and low contaminant inputs.
- Minimize release of unnaturally warm water in the fall and summer by altering intake/release structures.
- Protect groundwater recharge zones (e.g., identify land-use practices that protect and enhance groundwater recharge)

- Reduce erosion from logging, agriculture, grazing, roads, and other activities that could disturb soil or destabilize streambanks. Strategies include: terracing fields, filtering runoff before it enters aquatic systems, installing sediment control basins to reduce erosion, and practicing conservation tillage. When constructing new roads, consider sediment removal capabilities in road design.
- Consider the effects of size, location, and configuration of timber harvest units on snow capture and subsequent melting when designing silvicultural prescriptions (Lundquist et al. 2013).
- Consider hillshading effects, overstory tree shading effects, and microclimate edge effects to retain cool, moist microhabitats and surface waters on managed forest landscapes.

Marine and Estuarine (Including Dunes and Beaches)

Marine and estuarine ecosystems provide habitat for numerous shorebirds and waterfowl, including western snowy plovers. Sea cliffs provide nesting structure for cliff-dwelling birds such as peregrine falcons and purple martins. However, it is projected that almost half of the world's beaches may disappear as a result of sea-level rise and shoreline erosion due to climate change (Vousdoukas et al. 2020). In some cases, there is potential for local expansion of dunes and beaches, but this is limited for the OCAP assessment area owing to limited capacity for expansion eastward given the steep topography along much of the coast.

Assessment of Climate Change Effects

Exposure—
Climate models project higher sea level, warmer and drier conditions in summer, and stronger storm events, particularly in winter.

Sensitivity—
Higher sea level will reduce the extent of sandy beaches, dunes, and estuaries. Cliff erosion will increase owing to sea-level rise and severe weather events.

Adaptive capacity—
Minimal capacity exists for this habitat type to expand. Removing the foredune and invasive beachgrass would allow storm events and sea-level rise to reshape dunes farther inland, promoting greater resiliency of the dunes to adapt to higher surf and storm events. If this restoration does not happen, the ocean will erode all existing beach and sand against the wall of beachgrass.

Adaptation strategies—
- Implement seasonal restrictions on management and recreational activities that would disrupt sensitive wildlife species, particularly during the breeding season
- Implement educational programs and signage to inform the public of sensitive wildlife habitats.

- Restore natural vegetation and habitat conditions. Potential activities would include removal of nonnative vegetation, especially European beachgrass, which halts the natural movement of sand and inhibits in dune-plant community dynamics.

Dune Shrub Forest

The Dune Shrub Forest is comprised of a mosaic of dwarf shore pine forests often with dense patches of understory shrubs including salal and evergreen huckleberry. These forests are interspersed with sandy dunes dominated by sand fescue and seashore bluegrass. This ecosystem occurs along a relatively narrow strip between the ocean beaches and either the mixed conifer or Sitka spruce forest habitats, with much of it occurring west of Highway 101. Dune shrub forest has diverse and abundant fungi and huckleberries supported in part by the moist maritime influence of the Pacific Ocean. Rare species found in this habitat include white-footed voles and a subspecies of marten. Most common terrestrial vertebrates found in the OCAP assessment area are found here, including varied thrush, North American porcupine, Anna's hummingbird, western toad, rough-skinned newt, rubber boa, and a relatively high-density black bear population.

Shore Pine

Shore pine seeds are used by squirrels, other rodents, and birds such as red crossbills that specialize in eating seeds from cones (Smith and Balda 1979, Sullivan et al. 2000). Shore pine can retain their cones year-round, thus providing a continuous food source. Shore pine relies on mycorrhizal hosts for uptake of nutrients, an association that promotes fungal production. Tree cavities provide nesting sites for woodpeckers, small birds, and squirrels.

Assessment of Climate Change Effects

Exposure—
Climate models project higher sea level and warmer and drier conditions.

Sensitivity—
Sea-level rise will reduce the extent of this habitat. The surrounding steeper, adjacent topography limits the capacity of this habitat to expand eastward in some locations. Private land and forest plantations also limit eastward migration. Historically, this habitat stretched for several kilometers into the foothills.

Adaptive capacity—
Minimal capacity exists for this habitat type to expand through management activities. There may be some eastward expansion of habitat, but this will not offset the broader loss of habitat from sea-level rise.

Adaptation strategies—

- Restrict management and recreational activities on a seasonal basis to minimize disruption for sensitive wildlife species during critical life history stages (e.g., during breeding or offspring rearing).
- Implement educational programs and signage to inform the public of sensitive wildlife habitats.
- Restore natural vegetation and habitat conditions, including removal of non-native vegetation.
- Develop partnerships with adjacent landowners to help protect existing habitat.

Adaptive Capacity of Wildlife to Climate Change

The adaptive capacity (AC) of a species or population has implications for management and conservation decisions, including assessments of conservation status or vulnerability, setting of harvest limits, allocation of conservation effort and resources, and prioritization of control of exotic species. However, AC is often omitted from vulnerability assessments, lumped with sensitivity, seen as the inverse of sensitivity, or considered a research frontier where further information is needed (Beever et al. 2016, Thompson et al. 2015). AC is a critical component of climate change assessment for conservation and management because it comprises the "levers" that are most likely to be relevant (and occasionally responsive) to climate adaptation.

AC includes evolutionary AC (the ability to evolve to new conditions), dispersal and colonization abilities, and phenotypic flexibility (Dawson et al. 2011, Glick et al. 2011). More recently, AC was characterized as reflecting 36 attributes that can be hierarchically organized into 7 attribute complexes (Thurman et al. 2020). This approach provides explicit criteria that rank each target species or population as having low, moderately low, moderately high, or high AC. We classified each of the 36 attributes as one of these levels of AC for each of the nine focal species.

Species possess numerous traits that can promote AC. Such traits include numerous aspects of **distribution**, such as spatially extensive area of occupancy and extent of occurrence, low degree of habitat specialization, high degree of commensalism with humans, lack of geographic rarity, and high degree of connectivity. Attributes conferring high AC also involve aspects of **movement**, such as high dispersal distances, engaging in dispersal throughout the lifespan rather than only as juveniles, and dispersing without regard to climatically-based environmental cues. Other attributes that confer high AC relate to **evolutionary potential**, such as a high (range-wide) population size. Other attributes that can bolster the realized AC of a species (*sensu* Beever et al. 2016) include things related to **ecological role**, such as a broad dietary niche, no obligate relationships to one or a small number of other species, and reasonably robust competitive ability so that fitness is not strongly compromised by the presence of other species.

In terms of attributes related to **abiotic niche,** characteristics that confer high AC include the ability to behaviorally regulate their physiology, such as through their behavioral repertoire. Attributes for **life history** that confer high AC include an even sex ratio, chromosomal sex determination for mammals and birds, precocial offspring (relatively mobile after birth or hatch), iteroparity (capacity to reproduce multiple times), and viviparity (embryo development inside the body of the mother) or ovoviviparity (egg development inside the body of the mother). Finally, **demographic** attributes that confer high AC include a young age at which sexual maturity occurs, short generation times, and a higher proportion of the population being younger than the age at first age of reproduction.

We chose nine animal species found across one or more of the OCAP ecosystems to illustrate diverse levels of AC and conservation status, span diverse taxonomic clades and life-history strategies, and span diverse levels of information available for the region in published and gray literature. This group of species illustrates mechanisms by which particular species may be affected by climate change, documenting how their life history may alternatively exhibit resilience or vulnerability. However, this group should not be assumed to represent responses from all species.

These example species suggest different management strategies may be needed, depending on AC traits that might limit their adaptive capacity to climate change. For example, North American porcupines have high AC in terms of their ability to occupy diverse ecosystems but have low AC in terms of their ability to reproduce (one offspring per year, long gestation period) and disperse (Verts and Carraway 1998, Woods 1999). Because population levels are assumed to be very low in the OCAP assessment area, translocation and monitoring might be an appropriate strategy. American beavers also have a relatively low reproductive rate and could benefit from conservation translocation, especially in riparian systems where they occurred before widespread trapping and removal. Humboldt's flying squirrels also have relatively low AC for reproduction (one litter per year; most small mammals have more [Verts and Carraway 1998]), but they are common in most forests in the assessment area and abundant in structurally complex conifer forests and young forests with high stem densities. Because they are a prey species for many owls and mustelids, adaptive strategies that promote retention or development of structurally complex forest could be important (Wilson and Forsman 2013).

Acorn woodpeckers have a low AC for habitat specialization because they rely heavily on oak for nesting and foraging (Koenig and Walters 2014, Scofield et al. 2011). This suggests strategies are needed to improve connectivity among oak woodlands to allow for dissemination of associated fungi needed for oak seedling survival. Similar to acorn woodpeckers, marbled murrelets have low AC for habitat specialization because they rely on old-growth forests for nesting (Hamer and Nelson 1995). As with flying squirrels, they could also benefit from retention and promotion of structurally complex conifer forest. Western snowy plovers also have a low AC due to their habitat specialization for nesting habitat adjacent to ocean beaches and susceptibility to human disturbance (USFWS 2007). Rising sea level is expected to reduce habitat, but management of human disturbance along high-quality beaches for nesting could help improve reproduction and ameliorate declining habitat.

Three of the example species are more problematic in terms of management strategies that might help them adapt to climate change. As mentioned earlier, rufous hummingbird populations have been declining on the Oregon Coast. Some studies suggest a connection to warmer spring temperatures, leading to changes in migration routes away from the coast and farther northward or inland where phenology and flower nectar availability may be more predictable (Courter 2017). The federally listed Oregon silverspot butterfly has declined to the point that it is now reliant on artificial propagation and dispersal at a few coastal meadows within the assessment area for survival. This butterfly has low AC for habitat specialization based on reliance on a single violet species for several life history stages, and invasive grasses compete with the violet (USFWS 2001). Attempts to stabilize or increase populations over the past 30 years have largely failed, and it is unclear whether any adaptation strategy would be useful for this species without a better understanding of other stressors limiting its capacity to persist.

Finally, rubber boas are an example of a species for which there is minimal information for many of its AC traits, making it challenging to project climate change effects or develop strategies to mitigate negative effects.

Adapting Wildlife Habitat Management to Climate Change

There will be both winners and losers as climate changes over the next several decades (Smith et al. 2019). Species with adaptive traits and habitat requirements that align with climate-induced changes will generally persist or even thrive. Species with highly specialized habitat needs or that have climate-sensitive adaptation strategies may not do well or may go extinct without assistance. We propose adaptation options that can be applied in the eight ecosystems described above, including restoring American beavers to aquatic systems to aid in water storage and flooding, restoring late-seral forest, and engaging stakeholders and partners to address cross-ownership management issues.

A broad strategy encompassing all proposed actions is to develop a region-wide plan to ensure a mosaic of landscape conditions that includes refugia, areas managed for diverse and resilient forests and grassland landscapes supported under current climatic conditions, and transition areas where plants and wildlife are allowed to adapt to new ecological conditions. This bet-hedging strategy will be more successful if management actions are coordinated strategically to maximize the likelihood that species-level adaptive capacity is not compromised (Magness et al. 2011). Natural history evidence exists for the success of such an approach. For example, climatic refugia have facilitated persistence of species through periods of paleoecological climate shifts for millennia (Moritz and Agudo 2013). Similarly, areas with high geomorphic diversity (i.e., areas with high diversity of land facets or enduring features [Brost and Beier 2012]) will likely provide more opportunities for species to redistribute across local landscapes or persist in microclimatic refugia.

Habitat connectivity helps ensure a mosaic of conditions at multiple spatial scales (Mawdsley et al. 2009, Olson and Burnett 2007, 2009). This includes: (1) forested corridors that connect quality habitat for aquatic, terrestrial, and arboreal species, (2) passage structures to facilitate safe crossing of major highways, and (3) project designs that consider the effects that spatial and temporal scales of management activities have on individual species. Much of the current forested landscape within the OCAP assessment area has been harvested for timber at least once. Although practices like clearcutting have now been largely replaced in the assessment area with thinning to develop late-seral condition (at least on federal lands), the effects of these earlier practices have left a footprint that can be observed today. This footprint has ecological consequences for some wildlife and their ability to move unimpeded through the landscape, including size and extent of forest edges, gaps, roads, overall stand size, structural and biological complexity, and availability of thermal refugia.

Protected areas help preserve the existing biological and structural diversity found in the OCAP assessment area, allowing for adaptation to climate change in place for some species. All USFS, BLM, and state lands are protected areas within which wilderness, research natural areas, parks, and special interest areas have a high level of protection for valued species and systems. This high level of protection can provide corridors, or stepping stones, facilitating movement between habitats and assisting migration (Mawdsley et al. 2009). An assessment may be warranted to determine if current protections are sufficient to maintain plant and wildlife diversity, preserve endemic habitats, and facilitate landscape permeability.

Conservation translocation is another strategy that can be considered for dealing with climate change. Historical evidence suggests that plant extirpation may exceed immigration during the initial onset of major climate change events (Betancourt 1990). Direct assisted migration throughout the assessment area, such as for beaver recolonization, appears warranted given their historical distribution. It may also be worth considering assisted migration through plantings along the leading (e.g., upper elevational or northern) edges of current distributions for tree species that are projected to move upslope, using locally-sourced genetic stock. Candidate tree species include Oregon white oak, tanoak, grand fir, and Pacific madrone.

As noted in previous sections, developing structural and biological complexity in managed forest stands is a critical management objective. This helps animal species that depend on late-seral habitat, promotes carbon storage, and may help promote some resilience to wildfire, insect outbreaks, and diseases. The water retention capacity of late-seral forests can also help with summer streamflows (Perry and Jones 2016). Promoting the diversity and abundance of shrubs and other plants will help provide abundant, year-round sources of food, cover, and nesting and denning resources. This could include protection of important trees, shrubs, and other plants during timber harvesting, and planting locally-sourced native plants following harvest (including thinning).

Research and Monitoring Needs

Long-term monitoring will be needed to determine the response of species to climate change (e.g., Johnson et al. 2008). Ecological linkages among components within ecosystems are complex, and our knowledge is incomplete for many species. Projected changes in forest vegetation will be preceded by near-term stress on organisms and ecosystems prior to a shift to a different forest type. Therefore, it will be important to follow the trajectories of key wildlife and habitats to better project actual changes in ecosystems over time. Multiple wildlife species need to be monitored because the potential vulnerabilities for any given species may be unknown or limited. A monitoring program that includes animals from diverse taxonomic groups would also provide a more comprehensive understanding of overall climate change effects, given the ecological connections associated with each species (Beever 2006).

Monitoring changes in ecosystems in the OCAP assessment area is also needed, especially as our ability to project future changes to wildlife may require monitoring at multiple spatial scales (IPCC 2013). Research natural areas contain a significant amount of the ecological diversity found in Oregon and Washington, and the assessment area includes several natural areas that can be included in a regional-scale monitoring effort (Massie et al. 2016, 2019). Including these natural areas as monitoring sites would help document resource trends while connected to a network of monitoring sites involving multiple agencies, thus informing our understanding of climate change effects beyond the boundaries of the assessment area.

Finally, the AC of wildlife species, beyond the nine described here, needs to be quantified. Our understanding of how AC differs within and among species will better inform managers about how best to maintain or enhance populations that are likely to adapt successfully to changing conditions (Hamann and Aitken 2013).

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Chapter 7: Outdoor Recreation Vulnerability and Adaptation to Climate Change in Coastal Oregon

Anna B. Miller, Trevor Robinson, Paris B. Edwards

Introduction

Public lands provide opportunities for people to participate in outdoor recreation and connect with nature. Outdoor recreation provides numerous physiological, psychological, social, and cultural benefits to public land visitors (Bowler et al. 2010, Thompson Coon et al. 2011), as well as economic benefits to local communities (White et al. 2016). Access to recreation opportunities is a key consideration that shapes where people live, work, and travel. Outdoor recreation opportunities and environmental quality attract new residents to the western United States. (Hamilton et al. 2016, Rudzitis 1999). However, the ways people enjoy outdoor recreation will be affected by climate change. The increasing population and specific interest in outdoor recreation opportunities, coupled with a nationwide increase in outdoor recreation participation for many activities (White et al. 2016), emphasizes the importance of understanding the vulnerability of outdoor recreation to climate change, which will help land managers adapt to expected effects of climate change.

Broad trends in recreation participation under climate change are becoming better understood at the regional and sub-regional scales (Miller et al. 2022a), including in the Pacific Northwest (Halofsky et al. 2019, Hand et al. 2019, Miller et al. 2022b). To explore the expected effects of climate change on outdoor recreation in the Oregon Coast Adaptation Partnership (OCAP) assessment area, this chapter will present current outdoor recreation visitation patterns in the area, review the relevant literature on outdoor recreation vulnerability and response to climate change, and consider the application of climate science performed in accompanying chapters of this volume to identify vulnerabilities of outdoor recreation to climate change in the assessment area. We will organize our discussion by considering five geographic zones where outdoor recreation occurs in the assessment area (fig. 7.1) and are expected to be vulnerable to climate change. For each zone, we assess the likely effects of projected climate change on visitor-use patterns and the ability of outdoor recreationists to obtain desired experiences and benefits. We conclude with general discussion of adaptations, which are discussed in further detail in chapter 9.

Relationships Between Climate Change and Recreation Participation

In general, changing climatic conditions may alter the supply of and demand for outdoor recreation opportunities, affecting recreationists’ visitation and attainment of benefits through both direct and indirect routes (Bark et al. 2010, Matzarakis and de Freitas 2001, Morris and Walls 2009). 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, and (2) an indirect effect of climate on the characteristics and ecological conditions of recreation settings (Loomis and Crespi 2004, Mendelsohn and Markowski 2004, Shaw and Loomis 2008) (fig. 7.2).

The direct effects of altered temperature and precipitation patterns are likely to affect most outdoor recreation activities in some way. Direct effects of climate change are especially important for warm-weather activities (hiking, camping, etc.). The number of projected warm-weather days is positively associated with expected public land visitation (Albano et al. 2013, Fisichelli et al. 2015). Other research has found that increases in minimum temperatures have been associated with increased visitation to protected areas, particularly during non-peak seasons (Scott et al. 2007).

Historical data from the National Park Service suggest that, at the national level, overall visitation levels will increase as temperatures increase, although visitation starts decreasing when temperatures reach the very warm end of the spectrum (i.e., exceeding 25 °C with the caveat that this threshold varies with the local maximum temperatures) (Fisichelli et al. 2015). Most parks see their highest visitation levels in the summer, so warming is expected to result in increased annual visitation. While overall visitation is expected to be lower during extreme heat scenarios (i.e., heat waves) (Richardson and Loomis 2004), water-based recreation may increase during these events. Visitors can also disperse spatially within public lands in response to altered temperatures by concentrating around water bodies (Loomis and Crespi 2004, Mendelsohn and Markowski 2004) or moving to higher elevations (Hand and Lawson 2018).

In addition to the summer, warm-weather recreation occurs in the "shoulder" seasons, typically late spring and early fall, when the weather is pleasant for warm-weather recreation. As temperatures become more comfortable for recreation earlier in the spring and cooler temperatures come later in the fall, the length of time amenable to warm-weather recreation will expand, increasing aggregate visitation levels. Lengthened shoulder seasons have been found in the southeastern United States (Bowker et al. 2013), Alaska (Albano et al. 2013), the Intermountain West (Hand et al. 2018), the Cascade Range of northern Oregon (Miller et al. 2022b), and south-central Oregon (Halofsky et al. 2019).

Indirect effects are important for recreation activities and opportunities that depend on ecosystem inputs such as wildlife, vegetation, and landscapes. Recreation visits to sites with highly valued natural characteristics, such as tide pools or coastal dunes with wildlife species popular for fishing and viewing (chapters 4, 6), may be reduced under some future climate scenarios if the quality of those characteristics is threatened (Scott et al. 2007). Likewise, climate change may indirectly reduce recreation participation through restricted access to recreational areas; for example, increased frequency or length of precipitation events could cause roads to flood or become washed out. Lastly, temperature and precipitation can directly affect the comfort and enjoyment that participants derive from engaging in an activity on a given day (Mendelsohn and Markowski 2004).

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 et al. 2018, Hand and Lawson 2018, Loomis and Crespi 2004, Mendelsohn and Markowski 2004). However, climate change may reduce the availability of different types of recreation opportunities in certain locations, which has the potential to displace recreationists from their preferred recreation sites. These displaced visitors will need to choose: (1) alternative recreational activities, (2) a different location where equivalent opportunities are available, or (3) a different time in which to participate in the preferred recreational activity. Unfortunately, we have minimal knowledge about the effects of climate-related tradeoffs on the benefits that recreationists receive.

Overview of Oregon Coast Recreation in the Face of Climate Change

Recreation occurs on the Oregon Coast throughout the year, but most of this use can be classified as warm-weather recreation. Visitation in the OCAP assessment area is highest during the summer season, with camping, off-road vehicle recreation, hiking, scenic driving, and water-based recreation accounting for most recreational activity. The shoulder season is also an important time for outdoor recreation, as temperatures are relatively mild compared with alternative locations in the region (such as the Oregon Cascade Range). Considering the role of coastal Oregon in outdoor recreation at a regional level, relatively large increases in visitation can be expected during the summer, as visitation to water bodies increases when other areas experience extreme heat (Loomis and Crespi 2004, Mendelsohn and Markowski 2004). Additional use during the shoulder seasons is expected as the frequency of warm-weather days increases (box 7.1).

During the winter months, certain recreation sites in the OCAP assessment area may be at a higher risk of flooding because of changing precipitation patterns and/or sea-level rise. These flood events will displace prospective visitors to other recreation areas. Sea-level rise and flooding could also potentially cause the density of recreationists to increase; flood-related closures (especially for extended portions of the recreation season) may cause recreation activity to become more concentrated in fewer areas.

Recreationists often value specific places in particular ways. Although preferences for certain landscapes may be somewhat innate, individual experiences and sociocultural components play important roles in a recreationist's sense of place (Farnum et al. 2005). For the individual, repeated experiences can strengthen attachments or emotional ties to a place (Stedman 2003). Social relationships can also play a role in the meanings that individuals ascribe to a place (Smith et al. 2011). Different communities have been found to value areas that are closer to their home for different reasons, such as enabling time spent with family and friends or economic benefits (Eisenhauer et al. 2000). For example, Marys Peak Scenic Botanical Area (Siuslaw National Forest, near Philomath, Oregon), is valued for its expansive views, unique plant communities, and snow-based recreation. Being close to several population centers, climate-related alterations to this area, such as to vegetation and snowpack, will likely affect many who value the unique attributes of Marys Peak. Additional examples of highly valued places in the OCAP assessment area, and some of their unique values, are summarized in table 7.1.

Although the direct and indirect effects of climate change can be felt locally, it is also important to consider large-scale effects of climate change. For example, as decreased precipitation combined with increased temperatures contribute to more frequent fires and more area burned, access to and interest in recreation may be affected by related area closures, fire restrictions, and the presence of smoke. During times when intense fires close inland trails, the Oregon Coast Trail has seen higher use levels as an alternative to the Pacific Crest Trail (Miller et al. in press; D. Hendricks, personal communication[1]). In addition, inland heat waves in Oregon correspond with higher visitation levels in coastal areas where temperatures tend to be lower than inland areas. Although these heat waves may not be directly related to climate change, the combination of heat waves and increased incidence of wildfires in inland areas corresponds with increased visitation to coastal areas, which have a more temperate climate. Such shifts might result in increased crowding in areas that retain access or have preferred weather conditions, such as the Oregon Coast Trail and water-based recreation areas.

Recreation Participation and Management

Recreation is an important component of public land management in the OCAP assessment area. As a guiding principle for planning and management on lands managed by the U.S. Department of Agriculture Forest Service (USFS) (USDA FS 2010, 2012), sustainable recreation has been defined as “the provision of desirable outdoor opportunities for all people, in a way that supports ecosystems, contributes to healthy communities, promotes equitable economies, respects culture and traditions, and develops stewardship values now and for future generations” (Cerveny et al. 2020). This definition emphasizes the importance of incorporating climate adaptation in current outdoor recreation planning.

The National Visitor Use Monitoring (NVUM) survey, conducted by the USFS to monitor recreation visitation and activity on national forests, identifies 27 recreation activities in which visitors participate, 22 of which are represented in Siuslaw National Forest in the latest NVUM report (USDA FS 2016). The Bureau of Land Management (BLM) also accounts for visitation to the land they manage within the OCAP assessment area, through the Recreation Management Information System (USDOI BLM 2016). Although no visitation counting system is perfect (see English et al. 2020 for discussion of limitations), these programs provide estimates that illustrate the diversity and importance (e.g., economic contributions) of recreation in the assessment area.

In the OCAP assessment area, Siuslaw National Forest hosts an estimated 1.5 million visitors per year (USDA FS 2016) (table 7.2), and BLM lands host an estimated 114 thousand visitors per year (USDOI BLM 2016). The assessment area contains several geographic zones (i.e., coastal dunes, headlands, beaches, estuaries and coastal lagoons, and upland areas) with varied recreational profiles associated with the distinctive landscape features present. For example: (1) coastal dunes provide motorized recreation and sand camping opportunities; (2) headlands offer opportunities to visit historic lighthouses, view whales and natural features such as cliffs, and participate in nature study in tidepools; (3) marine areas host fishing and kayaking; (4) upland areas provide opportunities for hiking, camping, limited snow-based recreation, and fishing; and (5) estuaries and coastal lagoons also host fishing and boating activities.

Many recreationists enjoy driving for pleasure along the Oregon Coast Highway (U.S.), which runs the length of the coast, passing through or near headlands, coastal dunes, estuaries, and some upland areas. Although the three main land management agencies in the area (USFS, BLM, and Oregon Parks and Recreation Department [OPRD]) manage lands that contain parts of each of these five zones, upland areas are generally managed by the BLM and Forest Service; the OPRD manages a high proportion of coastal areas with water-based activities.

Additional detail characterizing recreation participation in Siuslaw National Forest is provided in table 7.2 and described below[2], along with location-specific limitations of these data for each category. A map of developed recreation sites and trails is shown in fig. 7.2. The activities listed in table 7.2 account for the primary recreation activities by visitors to national forests that are most likely affected by climate change:

- *Warm-weather activities* have the highest participation rates amongst all activity categories in the OCAP assessment area, accounting for 62 percent of primary activities. This category includes hiking/walking, viewing natural features, developed and primitive camping, bicycling, backpacking, horseback riding, picnicking, and driving for pleasure. An estimated 76 percent of visits to BLM land fall within this category, including dispersed use, hiking, and camping; this is likely an underestimate, as data are not available for most dispersed-use areas on BLM land.
- *Wildlife-related activities* include hunting, fishing, and viewing wildlife. Wildlife activities accounted for 4.5 percent of visits to Siuslaw National Forest. Fishing was the most popular activity (i.e., highest participation rate) within this category (2.6 percent of all visits), followed by wildlife viewing (1.2 percent) and hunting (0.7 percent). However, because most marine access areas are managed by agencies other than the USFS, participation in fishing is likely underestimated by these figures.
- *Water-based activities* such as boating and swimming comprised 10 percent of documented visits to BLM land and 0.2 percent of visits in Siuslaw National Forest. However, the level of water-based recreation within this area is likely higher than these figures suggest, because many water-access areas are managed by OPRD and are not represented in these figures.
- *Gathering forest products* such as berries and mushrooms comprised 1.3 percent of recreation in Siuslaw National Forest. However, this activity is often considered secondary by visitors and is an important cultural activity for many participants. Because gathering forest products is not always defined as recreation, this number likely does not capture the full extent of participation in this type of activity.
- *Snow-based activities* are not widely available in the assessment area. These activities are restricted to intermittent snowfall on the two highest mountains (Marys Peak and Mount Hebo). Snowmobiling accounts for 0.3 percent of recreational visits to Siuslaw National Forest. Other snow-based activities such as sledding, snowshoeing, and cross-country skiing also occur but are not accounted for in the NVUM survey data.
- *Other recreation activities* include relaxing, visiting nature centers, visiting historic sites, and nature study. In Siuslaw National Forest, 10.8 percent of visitors listed one of these activities as the primary reason for their visit. Visiting historic sites and environmental education also consisted of 15 percent of visits to BLM land in the region. Because some historic sites are managed by OPRD, these figures likely underestimate the importance of these activities.

In 2016, non-local visitors spent $49.1 million while visiting Siuslaw National Forest, (table 7.3). We focus on spending by non-local visitors (i.e., those traveling over 80 km to the site) because these individuals spend money in local communities that would not have occurred otherwise. “Motel” was the highest spending category overall, at 27.4 percent ($13.4 million) of total annual expenditures. Restaurants (19.6 percent, $9.6 million) and gas and oil (18 percent, 8.8 million) are the second and third highest spending categories, respectively. The remaining expenditure categories of groceries, camping, recreation and entertainment, souvenirs and other expenses, entry fees, sporting goods, and other transportation comprise 35.1 percent of all spending for non-local visits to Siuslaw National Forest. Local spending for visits to Siuslaw National Forest totaled $6.6 million; the primary expenditures were gas and oil (34.8 percent,

$2.3 million), groceries (23.3 percent, $1.5 million), and restaurants (15.4 percent, $1.0 million).

Climate Change Vulnerability Assessment

To assess how recreation patterns may change in the OCAP assessment area, we identified six geographic zones with distinctive biophysical characteristics and recreation use patterns: coastal dunes, headlands, beaches, marine zone, estuaries and coastal lagoons, and upland areas. Within each geographic zone, we identified ways in which the range of recreational activities that exist in that zone might be affected by climate change. We also identified adaptation strategies that land managers can use to respond to these effects (chapter 9).

For the purposes of this assessment, an outdoor recreation activity is sensitive to climate change if altered environmental conditions that depend on climate would result in a substantial change in the demand for or supply of that outdoor recreation activity. For example, camping would be considered sensitive to climate change if increased precipitation dissuades potential campers from participating in this activity or results in flooded campgrounds. To assess these vulnerabilities, we combined results from studies investigating how outdoor recreation participation is influenced by climate-sensitive ecological parameters with projections of ecological changes specific to the OCAP assessment area as detailed in other chapters within this volume.

The effects of climate change on recreational activity are likely to differ by geographic zone and activity type. 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 motorized recreation, camping, hiking, kayaking, and mountain biking. Although climate models project drier summers in the assessment area, which generally facilitates wildfires (chapters 2, 5), fires will be more pronounced in interior Oregon. Thus, coastal Oregon may experience higher summer and fall visitation rates when inland recreation areas are closed due to fires or smoke. However, during other times of year (winter and potentially in the shoulder seasons), increased flooding of roads and recreation areas might decrease the frequency, duration, and quality of recreational visits in areas to which access is restricted by flooding.

When changing weather and wildfire patterns make a specific type of recreation unavailable in a certain location or time of year, recreationists may adapt by changing the activity they participate in, the location where they recreate, or the timing of their recreation (fig. 7.2). The substitutability of recreational activities, locations, and timing is not well understood, although some research has investigated this topic (e.g., Bristow and Jenkins 2018, Lamborn and Smith 2019, Orr and Schneider 2018). Furthermore, the ability of recreationists to change the activity, location, and timing of their participation differs greatly with socioeconomic and cultural factors, as discussed later in this chapter.

The following sub-section briefly describes current conditions and stressors on recreation resources in the OCAP assessment area. The section on *Effects of Climate Change on Recreation* provides a description of the likely effects of climate on major climate-sensitive recreation activities, organized by geographic zone. Potential adaptation strategies and responses are presented in the section on *Adapting Recreation Management to Climate Change in the OCAP Assessment Area*.

Current Conditions and Existing Stressors

Managing recreation on public lands is a complex enterprise that varies seasonally and annually and is highly dependent on weather conditions. Recreation management includes: (1) maintaining access to recreation areas via infrastructure and facilities (e.g., roads, hiking trails, campgrounds, boat ramps, parking areas), (2) regulating access for harvesting animals and plants (e.g., specifying hunting seasons and zones, operating permitting systems), (3) regulating access for motorized vehicle use (e.g., off-highway vehicles, snowmobiles), and (4) coordinating with private guides, outfitters, and concessionaires who operate ski resorts and other facilities (Cole et al. 1987, Seekamp et al. 2011).

Although both demand for and supply of outdoor recreation opportunities fluctuate with weather conditions, other factors are also present on both ends of the equation. Changing demographics, emerging recreational activities, and trends in recreation technology and social media contribute to a dynamic demand for outdoor recreation opportunities (Blahna et al. 2020, Sachdeva 2020). Meanwhile, land management agencies such as the USFS as well as private guides, outfitters, and concessionaires have varying opportunities to adapt to annual variation in weather patterns and to constantly changing demand. For federal agencies, lack of flexibility limits their ability to redesign, move, or expand recreation sites, even when factors such as climate change are a known stressor. Complex federal rules around fees, grants and agreements, contracts, and hiring can also lead to challenges for climate adaptation.

Although private recreation providers are sometimes able to modify operations on relatively short notice, these changes might negatively affect their business. Furthermore, businesses operating on federal lands must work within the limits of their special-use permit, which can reduce flexibility for adaptation. However, both private and public entities have their own strengths for providing outdoor recreation and opportunities for climate adaptation. In some cases, public-private partnerships can capitalize on the differences between these systems to improve response in both the short and long term (Cerveny et al. 2020, Kooistra et al. 2022).

Major concerns regarding climate change in the OCAP assessment area include:

- Rising sea levels that affect beach access and coastal recreation infrastructure.
- Increased likelihood of severe storm surges washing out recreational infrastructure such as roads and parking lots.
- Increased intensity of precipitation events, leading to flooding of roads and campgrounds, causing washouts of roads, and eroding trails.
- Expanding shoulder seasons (i.e., late spring and early autumn), when weather conditions allow warm-weather recreational activities and bring recreationists into areas when staff are unavailable in campgrounds and visitor centers. This is compounded by expectations for more heat waves and an increase in frequency and extent of wildfires in inland areas, bringing more visitors to coastal areas.

Current climatic and environmental conditions in the assessment area are characterized by high variability within and between years. These variable conditions include temperature, precipitation, storm surges, wildlife distributions, vegetative conditions, and water quality. Recreationists often make decisions with a degree of uncertainty about conditions at the time of participation.

Recreation on the Oregon Coast is affected by several challenges and stressors aside from changing climate patterns. Increased population, particularly in proximity to public lands, can strain visitor services and facilities because of increased use. Projected population increases may exacerbate the current strain on visitor services, posing threats to visitor safety in some cases, especially with outdoor recreation attracting population growth to inland areas near the Oregon Coast (Hamilton et al. 2016, Rudzitis 1999). Adequate preparedness is important in reducing risk in outdoor recreation activities, and people who are not well informed about the recreation areas they visit may be unprepared for harsh environmental conditions (Brandenburg and Davis 2015, Proctor et al. 2018).

Increased outdoor recreation participation can also contribute to degradation of natural areas, leading to crowded trails and campgrounds. Both recreational activity and environmental conditions contribute to changes in the physical condition of recreation sites and natural resources. Recreation sites and infrastructure need maintenance, and deferred maintenance may increase congestion at other sites that are less affected, or increase hazards for visitors who continue to use degraded sites. Increased use can create lasting impacts on natural resources, especially when capacity to maintain infrastructure (e.g., trails and campgrounds) is minimal (Manning 2010).

Furthermore, as expanding shoulder seasons make warm-weather activities available before seasonal staff are hired, the risks associated with unmanaged recreation, including hazards to recreationists and natural resource degradation (USDA FS 2010), are increasingly prevalent (box 7.2). Natural hazards and disturbances may create further challenges for the provision of recreation opportunities. For example, storm surges may damage physical assets or exacerbate natural hazards such as erosion (chapter 3). Working with local partners can help federal land management agencies address issues related to the capacity to adapt to climate change (Timberlake and Schultz 2017).

Effects of Climate Change on Recreation

Coastal Dunes

The OCAP assessment area contains several formations of coastal dunes on public lands. The largest coastal dune area, Oregon Dunes National Recreation Area (NRA), was Congressionally designated to provide outdoor recreation use and conserve scenic, scientific, historic, and other values for public enjoyment. This area is managed by Siuslaw National Forest and contains 12,750 ha of coastal dunes along 65 km of coastline between Florence and Coos Bay. Sand Lake Recreation Area is another coastal dune area within the assessment area that is managed by Siuslaw National Forest. These two areas have similar resources and provide opportunities for off-road vehicle riding, fishing, swimming, crabbing, kayaking, hiking, camping, and viewing wildlife and natural features (USDA FS 2016).

Coastal dunes that border the Pacific Ocean and are at or near sea level will likely experience flooding, with increased incidence of storm surges and changing precipitation patterns (i.e., more frequent winter rains for longer duration) (fig. 7.3). Roads used to access recreation areas, both paved and unpaved, have flooded frequently in recent years. Increasing incidence of storm surges along with changing precipitation patterns are expected to increase the frequency of flooded roads, restricting access to recreation areas and to existing evacuation routes (box 7.3). Extreme storms, including tsunamis, can wash out recreation sites entirely. This happened in 1964, when a parking lot near the mouth of the Siltcoos River that provided access to a coastal dune area was washed out by a tsunami[3]. The parking lot was moved to a new location where it remains today. The increased threat of extreme storms as well as smaller storm surges may create challenges for providing access to recreation sites, perhaps by using more temporary, moveable, or adaptable infrastructure.

Motorized recreation in the form of all-terrain vehicles (ATVs) and utility-terrain vehicles (UTVs) is a popular and economically important activity in the coastal dune zone (USDA FS 2016), with approximately 1 million annual days of off-highway vehicle (OHV) riding generating $33 million of expenditures within the assessment area (Lindberg and Bertone-Riggs 2015). Recreationists bring their own vehicles or use one provided by outfitters and guides in the area. Motorized recreation occurs year-round, with activity peaking in the summer months, as well as on weekends throughout the year. As temperatures increase throughout the year, motorized recreation in coastal dunes might continue to increase on non-summer weekends. However, increased incidence of flooding along roads and in parking areas will likely decrease the days per year that some of these areas are accessible.

Camping is another important type of recreation in this zone, peaking during the summer months. Developed and undeveloped or dispersed campgrounds are available both in dune areas and slightly inland from the dunes but within the general dune zone. With rising sea levels and changing precipitation patterns, some campgrounds have been increasingly flooded in recent years, a pattern which is expected to worsen with climate change (box 7.4). Hiking trails in the coastal dune area may also be at risk. The Oregon Coast Trail passes along the beach, which might become washed out with increased incidence of intense storm surges (box 7.5). Trails in this area at higher elevation and that cross steep topography on unstable sandy soils can become eroded if rainfall increases substantially (Olive and Marion 2009). Sandy soil in some dune areas can become quicksand when saturated, which could occur more frequently in the future with prolonged precipitation events (Brown and Newcomb 1963).

Finally, lake- and river-based recreation in the coastal dunes is also likely to be affected by climate change. Harmful algal blooms (HABs) are expected to increase as temperature increases and can deter lake recreation because of potential harm to humans and animals (box 7.6). Storm surges might wash out lake- and river-based recreational infrastructure such as boat ramps and launch sites, as well as access roads and parking areas. Although rare, situations when lakes and rivers have increased water levels without associated reduction in access could increase the supply of water-based recreation.

Headlands

The headlands region of the OCAP assessment area includes areas located along the coast but elevated from sea level. These areas typically have cliffs that drop off to the ocean, sometimes with small pocket beaches along the coast. Important recreation areas in the headlands zone (from north to south) are shown in figure 7.1; landslide risk level can be found in chapter 3 of this publication. Much of the Oregon Coast Highway (U.S. Highway 101) also runs through the headlands zone. The primary route providing access along the Oregon Coast, this highway was flooded several times in recent years. Availability of this road to access different regions of the Oregon Coast affects how and where people recreate. Projected increases in the frequency of flooding of this and other roads (fig. 7.3) are likely to alter recreation patterns in the headlands zone as well as other areas, depending on which zones and areas become inaccessible.

Headlands are exposed to coastal weather, including the increased frequency of storm surges projected along the Oregon Coast. Headlands may experience increased frequency and duration of flooding in the future. This is a particular concern for the Oregon Coast Highway and other roads that visitors use to access recreation sites. Flooding is associated with landslides, and areas with a high density of roads and trails are particularly susceptible to landslides, especially on steep slopes (Chatwin et al. 1994, Montgomery 1994, Swanson and Dyrness 1975, Swanston 1976) (chapter 3).

The relatively high elevation from sea level will protect recreation sites in the headland zone from some of the effects of increased storm surges and precipitation, especially in areas with good drainage. Popular activities in headlands include visiting historic sites such as lighthouses, nature study (e.g., tidepooling), interpretative programming such as guided nature walks, viewing natural features and scenery, driving for pleasure, hiking, and paragliding. Many of these activities are vulnerable to the effects of climate change, especially if landslides damage historic sites, natural features, and recreation infrastructure. Recreation in the headlands will also be affected if access roads and parking lots are flooded. Paragliding may be affected if wind patterns are altered by climate change,

Beaches

The Oregon Coast is well known for its picturesque ocean beaches. The shoreline within the OCAP assessment area is characterized by long stretches of open and continuous sandy beach, periodically interrupted by headlands, inlets, or the mouths of rivers. A total of 185 km of shoreline between Cape Lookout and Cape Arago are occupied by beach. Small, isolated “pocket beaches” can also be found at the bases of some headlands.

Oregon has a long tradition of keeping its beaches readily accessible for public use. Under the Oregon Beach Bill of 1967, all land within 4.9 m of the average low tide mark is considered public property, and the state government holds an additional easement up to the vegetation line. These provisions apply to the entire Oregon Coast, regardless of upland property owner. As a result, all of Oregon’s coastal beaches are available for a variety of outdoor recreation activities. Property ownership adjacent to beaches is a mix of private, local, state, and federal government, but public access points and parking lots are plentiful within coastal communities and within local, state, and federal lands.

Beaches host a wide variety of recreational activities for locals and visitors alike, including walking, beachcombing, riding motor vehicles, viewing wildlife and scenery, storm watching, picnicking, fishing, clamming, bicycling, horseback riding, surfing, and flying kites. Many activities, such as walking and beachcombing, can occur along any stretch of beach in the OCAP assessment area, though use is particularly concentrated near coastal communities and high-profile recreation sites. Other activities, such as surfing and tide pooling, are concentrated in certain areas due to favorable local characteristics (such as wave behavior and availability of high-quality tide pools). Still other activities are limited to specific areas and seasons because of land management regulations. For example, land management agencies institute measures to protect the snowy plover (*Charadrius nivosus* Cassin) during its nesting season from mid-March to mid-September; these measures include closures of dry sand areas and prohibitions on dogs, drones, kites, camping, and vehicles (motorized and non-motorized) o=in areas designated as "plover beaches" (USDA FS Forest Order 06-12-04-21-04).

Seasonal trends in beach-based recreation are similar to trends for other recreation zones. The beaches within the OCAP assessment area are accessible 365 days a year and receive year-round use from local residents. Peak use for most activities occurs during the summer, and most of the use by non-local visitors also occurs during the summer months. Storm watching, which primarily occurs during the winter, is an exception to this summer-peak pattern. The shoulder seasons also see surges in use from local residents on sunny weekends and during spring break, and whale watching opportunities draw non-local visitors during the fall and spring. For visitors from outside of the area, recreating on the beach is often a component of a larger trip that includes spending in communities and activities in multiple recreation zones.

The effects of climate change on beach-based recreation are similar to effects in other recreation zones. Though the amount of exposed beach is always variable based on tides, rising sea levels may reduce the area of beach available for recreation at all tidal stages. Depending on the magnitude of sea-level rise, the area of narrow pocket beaches could be severely reduced or lost altogether. Areas where the beach is already narrow might experience lower visitation rates if sea-level rise decreases the beach width substantially (Coombes and Jones 2009). Under average tidal conditions in most beach areas, activities such as walking, bicycling, or picnicking will not be significantly affected, but more site-specific activities such as tidepooling may lose access to high-quality features. All activities would be affected during exceptionally high tides (or king tides), which can inundate most of or the entire beach area, precluding access to the sand. Increased frequency of storm events will also cause increased frequency of storm surges, which will also temporarily inundate the beach above the mean high-tide mark. However, increased storm frequency or severity would create increased opportunities for storm watching from safe locations.

At the same time, hotter summer temperatures and increasing wildfire smoke in the interior of the state could trigger increased use of the beach as an alternative destination to the Cascade Range and Willamette Valley. Expanded shoulder seasons could encourage higher use from local residents across all activities.

Marine Zone

The Oregon Coast has over 580 km of shoreline, approximately 490 km of which lie within the OCAP assessment area. This coastline includes several marine protected areas (MPAs), including Cape Falcon, Cascade Head, Otter Rock, and Cape Perpetua Marine Reserves, all managed by the Oregon Department of Fish and Wildlife. Recreation activities in the marine zone include fishing (from the beach and from boats), crabbing, surfing, whale and sea lion watching (from shore and boats), exploring tide pools, sea and sea cave kayaking, and observing scenery.

Fishing is generally allowed along the coast, with some fishing activities allowed in MPAs, and marine reserves designated as no-fishing zones. Climate change is expected to alter the timing of upwelling events[4] which often result in greater availability of recreational fisheries species such as Chinook salmon (*Oncorhynchus tshawytscha* Walbaum) and other salmonids (The Research Group 2019), and thus improved recreational fishing opportunities for these species (chapter 4). However, climate change is also likely to increase the frequency and duration of HABs in marine areas (box 7.7). In addition, warmer water temperatures affect the pH and salinity of marine waters. Coastal Oregon is already experiencing ocean acidification, with a new “hypoxia season” taking place in late summer. During this time, sessile organisms such as shellfish, which cannot quickly move into areas with more oxygen, can die of oxygen starvation (Klampe 2019). These climate-associated shifts will likely alter the availability of fish and shellfish.

Storm surges are projected to peak in winter months in the future (chapter 2). These months are currently open for all shellfish and sport fish fisheries (ODFW 2020). Anglers who target marine fish and shellfish during the winter months might be affected by the increased frequency of strong storm surges in the future.

Because recreationists generally participate in multiple activities on a single trip, shifts in coastal visits for the primary purpose of fishing will likely affect other types of recreation as well. For example, if the availability of target fish decreases during peak summer months, anglers who had planned to camp in the coastal dune or upland areas might cancel their trips, potentially reducing participation in camping in those zones. Climate change may also affect coastal recreation and tourism more indirectly if effects decrease the availability of fresh seafood for consumption in restaurants or markets. Because outdoor recreation is just one part of the larger tourism system, this will have economic effects on communities near recreation sites, with a different volume or timing of recreationists staying in hotels, eating in local restaurants, and buying gasoline, groceries, and other supplies (Arabadzhyan et al. 2020).

Estuaries and Coastal Lagoons

Estuaries and coastal lagoons are interspersed throughout the OCAP assessment area, including locations in the Oregon Dunes National Recreation Area, Sand Lake Recreation Area, Nestucca Bay, Siletz Bay, Alsea Bay, Yaquina Bay, and Coos Bay. Estuary fishing may be the most important recreational activity in estuaries and coastal lagoons. Estuary fishing areas are in Oregon Dunes National Recreation Area (at the South Jetty area) and Sand Lake Recreation Area. Crabbing, kayaking, paddle boarding, and picnicking are also available in these areas. Recreational fishing is also popular in Tillamook Bay.

Climate change is expected to increase water levels in parts of Tillamook Bay, depending somewhat on the sheltering effects of topography within the bay (Cheng et al. 2015), and in Oregon Dunes National Recreation Area (chapter 3). Flooding changes the salinity of estuarine waters and could affect the distribution of fish species in these estuarine waters (chapter 4), which would likely affect participation in recreation associated with these species. Changes in water levels could also flood recreation infrastructure near estuaries and coastal lagoons (chapter 3), effectively shifting estuary-based recreation and possibly reducing the amount of space for this type of recreation.

Upland Areas

Uplands in the OCAP assessment area are lands set back from the shoreline that do not contain dunes. In effect, all terrestrial areas that are not classified as beaches, headlands, or dunes are classified as uplands. In the assessment area, upland elevations range from a few meters above sea level to the top of Mary's Peak (the highest mountain in the Oregon Coast Range) at 1,249 m. Upland areas host hiking, developed and dispersed camping, hunting, forest product gathering, picnicking, mountain biking, horseback riding, and fishing on small mountain lakes.

A small amount of snow-based recreation occurs in upland areas, where snow occurs annually but is intermittent through the winter months, typically from December through March. Although there are no ski resorts or other permanent infrastructure for snow-based recreation in the assessment area, there may be some local businesses such as outfitters, hotels, restaurants, gas stations, and grocery stores that benefit from snow-based recreationists. As temperatures rise, snow-based recreation seasons will get shorter with more years when insufficient snow is available to support recreation. Recreationists will need to substitute activities or locations as snow-based recreation becomes less available in western Oregon. Those who substitute locations may choose nearby areas with higher elevations, such as in the Cascade Range. However, these areas will be experiencing shorter snow-based seasons and smaller areas with sufficient snowpack to support snow-based recreation, exacerbated by higher demand from a larger population interested in such activities (Miller et al. 2022b). If recreationists choose to substitute locations rather than activities in the absence of snow, local businesses will experience lower profits.

Upland areas with steep slopes are vulnerable to road washouts and landslides (chapter 3). Projected changes in rainfall patterns associated with climate change may increase this vulnerability. This could affect access to recreation sites, as well as the availability of recreation areas, as trails and campgrounds are also at a risk of becoming eroded and washed out. Water is the primary direct cause of trail erosion, accompanied by other direct forces such as wind and recreational use (by foot, horse hoof, or tire) (Newsome et al. 2004, Summer 1980). Recreation managers may find that trails need to be closed more often, especially those that are aligned with a fall line, cross steep terrain, or are in valley-bottom alignments near streams, all locations at risk of erosion from precipitation (Olive and Marion 2009, Wilson and Seney 1994). Horse traffic causes more erosion than hiking and mountain biking (Marion and Wimpey 2007, Newsome et al. 2004, Wilson and Seney 1994), and motorized traffic causes more erosion than non-motorized traffic (Liddle 1997). Managers may find that equestrian trails and trails or unpaved roads with motorized use become increasingly washed out with higher precipitation intensity. Trails currently traversing areas with high landslide risk may need to be rerouted to areas with lower landslide risk, and future recreational infrastructure can be planned to avoid high-risk areas (e.g., Strauch et al. 2015).

Social Equity in Climate Change Adaptation for Outdoor Recreation

Climate change has disproportionate effects on different populations of recreationists and potential recreationists. Recognition and careful consideration of these disparities is critical to reduce inequalities through climate adaptation planning. Visitors' ability to substitute activities, locations, or timing differ greatly with factors such as socioeconomic and cultural influences (Miller et al. 2022a).

Climate-threatened activities that have relatively high participation from traditionally underrepresented groups present a particular concern for climate adaptation planning. For example, studies indicate that some underrepresented populations, such as Latino visitors, participate disproportionately in recreation occurring in developed areas (OPRD 2019, Winter et al. 2021). In the OCAP assessment area, these zones are some of the most threatened by climate change, relying on infrastructure vulnerable to being washed out by flooding, storm surges, and sea-level rise. Oregon Latino and Asian residents, both underrepresented populations in outdoor recreation participation across the state, listed “walking on local trails” as the second most popular activity (73 percent [Latino] and 69 percent [Asian] participation rates), a climate-threatened activity in some areas because of the risk of washouts and flooding. In addition, 54 percent of Oregon Asians participate in sightseeing, driving, or motorcycling for pleasure, an activity threatened by road washouts and flooding. Fifty percent of Oregon Latinos participate in beach and ocean activities, another climate-threatened activity at certain times of year due to increased frequency of HABs. Planning for sustainable access to opportunities for these and other activities popular among underrepresented groups is critical, as is communication to these groups about opportunities to participate in recreational activities (OPRD 2019).

Recreation sites that have special importance (table 7.1) might be irreplaceable for recreationists highly attached to a site, whereas those with weaker ties to specific locations might not mind or even notice a closure. Disproportionate effects to Siuslaw National Forest visitors were detected by the 2016 NVUM survey. Oregon Dunes NRA visitors were much more interested in finding a substitute location for their preferred activity within 40 km (44.9%) compared to visitors in other parts of the Siuslaw NF, who were split between finding an alternate location nearby (23.3% within 40 km) and traveling over 500 km to find an alternate location for their preferred recreation activity (26.4%) (USDA FS 2016).

Summary of Climate Change Vulnerabilities

The vulnerability of recreation to climate change in the OCAP assessment area varies primarily by the geographic zone in which the activity takes place, as well as by its seasonality. Recreation that occurs in areas susceptible to flooding, landslides, and sea-level rise are arguably the most vulnerable to climate change and are expected to be displaced and possibly concentrated in smaller spaces. Although recreationists can adapt to changing opportunities influenced by the effects of climate change, the degree to which different activities and locations are satisfactory substitutes is not well understood.

Overall, participation in climate-sensitive recreation activities is expected to increase, as longer warm-weather seasons make more recreation sites available for longer periods of time. Participation is also expected to increase because of a growth in population size in the region, particularly when new residents are attracted to the area for its outdoor recreation opportunities. At the regional scale, climate change is expected to make the Oregon Coast increasingly attractive for outdoor recreation and tourism in the summer months, when conditions along the coast are likely to be preferred to those in inland areas that are more likely to experience extreme heat and wildfires. Increased participation in recreation during the summer is likely to be offset somewhat by worsened conditions for winter recreation and tourism. Storm surges and more frequent rainfall are expected to cause increased flooding, threatening many winter activities.

Beyond these general conclusions, the details of changes to recreation patterns in response to climate changes are complex. Recreation demand is governed by several economic decisions with multiple interacting dependencies on climate. For example, decisions about whether to engage in warm-weather recreation, which activity to participate in (e.g., hiking, camping, mountain biking, etc.) where to go, 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 greatly from one location to another. Therefore, the effects of climate change on recreation depend on spatial and temporal relationships among sites, environmental conditions, and human decisions.

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 characteristics are difficult to project and are likely to be diverse across the OCAP assessment area, but 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), but recent research has focused on this topic (e.g., Bristow and Jenkins 2018, Lamborn and Smith 2019, Orr and Schneider 2018, Winter et al. 2021). 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 be costlier to access or lower quality than the preferred visit prior to climate change. Furthermore, increased recreational activity in smaller areas may lead to crowding, although not all recreationists will be sensitive to this (e.g., Nickerson 2016, Schultz and Svajda 2017). This represents a decrease in benefits to the recreationist.

Adapting Recreation Management to Climate Change

Warming temperatures will be the primary driver of climate change effects on recreation, allowing the warm-weather recreation season to start earlier and end later in the year. As this happens, human-wildlife interactions will likely change, with recreationists more prevalent during periods of animals' life cycles when people were previously absent, compounded with habitat and seasonal shifts for animals (chapter 6). This might increase the risk of human-wildlife conflict and will likely affect wildlife-based recreation. In addition, smaller areas suitable for recreation during the peak summer and winter seasons might result in crowding for some recreationists, and potential conflict between recreational activities.

Climate change effects will lead to new maintenance issues for recreational infrastructure and facilities. More frequent and prolonged rain events will likely bring increased erosion, flooding, and landslides that will require road and trail maintenance and add public safety risks. If recreationists visit infrastructure such as trails and campgrounds outside of the periods during which seasonal staff are in place to maintain and manage them (because of extended shoulder seasons), risks will be higher for both recreationists and facilities. If recreational use becomes more concentrated in smaller areas during the peak summer season, and if sea-level rise reduces the spatial extent of coastal areas, increased attention might be required to maintain facilities; however, this might also result in staff being able to focus on smaller areas if recreation is not as widely dispersed. Increased demand relative to other areas in the region emphasizes the need to address concerns regarding access and use.

Organizational flexibility and responsiveness to changes will help adapt recreation management to climate change in the OCAP assessment area, with most adaptation strategies focused on providing sustainable levels of recreation opportunities (chapter 9). Redirecting recreational use to minimize conflict between users and wildlife, optimize recreational opportunities, and protect vulnerable areas may help maintain the quality of recreational experiences in the future. Public safety may also be a concern as disturbance patterns change. Partnerships with other land management agencies and organizations might provide opportunities to increase flexibility, such as informing the public of closed recreation areas, directing recreationists to alternative open areas, and hiring seasonal staff to cover expanding warm-weather recreation seasons.

Regional and inter-organizational strategies for communicating alternative recreation opportunities both within and between the zones described above will facilitate the continued provision of recreational opportunities in the assessment area. The public generally supports this idea as well, with the desire for improved communication regarding outdoor recreation opportunities stated by both recreation participants and non-participants in Oregon's 2017 Statewide Comprehensive Outdoor Recreation Plan (SCORP) survey (OPRD 2019). Furthermore, efforts to communicate outdoor recreation opportunities in a changing climate targeted toward underrepresented populations can facilitate increased participation in outdoor recreation from these communities, as lack of information was cited as a major barrier to participation by Oregon Latino and Asian residents (OPRD 2019).

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. When management capacity cannot be extended, such as through partnerships with other recreation providers, access to some areas may need to be restricted to protect resources, especially when roads, trails, and facilities are not open (and may not be safe) during floods or wildfires. 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 to adjust to altered recreational demands and opportunities in the future.

Conclusions

The Oregon Coast is projected to experience increased flooding, more frequent landslides, and longer warm-weather seasons. Changes in the OCAP assessment area, combined with changes in the larger region (e.g., areas with large population centers) will alter the landscape and seasonality of outdoor recreation. Considering climate-related changes in outdoor recreation supply and demand is critical in planning new recreation infrastructure and proactively managing for expected shifts in recreation at the regional scale. Recent research attention is focused on understanding how individual recreationists will modify their behaviors in future climate scenarios. Combining this information with statistics about local participation rates by demographic groups in climate-threatened outdoor recreation activities will improve projections of climate change effects on outdoor recreation in the OCAP assessment area.

Adaptation priorities for the OCAP assessment area include:

- Regional interagency communication efforts regarding shifting recreation opportunities.
- Investments in partnerships that can help improve flexibility in climate adaptation planning and response.
- Boosting visitor capacity within recreation areas projected to have higher recreation participation.
- Identifying strategies to boost internal and external capacity for recreation site management.
- New designs for recreation infrastructure that will increase climate resilience.
- Planning for new recreation infrastructure that avoids climate-sensitive areas.

Practitioners within the OCAP area already work on several of these topics. Examples of ways in which climate adaptation is being integrated into USFS planning and management include:

- *Recreation site planning*—Siuslaw National Forest recently created a 5-year program of work for developed recreation sites that identifies projects and management actions that practitioners want to accomplish at campgrounds, trailheads, picnic sites, and other recreation sites. For example, the program of work identifies sites where parking capacity can be increased, sites vulnerable to flooding, and improvements for water-based recreation sites.
- *All-lands management*—Siuslaw National Forest is working to adopt more of a "recreation-shed" perspective on providing recreation services and addressing cross-boundary recreation management challenges. Established partnerships with other agencies in the region can enable a more integrated response to cross-boundary challenges such as climate change.
- *Staffing*—Recognizing that recreation is becoming increasingly complex, the USFS conducted a hiring event at the national and regional levels in summer 2022. This hiring event aimed to fill vacancies and new positions to improve the agency's ability to provide high-quality recreation amenities and respond to emerging challenges. At the local level, Siuslaw National Forest is improving the management and organization of volunteer programs, which will increase capacity and effectiveness of on-site volunteers.

Additional research is needed to improve our understanding of outdoor recreation vulnerabilities to climate change and point toward potential adaptation solutions. For example, studies investigating recreationists' weather preferences and planned adaptations to climate change in Oregon would improve expectations of how recreationists and tourists will adapt to future climatic conditions. Adaptation efforts would benefit from more detailed information about the relative number of people participating in multiple recreational activities and their geographic distribution across public lands in Oregon. These data would help managers and researchers project future displacement of recreationists and the benefits they receive in a warmer climate.

Public land managers are increasingly aware of how climate change will influence recreation patterns and preferences on the Oregon Coast. Warm-weather days are likely to become more frequent, especially in the shoulder seasons, leading to increased visitation levels during times of year that traditionally have lower use. Accordingly, managers should be prepared for higher visitor demand for off-road vehicle riding, hiking, horseback riding, scenic driving, picnicking, and camping activities in the spring and fall. This may require flexibility in staffing arrangements and seasonal site closures during the shoulder seasons.

In summer, hot weather and wildfire in the interior of Oregon may push additional use to the coast. This increased summer use will amplify crowding and congestion at recreation sites that have limited capacity. In turn, this will require managers to explore site expansion and "right-sizing" efforts to better match capacity with demand. It will also require interagency messaging strategies to help visitors find new destinations if their desired sites are full.

In winter, climate change is likely to increase the intensity and frequency of storm surges and high-precipitation events, causing more landslides and flooding, especially in coastal areas. In response, managers would benefit from exploring opportunities to enhance the resilience of existing infrastructure, while planning for new infrastructure in locations that have lower flood probability. Interagency messaging protocols will also be useful for directing visitors away from locations that have been flooded or affected by slides.

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Chapter 8: Climate Change and Ecosystem Services

Robert W. Hoyer, Paris B. Edwards, Anne Poopatanapong, Brye J. Lefler, Haley Case-Scott, Duncan C. McKinley, Kevin L. Bruce, Doug A. Glavich, Aurora A. Cutler, Alexa J. Dugan

Introduction

"Ecosystem service" is a term used to describe the benefits human beings receive from natural processes taking place in the environment. Human societies require ecosystem services to function and thrive. Many discussions of the topic have occurred over the years, but it was the United Nations-sponsored Millennium Ecosystem Assessment (MEA) that popularized the concept. In a detailed synthesis of the state of science, the MEA reported that 60 percent of ecosystem goods and services are being degraded or used unsustainably (MEA 2005). The MEA describes a set of interrelated drivers operating at multiple scales leading to ecosystem service declines, especially over the latter half of the 20th century.

Much of the documented human-caused degradation is from a lack of understanding of how the benefits from ecosystem services flow to human populations. As a result, intact functioning ecosystems are routinely undervalued in resource decision making, leading to unbalanced tradeoffs in which true costs are placed on vulnerable populations and/or are deferred to future generations. The MEA used four primary categories to illustrate how ecosystem services influence human well-being: (1) *provisioning services* such as food, fiber, energy and water; (2) *regulating services*, including erosion and flood control, water and air purification, and temperature regulation; (3) *cultural services*, such as spiritual connections with land, history, heritage, and recreation; and (4) *supporting services*, or the foundations of systems such as soil formation, nutrient cycling, and pollination.

Goods and services that benefit humans are derived from ecosystem processes broadly defined as physical, chemical, and biological interactions taking place on the landscape that support terrestrial and aquatic life. Most of these processes fall under the supporting services category, and the amount and quality of the other ecosystem services rely on their functionality. The amount of living space (or habitat), as well as matter and energy inputs, are necessary for functional ecosystems. Climate change is expected to alter ecosystem function and have negative consequences on many goods and services. Examples include water availability and quality, flow regulation, pollinator/plant interactions, and forest products (Montoya and Raffaelli 2010, Mooney et al. 2009). Previous chapters in this assessment discuss the potential changes to resources of the Oregon Coast that could alter the provision of vital services to human populations. By compiling information on the current understanding of biophysical processes that produce ecosystem services, this effort will be instrumental in informing actions to reduce negative impacts, increase resilience, and facilitate adaptations over time (Seidl et al. 2016).

The U.S. Department of Agriculture, Forest Service (USFS) has adopted the valuation of ecosystem services as an integral component of policy and practice. A team of agency managers and scientists from the National Forest System, State and Private Forestry, and the Pacific Northwest Research Station came together as the National Ecosystems Services Strategy Team in 2013. The group's report, *Integrating Ecosystem Services into National Forest Policy and Operations*, identifies opportunities for incorporating the ecosystem services framework into the agency's mission of meeting the need of present and future generations (Deal et al. 2017).

The USFS 2012 Planning Rule (36 CFR 219) requires national forests to take ecosystem services into consideration in revising land management plans (forest plans). Climate change vulnerability assessments are intended to inform the plan revision process by analyzing potential climate change effects relevant to land management. Considering the influence of climate change on ecosystem function and thus the provision of ecosystem services, this chapter describes priority climate change considerations for natural resource assets, which can then be used in forest plan revision.

This chapter analyzes key ecosystem services chosen in consultation with staff of Siuslaw National Forest (NF). It also covers the Bureau of Land Management (BLM) lands of the Northwest Oregon and Coos Bay Districts within the Oregon Coast Adaptation Partnership (OCAP) assessment area. By focusing on a limited selection of important services, the assessment provides relevant information on climate change effects. This mirrors the criteria outlined in the 2012 Planning Rule directives, which advise resource managers to focus on key ecosystem services in forest land management plan revisions that are: (1) important outside the planning area and (2) can be affected by USFS decision making. 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.

This chapter is divided into three sections:

1. An introduction that includes a discussion of cross-cutting drivers of change or a set of unique social and biophysical characteristics that will likely influence the provision of all ecosystem services found in the assessment area.
2. Assessments of key ecosystem services—forest products, forest carbon, pollinator services, and cultural values—including an overview along with subsections discussing aspects of each service such as service subcategories or climate change effects. The cultural values section covers provisioning services of forest products, fish, and game discussed elsewhere but through the lens of tribal relationships to the land. Short discussions are provided for resource areas that are already treated in depth in other chapters in this assessment—recreation (chapter 7), fish and wildlife (chapters 4 & 6), and water resources (chapter 3).
3. A summary of information from the chapter including: (1) quantification of key ecosystem services on federal lands in the assessment area, (2) anticipated responses to climate change for select ecosystem services, and (3) key uncertainties and information gaps. The chapter concludes with a discussion on how the information can be used by resource managers.

Cross-cutting Drivers of Change

Changing social and biophysical characteristics (e.g., population dynamics, temperature and precipitation regimes) have implications across multiple resources in the land-ocean continuum within the OCAP assessment area. Here, we highlight regional drivers that influence ecosystems and their services. Population growth, shifting demographics, and increased development (chapter 3) are expected to alter visitation and increase demands on ecosystems (English et al. 2014). Changes in plant and animal phenology are expected to alter the distribution and abundance of different species, with implications for long-term sustainability and ecosystem services in the assessment area.

Population growth is likely to exacerbate climate change vulnerability by increasing demand on forest lands and the ecosystem services they provide. The three largest population centers in Oregon outside of the Portland metropolitan area (and their population size)—Eugene (urban growth boundary population [UGB] 192,607), Salem (UGB 223,863), and Corvallis (UGB 63,044)—are within about 100 km of Siuslaw National Forest]. Populations for these locations, as well as for 10 smaller towns[2] adjacent to the OCAP assessment area, are projected to increase by 40 percent by the end of the century (PSU 2019). Therefore, increased visitation and demands on ecosystem services are expected, but if climate change sufficiently degrades an ecosystem service, demand could be reduced.

Phenology relates to the influence of seasonal and interannual climatic variation on cyclic and seasonal patterns of plants and animals. Changes in temperature and precipitation may alter the distribution, growth, morphology, reproduction, and abundance of plants and animals, which in turn modify food webs and ecosystem services. As species alter cycles and seasonal patterns to adapt to changing climatic conditions, species interactions may be altered, causing mismatches between synchronized species (changing at different rates or locations), which may affect plant-animal interactions such as seed dispersal, pollination, and insect populations (Burkett et al. 2005).

Specialized species are expected to have heightened vulnerability to phenological change. For example, the threatened Oregon silverspot butterfly (*Speyeria zerene hippolyta* W.H. Edwards) and its dependence on the early blue violet (*Viola adunca* Sm.) as its sole host plant, are an example of specialized plant-pollinator dependence, with vulnerabilities exacerbated by likely limitations to violet habitat migration. Species with shorter life cycles, including some invasive species, insects, and pathogens, may be more resilient to phenological change, causing increased virulence, range, and disease spread (Lovett et al. 2006).

Little is known about the resilience of species in the OCAP assessment area to phenologic shifts, although expected changes in temperature, precipitation, and seasons (e.g., early onset of spring conditions) will likely alter existing systems. Managers can reduce negative impacts to sensitive, culturally important, and economically valuable species through targeted monitoring, invasive species control, and outreach and education. Ongoing data collection on phenology can be accessed through the National Phenology Network, which hosts data and other information for species across the United States.

Marine fog is an iconic feature of Oregon Coast beaches, forests, and mountains, with cascading influence across multiple human and environmental systems. The physics of marine fog development is complex, and conditions are hard to predict due to dynamic ocean, air, and land surface processes that interact at regional and local scales. In brief, fog can form when warm land air masses converge with the cooled ocean air. Because of Oregon's relatively cool ocean temperatures, fog currently forms throughout the year and frequently occurs during the spring and summer when air temperatures are highest and ocean temperatures are coolest, because of upwelling (ocean-bottom water is advected to the surface) (Torregrosa et al. 2014, Wang et al. 2015).

Fog occurrence during the spring and summer reduces solar radiation, moderating temperatures in riparian and intertidal systems important to salmonids. It benefits human health by filtering pollution and providing natural air conditioning. Terrestrial systems receive increased humidity and water during dry periods (fog drip and direct uptake), reduced evapotranspiration, increased soil metabolism, and improved photosynthesis (Johnstone and Dawson 2010, Limm et al. 2012, Torregrosa et al. 2014). Recent documentation of potential declines in fog frequency in California raise concern over how continued increases in average air temperatures and altered timing and intensity of ocean upwelling will affect the dynamics of coastal fog formation in Oregon (O’Brien 2011, O’Brien et al. 2013).

Increased monitoring and research on coastal fog is necessary to understand more fully the role this phenomenon plays in resource vulnerability in the OCAP assessment area. Current efforts include the Pacific Coastal Fog Project, whose objective is to improve data access and interdisciplinary communication, (http://www.usgs.gov/centers/western-geographic-science-center/pacific-coastal-fog-project), and FogNet, a network of scientists who are monitoring sites in California along the land-ocean continuum (http://fognet.ucsc.edu).

Changing nearshore ocean conditions, including altered temperature, acidity, and oxygenation, are affecting coastal Oregon and are expected to intensify in the future (Gunderson et al. 2016, Marshall et al. 2017). Coastal upwelling is a driver of ocean conditions that occurs during the spring and summer as part of an annual pattern of wind-driven ocean turnover, bringing cool water and nutrients from the bottom of the ocean to the surface. In addition to influencing coastal fog formation, ocean upwelling affects the chemistry and temperature of nearshore waters (Wang et al. 2015). The timing, duration, and intensity of upwelling influence annual productivity and affect ecosystems from ocean plankton and forage fish, to seabird reproduction and estuarine nutrient transport (Barth et al. 2007, Colbert and McManus 2003, Reum et al. 2011). Increased frequency of intensified upwelling events (longer duration from deeper depths) may exacerbate ocean acidification along the Oregon Coast (Hauri et al. 2009). The California Current, which affects coastal Oregon waters, already experiences low pH levels owing to upwelling events; additional increases in acidity could intensify impacts on marine ecosystems (Marshall et al. 2017).

Species that are vulnerable to changing ocean conditions include all shellfish, nearshore marine mammals, and many coastal bird species (Branch et al. 2013, Gardali et al. 2012). Vulnerable coastal bird species include the federally threatened marbled murrelet (*Brachyramphus marmoratus* J.F. Gmelin) and western snowy plover (*Charadrius alexandrinus nivosus* Cassin), whose feeding and reproductive habits range from the nearshore ocean to forest and sand dune regions, respectively, and are influenced by the timing, duration, and intensity of upwelling (Becker and Beissinger 2003, Peery et al. 2009). Additional vulnerable shorebird species include the tufted puffin (*Fatercula cirrhata* Pall.), black oystercatcher (*Haematopus bachmani* Audubon), pelagic cormorant (*Phalocrocorax pelagicus* Pall.), double-crested cormorant (*Phalocrocorax auratus* Lesson), pigeon guillemot (*Cephus columba* Pall.), Leach’s storm petrel (*Oceanodroma leucorhoa* Vieillot), Brandt’s cormorant (*Phalocrocorax penilillatus* Brandt), common murre (*Uria aalge* Pontoppidan), and rhinoceros auklet (*Cerorhinca monocerata* Pallas) (Gardali et al. 2012, Hixon et al. 2010) (chapter 6). Recovery of the currently extirpated sea otter (*Enhydra lutris* L.) and the endangered Steller sea lion (*Eumetopias jubatus* Schreb.) is also contingent on ocean conditions off the Oregon coast.

Shellfish are strongly affected by ocean pH, and rates of acidification along the Oregon Coast are higher than elsewhere due to upwelling influences (Gruber et al. 2012). Shellfishing (commercial and recreational) is an economic mainstay and quintessential to sense of place for many coastal communities. Shellfish are also culturally valued and are a food source for local American Indians. Through filter feeding, shellfish help regulate water quality and are preyed upon by birds and mammals (Lepofsky et al. 2015, Poe et al. 2016, Zobel 2002, Zu Ermgassen et al. 2012). High-resolution, offshore monitoring data are available for Oregon coastal waters through the Ocean Observatories Initiative (https://oceanobservatories.org/data-portal/), providing an opportunity to improve our understanding of altered ocean conditions.

Assessments of Key Ecosystem Services

Forest Products

Ensuring a sustainable supply of forest products is one of the original mandates for federal public land agencies. Traditionally, the primary goal of forest management activities has been timber production, and Siuslaw National Forest and BLM districts of western Oregon produce significant volumes of saw timber and other products. Non-timber forest products (NTFPs) are not fully integrated into forest management but are increasingly recognized for their socioeconomic and cultural importance (Chamberlain et al. 2018a). As the vegetation assemblages present in the assessment area experience climatic influences (chapter 5), the timing, amount, and quality of forest products may be affected, with potential effects on local communities.

Timber

For counties contained in the OCAP assessment area (fig. 8.1), timber production has varied over time on USFS and BLM lands (fig. 8.2). Harvest levels for saw timber, pulpwood, biomass, and fuelwood from Siuslaw National Forest are shown in figures 8.3 and 8.4. Siuslaw National Forest averaged 72.4 million board feet (MMBF) of saw timber per year during the period 2013–2018, falling within the top half of national forest units in the Pacific Northwest Region for volume, despite its relatively small size. Northwest Oregon BLM and Coos Bay BLM Districts averaged 109 and 250 MMBF, respectively, over the same time period. Both districts have significant ownerships outside of the assessment area, including the Cascade Range foothills. Much of the timber harvested on Siuslaw National Forest over the past 20 years has been done under stewardship contracts; currently, about half of the forest's timber sales are stewardship sales (Cascade Pacific Resource Conservation and Development 2019). Revenues from these sales are used to fund restoration projects that improve habitat, remove invasive species, and restore watershed function. This approach uses one ecosystem good to enhance the provision of other ecosystem goods and services and benefit local economies.

Climate Change Effects on Timber

Forests of the Oregon Coast Range are some of the most productive in the Pacific Northwest. These forests are expected to remain productive and may even experience higher productivity owing to longer growing seasons and higher levels of atmospheric carbon dioxide, although these gains may be offset by increased summer drought (chapter 5). Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), the primary commercial species, is expected to remain dominant across coastal Oregon. However, at smaller spatial scales, shifts in species distribution and abundance could occur over time, affected by changes in plant phenology, marine fog, summer water availability, insect outbreaks, pathogens, and nonnative species. Disturbance events, including extremely large fires and windstorms, have the potential to affect forest landscapes throughout the assessment area.

For all public and private timberlands, disturbances are anticipated to have the greatest effects on timber productivity and to be the main driver of disruptions in timber markets (Joyce et al. 2014). As a global phenomenon, climate change will affect timber-producing regions worldwide. Altered supplies and demand and subsequent effects on prices will have implications for local and regional socioeconomic conditions in industries and communities that participate in the timber economy (Kirilenko and Sedjo 2007). In the future, new technologies and product innovation may help communities to adapt to changing conditions through improved utilization of timber resources and by opening a more diverse timber market. Cross-laminated, glue-laminated, and nail-laminated timber is well-established in Europe as replacements for concrete and steel in mid- to high-rise buildings and have the potential for expansion in North American construction (Abed et al. 2022, Ahmed and Arocho 2020). Bioenergy and biochar production may also represent opportunities but only under appropriate ecological and economic conditions.

Non-timber Forest Products

Humans have harvested, and in some cases managed, non-timber forest products (NTFPs) on the central Oregon Coast for at least 14,000 years (Aiken et al 2011). NTFPs include plants, fungi, and derivative products. These serve as food, medicine, fuel, decoration, and spiritual uses (McLain and Jones 2005). Here, we limit our discussion of NTFPs to those originating from plants and fungi, although a broader definition of NTFPs could include shellfish, fish, animal products, and minerals.

The range, distribution, and abundance of NTFP species have shifted in response to climatic variability for millennia, with humans adapting to these changes in order to harvest and use NTFPs. Pastoralist, nomadic, and semi-nomadic groups (including American Indians) have used mobility to adapt to fluctuations in resource availability. Humans have also used fire, pruning, and other methods to influence the presence, abundance, and health of NTFPs (Anderson 2005, Deur and Turner 2005). This has resulted in some locations being considered anthropogenic landscapes, including camas (*Camassia* spp.) in meadows and oak savannas. Recent collaborative efforts between land management agencies and American Indian tribes have shown that traditional ecological knowledge[3] and science-based management practices can both be used in some situations to inform adaptive management (Donoghue et al. 2010, Ross et al. 2011, Spoon et al. 2013).

NTFPs are harvested on public and private lands and in urban and rural environments, and include native, introduced, naturalized, and invasive species. NTFP gathering occurs across cultures, genders, ages, and classes and is practiced in most American subcultures (Chamberlain et al. 2018a). In New England, a study found that 26 percent of the population had gathered NTFPs within the last 5 years and 18 percent in the last 12 months (Robbins et al. 2008). Another study found that 18 percent of people in West Virginia were regular NTFP harvesters and 8 percent were occasional harvesters (Bailey 1999). Similar studies do not exist for the Pacific Northwest.

People who harvest NTFPs come from diverse backgrounds and have different motivations for harvesting. Harvesters can be grouped into several categories, including subsistence harvesters, commercial harvesters, recreational harvesters, cultural/spiritual harvesters, botanical medicine practitioners/herbalists, and scientific harvesters. Although these categories help with understanding different motivations, scales, and approaches to harvesting NTFPs, the categories often overlap, and harvesters themselves may or may not identify with them.

NTFPs are harvested for traditional use by American Indians and for personal use of edible and medicinal mushrooms, plants, and seaweeds by wild-food foragers and herbalists. NTFP harvesting, such as berry picking, occurs as both a sole pursuit and as a secondary activity, versus hunting, fishing, hiking, or otherwise recreating on public lands (chapter 7). Commercial harvesting of NTFPs supplies raw materials for cottage industries and corporations alike, including the pharmaceutical and floral industries (Chamberlain et al. 2018a, McLain and Jones 2005). The USFS classifies NTFP harvesters as recreational/personal use, commercial, or American Indian traditional cultural use/treaty rights (sometimes codified in a memorandum of understanding or similar documentation). Some NTFP harvesting is tracked through permits, whereas other use is either unknown or untrackable. Schlosser and Blatner (1992) estimated the commercial value of the Pacific Northwest NTFP industry at more than $190 million. The value of personal-use collection is believed to be three times that number (Vance et al. 2001).

Many NTFPs are gathered in the OCAP assessment area. Figures 8.5 through 8.9 show recent trends from 2013 to 2018 for NTFPs with reported harvest totals. As with timber, the numbers reported for Northwest Oregon and Coos Bay BLM Districts represent a larger area than the area of focus in this report. The Siuslaw National Forest limits harvest of NTFP plants to 43 species (table 8.1). Trees used for firewood (3 conifer and 1 hardwood species) are categorized separately. Mushroom harvesting for personal use is not limited to select species, although permits for commercial use restrict harvesting to 12 species and/or genera of mushrooms.

The Northwest and Coos Bay BLM Districts categorize NTFPs by plant part or type of use. Permitted NTFPs include 6 types of berries, 9 tree bough species, 11 burl-producing tree species, 9 Christmas tree species, 18 species of edibles and medicinals, 10 types of floral greens, 11 types of fungi, 7 types of ornamental wood, 3 ornamental landscaping plants, 12 types of decorative and/or seed cones, and 25 plants for transplants, seedlings, and roots. Other BLM NTFP categories include firewood, wood products, and miscellaneous products such as pitch, sap, biomass, and wood chips (table 8.1).

The Oregon Department of Forestry, Northwest Oregon Area, lists 14 categories of botanical NTFPs for personal and commercial use, including huckleberries, mushrooms, ferns, mosses, and specific plant parts (e.g., seedlings, bark, and boughs) (table 8.1). Firewood, round and split poles, and certain types of rock are also available for harvesting through the Oregon Department of Forestry special forest products program.

The actual number of NTFPs in the project area is much higher than those permitted for harvesting through state and national forest programs. More than 20 species of fungi are harvested in the Pacific Northwest (Pilz and Molina 2002), and over 100 plants and fungi are harvested on national forests in the region (Vance et al. 2001). Commonly gathered edible fungi include chanterelles (*Cantharellus* spp.), morels (*Morchella* spp.), and boletes (*Boletus* spp.). Frequently harvested floral greens include common beargrass (*Xerophyllum tenax* [Pursh] Nutt.), salal (*Gaultheria shallon* Pursh), evergreen huckleberry (*Vaccinium ovatum* Pursh), and various moss and fern species. Edible fruits are abundant in the region and include huckleberries (*Vaccinium* spp.), salmonberry (*Rubus spectabilis* Pursh), thimbleberry (*R. parviflorus* Nutt.), and multiple blackberry species (*Rubus* spp.).

Climate Change Effects on Non-Timber Forest Products

Climate change driven distribution shifts and potential for increased competition among harvester groups are key vulnerability consideration for NTFPs (table 8.2). Harvesting and other potential stressors may interact with climatic variability to increase risks to some NTFP species (Brook and McLachlan 2008, Mandle and Ticktin 2012, Souther and McGraw 2014). Long-lived perennial plants are vulnerable to harvest activities, with long-term population survival being affected when plant parts such as bark and underground portions are harvested (Ticktin et al. 2018). Harvest practices can, in some cases, increase the vigor and reproduction of some NTFP species (Anderson 2005, Deur and Turner 2005, Lefler 2014, Spoon et al. 2015). Regulations can be used to enforce behaviors that avoid overexploitation (Ostrum 2015). Where economic gain is not a driving factor, NTFP harvesters have a propensity for sustainable NTFP use, whereas commercial harvesters may be prone to unsustainable harvest practices owing to economic motivations (Crook and Clapp 2002).

Sustainable practices have been promoted in different ways (Watson et al. 2018). The Oregon Mycological Association conducted a 13-year study to determine the impacts of different harvest techniques on chanterelles (Pilz et al. 2006). An Oregon-based botanical medicine school promotes ethical wildcrafting practices that include awareness of sensitive species, minimizing harvest impacts, and monitoring of NTFPs over time (CSBM 2020). Vance et al. (2001) have described sustainability-oriented techniques developed by long-time harvesters. Public land managers can draw upon the expertise and experience of harvesters, citizen scientists, and others to monitor population dynamics and develop sustainable harvest guidelines (Donoghue 2010, Spoon et al. 2013).

Best practices for harvest of NTFPs (adapted from Watson et al. [2018]) include:

- Avoid harvesting during vulnerable life stages.
- Avoid damaging vulnerable plant parts.
- Leave some mature plants.
- Avoid sensitive, threatened, and endangered species.
- Monitor health and abundance of populations and modify harvesting approach accordingly.
- Limit amount harvested from a given population.
- Do not publicize or share harvest location.
- Rotate harvests among different locations.
- Assist reproduction and reestablishment by planting/spreading spores, seeds, and cuttings.

The effects of climate change on NTFPs can influence harvesters socially, culturally, and economically. Phenological asynchronies with pollinators, or early blooming following a hard frost, can reduce fruit production. Altered phenology of edible and medicinal plants can cause misalignment with key cultural events, such as American Indian first foods ceremonies. Disturbances such as wildfire, drought, and flooding can reduce access for harvesters. Disturbances, coupled with other long-term effects of climate change, may result in reduced availability of some species (Frey et al. 2018). For some disadvantaged populations, NTFPs provide a buffer to possible disruptions in commodity supplies, providing food, medicine, and other raw materials.

Climate change effects on NTFPs will vary across large landscapes, with some species and habitats more vulnerable than others (Emery et al. 2018). Altered habitat characteristics, such as the relationship between forest overstory and understory, can affect the abundance and distribution of some NTFPs. Some insect and disease populations may experience higher survival rates during mild winters, affecting growth, survival, and reproduction of some plant species (Chamberlain et al. 2018b).

Altered precipitation and temperature coupled with forest fragmentation may affect some understory NTFP species, especially those requiring dispersal by ants (Chamberlain et al. 2018b). For example, altered overstory composition and disturbance may affect thinleaf huckleberry (*Vaccinium membranaceum* Douglas ex Torr.) and other commonly harvested huckleberry species (table 8.3). If the timing, location, and quantity of fruiting change, there could be effects on harvest quantities and practices, as well as effects on various animal species.

NTFPs that have small populations, have limited dispersal, or grow in specialized conditions or at distributional limits (e.g., alpine habitats) are most at risk of population reductions, local extirpation, or extinction (Chamberlain et al. 2018b, Ticktin et al. 2018). Land ownership patterns, management, and development can either facilitate or hinder NTFP adaptive migration into suitable habitat. The long-term survival of vulnerable NTFP species will benefit from cross-jurisdictional planning and monitoring to inform population-level conservation strategies.

Management Challenges and Opportunities for Non-Timber Forest Products

Many options are available for managing forest environments to support sustainable NTFP production in a changing climate. These include reduction of stressors such as invasive species and conserving climate refugia and habitat corridors to allow species movement to higher latitudes and elevations. However, some NTFP species have short dispersal distances and/or low rates of seed production and may not be able to shift their distribution even if habitat corridors are available. *Ex situ* conservation approaches such as assisted migration (moving species or genotypes beyond the edge of their current distribution) may be appropriate for species that would otherwise have low potential for movement in response to climate change (Ticktin et al. 2018). However, given the potential risks of assisted migration (e.g., low resistance to insects and pathogens in a new environment), more research is needed to assess this approach as a conservation strategy.

Silvicultural techniques can increase the distribution and abundance of NTFPs in some cases. Pilz et al. (2006) found that shade-adapted chanterelles were less productive following heavy thinning of Douglas-fir forests in the Oregon Cascade Range. Common beargrass produces higher quantities of commercially valuable leaves in areas of moderate shade (Higgins et al. 2004). Some NTFP species support ecosystem processes and functional diversity of forests. For example, oyster mushrooms (*Pleurotus* spp.) and chanterelles contribute to nutrient cycling and mycorrhizal associations, respectively (Chamberlain 2018a). Inclusion of such NTFPs in forest planning and silvicultural prescriptions can result in positive economic, recreational, and ecological outcomes.

NTFPs play an important role in American Indian communities and among recreational and commercial harvesters, providing cultural connections and offering economic opportunities in rural areas. Federal resource managers can engage these harvesters to improve our knowledge of ecological relationships and seasonal patterns, thus contributing to conservation efforts that ensure sustainable resource production and harvests. Commercial harvesters, local mushroom clubs, and botanical medicine schools also offer opportunities to engage citizens in developing sustainable management plans.

Forest Carbon

Background

Carbon in forests is mostly derived from carbon dioxide in the atmosphere. This carbon is sometimes called *biogenic* carbon, because it cycles through living organisms. Trees draw carbon dioxide from the atmosphere through photosynthesis, which plants use to produce various carbon-based sugars necessary for tree function and wood synthesis. Dried tree material is about 50 percent carbon by weight. Trees also release carbon dioxide into the atmosphere through respiration. When tree components decompose (an oxidation process) after the death of those components or the whole tree, carbon is released to the atmosphere. Thus, the amount of carbon in forests closely mirrors the natural cycle of tree growth and death.

Carbon is also a significant component of soils. Soil carbon, which is derived from organic matter in trees and other vegetation in varying degrees of decomposition, comprises about 50 percent of the total carbon stored in forest systems in the United States (Domke et al. 2017). Soils release carbon dioxide when soil microbes break down organic matter. Some organic matter can decompose in hours or days, but most resides in soils for decades or centuries. In some conditions, carbon resides in soils for thousands of years before fully decomposing (e.g., in deep organic soils in boreal forests). Soil carbon is generally considered stable, because it does not change much or quickly in response to vegetation dynamics, except when soils are disturbed significantly by tillage, erosion, or fires that remove most of the surficial organic layer.

Carbon sequestration refers to the long-term storage of carbon by forests in biomass and soils. Forests are dynamic systems, so carbon storage and uptake in forests change over time. On the scale of minutes, forests can simultaneously take up and store carbon through photosynthesis and release carbon as trees respire and soils release carbon through decomposition by soil microbes. Over months and years, the balance of uptake and loss of carbon in a forest determines whether the forest is gaining or losing carbon. The amount of carbon uptake and storage depends on growing conditions and tree species in a particular location. Younger forests generally take up carbon at a higher rate than older forests, whereas older forests generally store more carbon. As a regulating ecosystem service, carbon sequestration helps to maintain or reduce atmospheric carbon dioxide concentrations (USDA FS 2015).

Collectively, forests of North America, including most forests on National Forest System (NFS) lands, are currently 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 11.5 percent of total annual greenhouse gas emissions in the United States (US EPA 2018), making forests the nation’s largest terrestrial carbon sink. The NFS accounts for 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).

Carbon pricing is a policy mechanism that can stimulate reductions in greenhouse gas emissions. Numerous carbon pricing schemes exist across the world with the price of 1 metric tonne (t) of carbon dioxide equivalent (CO_2e) varying significantly across regions and markets. The mandatory economy-wide cap-and-trade program in California (California Global Warming Solutions Act 2006) currently prices carbon at about \$30 t CO_2e (The World Bank, 2022), whereas the average forestry project in the voluntary market currently prices carbon at \$5.80 t CO_2e (Forest Trends' Ecosystem Marketplace 2022).

The social cost of carbon (SCC) is another form of pricing that estimates the economic cost or damages from emitting an additional tonne of CO_2e and hence the benefit of avoiding those emissions. The SCC depends on methods and future assumptions, so estimates of carbon price can vary substantially from tens to thousands of US dollars (Tol 2018). The USFS does not participate in any carbon markets, or price the carbon stored in its forests, although these monetary values can provide a measure of the value of carbon in Siuslaw National Forest.

In a changing climate, forests will be increasingly affected by factors such as multi-year droughts, insect outbreaks, wildfires, and high-intensity wind events (Cohen et al. 2016, Westerling et al. 2006). In 2020, 289,000 ha were burned by four large fires in the western Oregon Cascade Range and two small fires in the Oregon Coast Range, emitting a large amount of carbon into the atmosphere. Natural and human-caused disturbances can cause both immediate and gradual changes in forest structure, influencing forest carbon dynamics and the transfer of carbon between different ecosystem carbon pools and the atmosphere.

Forest harvesting and the use of harvested wood products (HWP) can play an important role in reducing carbon emissions along with good management for healthy forests (McKinley et al. 2011). According to the Intergovernmental Panel on Climate Change, the best way to explain the effects of forest management is to take the viewpoint of the atmosphere when considering carbon (IPCC 2007). This requires looking at how management influences forest carbon stocks, emissions associated with harvesting activities, and how carbon is stored in HWP once it leaves the forest (McKinley et al. 2011). This perspective also considers whether there is an associated permanent change in land use or land cover that will alter the ability of the harvested area to regrow as a forest and continue to take up and store carbon in the future. Reducing conversion of forestland to non-forestland is a standard approach to reducing emissions. NFS lands provide a buffer against land-use change, keeping forests as forests.

Increased risk of carbon loss through disturbances can reduce carbon storage in forests. Tree regeneration can be delayed after natural disturbances, in some cases leading to a transition to non-forest vegetation with lower potential for carbon storage (Serra-Diaz et al. 2018). Managing tree densities and forest structure can help increase overall tree vigor and reduce fuels. This approach initially reduces carbon storage, but these losses can be ameliorated through transfer of carbon to wood-based products or energy use in some cases (Birdsey and Pan 2015, McKinley et al. 2011, Nunery and Keeton 2010). Density management also regulates the release of carbon emissions over time by limiting emissions to periodic small pulses rather than a large emission pulse from a high-severity fire (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 regrow and take up and store carbon over time (Fu et al. 2017).

When considering both forest carbon and the use of forest products, carbon emissions can in some cases be lower than if the forest was unmanaged (McKinley et al. 2011). Wood harvested from the forest, especially timber used for durable structures, can store carbon for a long period of time, substituting for materials (especially steel and cement) that require much higher levels of carbon to be produced (Bergman et al. 2014, McKinley et al. 2011, Miner et al. 2014). Some wood products can store carbon for months to decades depending on the product (e.g., paper, furniture, homes). Carbon storage continues when forest products enter landfills at the end of their usable life. Harvested wood and residues may also be burned to produce heat or electrical energy and converted to liquid transportation fuels or chemicals that would otherwise come from fossil fuels.

Total carbon emissions can be reduced when substituting wood products for fossil fuels and fossil fuel-intensive materials (Gustavsson et al. 2006, Lippke et al. 2011). For many forests, recurring timber harvests on a sustainably managed forest will effectively store more carbon over time than if the forest is unmanaged (fig. 8.10). “Store” in this sense refers to carbon in the forest, carbon in HWP, and avoided carbon emissions in the atmosphere. New tree growth restarts the process of storing carbon in the forest, even as the previously harvested trees continue to store carbon in wood products. Thinning that is implemented to reduce stand density reduces competition for resources, leading to increased growth in the remaining trees and neutral to positive carbon storage in the long term. Many factors need to be evaluated using a whole-system perspective which includes the full life cycle of HWP and energy production, forest type and productive capacity, temporal and spatial scale of analysis, and a robust comparison to a fossil fuels-based, business-as-usual scenario (Cowie et al. 2021). Forest bioenergy provides the most benefit when fuel materials are obtained while meeting other sustainability and conservation objectives (Reid et al. 2019).

In response to a growing need for guidance on carbon management and stewardship on NFS lands, the USFS created a set of “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 a diversity of approaches (diverse approaches).
- Consider system dynamics and scale in decision-making (scale and time frame).
- Use the best information and analysis methods (decision quality).

These principles are intended to assist USFS 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 USFS promotes integrating climate adaptation and mitigation, and balancing carbon uptake and storage with public benefits. This includes protecting existing carbon stocks, as well as building resilience to environmental and climate-related stress through adaptation, restoration, and reforestation. Carbon estimates improve understanding of patterns and trends at large spatial scales, providing context at the scale of a national forest.

Baseline Carbon Estimates

The USFS has developed a nationally consistent assessment approach for reporting carbon components on every national forest. Estimates of total ecosystem carbon and stock change (flux) are based on four models that have been produced at the scale of the national forest and region across the entire country.

Baseline estimates produced by the USFS Office of Sustainability and Climate and other collaborators include carbon stocks and trends for the period 1990–2013 for 7 carbon pools in national forests: aboveground live tree, belowground live tree, standing dead, understory, down dead wood, forest floor, and soil organic carbon. Storage in HWP at the regional scale are included where data are available. These results are based on the Carbon Calculation Tool (Smith et al. 2007) that summarizes plot-scale data from the Forest Inventory and Analysis (FIA) program (USDA FS 2015). Although other carbon calculation approaches are available for the Pacific Northwest (Battles et al. 2018, Fried et al. 2017), the USFS prefers a standardized national approach for NFS carbon assessments, thus facilitating comparisons within and outside of each region (Smith et al. 2007, USDA FS 2015).

Carbon stocks and carbon density have increased on Siuslaw National Forest. Carbon (C) storage increased by 23.6 percent, from 89.4 ± 18.3 Tg (95 percent confidence interval) in 1990 to 110.5 ± 21.0 Tg in 2013 (1 Tg [teragram] equals one million metric tonnes) (fig. 8.11). Carbon density is an estimate of forest carbon stocks per unit area and can be used to control for increases in forested area. Similarly, carbon density on Siuslaw National Forest increased by 8.1 percent, from 374.5 Mg ha^{-1} in 1990 to 404.8 Mg ha^{-1} (1 Mg [megagram] equals one metric tonne) in 2013 (fig. 8.12). Although mean stocks are increasing, the high statistical uncertainty in these estimates make it difficult to infer whether there is a statistically significant increase in forest carbon stocks over this period.

Carbon stock information is also available for the BLM Northwest Oregon and Coos Bay Districts. In 2013, the BLM Northwest Oregon District stored 136 Tg C (estimates for Eugene and Salem Districts combined), and the Coos Bay District stored 59 Tg C (BLM 2016). Although Northwest Oregon stores more carbon than Coos Bay, it is over double the size of Coos Bay, and the districts have similar carbon density estimates; density is 487 Mg C ha^{-1} on the Northwest Oregon District and 469 Mg C ha^{-1} on the Coos Bay District.

Carbon Storage in Harvested Wood Products

Although timber harvesting transfers carbon out of the forest ecosystem, much of that carbon is not emitted immediately to the atmosphere. Rather, HWP (e.g., lumber, panels, and paper) can account for a significant amount of off-site carbon storage. Estimates of this contribution are important for both national- and regional-level accounting (Bergman et al. 2014, Skog 2008).

The USFS baseline assessment of forest ecosystem carbon (USDA FS 2015) also contains an assessment of regional carbon storage in HWP across all national forests in Oregon and Washington from 1909 to 2012 (Butler et al. 2014). Carbon accounting for HWP was conducted by incorporating data from harvests on national forests documented in cut-and-sold reports within a production accounting system (Skog 2008). This accounting approach 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). HWP carbon pools include both products in use and products that have been discarded to solid waste disposal sites (SWDS), such as landfills and dumps.

Historical timber harvest trends provide a context for understanding sequestration through wood production. In national forests in the Pacific Northwest Region, annual harvest levels remained low (below 0.75 Tg C yr^{-1}) until after the start of World War II (early 1940s), when they began to increase, eventually peaking at 8.3 Tg C yr^{-1} in 1973 (see fig. 8 in USDA FS [2015]). Increased timber harvest caused a steady rise in the amount of carbon stored in products in use and in SWDS (fig. 8.13). Harvest levels fluctuated through the 1980s, declining sharply in the early 1990s. As a result, carbon storage in products in use peaked at 97.6 Tg C in 1992 and has since declined because harvest levels have remained below 1 Tg C yr^{-1} since 2001.

Despite the decline, carbon storage in SWDS has increased as products continue to be retired. Total carbon storage in HWP (products in use and SWDS) reached a peak of 144 Tg C in 1994 but declined to 131 Tg C in 2013. This decline in total HWP carbon storage indicates that the contribution of timber harvests on national forests to the HWP carbon pool is less than the decay of retired products. This is causing the HWP pool to be a net source of atmospheric carbon since the mid-1990s. Carbon stocks in HWP in the Pacific Northwest Region represent about 5 percent of total forest-sector carbon storage (both ecosystem and HWP carbon) associated with national forests in the Pacific Northwest Region in 2012. As more forests are harvested and more commodities are produced and stay in use, the amount of carbon stored in products accumulates (fig. 8.13). Although products may be retired in SWDS, they decompose slowly, and carbon continues to be stored for many decades.

Factors Influencing Carbon Storage

The USFS expanded on baseline assessments by developing national forest-scale assessments of the influences of disturbances, management activities, climatic variability, atmospheric carbon dioxide, and nitrogen deposition on forest carbon stocks and flux (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, integrating high-resolution disturbance maps based on Landsat satellite imagery (Healey et al. 2014), monthly climate observations, and data on atmospheric carbon dioxide concentrations. Given the application of different datasets, modeling approaches and parameters, some discrepancies between trends in baseline assessments and expanded assessments can be expected (Dugan et al. 2017).

For Siuslaw National Forest, wildfire affected 4.1 percent of the forested area from 1990 to 2011, or about 0.2 percent annually. Effects of wildfire and insects were negligible over the 21-year period (less than 0.1 percent of the forested area) (fig. 8.14). Annual area burned in the western United States is projected to increase owing to a warmer climate (Kitzberger et al. 2017, McKenzie et al. 2004), exacerbated in some locations by high fuel loadings (e.g., Perry et al. 2011).

The Forest Carbon Management Framework (ForCaMF) model estimates how much more carbon would occur on each national forest if the disturbances and harvests from 1990 to 2011 had not occurred. ForCaMF simulates the effects of disturbance and management on non-soil carbon stocks (vegetation, dead wood, and forest floor). Forest carbon losses associated with disturbances and harvesting have been small compared to the total amount of carbon stored in the forests. By 2011, Siuslaw National Forest contained about 1.4 percent less non-soil carbon because of harvests, wildfire, and insects since 1990, with nearly all carbon loss caused by harvesting, compared with a hypothetical undisturbed scenario.

The ForCaMF analysis was conducted over a relatively short time. After a forest is disturbed, it will eventually regrow and recover the carbon removed or released from the ecosystem. However, several decades may be needed to recover the carbon lost depending on the type of the disturbance or harvest (e.g., clearcut versus partial cut), as well as the conditions prior to disturbance (e.g., forest type and amount of carbon). The time required for a forest to reach pre-disturbance stand density is proportional to the amount of biomass removal and to the amount of aboveground live-tree carbon prior to disturbance.

Disturbances cause immediate emissions and directly affect carbon stocks in the shorter. They also influence long-term carbon trend through their influence on forest age structure. For example, in 2011, 58 percent of Siuslaw National Forest stands were younger than 100 years old with a peak age class of 30–39 years (fig 8.15). Forests are generally most productive when they are young to middle age, then productivity declines or stabilizes as the forest canopy closes. As forests continue to age and their productivity declines, the rate of carbon dioxide uptake typically decreases.

Carbon stocks on Siuslaw National Forest are increasing at 0.9 Tg C yr^{-1} (USDA FS 2015), representing a balance of gross productivity and growth and loss from disturbances and decomposition. All disturbances (including harvesting) removed only 0.002 Tg C yr^{-1} over a recent 21-year period, indicating that the influence of disturbances on carbon stocks was negligible. Moreover, the relatively young age structure indicates that carbon uptake in the next few decades will remain high, and carbon storage will continue to increase.

Pollinator Services

Pollination is fundamental to plant reproduction, providing food and other botanical resources for humans. Pollinators are a diverse group of organisms including birds, bats, bees, and many other insects. Animal pollinators are required for reproduction of many globally important crop species and the majority of wild plants (Klein et al. 2007). Globally, 380,000 flowering plants are pollinated by animals, comprising 88 percent of flowering plant diversity (Ollerton et al. 2011). The estimated total economic value globally is over $200 billion (Gallai et al. 2009). The production of 39 of the leading 57 single crops grown around the world would be lower than current levels without animal pollination (Klein et al. 2007).

Insects, and bees in particular, make up the majority of pollination services in agricultural landscapes (USDA NRCS 2008). In the United States, honeybee pollination alone adds more than $15 billion in value annually to agricultural crops (Pollinator Health Task Force 2015). Some insects that primarily occupy natural habitats such as forestlands often forage in adjacent agricultural landscapes. These pollination services improve crop quantity and quality over relying solely on managed species like the European honeybee (*Apis mellifera* L.) (Garibaldi et al. 2013, 2014; Rader et al. 2016; Ricketts 2004).

Coastal Oregon is home to a wide variety of bees. Although the European honeybee is the insect most commonly associated with pollination, native bees are equally important. Some crops, such as alfalfa (*Medicago sativa* L.) and red clover (*Trifolium pratense* L.) can be pollinated only by native bees. Native bees are diverse, with about 500 species documented in Oregon. The following genera of bees have been identified as primary agricultural pollinators: bumblebees (*Bombus*), sweat bees (*Halictus, Lasioglossum, Dialictus*), metallic and non-metallic sweat bees (*Seladonia, Agapostemon*), long-horned bees (*Melissodes*), carpenter bees (*Ceratina*), mason bees (*Osmia*), leafcutting bees (*Megachile*), and mining bees (*Andrena*). Bees are so important to Oregon agriculture that three native species are managed year-round to support pollination services: solitary blue orchard bee (*Osmia lignaria* Say) for cherries and pears, and the solitary alkali bee (*Nomia melanderi* Cockerell) and leafcutting bee (*Megachile rotundata* Fabricius) for alfalfa (Oregon Bee Project 2018, Oregon Department of Agriculture 2017, Pacific Northwest Extension 2016).

In addition to benefits to agriculture, pollination services also help maintain diverse, functional ecosystems. Too strict a focus on agricultural benefits when making conservation management decisions could miss species that do not currently support crop productions but may do so under changing conditions (Kleijn et al. 2015). Beyond crops, wildflower species rely on pollinators for reproduction and maintenance of genetic diversity. Flowers provide forage and shelter for non-pollinator species, and their blooms often contribute to the visual aesthetics of places that people value. Pollination also helps sustain NTFPs.

Recognition of the "…critical importance of pollinators to the economy, including to agricultural production and general ecosystem services" led to the creation of the Pollinator Health Task Force, led by the U.S. Environmental Protection Agency and USDA (Pollinator Health Task Force 2015). One goal of this task force was to restore or enhance 2.8 million hectares of land for pollinators through federal actions and public-private partnerships. Pollinator habitat enhancement involves increasing native vegetation through application of pollinator-friendly seed mixes during aquatic and terrestrial revegetation, rehabilitation, and restoration projects and generally creating conditions that promote habitat for native species.

Although most trees are wind pollinated, midstory and understory plants require some level of animal pollination. Forests in the OCAP assessment area provide habitat for many native pollinator species, including open soil, sand, mud, hollow logs, and stumps used by insects. Butterflies can be found throughout forested landscapes and coastal meadows. Some endemic insects, such as the Oregon silverspot butterfly, occur almost entirely in coastal meadows. Snags and caves provide habitat for birds and bats.

Climate Change Effects on Pollinators

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 life span) and behavior (e.g., altered foraging behavior) (Scaven and Rafferty 2013). The ability of pollinators to track temperature and other climatic characteristics will have implications for plant-pollinator mutualisms.

Human actions and climate-induced stressors, including introduction of nonnative species, habitat modification, and land use, affect native plant communities and species that depend on them, including both native and managed pollinators (BLM 2016). If the geographic distribution and extent of contemporary ecosystems change as a result of a warmer climate, novel ecosystems may develop (chapter 5), potentially altering habitat requirements, such as floral resources (nectar, pollen) and other basic needs such as nesting sites and materials (GBNPP 2020).

Climate change is also expected to affect the phenology of some plant species (Miller-Rushing and Primack 2008, Panchen et al. 2012, Thackery et al. 2016). Earlier flowering by non-native species under increasing temperature may facilitate the spread of those species (Zettlemoyer et al. 2019). Potential mismatches in timing of flower and pollinator emergence have the potential to affect plant reproduction, especially when either the flowers or pollinators are short-lived (Fagan et al. 2014). Specifically, 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.

Native bees may be more capable than honeybees of shifting their phenology to compensate for warming temperatures, thus keeping pace with host-plant flowering (Bartomeus et al. 2011). Native bees may also be able to shift their range 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).

Pollinators in the Assessment Area

In recent years, the importance of pollinators has been highlighted in large part due to the widespread loss of European honeybees caused by colony collapse. The decline of native bees, especially western bumblebees (*Bombus occidentalis* Greene) and the decline of charismatic butterflies such as the western monarch (*Danaus plexippus* L.) have stimulated greater awareness of the importance of conservation for maintaining viable populations of native pollinators. Collaborative efforts such as the Pacific Northwest Bumblebee Atlas (https://www.pnwbumblebeeatlas.org), Bumblebee Watch (https://www.bumblebeewatch.org) and Monarch Joint Venture (https://monarchjointventure.org) harness the power of people at different levels to conserve pollinators and their habitats.

The decline of the Oregon silverspot butterfly has brought together the USFS, the U.S. Fish Wildlife Service (USFWS), The Nature Conservancy, the Oregon Department of Corrections, the Oregon Zoo, the Woodland Park Zoo, and various land owners in Lane County to create conservation efforts for this species. In 1999, the zoos and the USFWS started a captive-rearing program for caterpillars to augment the declining populations. Caterpillars or pupae are released annually into habitat to increase reproduction and survival. Multiple years of augmentation are intended to minimize annual variation in populations and stabilize populations. Host and nectar plants are also being propagated to help restore and enhance habitats. Siuslaw National Forest removes non-native grasses and weeds and encroaching woody vegetation in coastal meadows, and conducts surveys for new populations of the Oregon silverspot butterfly.

Ecological Restoration and Pollinators

Maintaining a high diversity of native flora provides the habitat needed for viability populations of native animal species. In turn, native insects such as the Oregon silverspot butterfly, western bumble bee, and solitary silver bee contribute to ecosystem function as pollinators for multiple plant species (see boxes 8.1, 8.2, and 8.3). Providing the largest set of options for species maximizes their adaptive capacity to climate change. In order to improve ecosystem function and increase resilience to climate stressors along coastal Oregon, federal agencies can restore, maintain, and enhance pollinator habitats.

Efforts to increase the conservation of pollinators include the “Plants for Pollinators” and the “Forested Pathways for Pollinators” initiatives. These initiatives integrate best management practices in forest management for the benefit of pollinating species such as insects and hummingbirds. Many groups are interested in pollinator conservation on the Oregon coast, although a partnership and framework for making decisions about pollinator habitats do not currently exist. As a result, “standard” plants are often used although they may not be optimal for local pollinators, and more effective plant materials are not always available.

Through the “Plants for Pollinators” initiative, Siuslaw National Forest is leading pollinator conservation through partnerships with plant nurseries in the Pacific Northwest, a cooperative effort to collect, reproduce, harvest, and store native plant materials that will benefit pollinator species. The national forest is also creating a pollinator toolkit that highlights available partners, native plant materials and plant species mixes for large restoration projects.

Through the “Forested Pathways for Pollinators” initiative, Siuslaw National Forest accomplishes habitat restoration through forest management actions such as road decommissioning and rehabilitation of timber landing sites. Areas with temporary disturbance and bare soil can be planted/seeded with pollinator-friendly native seed. Seeds are selectively gathered and propagated and then used as the source for rehabilitation of disturbed sites. These areas provide patches of early-seral habitat, thereby creating a mosaic of pollinator habitat.

Partners with interest in conserving pollinator habitats include the Grande Ronde and Confederated Tribes of Coos, Lower Umpqua, and Siuslaw with respect to maintaining populations of first foods. Other groups such as the Xerces Society, Oregon State University, Oregon Bee Atlas, and Western Hummingbird Partnership support efforts to prevent the decline of at-risk insects and birds. By taking advantage of forest openings and early-seral habitats created by management actions, Forest Pathways for Pollinators ensures that pollinator species have the floral resources needed for resilience to climate change.

Siuslaw National Forest works with the Western Hummingbird Partnership to expand research on the rufous hummingbird (*Selasphorus rufus* J. F. Gmelin) through monitoring of responses to habitat restoration and the effect of fire, other disturbances, and pesticides along migration routes. Western Hummingbird Partnership members also raise awareness about hummingbird conservation by encouraging the planting of native floral species and minimizing pesticide use. The national forest also works with the Environment for the Americas on education about avian conservation. Interns provide information at various venues (e.g., Portland Zoo and Newport Aquarium), educating recreational users about the importance of pollinators.

Siuslaw National Forest also collaborates with USFS International Programs to increase habitat management and conservation for migratory species such as the rufous hummingbird and monarch butterfly. Through their life history, these long-distance migratory species rely on functional ecosystems in multiple countries. Promoting best management practices across multiple countries enhances breeding and survival success of these species.

Cultural Values

Cultural ecosystem services include connections between people and the land. The benefits can most often be identified in non-material terms such as spiritual enrichment, heritage, identity and aesthetic values. Numerous activities and practices, from rituals in sacred spaces to tourism and recreation, are included within this group. Cultural ecosystem services are interconnected with each other and with provisioning and regulating services (FAO 2020). Harvesting of first foods (native plants that American Indian communities have traditionally harvested), fishing, and hunting provide economic and nutritional benefits to those who engage in these practices, grounding them in a lifeway and as a member of a community. People and communities can develop connections to specific locations, features, and landscapes, and the expression of these connections can often be subtle and indirectly expressed (Milcu et al. 2013). Memories, interactions, and history play a role in attachment to the land (Eisenhauer et al. 2000, Kruger and Jakes 2003). The draw of these places and experiences can influence where people live, work, and recreate (Smith et al. 2011).

Climate Change Effects on Cultural Ecosystem Services

Climate change effects on ecological processes, plants, and animals will affect culturally important natural resources, places, and traditions. They also have the potential to influence how people and landscapes are connected (Hess et al. 2008, Lynn et al. 2011). Alterations of hydrologic regimes, increased vulnerability of vegetation to insects and disease, shifts in species composition, and changes in pollinator patterns may affect related habitats, products, and cultural uses of forests.

Tribal Relationships with the Land

Climate change may affect tribal communities in the OCAP assessment area, with specific effects on tribal sovereignty, maintenance of cultural identity, and community health (Cordalis and Suagee 2008, Lynn et al. 2011, Norton-Smith et al. 2016). In general, American Indians are disproportionately affected by climate change as a function of geographic location, degree of association to climate-sensitive environments, and specific cultural, economic, and political characteristics (Lynn et al. 2011). Federal lands are a source of ecosystem services that benefit American Indians. Tribes reserve treaty rights to hunt, fish, and gather throughout USFS and BLM lands. In recognition of Tribes as self-governing entities and their special relationship with federal lands, federal agencies consult directly with tribal governments before taking actions that may affect ecosystem service benefits that tribes receive from federal lands (Norton-Smith et al 2016).

Members of the Confederated Tribes of Siletz Indians (CTSI), the Confederated Tribes of the Coos, Lower Umpqua, and Siuslaw Indians (CTCLUSI), and the Confederated Tribes of Grand Ronde (CTGR) have depended on resources in USFS and BLM lands for millennia. These resources provide opportunities for cultural, subsistence, fishing, hunting and gathering benefits, as well as for commercial and economic purposes.

Background—
The CTCLUSI is comprised of three tribes (4 bands) with traditional homelands encompassing much of coastal Oregon (CTCLUSI 2016). The CTSI is made up of 19 bands whose traditional homelands run throughout northern California, the Oregon Coast, and the Umpqua, Rogue, and Willamette River Valleys. The CTGR includes 41 tribes and bands from western Oregon, northern California, and southwest Washington (CTGR 2023).

With the establishment of the Oregon Trail and subsequent formation of the Oregon Territory, European-American settlement in western Oregon increased. Ratified and unratified treaties between the Tribes and the United States Government from 1853 through 1855 resulted in the forced removal of tribal members to the Coast (Siletz) Reservation between Cape Lookout and the Siltcoos River or the Grand Ronde Reservation located along the South Yamhill River (CTGR 2018).

For American Indian people of western Oregon, cultural practices and lifeways differed between coastal tribes and bands located on the east side of the Coast Range. The traditional economy of American Indians along the central Oregon coast was based on fishing, hunting, and gathering in marine and estuarine environments. Interior habitats of the Coast Range were also regularly managed and utilized to promote plant and animal resources of importance to American Indians.

Winter villages were near estuaries or coastal lakes, with small parties moving out during the spring through fall to harvest food in interior river valleys and uplands (Beckham et al. 1982, Zenk 1990a). The taking of salmon during spawning runs was the most important subsistence pursuit. In addition to salmon, a variety of other saltwater and freshwater species of fish were also targeted including shellfish, seals, sea lions, black-tailed deer (*Odocoileus hemionus hemionus* Rafinesque), elk (*Cervus elaphus* L.), and occasionally stranded whales. Hunting of terrestrial animals was done primarily in the fall. A wide variety of plants were collected as food, medicine, and raw material for the manufacture of cultural items (e.g., baskets, planks, tools) starting in the late spring and continuing through the fall in the interior valleys.

American Indians occupying the Willamette Valley and the east side of the Coast Range lacked marine and estuarine resources, leading to a traditional economy more focused on locally available plant resources. Like their coastal neighbors, these bands had permanent winter villages and occupied temporary camps to track seasonally available foods and materials at other times of the year (Juntunen et al. 2005, Zenk 1990b). A variety of habitats were managed using tools like controlled fire to maintain healthy populations of culturally significant plants, especially camas, and create habitat for animals harvested for food (Boyd 1999, Juntunen et al. 2005). Seasonal runs of salmon and lamprey (chapter 4) were also important resources.

Traditional knowledge—

Language, cultural identity and management, and community health depend on access to natural resources on federal lands. Traditional ecological knowledge (TEK) focuses on relationships among humans, plants, animals, natural phenomena, and the landscape (Jantarasami et al. 2018). TEK can also be defined as a cumulative body of knowledge, cultural practices, and management that has evolved through adaptive processes and has been transmitted from generation to generation (Berkes et al. 2000). This knowledge has adapted over time to human impacts such as settler-colonialism. A warmer climate and additional stressors could threaten resources used by members of the CTSI, CTGR, and CTCLUSI. TEK can be considered in the assessment of climate change effects and identification of adaptation options (Vinyeta and Lynn 2013).

Archaeological sites at risk—

Coastal cultural heritage sites throughout the world are vulnerable to sea-level rise and erosion (Erlandson 2008). In the OCAP assessment area, archaeological sites situated along the coastline may be affected by higher sea level, higher waves, and more frequent and stronger storms. The direct threat of inundation with future sea-level rise is obvious for sites located at lower elevations and near the current shoreline. Sites located at higher elevations that would appear safe from sea-level rise may be at risk from storm surges that undercut bluffs, depending on the erodibility of underlying deposits. Sites adjacent to estuaries, rivers, and streams are also at risk of increased erosion and potential submersion.

Impacts that are similar to those expected with climate change can be observed at archaeological sites located just west of Highway 101 between Newport and Florence, where bluffs are being undercut adjacent to archaeological sites. Estuaries at the mouth of the Salmon River could be reconfigured with rising sea levels and increased storm surges, leading to erosion and submersion of archaeological sites.

Culturally significant species and habitats at risk—

First foods, or foods that have held an important role in American Indian cultures for long periods of time, play an important role in maintaining the physical, mental, and spiritual health of tribes and indigenous peoples. Climate change impacts on ecological processes, habitat quality, and species populations present a growing threat to traditional food use (Lynn et al. 2013). Climate change may affect the use of and distribution of first foods. Increasing temperatures, drought, rising sea level, and wildfires are all projected to cause negative effects on animal and plant species in the assessment area.

Fish and wildlife—

Salmon are an important food for many tribes in the Pacific Northwest. Coho salmon (*Oncorhynchus kisutch* Walbaum) and steelhead (*O. mykiss* Walbaum) are the most common salmon species in the OCAP assessment area. Salmon are a critical component of aquatic and terrestrial food webs, delivering marine nutrients to terrestrial flora and fauna and serving as an indicator of ecosystem health (DNR CTCLUSI 2015).

Changes in precipitation patterns, air temperature, and water temperature, as well as non-climate stressors, pose significant threats to salmon populations in the assessment area (chapter 4). Salmon traverse a range of different habitats throughout their life cycle, including lotic, estuarine, and marine habitats. Rather than experiencing the impacts of climate change in one environment, salmon will be affected in multiple environments (Flitcroft et al. 2013). Water diversions, wildfires, non-native fish species, and urbanization all degrade habitat, reducing salmon productivity and potentially leading to extirpation of local populations. Sea-level rise may also have negative effects on estuaries and freshwater habitat (Flitcroft et al. 2013).

The Pacific lamprey (*Entosphenus tridentatus* Richardson) and western brook lamprey (*Lampetra richardsonii* Vladykov and Follett) are also harvested by American Indians in Oregon. Although lamprey populations are not as abundant as they once were in the North Coast subregion (Gray and Pourier 2019), they are still a culturally important species. Lamprey depend on the same habitats as salmon and face similar stressors, including stream and floodplain degradation and declining water quality.

Shellfish are another important food for coastal American Indians. Sea-level rise in coastal and estuarine habitats leave clam and mussel beds vulnerable to inundation, and human land uses and the hardening of infrastructure inhibit shellfish movement and, in some cases, expose them to pollution. Higher temperatures expose shellfish to pathogens, and ocean acidification corrodes calcium carbonate in exoskeletons and shells (Lynn et al. 2013).

Climate change is not expected to negatively affect habitat for black-tailed deer and elk, and increased disturbance could improve the mosaic of vegetation that is preferred by these species (chapter 6). If forage species shift to higher latitudes or elevations, grazing patterns might be altered, which could in turn influence traditional hunting areas for tribal members and others.

Culturally significant plant species—
American Indianss in the study area have traditionally gathered and harvested a variety of roots, bulbs, nuts, seeds, berries, and other plants for subsistence and other purposes. For the CTCLUSI, bracken ferns (*Pteridium aquilinum* Gled. Ex Scop.), cattails (*Typha spp.*), skunk cabbage (*Lysichiton americanus* Hultén & H.St.John), springbank clover (*Trifolium wormskioldii* Lehm.), shore lupine (*Lupinus littoralis* Dougl.), chocolate lily (*Fritillaria camschatcensis* (L.) Ker-Gawl), wapato (*Sagittaria latifolia* Willd.), Pacific silverweed (*Argentina pacifica* Howell), and camas were traditionally harvested for food and textiles (DNR CTCLUSI 2015). The potential climate change effects on culturally important flora are the same as for other NTFPs. Their individualistic response to direct and indirect effects of climate change (chapter 5) will potentially alter the quality, quantity, and seasonality of plant materials. Altered hydrologic regimes and water quality can influence the plant productivity in wetlands and estuarine habitats. Climate change can interact with runoff from agricultural and urban areas, development, habitat fragmentation, and invasive species to degrade habitat for culturally important plant species. Climate change effects may compound challenges with institutional barriers and access that American Indian gatherers face in exercising treaty rights (Dobkins et al. 2017)

Climate change may affect plant resources in several Coast Range environments (chapter 5) (table 8.3), including the fog belt delineated by the Sitka spruce (*Picea sitchensis* [Bong.] Carrière) vegetation zone, high-elevation areas delineated by the silver fir (*Abies amabilis* Douglas ex J. Forbes) vegetation zone, and wetlands, and estuaries. The extent of high-elevation species such as beargrass and huckleberries, may become more limited. Altered hydrologic cycles may affect wetland species, such as camas, wapato, and skunk cabbage. Climate change risks to a selection of important cultural plants in the assessment area are presented in table 8.3. A recent paper that uses bioclimatic envelope modeling suggests that thinleaf huckleberry could decrease at lower altitudes and latitudes (Prevéy et al. 2020b), although this type of modeling has high uncertainty. Phenology modeling suggests over a month advance in flowering and ripening of fruits and nuts under in the late 21st century (Prevéy et al. 2020a)

Recreation

Public lands provide outdoor recreation opportunities that provide many benefits to human well-being. Both local and non-local expenditures on recreation make a substantial contribution to the economies of local coastal communities (chapter 7). Expenditures related to recreation in Siuslaw National Forest are above-average compared to the NFS as a whole (White 2017). Siuslaw National Forest and Oregon Dunes National Recreation Area are only one piece of a multi-agency public land base that undergirds an economy reliant on tourism and outdoor recreation.

Beyond economic benefits, recreation provides cultural ecosystem services. Outdoor recreation in natural settings is highly valued and often affects where people choose to live, work, and travel. People perceive the areas they choose to recreate as more than just a mere commodity that can be easily replaced or substituted. Place attachments between recreationists and a place can influence one's sense of self, leading to strongly held notions about appropriate use and acceptable experiences within it (Williams 2008). Feelings of distress and psychological damage can occur when places are perceived to be negatively transformed (Albrecht et al. 2007, Doherty and Clayton 2011, Dodgen et al. 2016).

Climate change is expected to alter the supply and demand for recreational activities, potentially altering the location and timing of visitation across the Oregon Coast landscape (chapter 7). The abundance and distribution of plants and animals that currently help define the character of the landscape could change, including those that people routinely harvest. In addition, population growth, higher demand for the relatively cool and wildfire-free coastal region during the summer, and limited (and often deteriorating) infrastructure could create stress for transportation networks, recreation sites, and other amenities. The character of places that have high value for local residents and non-local visitors may no longer exist in their current form (e.g., a formerly productive clamming beach, an increasingly crowded beachside community).

Although recent trends suggest that the demand for recreation is increasing, real or perceived degradation of recreation facilities or infrastructure may lead to suppression of visitation, at least locally. There is also the potential for cultural changes and development of new activity types that motivate formulation of new place identities, creating their own set of demands on available supplies of recreational opportunities. Regardless of the exact nature of future changes in recreation, social and environmental factors will need to be considered concurrently to provide sustainable recreation opportunities.

Fish and Wildlife

Fish and wildlife resources in the OCAP assessment area provide substantial benefits to human well-being (chapter 7). Although recreational activities related to fish and wildlife account for a small percentage of activities on federal lands, they are common in coastal lands and waters. Fishing, clamming, crabbing, hunting, and wildlife watching are a major draw for visitors, creating economic benefits for local communities. Recreational harvest permits contribute income for state natural resource agencies.

Fisheries of the Oregon Coast are a major component of the social, cultural, and economic fabric of the Pacific Northwest. Recreational angling and other activities are often done by multiple generations of families and/or groups of friends helping to reinforce social bonds. Even those who do not participate in recreational fisheries buy and eat locally caught, fresh seafood provided by the commercial fishing industry, which contributes more than $500 million dollars annually in personal income to the state of Oregon (ODFW 2019a). The two ports with the largest landings of commercial food fish, Astoria and Newport, are in the assessment area. The coastal rivers and associated estuaries of the assessment area—including the Nestucca, Salmon, Yaquina, Alsea, Siuslaw, and Umpqua Rivers—represent a large share of the state's annual sport catch for salmon and steelhead (ODFW 2019b).

Charter guides provide ocean, bay, and river fishing opportunities to visitors. Razor clam (*Siliqua patula* Dixon) and bay clam harvesting and Dungeness crab (*Cancer magister* Dana) fishing are also popular recreational activities that make significant economic contributions to the region (Ainsworth et al. 2012, 2014). Dungeness crab, which comprises the largest commercial fishery in Oregon, was worth $73,000,000 in 2018 (ODFW 2019a).

Viewing whales, shorebirds, and pinnipeds draws thousands of visitors to the Oregon coast. Uplands and wetlands provide hunting opportunities for black-tailed deer, elk, black bear

(*Ursus americanus* Pall.) wild turkey (*Meleagris gallopava* L.), ruffed grouse (*Bonasa umbellus* L.), sooty grouse (*Dendragapus fuliginosus* Ridgway), mountain quail (*Oreortyx pictus* Douglas), and valley quail (*Callipepla californica* Shaw) (ODFW 2016, 2020). Several species of migratory birds are also hunted, including mourning dove (*Zenaida macroura* L.), band-tailed pigeon (*Patagioenas fasciata* Say), and several species of waterfowl (ODFW 2016).

Although imperfect, the 2015 warm-water anomaly known as "the Blob" may have been a preview of the effects of shifting ocean temperatures because it was similar to projected water temperatures for climate change (Cavole et al. 2016). This large patch of warm water throughout the eastern portion of the Pacific greatly modified upwelling and nutrient cycling. Safety concerns over harmful algal blooms closed crabbing and clamming. Distributions of marine invertebrates and fish shifted northwards to track preferred temperatures and plankton food sources. Mass stranding of juvenile shorebirds and pinnipeds occurred.

Ocean acidification limits the availability of dissolved calcium minerals needed by many shellfish species, especially at an early stage of development (Barton et al. 2015). Acidifation studies have focused on oysters and clams, but new evidence suggests impacts are also occurring to larval Dungeness crabs (Bednaršek et al. 2020). Sea-level rise and its contribution to coastal storms could cause narrowing of beaches and erosion and inundation of clam beds used by recreationists. Vegetation and habitat change could have consequences for abundance and seasons for target species for hunters (chapter 6), affecting public and non-public lands throughout the region. Although climate change may make it more difficult to participate in certain activities and decrease visitor use on the Oregon Coast, new activities could emerge to replace them. Land managers will need to understand and plan for the effects of shifting patterns in fish and wildlife activities on visitation patterns.

Water Resources

The OCAP assessment area provides many hydrologic services, ranging from water supplies for human use to the aesthetics of rivers and lakes. Federal lands in the assessment area contribute significantly to local municipal water supplies. Siuslaw National Forest had a mean annual renewable water supply over 4×10^9 m^3 from 1981 to 2010 (Brown et al. 2016). The USFS Ecosystem Management Coordination economic analysis estimates that 167,000 people are served by protected areas overlapping Siuslaw National Forest by at least 25 percent (USDA FS 2019).

Strained water-related ecosystem services have the potential to be a major vulnerability to the socioeconomic vitality of the region. Water is a high-value amenity, attracting new residents and visitors to the area. The Oregon Coast has largely transitioned from a natural resource-based economy to one based on tourism, second homes, and social and health services for an aging population driven by in-migration of retirees (ODLCD 2014). As population growth continues, development along estuaries and shorelines will be driven by demand for tourist infrastructure and new residences, requiring a focus on whether or not communities will be resilient to expected changes in hydrologic ecosystem services.

Climate change has influenced hydrologic systems in the Pacific Northwest, with additional effects expected in the future (chapter 3). Higher peak flows have the potential to stress infrastructure, particularly if rainfall intensity increases (Kormos et al. 2016). Issues related to surface water and groundwater systems include potential supply shortfalls in late summer, increased turbidity and contaminants, and harmful algal blooms driven by high temperatures. In addition, transportation corridors are vulnerable to landslides and flooding. The geography of the OCAP assessment area limits options for alternate and redundant travel arterials, leaving it heavily reliant on Highway 101. Valley bottom areas that contain roads are also vulnerable to transportation disruptions (chapter 3).

Commercial and industrial sectors on the Oregon coast may be constrained by a lack of transportation infrastructure (ODLCD 2014). Extended closure events have already occurred, disrupting routes for local residents, access to critical services, and travel routes for tourists. Another concern is vulnerability of evacuation routes for a tsunami that could be triggered by an earthquake in the Cascadia Subduction Zone. In addition, uncertainty exists about whether the insurance industry will be willing to insure homes and businesses in the face of climate change in a region with several hazards (ODLCD 2014). Potential risks created by climate change will require that: (1) planning for economic development is resilient to current and future stressors, and (2) ecosystem processes that support a sustainable flow of hydrologic services will need to be maintained even if those stressors intensify.

Summary of Ecosystem Services Provided by Federal Lands

Since the publication of the Millennium Ecosystem Assessment (MEA 2005), there has been considerable debate on how to best show the linkage between ecosystem structure and function and the benefits humans receive from nature. Challenges remain in identifying, classifying and fully characterizing ecosystem services (de Groot et al. 2012, Häyhä and Franzese 2014). One of the core tenets of the concept is the need to quantify and assign value to ecosystem services (Daily et al. 2000), thus informing management decisions and estimating the amount, flow, and monetary value of ecosystem services. Quantification of ecosystem services helps to describe the benefits people receive from federal lands in the context of stressors like climate change (Deal et al. 2017). Benchmarks and indicators like the USFS Inventory, Monitoring, and Analysis program help to articulate ecosystem services as quantifiable outcomes.

Table 8.4 summarizes ecosystem services provided by Siuslaw National Forest and BLM Northwest Oregon and Coos Bay Districts where quantified information is available. Data in the table are influenced by factors that control the supply of goods and services, land base, and distribution of ecosystem types, as well as by factors that control demand such as market conditions, management regulations, and accessibility to human populations. Although Siuslaw National Forest is relatively small compared to other units in the USFS Pacific Northwest Region, it produces ecosystem services in many categories (fig. 8.16). The recreation and timber categories serve as a foundation for economic activity derived from national forest lands in the assessment area (box 8.4).

Many benefits of ecosystem services do not lend themselves to the simple metrics reported here. Special techniques are required to estimate the values of general and non-market services, including specific economic methods (Farber et al. 2002, Häyhä and Franzese 2014). Fortunately, identifying key ecosystem services and describing their value in detailed narratives are usually sufficient to capture the nature of benefits that are difficult to value monetarily. These descriptions can then be used to communicate public benefits and assess tradeoffs among management alternatives in natural resource planning (Jaworski et al. 2018, Kline and Mazzotta 2012).

Table 8.5 summarizes findings that are applicable to the ecosystem services discussed in this chapter. Some of the key effects include the potential for temperature-driven productivity gains to be offset by summer water deficits, the frequency and severity of disturbances, and potential shifts in precipitation patterns. It is likely that the specific effects of climate change will differ for the various ecosystem services provided in the OCAP assessment area. Ecosystem services are embedded within many natural and human systems, making projections of their response to climate change uncertain. The COVID-19 pandemic demonstrated the potential for unforeseen rapid change in response to social stressors associated with a public health crisis. The pandemic prompted a significant increase in demand for USFS campsites nationwide (Shartaj et al. 2022), creating management challenges for the agency. When considering effects on the timing, quantity, and quality of services, a mix of both positive and negative outcomes is likely.

Uncertainties and Information Gaps

Uncertainties in the response of ecosystem services to climate change in the OCAP assessment area include variability in the timing and location of response to projections of increased temperatures, soil moisture deficits, and wildfire (chapter 5). For example, altered teleconnections between offshore and onshore systems (e.g., coastal fog) is a key uncertainty with major consequences for the ecology of the Oregon Coast. A better understanding of fog formation and timing, as well as its interactions with coastal plant and animal communities, will inform climate change adaptation options. Ocean temperature, upwelling patterns, and sea-level rise all have the potential to alter habitats and species in coastal regions, but the rate and magnitude of changes are uncertain.

The effects of climate change may be detrimental to understory shrubs such as huckleberry and salal (Prevéy et al. 2020a, 2020b). However, more research is needed to understand how increased temperatures, more frequent disturbances, and altered phenology will affect these shrubs and the species with which they compete. The large wildfires of 2020 in the western Cascade Range and foothills, as well as a history of large fires and windstorms on the Oregon coast, illustrate that large disturbances could occur in the future, with consequences for ecosystem services.

Future human demographic patterns in the OCAP assessment area and beyond will affect demands for ecosystem services. A transition towards an economy based on tourism and retirees is projected for this area (ODLCD 2014). Climate change could reinforce this trend with visitor demand increasing as people seek relief from heat waves and smoke events that occur elsewhere. The potential for an influx of climate migrants from other regions experiencing more acute climate change effects could influence demographic and socioeconomic trends.

Development demands are expected to increase in watersheds of the OCAP assessment area (chapter 3). Many of the low-elevation lands that could be targeted for development contain special habitats (e.g., estuaries, swamps, and meadows) that provide high levels of ecosystem services, posing potential social and political conflicts. In addition, projections of amplified extremes in precipitation and large disturbances will create higher risks for that development. National and global trends suggest that affordable insurance for individuals and businesses who live in high-risk areas will become difficult to obtain (World Economic Forum 2019). Social values and cultural attitudes will also evolve, leading to altered demand for ecosystem services that are difficult to anticipate.

Conclusions

The ecosystem services concept is now a well-established component of sustainable management in the USFS, providing a framework for linking social valuation and natural and cultural resources. The USFS 2012 Planning Rule *requires* consideration of ecosystem services. It also requires consideration of climate change in developing land management plans. The information provided in this chapter can be used by the USFS and other agencies and organizations to help resource managers anticipate how ecosystem services might change. It can also be used in conjunction with the tactics and strategies presented in chapter 9 of this report to develop options for adapting to altered ecosystem services. Finally, it can inform specific plans, programs, and projects. Quantitative and qualitative information presented here can be used to assess tradeoffs among alternatives in a planning context. Tracking of climate change effects and assessing the effectiveness of adaptation actions through monitoring and a process of continual learning will be necessary for long-term, sustainable management of ecosystem services.

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Chapter 9: Adapting to the Effects of Climate Change along the Oregon Coast

Benjamin S. Soderquist[1]

Introduction

Adapting to climate change involves taking action to adjust both natural and human systems in response to direct and indirect climate change effects (Lempert et al. 2018). Climate change is currently affecting ecosystems and natural resources in the Oregon Coast Range and the broader Pacific Northwest (Halofsky et al. 2019, chapter 2), and adaptation actions will be needed to ensure resilient ecosystems and sustainable natural resources. Federal land management agencies like the U.S. Department of Agriculture, Forest Service (USFS) are currently mandated to sustainably manage national forests and consider climate change during planning processes and management activities. Adapting forest ecosystems to climate change requires: (1) education on climate change science and integration with knowledge of local resource conditions and issues, (2) evaluation of the sensitivity of specific natural resources to climate change, (3) development and implementation of adaptation strategies and tactics, and (4) monitoring of the effectiveness of adaptation options, with adjustments as needed (Halofsky et al. 2018, Peterson et al. 2011).

Climate change vulnerability assessments are management tools that can inform each step of the adaptation process. The Oregon Coast Adaptation Partnership (OCAP) is a collaborative science-management partnership established to develop a regional vulnerability assessment and local climate change adaptation options resource managers can implement in response to climate change stressors. Initial meetings included resource managers from Siuslaw National Forest and the Bureau of Land Management (BLM), and scientists from USFS Research and Development and the University of Washington. Following an orientation around the purpose of an adaptation-focused partnership, a climate change vulnerability assessment was developed for key resource areas including water resources and hydrology (chapter 3), fisheries and aquatic ecosystems (chapter 4), forest and non-forest vegetation (chapter 5), wildlife and wildlife habitat (chapter 6), recreation (chapter 7), and ecosystem services (chapter 8). A synthesis of the effects of climate change stressors on each of the resource areas was presented to OCAP participants to help inform collaborative workshops in which adaptation options were identified.

This chapter describes the outcomes of these adaptation workshops in which resource managers collectively: (1) identified high-priority climate change stressors, (2) defined overarching adaptation strategies to address each stressor, and (3) developed a series of targeted adaptation tactics to support each adaptation strategy using a tabular format modified from the assessment approach described in Janowiak et al. (2014) and Swanston et al. (2016).

Online workshops were organized by resource area, and the presentation of adaptation options in this chapter follows the overall structure of the OCAP climate change vulnerability assessment. The adaptation options described here reflect regional climate change vulnerabilities and management priorities but are not a comprehensive summary of all potential adaptive responses. Rather, the findings presented in this chapter are summaries of top climate change priorities and adaption options identified during workshop discussions. Although this chapter represents only a subset of potential adaptation options, resource managers may find the information presented in this and other chapters useful as they identify innovative ways to manage the ongoing and future effects of climate change.

Water Resources and Hydrology

Climate change will likely lead to shifts in seasonal streamflows and marine hydrology. Interactions between freshwater and marine hydrologic processes may lead to climate change vulnerabilities that are unique to the Oregon Coast region (chapter 3). Although precipitation in the OCAP assessment area is currently rain dominated, warming temperatures will further reduce the amount of already infrequent and transitory high elevation snowpacks (Lute and Luce 2017, Wenger et al. 2011, chapter 3,). This can lead to lower winter flows and longer periods of decreased base flows during the summer (Dwire and Mellmann-Brown 2017).

Increasingly variable or more intense winter precipitation may also increase streamflows, potentially increasing flood risk in some areas (Hamlet et al. 2013). In low-elevation coastal floodplains, higher sea level and shifting tidal patterns can interact with increased streamflows, potentially resulting in more frequent or severe flood events (Cheng et al. 2015). Resource managers in the OCAP assessment area identified high-priority climate change stressors that will likely influence streamflow timing and magnitude, water quality, aquatic habitats, and built infrastructure. The following sections summarize adaptation options identified by workshop attendees to manage these climate change stressors.

Adaptation Options for Changing Streamflow and Coastal Hydrology

Shifts in the amount, timing, and form of precipitation in the OCAP assessment area will likely lead to increased flooding in some watersheds (chapter 3). To adapt to shifts in riparian and marine hydrology, adaptation strategies that increase the resilience of floodplains can be considered during land management plan development and project implementation. For example, in lower-elevation depositional floodplains that support critical ecosystems and human communities, restoring hydrologic connectivity and channel structure can support resilience to increasing flood frequency and severity (Luce et al. 2012, Pollock et al. 2015). Additional tactics that support increased connectivity and restore hydrologic function include: (1) reintroducing American beavers (*Castor canadensis* Kuhl) or constructing beaver dam analogs where appropriate, (2) working with landowners and other agencies to conduct land swaps or acquisitions, or implementing easements to increase the scale and effectiveness of restoration efforts, and (3) reincorporating large woody debris (LWD) in streams to slow flows, reduce erosion, and improve aquatic habitat (table 9.1).

Many adaptation tactics that support floodplain resilience are well-established management practices and have been used in restoration efforts for decades. However, the rate and scale of implementation need to be increased across vulnerable locations in the assessment area. For example, opportunities to expand these practices can be prioritized in degraded wetlands, streams that provide anadromous fish habitat, and areas where restoration efforts have been minimal (Staffen et al. 2019). Restoration efforts following disturbances such as wildfire also present opportunities to expand adaptation in vulnerable watersheds (Hessburg et al. 2015, Luce et al. 2012). In some locations where management is limited by cost or logistics, decommissioning or removing existing infrastructure may be the most effective adaptation option.

Adaptation Options for Flooding and Infrastructure

Low-gradient depositional valleys in the OCAP assessment area contain considerable human-made infrastructure. Adapting to shifting precipitation regimes and altered streamflows will require implementation of adaptation strategies that increase the resilience of existing infrastructure such as roads, bridges, utility corridors, and facilities. For transportation infrastructure specifically, tactics that build resilience include upsizing culverts and other road crossings to withstand more frequent and severe flood events (table 9.1). However, the vulnerability of some locations may reach a level that is unacceptable for human safety or budgets. In these instances, resource managers can identify where roads should be moved or decommissioned. This tactic can be applied on roads located on unstable slopes, in low-lying floodplains, or in areas where use is minimal. Pre- and post-disturbance restoration efforts can also be leveraged to improve the resilience of infrastructure. For example, culverts can be upsized following wildfires or landslides, hazardous fuels can be removed from utility corridors, and slopes can be stabilized to protect flood-prone or unstable infrastructure in watersheds with erodible soils.

Adaptation Options for Changing Water Quality

Climate change effects on water quality are also a concern in the OCAP assessment area (chapter 3). Siuslaw National Forest contains many high- and middle-elevation watersheds that provide water to downstream ecosystems and communities. Higher temperatures and shifting streamflows can have a variety of effects on stream temperature, turbidity, and nutrient loading (Emelko et al. 2011, Isaak et al. 2012). To adapt to potential reductions in water quality, resource managers can prioritize management strategies that protect existing water resources and improve water quality where human activities are a primary stressor. For example, in watersheds where stream temperatures are projected to exceed thermal thresholds for freshwater fish species, cold-water refugia can be enhanced by restoring riparian vegetation to increase shading. Increasing stream channel connectivity where channelization or barriers have constricted access to aquatic habitats can also buffer water temperatures and increase access to refugia (table 9.1).

In watersheds where erosion has led to increased sedimentation inputs, restoration efforts can be implemented to stabilize streambanks or slow the rate of streamflows. These treatments may be particularly beneficial in streams that are near unstable slopes, agricultural fields, or drinking water sources. To prepare for events when water quality is adversely affected (e.g., algal blooms), early warning systems and public outreach efforts can help reduce risks to human safety and public health. Coordination with agency partners, community groups, and public health organizations will provide consistent and far-reaching communication (table 9.1).

Aquatic Ecosystems and Watersheds

The OCAP assessment area contains diverse aquatic ecosystems that include inland freshwater lakes and streams, coastal estuaries, and nearshore marine environments. These freshwater and marine aquatic ecosystems are influenced by shared hydrologic processes but may respond differently to direct and indirect climate change effects (chapter 4). High-priority climate change stressors identified by resource managers focused primarily on shifts in watershed condition, stream hydrology and function, and estuarine conditions that could reduce or degrade aquatic habitat. Adaptation strategies identified by resource managers focused on improving habitat resilience, restoring hydrologic function, and increasing aquatic habitat connectivity in high-priority watersheds and degraded floodplains (table 9.2). These strategies are well-documented approaches for increasing resilience (Luce et al. 2012, Mantua and Raymond 2014). However, the rate and scale of implementation will need to be increased to effectively manage the effects of climate change across the assessment area.

Adaptation Options for Changing Streamflows and Riparian Habitats

Streamflows in the OCAP assessment area are projected to become more variable with climate change. Winter precipitation may become more intense, leading to flashier and higher peak flows in winter and spring (chapter 3). Conversely, seasonal low flows are projected to occur over longer periods of the summer as conditions become warmer and drier. Shifts in stream hydrology will have direct effects on riparian habitats and the aquatic species that depend on them (chapter 4). For anadromous fish species, changes in the frequency and magnitude of streamflows may reduce the availability or quality of critical spawning habitat (Isaak et al. 2012; Luce et al. 2012). However, restoring streams and floodplain processes that support both thermal refugia in the summer and flow refugia in the winter can increase the amount of available habitat and support more resilient fish populations (table 9.2).

Adaptation tactics that support this strategy include removing or replacing barriers that impede fish movement to headwater streams, introducing beavers or beaver dam analogs to slow the flow of water and increase storage at higher elevations, and restoring stream channel structure to maximize habitat connectivity and support more natural floodplain function (Pollock et al. 2015) (table 9.2). Restoration efforts can be prioritized in locations that have been recently disturbed or degraded for long periods of time and may support recolonization of native aquatic species (Isaak et al. 2016). In watersheds where transportation infrastructure increases the vulnerability of aquatic habitats, resource managers can storm-harden roads or decommission low-priority roads where appropriate to reduce sedimentation.

Adaptation Options for Estuarine Habitats

Estuaries provide critical habitat throughout the reproductive and migratory stages of anadromous fishes, birds, and other species (chapter 4). Shifts in streamflows in high- and middle-elevation watersheds can affect downstream estuarine ecosystems whose function depends on freshwater and marine hydrologic processes (chapter 3). In addition, development and alteration of coastal floodplains that support estuaries has created additional vulnerabilities that will be exacerbated by climate change (Brophy et al. 2019) (chapter 4).

Adapting these ecosystems to be more resilient to hydrologic shifts and continue supporting fish and wildlife will require management strategies that increase access to critical habitat and allow vulnerable species to travel to refugia as efficiently as possible. Removing tide gates that have historically limited access to marshes and wetlands to allow periodic flooding across larger areas of the floodplain can increase the extent of estuarine habitats (table 9.2). Restoring the structure and ecological function of wetlands, marshes, beaches, and dune ecosystems can further increase the area and resilience of habitats adjacent to estuaries (chapter 3). Following restoration, preventing the establishment and spread of invasive species will help maintain habitat connectivity and composition. Leveraging existing and new partnerships and increased coordination with local environmental groups, state agencies, and private landowners will help ensure restoration efforts are implemented in an ecologically meaningful way across floodplains with diverse ownership and land uses.

Adaptation Options for Altered Water Quality Following Disturbance

Disturbances in terrestrial ecosystems such as wildfire and insect outbreaks are projected to increase in frequency across the OCAP assessment area as summer conditions become hotter and drier (chapters 2 and 5). Streams in watersheds that experience more frequent and severe wildfires may experience: (1) higher rates of sedimentation from destabilized slopes, and (2) higher stream temperatures following the loss of riparian vegetation (Goode et al. 2012) (table 9.2,). Much like the adaptation options described above, strategies that minimize the negative effects of disturbance on vulnerable aquatic species and their habitats largely involve increasing the availability and quality of aquatic refugia. Access to cold-water and high-flow refugia can be increased by upgrading stream crossings, placing LWD in stream channels, and removing barriers downstream of high-elevation stream reaches (table 9.2). In watersheds where fire risk is high, proactive fuel treatments and fire breaks may help reduce future fire spread or severity. Forest vegetation can also be managed to maximize heterogeneity of stand structure and composition to prevent the spread of large and high-severity wildfires (Hessburg et al. 2015). Replanting riparian vegetation, slope stabilization, infrastructure upgrades, and road decommissioning following disturbances (wildfires, floods, landslides) can also expedite the rate of stream recovery, decrease negative impacts of human use, and reduce the establishment of invasive species.

Vegetation Management

The OCAP assessment area contains terrestrial ecosystems characterized by diverse age and stand structures and numerous rare plant species and communities. Historically, climate and precipitation regimes have supported productive forests with some late-successional stands still scattered across the assessment area (chapter 5). Climate change will continue to alter seasonal conditions and disturbance regimes, which may facilitate significant changes in vegetation type or structure. Although it is uncertain when and where future vegetation shifts may occur (chapter 5), resource managers identified climate change stressors related to increasing drought, shifts in disturbance regimes (e.g., frequency and extent of wildfire and insect outbreaks), and establishment of invasive species as high priorities for vegetation management. During workshops, adaptation options were developed separately for forest and non-forest vegetation. However, these adaptation approaches for different ecosystems are often grounded in similar concepts (e.g., increase heterogeneity, reduce risk from climate stressors) that inform the implementation of adaptation options.

Adaptation Options for Forest Vegetation

Climate change will likely lead to hotter and drier conditions across much of the OCAP assessment area (chapter 2). The effects of these climatic shifts on forest ecosystems will differ locally based on subregional precipitation patterns, topography, geology, and vegetation type (Halofsky and Peterson 2016; chapter 5). Disturbance regimes can also be directly and indirectly affected by altered temperature and precipitation and will likely be a primary driver of future vegetation shifts in many parts of the Pacific Northwest (Hessburg et al. 2016). Resource managers in the assessment area identified increasing drought, reduced fog, and subsequent interactions among insect outbreaks, fire, and forest productivity as prominent climate change stressors (table 9.3).

Adapting to these interconnected stressors will require adaptively managing forest vegetation to maintain heterogeneity and increase species diversity (Lehmkuhl et al. 2015). Increasing our understanding of vegetation responses to uncertain and potentially unprecedented changes will also improve decision making and the effectiveness of management responses. Specific vegetation management tactics that can be implemented to support forest resilience include: (1) conducting silvicultural treatments to increase forest diversity and heterogeneity (composition and/or structure), (2) increasing monitoring of forest regeneration following disturbance, (3) increasing the scale of thinning to reduce hazardous fuels, (4) and considering climate-informed modeling approaches to estimate appropriate stand densities (table 9.3). Stands managed as forest plantations are suitable candidates for many of these tactics, although forest areas that are vulnerable to disturbance or have recently experienced disturbance (e.g., stands with high hazardous fuels or recently burned areas) are also a high priority.

Forest managers in the assessment area are also particularly concerned about potential increases in the frequency and extent of wildfires. Increased drought frequency and intensity may create conditions in which fires can burn longer and in parts of the landscape where wildfire events have been historically infrequent (Stephens et al. 2013; chapter 5). Adapting to altered fire regimes will require managers to strategically reduce fire risk to communities, water resources, critical habitats, and other high-value resources. However, many aspects of future wildfire characteristics are uncertain and unpredictable, making proactive management difficult. Implementing practices to protect communities in the wildland-urban interface, increasing public outreach to reduce human-caused ignitions, and early warning systems and protocols (e.g., red flag warnings, forest closure, fire bans) can be used to proactively reduce risk exposure (table 9.3). Tactics that increase organizational capacity and flexibility, such as modifying the timing of seasonal hiring or project implementation, can also improve the efficiency and effectiveness of management responses to increasing wildfire events.

Extreme weather events (e.g., windstorms, intense precipitation) are projected to occur more frequently in the future, although the frequency and severity of these events are uncertain and difficult to project at local scales (chapter 5). However, managers can develop a better understanding of these disturbances and manage stands to reduce widespread damage to forests from wind and rain (table 9.3). For example, fine-scale modeling approaches can be used to identify positions across the landscape where forest vegetation is vulnerable to high-severity winds. In these locations, managers can alter stand structure to favor stronger trees and consider this additional aspect of risk during planning, monitoring, and restoration.

Adaptation Options for Non-forest Vegetation

Reducing the establishment and spread of invasive plants in both forested and non-forested ecosystems has been a management concern in the OCAP assessment area for decades. More disturbances and altered growing conditions with climate change may facilitate the spread of invasive species (Hellmann et al. 2008; chapter 5). There is considerable overlap in the strategies to reduce invasive plants in forest and non-forest vegetation (tables 9.3, 9.4). Broad strategies that build resilience of native plant communities and rare plant populations combined with active invasive species prevention programs were the primary adaptive approaches identified by OCAP managers.

Adaptation tactics supporting the management of invasive plants include: (1) expanding monitoring and implementing early detection programs, (2) increasing public outreach and education to promote best practices that limit the spread of invasive species, (3) increasing the scale of herbicidal, mechanical, and restoration treatments that build resilience in native plant communities, and (4) reducing existing invasive species populations or seed sources in riparian corridors and cleaning equipment before and after forest operations. High priority areas where tactics can be implemented are high-use locations, sites with rare plants, and recently disturbed areas where there is a high potential for invasive plant establishment. Working with recreation and conservation groups can be an effective approach to engage citizens and communicate management priorities to broader audiences (table 9.4).

Some native plant communities may also be vulnerable to increasing drought conditions and reduced fog moisture inputs (chapter 5). Management strategies that build resilience in montane meadows, dune communities, transition zones, and recently disturbed sites will help sensitive plant communities withstand increasing drought stress and human pressures. Expanding or developing new monitoring programs to better understand vegetation responses to extreme events and identify potential refugia will help managers prioritize resources and develop strategic restoration treatments. In addition, actively removing vegetation, such as invasive species or encroaching woody plants can reduce non-climatic stressors where drought is a concern. Like many other vegetation management activities, working across boundaries is essential for effectively treating landscapes with mixed ownerships. Managers can establish or expand partnerships with local conservation groups, landowners, and county and state agencies to increase the scope of adaptation efforts.

Wildlife Habitat Management

Climate change can affect wildlife populations directly and indirectly, with the magnitude of future climate change effects across the OCAP assessment area differing by habitat type and species (chapter 6). During adaptation workshops, resource managers identified several high-priority climate change stressors that would likely require adaptive management responses.

Climate sensitivities included regional temperature and precipitation shifts; subsequent effects on vegetation distribution and productivity, phenology, and physiological tolerances for temperature-sensitive species; and the frequency and extent of future disturbances that alter habitat structure and connectivity. These climate change stressors will likely interact with increasing human-related conflicts such as continued development and habitat fragmentation, introduction of invasive species, and more frequent human-wildlife interactions. Adaptive strategies identified by managers focused on maintaining or building resilience in key habitats and improving our understanding of species interactions driven by future transitions and range shifts.

Adaptation Options for Focal Habitats

Climate change vulnerabilities described in chapter 6 were considered for a range of individual species as well as eight critical focal habitats that support wildlife in the OCAP assessment area. Specific stressors that may increase the vulnerability of focal habitats include increasing drought, altered timing and magnitude of precipitation, and potential loss of fog moisture (chapters 5, 6). To increase resilience of wildlife populations that rely on moisture-dependent habitats, resource managers can implement tactics that increase access and connectivity to habitat refugia as well as bolster surface water and groundwater storage across the landscape (table 9.5).

In locations where water shortages and drought may exceed species tolerances, managers can increase connectivity with higher-elevation or cooler habitats to help facilitate wildlife movement during periods of excessive heat or drought. For example, protecting or restoring existing habitats such as alpine meadows and groundwater-dependent ecosystems can help maximize the extent of wildlife refugia at higher elevations. Reintroducing beavers or using beaver dam analogs to increase water retention in middle- and high-elevation watersheds can also support wildlife and native plant communities and increase the amount of habitat available throughout the year (Pollock et al. 2014, 2015). Many species in the assessment area occupy and travel across ownership boundaries. Effectively managing resilient habitats across management boundaries will require collaboration with state agencies, governments, and private landowners to conduct treatments that increase resilience across a species range. Partnerships with local conservation groups, land trusts, and local nongovernmental organizations can be effective ways to increase communication and education efforts and build trust with stakeholders.

Adaptation Options for Shifts in Species Range or Phenology

Climatic changes across the OCAP assessment area may alter the timing and location of species interactions as they compete for resources. For example, increasing temperatures and drought may change seasonal patterns of habitat use and available food sources, alter animal behavior and ranges, and shift the phenology of vegetation that supports wildlife (chapter 6) (table 9.5). Changes in wildlife behavior and interactions are complex and difficult to project with much certainty. However, increasing our understanding about how animals respond to both climatic and non-climatic stressors will help managers reduce wildlife vulnerabilities and facilitate transitions where appropriate (Mawdsley et al. 2009). Protecting and monitoring habitats that are critical for wildlife dispersal, reproduction, and foraging (e.g., meadows, edge habitats, transition zones) will increase resilience and allow managers to detect shifts in populations or habitat availability and help inform adaptive actions. For example, early detection and treatment of invasive species in native plant communities or critical habitats can prevent vegetation conversion and habitat loss.

Adaptation Options for Shifting Disturbance Regimes

Shifting climate and disturbance regimes may affect the distribution and structure of vegetation and wildlife habitat across the OCAP assessment area (chapter 5). Wildlife habitats in forested ecosystems will need to be resilient to increasing wildfires and perhaps insect outbreaks as temperatures increase. Broad strategies that protect and increase ecosystem resilience will have numerous benefits to wildlife along with other natural resources and ecosystem services. For example, many of the tactics that adapt vegetation to shifts in disturbance regimes (table 9.3) can also be used to support climate-informed wildlife management (table 9.5).

The OCAP assessment area contains a mix of forest stands where timber harvest occurs, as well as scattered old-growth stands that provide habitat to old-growth obligate animal species (chapter 6). Management of all forests can be adjusted to increase resilience to changing conditions (table 9.5). For example, old-growth stands can be protected from insects and disease through careful monitoring and preventative treatments.

In locations where timber harvest occurs, managers can adjust harvest operations or conduct pre-commercial thinning treatments to reduce stand density and increase stand heterogeneity and habitat connectivity. Following harvest or other disturbances, reforestation or restoration efforts can also be modified to increase species diversity and alter stand characteristics in ways that increase resilience to more frequent disturbances. For example, stands can be replanted at lower densities and with more drought-tolerant species or genotypes. Where possible, managers can also alter the age structure of restored stands to promote heterogeneity and habitat diversity. Wildlife corridors that allow passage between habitats can be managed for resilience to disturbances, facilitating access to a larger area of habitat refugia.

Recreation

The OCAP assessment area provides many recreation opportunities to visitors and residents of nearby communities and urban centers like Portland, Oregon. There is high seasonal demand for warm -weather recreation and water-based recreation in the Oregon Coast Range, whereas snow-based recreation is limited (chapter 7). Changes in temperatures, precipitation, and disturbance regimes will likely lead to altered timing and patterns of recreation use. During adaptation workshops, attendees prioritized climate change stressors that drive increased flooding and infrastructure damage, increasing disturbance frequency and severity, and altered seasonal recreation patterns. Broad adaptation strategies to manage potential changes focused on proactive and climate-informed recreation planning, as well as increasing programmatic flexibility to adaptively manage recreation access and use when conditions are uncertain or unsafe.

Adaptation Options for Recreation and Hydrologic Changes

Recreation and infrastructure often have similar climate change vulnerabilities, particularly with respect to shifts in hydrology and water resources. Infrastructure damage, reduced access to recreation, and safety hazards associated with extreme events may reduce recreational opportunities that can be accessed safely by the public (tables 9.2, 9.6). For example, altered timing and amount of precipitation can alter streamflows, and higher sea level can exacerbate flood risk in coastal floodplains, potentially limiting access to recreation or increasing hazard risk near water-based recreation opportunities (chapter 3). At middle and higher elevations, increased flooding and erosion can damage recreational facilities and infrastructure near streams and unstable slopes.

Successfully adapting to changing conditions and extreme events will require strategic consideration of climate change effects and vulnerabilities during the development of recreation programs and management plans. Adaptation tactics that support climate-informed recreation planning include: (1) identifying sites across the assessment area that are vulnerable to flooding and fortifying or decommissioning infrastructure where necessary, (2) constructing new facilities and infrastructure in areas that may see increased use under future conditions, and (3) improving public outreach and education for recreation alternatives, risk to public safety, and best practices for reducing human-related stressors in vulnerable locations (table 9.6). Public expectations will likely need to be managed with respect to recreation in areas where access is limited or where infrastructure may need to be decommissioned. However, leveraging existing partnerships or building new ones with local communities and recreation-focused groups can help managers identify vulnerable sites, monitor changes, and develop clear and consistent public communication to support sustainable recreation use.

Adaptation Options for Shifts in Seasonal Recreation

Warmer temperatures can also lead to changes in the timing and location of seasonal recreation use. For example, increased access and pressure during the spring and fall shoulder seasons may strain existing infrastructure and natural resources at popular recreation sites (chapter 6). Alternatively, warmer summer temperatures may result in less recreation at hotter and drier locations with a simultaneous increased demand for water-based recreation. Adaptation tactics that support flexible management will help managers balance finite recreational opportunities with increasing public demand (table 9.6). Managers may need to consider adjusting seasonal openings and closures in response to changing conditions or utilize special-use permits or visitation quotas to regulate the number of visitors. Maintenance costs may also increase with climate change and increasing use. Updating fee and permit programs to reflect additional costs may be necessary to support recreational opportunities that will see prolonged use. Collaborating with other agencies, local communities, and recreational groups will be essential if new rules and standards for recreation are considered.

Adaptation Options for Recreation and Shifting Disturbance Regimes

Forest disturbances such as wildfire and insect outbreaks may increase in some forest ecosystems in the OCAP assessment area (chapter 5). Access to recreation opportunities in middle- and high-elevation watersheds may be subsequently affected during and following disturbance events. Recreation use in the assessment area is limited not just by local conditions but can also be influenced by broader regional conditions. For example, demand for recreation in the assessment area may fluctuate depending on smoke and air quality in other parts of the Pacific Northwest (chapter 7). Management strategies that support proactive planning and preparation for periods of increasing disturbance will help promote reliable and sustainable recreational opportunities.

Like other recreation-focused adaptation tactics, effective communication with the public and agency partners will be essential to ensure safety and manage community perceptions around alternative recreation options (table 9.6). Following disturbance events, access to sites may need to be limited so that hazards can be removed (e.g., hazardous trees) and infrastructure can be repaired. When the risk of disturbance is high and public safety is a concern, temporary closures of certain sites or much larger areas may need to be implemented. Proactively managing public expectations and answering questions will ease the burden on managers as they implement these tactics.

Ecosystem Services

The diverse ecosystems across the OCAP assessment area provide ecosystem services that benefit human communities within and outside the assessment area. However, provision of these services may fluctuate or decrease with continued climate change (chapter 8). High-priority ecosystem services identified during adaptation workshops include traditional food sources, pollinators, non-timber forest products, and water resources (table 9.7). Workshop attendees noted that many of these ecosystem services are increasingly vulnerable to both climate change stressors as well as non-climatic stressors associated with growing populations and human demand.

Adaptation Options for First Foods and Non-Timber Forest Products

Forest and non-forest vegetation may experience shifts in distribution and abundance, structure, and diversity, often mediated by changes in disturbance regimes (chapter 5). Native vegetation serves many ecological and social functions including traditional foods (or first foods) and other non-timber forest products (e.g., fish, berries, ceremonial materials) that have supported Native American populations for centuries. First foods are culturally important and may be sensitive to climate change, invasive species, and overharvest (chapter 8). Increasing the resilience of existing first food supplies and other non-timber forest products will help ensure sustainable harvests under more variable climatic conditions. Resource managers can: (1) collaborate with local tribes to identify and monitor culturally important sites, (2) protect vulnerable or overharvested locations from continued human pressure, and (3) develop best management practices to restore or increase the distribution of first foods and other non-timber forest products across the assessment area (table 9.7).

Adaptation Options for Water Resources

Altered hydrologic processes and a higher frequency of drought can reduce the availability and quality of water resources on which communities in the OCAP assessment area depend (Mockrin et al. 2014) (chapter 3). Strategies that protect and restore watersheds or sites that provide drinking water, irrigation, and other services will need to be integrated into planning processes that span ownership boundaries to ensure access to adequate water resources (table 9.7). For example, low-elevation wetlands and marshes can be protected or restored to reduce flooding in developed areas. Following implementation of these tactics, increased monitoring efforts can prevent overuse and inform conservation practices.

Water bodies such as lakes and reservoirs may be vulnerable to algal blooms during periods of high temperatures, creating a potential contamination risk (Chapra et al. 2017). Managers can support public health awareness at these sites by increasing public safety messaging during toxic algal blooms. Like many other natural resources and ecosystem services in the assessment area, the quality and abundance of water resources are influenced by land uses and demands that span multiple ownership boundaries. Coordination and collaboration with communities and landowners will increase the effectiveness and extent of adaptation efforts, particularly as populations continue to grow and access to ecosystem services becomes more vulnerable (table 9.7).

Conclusions

This assessment and the adaptation options described in this chapter provide a starting point for resource managers to begin integrating climate-informed management approaches into land management plans and projects. The OCAP science-management partnership and resulting adaptation workshops were a collaborative exercise in which adaptation options were identified in response to high-priority climate change stressors that will likely affect many parts of the Oregon Coast Range. Common adaptation themes across all resource areas include cross-boundary collaboration, coordination, and communication, and the need to respond to the direct and indirect effects of disturbances. Many of the management strategies focus on increasing ecosystem resilience and restoring natural processes in watersheds and forest ecosystems. However, the term resilience can be defined numerous ways (Moser et al. 2019). When considering management goals and objectives, managers may want to consider how ecosystem "resilience" is defined in project design and management plans prior to implementing adaptation actions.

Climate change adaptation efforts typically have numerous co-benefits to ecosystems and human communities. Fortunately, agencies like the USFS already use many management approaches that support climate change adaptation, meaning that climate-informed management will often require only slight adjustments to current practices. However, climate change adaptation will likely need to be implemented faster and across a broader portion of the landscape to fully address climate change effects in future decades. Where climate change stressors are particularly acute, resource managers may need to consider experimenting with innovative adaptation actions that have not been tried before. While the success of these management experiments will vary, the accumulated knowledge and learning experiences are valuable lessons that can be shared with the broader management community.

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Chapter 10: Conclusions

David L. Peterson[1]

The Oregon Coast Adaptation Partnership (OCAP) contributed to our understanding of climate change vulnerabilities and responses to potential climate change effects in coastal Oregon, encompassing Siuslaw National Forest (NF), Oregon Dunes National Recreation Area, Cascade Head Experimental Forest, and the Bureau of Land Management (Northwest Oregon District, Cascade Head Biosphere Reserve). This 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 Siuslaw NF in implementing climate change objectives originally described in the National Roadmap for Responding to Climate Change (USDA FS 2010a) (see chapter 1).

Relevance to U.S. Forest Service Climate Change Response Strategies

The OCAP process is directly relevant to the climate change adaptation plan of the U.S. Department of Agriculture, Forest Service (USFS) (USDA FS 2022). Information presented in this report is also relevant for other land management entities and stakeholders in the OCAP assessment area. This process can be replicated and implemented by any organization, and the adaptation options are applicable beyond USFS lands. As in previous assessment and adaptation efforts (e.g., Halofsky and Peterson 2017; Halofsky et al. 2011, 2018a,b, 2019, 2022a,b; Hudec et al. 2019; Raymond et al. 2014), a science-management partnership was critical to the success of the OCAP. Those interested in utilizing 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 USFS Climate Change Performance Scorecard (2011–2016) (USDA FS 2010b) and its successor the Sustainability Scorecard (USDA FS 2020), require building institutional capacity in management units through information exchange and training for employees. Information sharing and education were built into the OCAP process through a virtual workshop in which (1) scientists presented results of the vulnerability assessment (effects of climate change on water resources and infrastructure, fish and aquatic habitat, vegetation, wildlife, recreation, and ecosystem services), and (2) 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 OCAP 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 the USFS, BLM, stakeholders, and the University of Washington. This partnership will remain relevant for future forest planning efforts and restoration conducted by the USFS in collaboration with other partners and stakeholders. Working with partners enhances the capability to respond effectively to climate change.

Climate change response is a relatively new and evolving aspect of land management, and the OCAP 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

The USFS Climate Change Performance Scorecard (USDA FS 2010b) and the Sustainability Scorecard (USDA FS 2020) 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 OCAP vulnerability assessment describes the climate change sensitivity of multiple resources, and adaptation options developed for each resource area can be incorporated into resource-specific management plans. Adaptation options will also be added to the Climate Change Adaptation Library for the Western United States (Adaptation Partners n.d.).

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 OCAP process may not be feasible, resource managers can draw from the options as needed. Some adaptation options can be implemented now, whereas others may require changes in management plans or policies, or may become 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 that provide information for detecting climate change effects and additional monitoring needs were identified for some resources in the vulnerability assessment. Working across multiple jurisdictions and boundaries will allow OCAP 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 analysis for National Environmental Policy Act (NEPA) projects, and specific project design criteria and mitigations.

Implementation

Although challenging, implementation of adaptation options will gradually occur with 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 can facilitate effective implementation, 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,b, 2019, 2022a,b; Hudec et al. 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 be incorporated into everyday work through climate-informed thinking as well as assist planning and 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 structure. 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 10.1 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 10.2 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 (fig. 10.1). For example, water, infrastructure, and recreation are sensitive to winter soil saturation that can lead to erosion and landslides. Higher temperatures and earlier snowmelt clearly affect multiple 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 affect 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 (Adaptation Partners n.d.). Looking across adaptation options for each chapter in this report, many of the resource areas share common climate change sensitivities. For example, water, infrastructure, and recreation are sensitive to winter soil saturation that can lead to erosion and landslides. Higher temperatures and earlier snowmelt affect most 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 affect 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. Recognizing shared goals can enhance organizational capacity to respond to climate change.

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 OCAP can be used by the USFS 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 to 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 required under the USFS 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 OCAP assessment area will continue to evolve. We anticipate that the following will be accomplished 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.
- Carbon management 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 OCAP assessment area.

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Tables

Table 2.1—United States Historical Climate Network (USHCN) stations evaluated with an estimate of annual temperature change as determined by a Theil-Sen's trend analysis

Location	Latitude	Longitude	Elevation	Mean annual temperature trend
	Degrees N	*Degrees W*	*Meters*	*°C per decade*
Astoria	46.16	-123.88	3	0.06
Corvallis	44.63	-123.19	69	0.10
Cottage Grove	43.79	-123.03	181	0.09
Drain	43.67	-123.33	89	0.18
Forest Grove	45.52	-123.10	55	0.11
McMinnville	45.22	-123.16	47	0.07
Newport	44.64	-124.06	37	0.16
North Bend	43.41	-124.24	2	0.16
Roseburg	43.21	-123.37	130	0.16
Tillamook	45.46	-123.87	3	0.09

Table 3.1—Landward Migration Zone area (hectares) by estuary and sea-level rise scenario. Estuaries are listed in alphabetical order. Data from Brophy and Ewald (2017)

	Sea-level rise (m)			
Estuary	**0**	**0.48**	**1.42**	**2.5**
Alsea Bay	380	425	274	134
Coos Bay	2599	2093	1256	784
Nestucca Bay	648	765	615	477
Salmon River	240	267	242	81
Sand Lake	270	310	263	101
Siletz Bay	412	495	526	374
Siuslaw River	1212	1087	552	225
Tillamook Bay	2129	2296	1613	1101
Umpqua River	1653	1833	1440	870
Yaquina Bay	824	739	446	284

Table 3.2—Landward migration zone (LMZ) loss or gain compared to baseline (percent change) by estuary and sea-level rise scenario (from Brophy and Ewald 2017). Estuaries are listed in alphabetical order. Negative numbers indicate loss of LMZ area, positive numbers indicate gain. Results must be interpreted relative to absolute areas shown in Table 3.1

	Sea-level rise (m)			
Estuary	**0**	**0.48**	**1.42**	**2.5**
Alsea Bay	0	12	-28	-65
Coos Bay	0	-19	-52	-70
Nestucca Bay	0	18	-5	-26
Salmon River	0	11	1	-66
Sand Lake	0	15	-3	-63
Siletz Bay	0	20	28	-9
Siuslaw River	0	-10	-54	-81
Tillamook Bay	0	8	-24	-48
Umpqua River	0	11	-13	-47
Yaquina Bay	0	-10	-46	-66

Table 3.3—Tidal inundation for 10 estuaries in the Oregon Coast Adaptation Partnership assessment area, combining sea-level rise (SLR) and river flood event (data from OCMP 2017)

	2030: 50% chance of flood			2100: 50% chance of flood		
Estuary	**SLR (cm)**	**Flood event height**	**Combined (cm)**	**SLR (cm)**	**Flood event height**	**Combined (cm)**
	Cm	*Cm in MHHW*[a]	*Cm*	*Cm*	*Cm in MHHW*	*Cm*
Alsea Bay	22.86	80.16	103.02	142.24	80.16	222.40
Coos Bay	22.86	74.98	97.84	142.24	74.98	217.22
Nestucca River	22.86	80.77	103.63	142.24	80.77	223.01
Salmon River	22.86	80.77	103.63	142.24	80.77	223.01
Sand Lake	22.86	80.47	103.33	142.24	80.47	222.71
Siletz Bay	22.86	80.77	103.63	142.24	80.77	223.01
Siuslaw River	22.86	78.03	100.89	142.24	78.03	220.27
Tillamook Bay	22.86	80.47	103.33	142.24	80.47	222.71
Umpqua River	22.86	76.50	99.36	142.24	76.50	218.74
Yaquina Bay	22.86	81.08	103.94	142.24	81.08	223.32

[a]MHHW = mean higher high-water

Table 3.4—Area of tidal water surface in 10 estuaries in the OCAP assessment area that combine sea-level rise and 50 percent probability of a river flood event (data from OCMP 2017) in the years 2030 and 2100

	Tidal inundation area		Difference between 2030 and 2100	
Estuary	**2030**	**2100**	**Area**	**Percent**
	Hectares	*Hectares*	*Hectares*	
Alsea Bay	1439	1633	194	113
Coos Bay	8534	10088	1554	118
Nestucca River	1165	1525	360	131
Salmon River	367	447	80	122
Sand Lake	474	570	96	120
Siletz Bay	1116	1435	319	129
Siuslaw River	2549	2953	404	116
Tillamook Bay	5734	6675	941	116
Umpqua River	5043	6138	1095	122
Yaquina Bay	2728	3118	390	114

Table 3.5—Watersheds (hydrologic unit code 12) in the OCAP assessment area for which national forests comprised 50 percent or more of the watershed area

Subwatershed	Percent national forest
Cummins Creek	87
Lower Drift Creek	86
Tenmile Creek	84
Cape Creek	83
Upper Five Rivers	83
Upper North Fork Siuslaw River	81
Upper Indian Creek	79
Middle Five Rivers	77
Lower Five Rivers	77
Canal Creek-Alsea River	74
Upper Yachats River	74
Three Rivers	73
Sweet Creek	71
Scott Creek-Alsea River	70
Lower Indian Creek	69
Niagara Creek-Nestucca River	67
Lower Drift Creek	67
Lower Deadwood Creek	64
Upper North Fork Smith River	63
Big Creek	63
Powder Creek-Nestucca River	62
Middle Little Nestucca River	60
Upper Deadwood Creek	60
Lower Yachats River	58
Lower North Fork Siuslaw River	56
Maple Creek	54
Fiddle Creek	50
Upper Drift Creek	50

Table 3.6—OCAP assessment area subwatersheds (hydrologic unit code 12) that serve municipal sources, listed in order by the number of people served (F2F2 2018)

Hydrologic unit code	Subwatershed	Population served	Forest	National forest	Private forest
			Percent	*Percent*	*Percent*
171003040306	Coos Bay	38000	34	1	31
171002040708	Schooner Creek	17940	79	47	27
170900070103	Upper Rickreall Creek	14030	64	4	51
171003040404	Clear Creek	6000	30	17	9
171002060804	Bernhardt Creek	4500	62	36	22
170900030205	Middle Marys River	4400	49	2	47
171002030301	Upper Tillamook River	4400	63	1	46
171002040707	Lower Drift Creek	4145	79	67	10
171002050503	Big Creek	3000	80	63	16
171002050405	Eckman Creek	3000	70	38	29
171002070103	Siltcoos Lake	2794	37	12	21
171002030901	Netarts Bay	2675	68	2	59
171002040301	Ollala Creek	1792	53	9	44
171003040403	Tenmile Creek	1700	47	6	30
171002060803	Knowles Creek-Siuslaw River	750	77	40	30
171002050602	Lower Yachats River	700	85	58	23
171002040803	Lower Salmon River	550	73	46	19
171002030207	Beaver Creek	550	70	24	36
171002050703	Cape Creek	450	92	83	1
171002030903	Neskowin Creek	300	79	48	28
171002030902	Sand Creek	250	63	34	24
171002050404	Canal Creek-Alsea River	200	86	74	11
171002050502	Collins Creek	200	66	1	61
171002040801	Slick Rock Creek	180	79	7	51
171002040303	Poole Slough-Yaquina River	100	57	7	49

Table 3.7—OCAP assessment area subwatersheds potentially affected by development[a][a], determined by projected housing density increase (from Forest 2 Faucets 1.0 Development Threat Index[b])

Hydrologic unit code	Subwatershed	Portion of subwatershed potentially affected by development
		Percent
171002030102	Middle Little Nestucca River	83
171003030803	Umpqua River Estuary	81
171002040801	Slick Rock Creek	81
171002040707	Lower Drift Creek	71
171002040803	Lower Salmon River	70
171003040307	North Spit	65
171002050704	Mercer Lake	65
171002040901	Devils Lake	64
171002040802	Upper Salmon River	63
171002040705	Bear Creek-Siletz River	63
171003040404	Clear Creek	61
171002030901	Netarts Bay	61
171002050502	Collins Creek	60
171003040403	Tenmile Creek	57
171002030101	Upper Little Nestucca River	57
171002070103	Siltcoos Lake	56
171002030301	Upper Tillamook River	56
170900030205	Middle Marys River	53
171002060804	Bernhardt Creek-Siuslaw River	50
171002040301	Ollala Creek-Yaquina River	49
171002050405	Eckman Creek-Alsea River	48
171003040306	Coos Bay	43
171002050501	Beaver Creek	42
171002040704	Cedar Creek-Siletz River	41
171002030903	Neskowin Creek	41
171002040708	Schooner Creek	39
171002050404	Canal Creek-Alsea River	39
171002030902	Sand Creek	38
170900030202	Tumtum River	37
171002050302	Middle Drift Creek	37
171002030207	Beaver Creek	35
171002060702	Lower North Fork Siuslaw River	33
170900030204	Greasy Creek	32
171002040303	Poole Slough-Yaquina River	31
171002070101	Maple Creek	29
171002050503	Big Creek	27
171002050303	Lower Drift Creek	25
171002030208	Three Rivers	25

[a]Includes subwatersheds with 25 percent or more area threatened by development (43 percent of OCAP subwatersheds).
[b]Using data for predicted housing density increase from Theobald (2005).

Table 3.8—OCAP subwatersheds with moderate to high risk of landslide and also considered to be important sources of surface drinking water (applies to 8 percent of all subwatersheds)

Southern subwatersheds	Northern subwatersheds
East Fork Millicoma River	Sunshine Creek
West Fork Millicoma River	Upper Drift Creek
Tenmile Lake	Lower Drift Creek
North Tenmile Lake	Elk Creek
Knowles Creek	Upper Mill Creek
Sweet Creek	
Fiddle Creek	

Table 3.9—Oregon Health Authority recreational-use health advisories related to cyanobacteria outbreaks in the OCAP assessment area[a]

Water body	County	Year	Duration	Drinking water source[b]	Recreation	Season
			Days			
South Tenmile Lake	Coos	2017	4	Unknown	Yes	Summer
Tenmile Lakes	Coos	2014	70	Unknown	Yes	Summer/fall
Devils Lake	Lincoln	2014	114	Yes, private wells	Yes	Summer/fall
Tenmile Lakes	Coos	2013	59	Unknown	Yes	Fall/winter
Devils Lake	Lincoln	2013	110	Yes, private wells	Yes	Summer/fall
Big Creek Reservoir	Lincoln	2012	96	Yes, City of Newport	Yes	Fall/winter
South Tenmile Lake	Coos	2011	88	Unknown	Yes	Summer/fall
Tenmile Lake	Coos	2011	110	Unknown	Yes	Fall/winter
Tenmile Lake	Coos	2009	72	Unknown	Yes	Summer/fall
Devils Lake	Lincoln	2009	40	Yes, private wells	Yes	Summer
Siltcoos Lake	Lane	2009	91	Yes, South Coast Water Dist. Inc.	Yes	Fall/winter
Devils Lake	Lincoln	2008	79	Yes, private wells	Yes	Summer/fall
Siltcoos Lake	Lane	2007	21	Yes, South Coast Water Dist. Inc.	Yes	Fall

[a]Oregon Health Authority Harmful Algae Bloom Surveillance (HABS) program (2007-present) archive data of recreational-use health advisories (Oregon Health Authority 2018).

[2]Drinking water data from the water rights database of the Oregon Water Resources Department, Oregon Department of Environmental Quality (ODEQ) domestic well dataset, and ODEQ surface water source areas.

Table 4.1—Lengths of streams in the OCAP assessment area, categorized by mean August stream temperatures during a baseline period and two future periods associated with the A1B emission trajectory. These summaries are for streams where mean summer flow >0.0057 $m^3 s^{-1}$, slope <15 percent

	< 8 °C	8–11 °C	11–14 °C	14–17 °C	17–20 °C	> 20 °C
All lands						
1980s (1970-1999)	126	234	2,207	4,345	846	144
2040s (2030-2059)	122	89	993	4,325	1,992	381
2080s (2070-2099)	122	29	485	3,133	3,438	690
Forest Service lands						
1980s (1970-1999)	1	25	793	620	42	6
2040s (2030-2059)	1	4	309	1,020	146	7
2080s (2070-2099)	1	2	91	1,023	340	28
BLM lands						
1980s (1970-1999)	1	47	329	481	37	-
2040s (2030-2059)	1	11	181	593	96	13
2080s (2070-2099)	1	2	98	434	336	24

Table 4.2—Summary of streamflow statistics relevant to fish populations in the OCAP assessment area, based on changes associated with the A1B emission trajectory. These summaries are for streams where mean summer flow >0.0057 $m^3 s^{-1}$, slope <15 percent

		All lands		Forest Service lands		BLM lands	
Flow metric	**Climate period**	**Day of year[a]**	**Days advance**	**Day of year**	**Days advance**	**Day of year**	**Days advance**
Center of flow mass	1980s	140	-	141	-	138	-
	2040s	137	-3	137	-4	134	-4
	2080s	135	-5	135	-6	132	-6
		Number of days	**Days increase**	**Number of days**	**Days increase**	**Number of days**	**Days increase**
Winter 95% flow	1980s	15.3	-	15.4	-	15.0	-
	2040s	15.2	-0.1	15.3	-0.1	14.9	-0.1
	2080s	15.2	-0.1	15.4	0.0	14.9	-0.1
		Cubic meters per second	**Percent change**	**Cubic meters per second**	**Percent change**	**Cubic meters per second**	**Percent change**
Mean summer flow[b]	1980s	2.26	-	0.38	-	0.32	-
	2040s	1.92	-15.0	0.33	-13.0	0.29	-9.4
	2080s	1.75	-22.6	0.30	-19.8	0.27	-15.6
Mean annual flow	1980s	6.23	-	1.24	-	1.08	-
	2040s	6.28	0.8	1.26	1.6	1.10	1.9
	2080s	6.20	-0.5	1.25	0.8	1.09	0.9

[a]Refers to day of water year starting October 1.
[b]Average flow across all reaches in the network.

Table 4.3—Summary of fishes and climate vulnerability for the Siuslaw National Forest and Bureau of Land Management in the OCAP assessment area. Climate vulnerability for Pacific salmon and steelhead are based on their biological risk summary from the National Oceanic and Atmospheric Administration (Crozier et al. 2019), which incorporated their sensitivity and exposure to potential changes. We received assessment information from the state of Oregon for the other fishes

Species or run	Population status/trend	Climate vulnerability
Spring spawning		
Winter steelhead	Depressed/stable	Moderate
Coastal cutthroat trout	Depressed/stable	Moderate
Pacific lamprey	Depressed/unknown	High
Western brook lamprey	Depressed/unknown	High
Green sturgeon	Depressed/unknown	Moderate
Eulachon	Depressed/unknown	High
Fall spawning		
Coho salmon[a]	Depressed/stable	High, borderline very high
Chinook salmon		
Spring run	Depressed/stable	Very high
Fall run	Depressed/stable	High
Chum salmon	Depressed/stable	Moderate

[a]Coastal Oregon are considered their own evolutionary significant unit and considered threatened under the Endangered Species Act.

Table 4.4—Streamflow and temperature characteristics for steelhead habitats based on changes associated with the A1B emission trajectory. Habitat extent matches the 5,254 km shown in figure 8 and is based on fish distribution datasets from the USFS Pacific Northwest Region, ODFW, and BLM. Values are stream kilometers, and those in parentheses are percentages of the total

		Number of high-flow days						
Stream metric	Period	<5	5-10	>10				
Winter 95% flow	1980s	-	-	5254 (100)				
	2040s	-	-	5254 (100)				
	2080s	-	-	5254 (100)				
		Cubic meters per second						
		<0.034	0.034-0.085	>0.085				
Summer flow	1980s	600 (11.4)	1182 (22.5)	3473 (66.1)				
	2040s	732 (13.9)	1224 (23.3)	3298 (62.8)				
	2080s	830 (15.8)	1240 (23.6)	3184 (60.6)				
		Stream kilometers						
		<8	8-11	11-14	14-17	17-20	20-23	>23
August temperature	1980s	-	3.5 (0.1)	32 (0.6)	1089 (20.7)	3183 (60.6)	804 (15.3)	143 (2.7)
	2040s	-	9.2 (0.2)	339 (6.5)	2822 (53.7)	1713 (32.6)	330 (6.3)	40 (0.8)
	2080s	-	4.7 (0.1)	113 (2.2)	1747 (33.3)	2726 (51.9)	548 (10.4)	115 (2.2)

Table 4.5—Streamflow and temperature characteristics for coastal cutthroat trout habitats based on changes associated with the A1B emission trajectory. Habitat extent matches the 6,634 km shown in figure 9 and is based on fish distribution datasets from the USFS Pacific Northwest Region, ODFW, and BLM. Values are stream kilometers, and those in parentheses are percentages of the total

		Number of high-flow days						
Stream metric	Period	<5	5-10	>10				
Winter 95% flow	1980s			6634 (100)				
	2040s			6634 (100)				
	2080s			6634 (100)				
		Cubic meters per second						
		<0.034	0.034-0.085	>0.085				
Summer flow	1980s	1071 (16.2)	1660 (25.0)	3903 (58.8)				
	2040s	1274 (19.5)	1669 (25.2)	3691 (55.6)				
	2080s	1408 (21.2)	1684 (25.4)	3542 (53.4)				
		Stream kilometers						
		<8	8-11	11-14	14-17	17-20	20-23	>23
August temperature	1980s	3.5 (0.1)	190 (2.9)	1651 (24.9)	3853 (58.1)	795 (12.0)	143 (2.2)	-
	2040s	-	79 (1.2)	722 (10.9)	3636 (54.8)	1828 (27.6)	329 (5.0)	41 (0.6)
	2080s	-	25 (0.4)	382 (5.8)	2453 (37.0)	3111 (46.9)	548 (8.3)	115 (1.7)

Table 4.6—Streamflow and temperature characteristics for Pacific lamprey habitats based on changes associated with the A1B emission trajectory. Habitat extent matches the 2,130 km shown in figure 10 and is based on fish distribution datasets from the USFS Pacific Northwest Region 6, ODFW, and BLM. Values are stream kilometers, those in parentheses are percentages of the total

		Number of high-flow days						
Stream metric	Period	<5	5-10	>10				
Winter 95% flow	1980s	-	-	2130 (100)				
	2040s	-	-	2130 (100)				
	2080s	-	-	2130 (100)				
		Cubic meters per second						
		<0.034	0.034-0.085	>0.085				
Summer flow	1980s	8.8 (0.4)	59.8 (2.8)	2061 (96.8)				
	2040s	17.2 (0.8)	68.2 (3.2)	2044 (99.0)				
	2080s	21.8 (1.0)	79.5 (3.7)	2028 (95.2)				
		Stream kilometers						
		<8	8-11	11-14	14-17	17-20	20-23	>23
August temperature	1980s	-	5.7 (0.3)	139 (6.5)	1176 (55.2)	666 (31.3)	143 (6.7)	-
	2040s	-	1.5 (0.1)	21 (1.0)	647 (30.4)	1107 (52.0)	313 (14.7)	41 (1.9)
	2080s	-	-	6.7 (0.3)	290 (13.6)	1234 (57.9)	484 (22.7)	115 (5.4)

Table 4.7—Streamflow and temperature characteristics for western brook lamprey habitats based on changes associated with the A1B emissions trajectory. Habitat extent matches the 350 km shown in figure 11 and is based on fish distribution datasets from the USFS Pacific Northwest Region, ODFW, and BLM. Values are stream kilometers, and those in parentheses are percentages of the total

		Number of high-flow days						
Stream metric	Period	<5	5-10	>10				
Winter 95% flow	1980s	-	-	351 (100)				
	2040s	-	-	351 (100)				
	2080s	-	-	351 (100)				
		Cubic meters per second						
		<0.034	0.034-0.085	>0.085				
Summer flow	1980s	5.4 (1.5)	69.7 (19.9)	275 (78.6)				
	2040s	13.4 (3.8)	67.8 (19.3)	269 (76.9)				
	2080s	21.2 (6.0)	70.5 (20.1)	259 (73.9)				
		Stream kilometers						
		<8	8-11	11-14	14-17	17-20	20-23	>23
August temperature	1980s	-	-	55 (15.8)	241 (68.8)	54 (15.4)	-	-
	2040s	-	-	3.6 (1.0)	220 (62.9)	117 (33.3)	9.7 (2.8)	-
	2080s	-	-	0.3 (0.1)	119 (33.9)	195 (55.7)	36 (10.4)	-

Table 4.8—Streamflow and temperature characteristics for green sturgeon habitats based on changes associated with the A1B emission trajectory. Habitat extent matches the 197 km shown in figure 12 and is based on fish distribution datasets from the USFS Pacific Northwest Region, ODFW, and BLM. Values are stream kilometers, and those in parentheses are percentages of the total

		Number of high-flow days						
Stream metric	Period	<5	5-10	>10				
Winter 95% flow	1980s	-	-	197 (100)				
	2040s	-	-	197 (100)				
	2080s	-	-	197 (100)				
		Cubic meters per second						
		<0.034	0.034-0.085	>0.085				
Summer flow	1980s	-	-	197 (100)				
	2040s	-	-	197 (100)				
	2080s	-	-	197 (100)				
		Stream kilometers						
		<8	8-11	11-14	14-17	17-20	20-23	>23
August temperature	1980s	-	-	-	4.5 (2.3)	76.5 (38.9)	116 (58.8)	-
	2040s	-	-	-	-	45.0 (22.8)	112 (56.6)	40 (20.5)
	2080s	-	-	-	-	20.3 (10.3)	75 (38.1)	102 (51.6)

Table 4.9—Streamflow and temperature characteristics for eulachon habitats based on changes associated with the A1B emission trajectory. Habitat extent matches the 37 km shown in figure 13 and is based on fish distribution datasets from the USFS Pacific Northwest Region, ODFW, and BLM. Values are stream kilometers, and those in parentheses are percentages of the total

		Number of high-flow days						
Stream metric	Period	<5	5-10	>10				
Winter 95% flow	1980s	-	-	36.8 (100)				
	2040s	-	-	36.8 (100)				
	2080s	-	-	36.8 (100)				
		Cubic meters per second						
		<0.034	0.034-0.085	>0.085				
Summer flow	1980s	-	-	36.8 (100)				
	2040s	-	-	36.8 (100)				
	2080s	-	-	36.8 (100)				
		Stream kilometers						
		<8	8-11	11-14	14-17	17-20	20-23	>23
August temperature	1980s	-	-	-	-	2.7 (7.4)	34 (92.6)	-
	2040s	-	-	-	-	-	37 (100)	-
	2080s	-	-	-	-	-	5.9 (16.1)	31 (84.0)

Table 4.10—Streamflow and temperature characteristics for Coho salmon habitats based on changes associated with the A1B emission trajectory. Habitat extent matches the 5,200 km shown in figure 5 and is based on fish distribution datasets from the USFS Pacific Northwest Region, ODFW, and BLM. Values are stream kilometers, and those in parentheses are percentages of the total

		Number of high-flow days						
Stream metric	Period	<5	5-10	>10				
Winter 95% flow	1980s	-	-	5200 (100)				
	2040s	-	-	5200 (100)				
	2080s	-	-	5200 (100)				
		Cubic meters per second						
		<0.034	0.034-0.085	>0.085				
Summer flow	1980s	607 (11.7)	1151 (22.1)	3442 (66.2)				
	2040s	734 (14.1)	1198 (23.0)	3268 (62.8)				
	2080s	817 (15.7)	1234 (23.7)	3149 (60.6)				
		Stream kilometers						
		<8	8-11	11-14	14-17	17-20	20-23	>23
August temperature	1980s	3.5 (0.1)	9.7 (0.19)	1006 (19.4)	3234 (62.2)	802 (15.4)	145 (2.78)	-
	2040s	-	6.2 (0.1)	251 (4.8)	2819 (54.2)	1755 (33.8)	326 (6.3)	42 (0.8)
	2080s	-	4.7 (0.1)	55 (1.1)	1707 (32.8)	2771 (53.3)	546 (10.5)	117 (2.2)

Table 4.11—Streamflow and temperature characteristics for Chinook salmon habitats based on changes associated with the A1B emission trajectory. Habitat extent matches the 2,979 km shown in figure 6 and is based on fish distribution datasets from the USFS Pacific Northwest Region, ODFW, and BLM. Values are stream kilometers, and those in parentheses are percentages of the total

		Number of high-flow days						
Stream metric	Period	<5	5-10	>10				
Winter 95% flow	1980s	-	-	2979 (100)				
	2040s	-	-	2979 (100)				
	2080s	-	-	2979 (100)				
		Cubic meters per second						
		<0.034	0.034-0.085	>0.085				
Summer flow	1980s	57 (1.9)	278 (9.3)	2644 (88.8)				
	2040s	81 (2.7)	310 (10.4)	2589 (86.9)				
	2080s	90 (3.0)	341 (11.5)	2548 (85.5)				
		Stream kilometers						
		<8	8-11	11-14	14-17	17-20	20-23	>23
August temperature	1980s	3.5 (0.1)	6.9 (0.2)	373 (12.5)	1748 (58.7)	705 (23.7)	143 (4.8)	-
	2040s	-	6.2 (0.2)	83 (2.8)	1223 (41.0)	1303 (43.7)	324 (10.9)	41 (1.4)
	2080s	-	4.7 (0.2)	21 (0.7)	647 (21.7)	1681 (56.4)	511 (17.1)	115 (3.9)

Table 4.12—Streamflow and temperature characteristics for chum salmon habitats based on changes associated with the A1B emission trajectory. Habitat extent matches the 460 km shown in figure 7 and is based on fish distribution datasets from the USFS Pacific Northwest Region, ODFW, and BLM. Values are stream kilometers, and those in parentheses are percentages of the total

		Number of high-flow days						
Stream metric	Period	<5	5-10	>10				
Winter 95% flow	1980s	-	-	460 (100)				
	2040s	-	-	460 (100)				
	2080s	-	-	460 (100)				
		m^3/s						
		<0.034	0.034-0.085	>0.085				
Summer flow	1980s	5.4 (1.2)	15 (3.3)	440 (95.5)				
	2040s	5.9 (1.3)	24 (5.1)	431 (93.6)				
	2080s	5.9 (1.3)	28 (6.1)	426 (92.9)				
		Stream kilometers						
		<8	8-11	11-14	14-17	17-20	20-23	>23
August temperature	1980s	-	-	27.8 (6.0)	244 (53.0)	172 (37.4)	17 (3.6)	-
	2040s	-	-	-	113 (24.4)	295 (64.2)	52 (11.4)	-
	2080s	-	-	-	61 (13.2)	278 (60.3)	118 (25.6)	4.0 (0.9)

Table 5.1—Crosswalk of different vegetation classifications and area of different vegetation types by management unit

					Area		
MC2 functional types	Group	Zone	Type	Dominant species	OCAP assessment area[a]	Siuslaw National Forest[a]	Bureau of Land Management[a]
						Hectares	
Moist temperate needleleaf forest	Moist	Western hemlock	Moist	Douglas-fir, western hemlock, western red cedar, big leaf maple, Pacific madrone, grand fir	1,487,937	191,436	389,646
			Inter-mediate		294	0	12
			Dry		41,896	216	7,553
	Cool	Pacific silver fir	Pacific silver fir	Pacific silver fir, noble fir, Douglas-fir	25,410	740	4,721
Temperate needleleaf forest	Dry	Grand fir	Moist	grand fir, Douglas-fir	103,740	0	105,447
			Dry		100	0	0
		Douglas-fir	Moist		2,030	962	3,358
			Dry		119,270	6	16,493
Temperate warm mixed	Warm, moist	Sitka spruce	Sitka spruce	Sitka spruce, Douglas-fir, western hemlock, western redcedar, bigleaf maple, Pacific madrone, grand fir	346,502	59,915	63,383
Subtropical mixed forest	Warm, wet	Does not currently exist in assessment area	Not applicable	Not applicable	0	0	0

[a]Total area: OCAP assessment area = 2,150,714 ha, Siuslaw National Forest = 253,635 ha, Bureau of Land Management = 503,031 ha.

Table 5.2—Common insects and diseases associated with important host-tree species in the OCAP assessment area

	Insect or pathogen	Host species
Bark beetles	Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins)	Douglas-fir
	Fir engraver (*Scolytus ventralis* LeConte)	True firs
	Ips spp.	Pines
	Cedar bark beetle (*Phloeosinus* spp.)	Western redcedar, Port Orford cedar
	Red turpentine beetle (*Dendroctonus valens* LeConte)	Shore pine
Insect defoliators	Western hemlock looper (*Lambdina fiscellaria lugubrosa* [Hulst])	Western hemlock (primary), feeds on other associated species during outbreaks
	Spruce aphid (*Elatobium abietinum*)	Sitka spruce
	Silver-spotted tiger moth (*Lophocampa argentata*)	Douglas-fir, shore pine, Sitka spruce, grand fir, noble fir
	Tent caterpillars (*Malacosoma disstria* Hubner, *M. californicum pluviale*)	Red alder, willows, black cottonwood, other hardwoods
Sucking insects	Balsam woolly adelgid (*Adelges piceae* Ratzeburg)	Grand fir, noble fir
	Leafhopper (*Empoasca elongata*)	Bigleaf maple
Terminal insects	White pine weevil (*Pissodes strobi* Peck)	Sitka spruce
Root diseases	Armillaria root disease (*Armillaria ostoyae* [Romagnesi] Herink)	Douglas-fir, true firs, western hemlock, shore pine, Sitka spruce
	Heterobasidion root disease (*Heterobasidion occidentale* Otrosina & Garbel)	True firs, western hemlock
	Black stain root disease (*Leptographium wageneri* var. *pseudotsugae* T.C. Harr. & F.W. Cobb)	Douglas-fir
	Laminated root rot (*Coniferiporia sulphurascens* [Pilat] L.W. Zhou & Y.C. Dai)	Douglas-fir, true firs, western hemlock
	Port Orford cedar root disease (*Phytophthora lateralis* Tucker and Milbrath)	Port Orford cedar
	Tomentosus root rot (*Onnia tomentosa*)	Sitka spruce
Foliar diseases	Swiss needle cast (*Nothophaeocryptopus gaeumannii* [T. Rohde] Videira, C. Nakash., U. Braun & Crous)	Douglas-fir
	Rhabdocline needle cast (*Rhabdocline* spp.)	Douglas-fir
Heart rots	Brown trunk rot (*Fomitopsis officinalis* [Vill.] Kotl. & Pouzar)	Douglas fir, Sitka spruce, western hemlock
	Ganoderma trunk rots (*Ganoderma tsugae*, *G. applanatum*)	Douglas-fir, true fir, western hemlock, Sitka spruce
	Red ring rot (*Porodaedalea pini* [Brot.] Bondartsev & Singer)	Douglas-fir, hemlock, grand fir, Sitka spruce
	Schweinitzii root and butt rot (*Phaeolus schweinitzii* [Fr.] Pat.)	Douglas-fir, Sitka spruce, shore pine
Dwarf mistletoe	Western hemlock dwarf mistletoe (*Arceuthobium tsugense* subsp. *tsugense* (Rosend.) G.N. Jones)	Western hemlock

Table 5.3—Common invasive plant species in the OCAP assessment area, primary mechanisms of invasion, and vegetation types where each species is currently or likely to be a threat in the future based on the scientific literature and expert knowledge

Species	Mechanism of invasion	Distribution	Ecological implications
Scotch broom (*Cytisus scoparius* [L.] Link)	Roads, trails, mechanical disturbance, recreational use (windblown seed dispersal, dispersal through soil/rock material or on equipment)	All but high-elevation forests	Long-lived seed bank; monoculture Scotch broom stands; increase in nitrogen availability; competition with tree establishment; increased fire intensity; sand stabilization in dunes ecosystems
Gorse (*Ulex europaeus* L.)	Roads, trails, mechanical disturbance, recreational use (windblown seed dispersal, dispersal through soil/rock material or on equipment)	All but high-elevation forests	Long-lived seed bank; monoculture gorse stands; increase in nitrogen availability; competition with tree establishment; increased fire intensity; excessive leaf litter prevents other species from growing
Portuguese broom (*Cytisus striatus* [Hill] Rothm.)	Roads, trails, recreational use (dispersal through soil/rock material or on equipment)	Primarily limited to dunes	Long-lived seed bank; increase in nitrogen availability; competition with tree establishment; seeds toxic to ungulates; sand stabilization in dune ecosystems
Himalayan blackberry (*Rubus armeniacus* Focke), evergreen blackberry (*Rubus laciniatus* Willd.)	Roads, trails, mechanical disturbance (dispersal via wildlife or mechanical means)	All but high elevation forests	Reduced understory diversity; effects on native riparian vegetation; competition for growing space
Butterfly bush (*Buddleia davidii* Franch.)	Ornamental escape, common along roads and adjacent to private property	Limited to lower- elevation forests, particularly towards the south	Reduced understory diversity; competition for growing space
English holly (*Ilex aquifolium* L.)	Ornamental escape, common along roads and recreation sites, and adjacent to private property	Widespread	Berries attract invasive bird species (e.g., European starling), which have competitive impacts on other native bird species
English ivy (*Hedera hibernica* [G. Kirchn.] Bean)	Ornamental escape, common along roads and recreation sites, and adjacent to private property	Widespread throughout low and middle elevations	Reduced understory diversity; effects on native riparian vegetation; competition for growing space; outcompetes epiphytic lichens and bryophytes
Cotoneaster (*Cotoneaster* spp.)	Ornamental escape, more common in open disturbed areas and meadows. Also roads, trails, and mechanical disturbance (dispersal via human, wildlife, or mechanical means)	Mostly coastal	Outcompetes meadow vegetation, reducing resources for pollinators and wildlife forage.
Canada thistle (*Cirsium arvense* [L.] Scop.)	Roads, trails, mechanical disturbance, recreational use (windblown seed dispersal, dispersal through plant fragments, dispersal in soil/rock products, dispersal in seed mixes, hay, or straw)	Widespread	May form dense thickets that reduce forage value for wildlife/grazing; reduce understory diversity
Bull thistle (*Cirsium vulgare* [Savi] Ten.)	Roads, trails, mechanical disturbance, recreational use (windblown seed dispersal, dispersal in soil/rock products,	Widespread	May form dense thickets that reduce forage value for wildlife/grazing, reduce in understory diversity

	dispersal in seed mixes, hay, or straw)		
Purple foxglove (*Digitalis purpurea* L.)	Roads, trails, timber harvest areas, any disturbed area; prolific seed production and high capacity for dispersal; moved in soil and on equipment	Widespread	Competition with natives for growing space
Himalayan balsam (*Impatiens glandulifera* Royle)	Roads, trails, mechanical disturbance, escapees from horticulture; seeds are transported via moving water, recreational use; dispersal on clothing, fur, and equipment; dispersal through soil/rock material or on equipment	Widespread, could be present in high elevations and near the coast	Primarily occurs in areas with high soil moisture such as riparian areas; rapid growth, shade tolerance, and fecundity allow it to outcompete native species
Oxeye daisy (*Leucanthemum vulgare* Lam.)	Roads, trails, recreational use; meadows are high risk; mechanical disturbance (windblown dispersal, dispersal in soil/rock products, or on equipment)	Widespread	Outcompetes native vegetation, can carry crop diseases
Cat's ear (Hypochaeris radicata L.*)*	Roads, meadows are high risk, trails, recreational use, mechanical disturbance (windblown dispersal, dispersal in soil/rock products, or on equipment)	Meadows, ephemeral in forests due to lack of shade tolerance	Outcompetes native vegetation
Knotweed (*Fallopia* spp. and *Polygonum* spp.)	Bank erosion, flooding, removal of native riparian shrubs, mechanical disturbance; dispersal via broken and floating plant fragments, rhizomes, and seeds; dispersal in soil or rock products	Coastal marshes and throughout Coast Range riparian and riparian areas	Reduction in riparian plant diversity; increased bank erosion
Shiny and Robert's geranium (*Geranium lucidum* L. and *G. robertianum* L.)	Roads, trails, timber harvest areas, any disturbed area (dispersal through prolific seed production, moved in soil on equipment)	Widespread in Coast Range	Reduction in understory diversity; can create a monoculture
Tansy ragwort (*Senecio jacobaea* L.)	Roadsides, meadows, timber harvest areas (windblown dispersal)	Widespread in Coast Range	Reduction in species diversity in meadows and open forest; toxic to wildlife and stock
Groundsel (*Senecio vulgaris* L.)	Roadsides, meadows, timber harvest areas (windblown dispersal)	Widespread in Coast Range	Less common than but similar to tansy ragwort; cinnabar moth has been used as biocontrol.
St. John's wort (*Hypericum perforatum* L.)	Roadsides, meadows, timber harvest areas; windblown dispersal, then once established, expands through underground rhizomes	Widespread in drier site locations	Reduction in species diversity in meadows and open forest
False brome (*Brachypodium sylvaticum* [Huds.] P. Beauv.)	Roads, trails, mechanical disturbance, recreational use; dispersal on clothing, fur, and equipment; dispersal through	Widespread at low and middle elevations	Reduced understory diversity; loss of native habitat

	soil/rock material or on equipment		
European beachgrass (*Ammophila arenaria* [L.] Link)	Disperse by rhizomes; can spread by fragmentation; legacy of past management	Restricted to sand	Alteration of sand movement causes succession and reduces the amount of habitat available to rare plants, requiring the continual disturbance of sand movement; causes type conversion.
Yellow flag iris (*Iris pseudacorus* L.)	Garden escapee, floats downstream.	Riparian wet areas	Outcompetes emergent wetland plant species
Cheatgrass (*Bromus tectorum* L.)	Equipment, clothing, mud on tires	Xeric meadows on east and southern end of assessment area	Outcompetes native meadow grasses and forbs
Pasture grasses*	Escapees from agriculture and homestead sites; propagules can be transported on clothing, animals, and vehicles.	Particularly abundant in meadows or early-seral environment; often found in seed mixtures	Can become a monoculture and eradicate native plant community from a site

*Pasture grasses include colonial bent grass (*Agrostis capillaris* L.), creeping bent grass (*Agrostis stolonifera* L.), orchard grass (*Dactylis glomerata* L.), tall fescue (*Lolium arundinaceum* Svhreb. Darbysh), velvet grass (*Holcus lanatus* L.), and sweet vernal grass (*Anthoxanthum odoratum* L.)

Table 5.4—Projections for future wildfire activity in the OCAP assessment area, based on published studies. Most studies project area burned or other variables associated with increased area burned (e.g. fire suitability, large fire occurrence), and there are relatively few projections for fire severity

Study	Method	Geographic extent	Greenhouse gas emission scenario	Time period	Projected change from current	Suppression effects	Variable
Stavros et al. 2014	Statistical	OR,WA	RCP4.5, RCP 8.5	2031–2060	+	No	Very large fire occurrence[a]
McKenzie et al. 2004	Statistical	OR,WA	A2, B2	2070–2100	+	No	Area burned
Littell et al. 2010	Statistical	WA	A1B	2020–2080	+ 200 to 300%	No	Area burned
Turner et al. 2015	Process	Willamette Valley, OR	RCP4.5, RCP 8.5	2100	+300 to 900%	No	Area burned
Krawchuk et al. 2009	Statistical	Global	A2, B1	2070–2090	+	No	Fire probability
Spracklen et al. 2009	Statistical	OR,WA	A1B	2050	+78%	No	Area burned
Rogers et al. 2011	Process	OR, WA	A2	2070–2099	+76 to 310%/ 29-41%	Yes	Area burned/ burn severity[b]
Sheehan et al. 2015	Process	OR, WA	RCP4.5, RCP 8.5	2071–2099	-82% to 14%	Yes	Mean fire Interval
Creutzburg et al. 2017	Statistical	OR	RCP 8.5	2100	Negligible	Yes	Area burned
Parks et al. 2016	Statistical	Western US	RCP 8.5	2040–2069	No change to decrease	No	Fire severity[c]
Davis et al. 2017	Statistical	OR, WA	RCP 8.5	2071–2100	No change to increase	No	Suitability for large wildfires[d]
Littell et al. 2018	Statistical	OR, WA western Cascades	A1B	2080	+400 to 500%	No	Area burned

[a]Very large fires are defined as >20,000 ha.
[b]Burn severity is based on combustion of biomass.
[c]Burn severity is based on a post-fire composite burn index based on changes in multiple strata including soil and rock, litter and surface fuels, low herbs and shrubs, tall shrubs, and trees.
[d]Large wildfires are defined as >40 ha.

Table 6.1—A list of common names and scientific names for plants and wildlife used in Chapter 6. Scientific names and authorities sourced from ITIS (2016) and USDA (2023).

Scientific name	Common name
Trees	
Abies grandis (Dougl. ex D. Don) Lindl.	grand fir
Abies procera Rehder	noble fir
Acer macrophyllum Pursh	bigleaf maple
Alnus rubra Bong.	red alder
Arbutus menziesii Pursh	Pacific madrone
Calocedrus decurrens (Torr.) Florin	incense cedar
Fraxinus latifolia Benth.	Oregon ash
Notholithocarpus densiflorus (Hook. & Arn.) P.S. Manos, C.H. Cannon, & S.H. Oh	tanoak
Picea sitchensis (Bong.) Carrière	Sitka spruce
Pinus contorta Douglas ex Loudon var. *contorta*	shore pine
Pinus monticola Dougl. ex D. Don	western white pine
Populus balsamifera L. ssp. t*richocarpa* (Torr. & A. Gray ex Hook.) Brayshaw	black cottonwood
Pseudotsuga menziesii (Mirbel) Franco.	Douglas-fir
Thuja plicata Donn ex D. Don	western redcedar
Tsuga heterophylla (Raf.) Sarg.	western hemlock
Shrubs	
Vaccinium ovatum Pursh	evergreen huckleberry
Cornus sericea L.	red-osier dogwood
Malus fusca (Raf.) C.K. Schneid.	Pacific crab apple
Quecus garryana Douglas ex Hook.	Oregon white oak
Ribes laxiflorum Pursh	black currant
Spiraea douglasii Hook. var. *douglasii*	hardhack
Ulex europaeus L.	gorse
Vaccinium membranaceum Douglas ex Torr.	black huckleberry
Vaccinium ovalifolium Sm.	Oval-leaf blueberry
Forbs, herbs and subshrubs	
Frageria chiloensis (L.) Mill.	coast strawberry
Calochortus tolmiei Hook. & Arn.	Tolmie star-tulip
Iris tenax Douglas ex Lindl.	toughleaf iris
Limnanthes pumila Howell ssp. *Grandiflora* (Arroyo) S.C. Meyers & K.l. Chambers	big-flowered woolly meadowfoam
Lupinus oreganus A. Heller var. *kincaidii* C.P. Sm.	Kincaid's lupine

Madia satica Molina	coast tarweed
Phlox diffusa Benth.	Spreading phlox
Rubis armeniacus Focke	Himalayan blackberry
Typha latifolia L.	cattail
Viola adunca Sm.	early blue violet
Graminoids	
Festuca idahoensis Elmer ssp. *Roemeri (Pavlick) S. Aiken*	Roemer's fescue
Ammophila arenaria (L.) Link	European beachgrass
Carex californica L.H. Bailey	California sedge
Danthonia californica Bol.	California oatgrass
Festuca ammobia Pavlick	sand fescue
Poa macrantha Vasey	seashore bluegrass
Fish	
Ameiurus nebulosus (Lesueur)	Brown bullhead
Lepomis macrochirus Rafinesque	bluegill
Micropterus salmoides (Lacepède)	largemouth bass
Oncorhynchus mykiss (Walbaum)	Steelhead
Perca flavescens (Mitchill)	yellow perch
Pomoxis nigromaculatus (Lesueur in Cuvier and Valenciennes)	black crappie
Pomoxys annularis Rafinesque	white crappie
Invertebrates	
Bombus occidentalis (Greene)	western bumblebee
Branchinecta lynchi End,Belk and Eriksen	vernal pool fairy shrimp
Icaricia icarioides fenderi (Macy)	Fender's blue butterfly
Plebejus saepiolus littoralis J. Emmel, T. Emmel, and Mattoon	coastal greenish blue butterfly
Speyeria zerene hippolyta (W.H. Edwards)	Oregon silverspot butterfly
Birds	
Leucosticte tephrocotis (Swainson)	Gray-crowned Rosy-Finch
Axis sponsa (Linnaeus)	wood duck
Bonasa umbellus (Linnaeus)	ruffed grouse
Brachyramphus marmoratus (J.F. Gmelin)	marbled murrelet
Calypte anna (R. Lesson)	Anna's hummingbird
Catharus ustulatus (Nuttall)	Swainson's thrush
Charadrius nivosus nivosus (Cassin)	western snowy plover
Corvus brachyrhynchos (C.L. Brehm)	American crow

Corvus corax (Linnaeus)	common crow
Dendragapus obscurus (Say)	blue grouse
Haliaeetus leucocephalus (Linnaeus)	bald eagle
Ixoreus naevius (Gmelin)	varied thrush
Junco hyemalis (Linnaeus)	dark-eyed junco
Loxia curvirostra (Linnaeus)	red crossbills
Melanerpes formicivorus (Swainson)	acorn woodpecker
Meleagris gallopavo Linnaeus	wild turkey
Nucifraga columbiana (A.Wilson)	Clark's nutcracker
Pandion haliaetus (Linnaeus)	osprey
Patagioenas fasciata (Say)	band-tailed pigeon
Poecile atricapillus (Linnaeus)	black-capped chickadee
Selasphorus rufus (J.F. Gmelin)	Rufous hummingbird
Spinus pinus (A. Wilson)	pine siskin
Spinus tristis (Linnaeus)	American goldfinch
Strix occidentralis caurina (Merriam)	northern spotted owl
Strix varia Barton	barred owl
Troglodytes aedon (Vieillot)	house wren
Zenaida macroura (Linnaeus)	mourning dove
Mammals	
Aplodontia rufa (Rafinesque)	mountain beaver
*Arborimus albipes (*Merriam)	white-footed vole
Arborimus longicaudus (True)	red tree vole
Bos taurus Linnaeus	cow
Canis latrans Say	coyote
Castor canadensis Kuhl	American beaver
Cervus elaphus roosevelti	Roosevelt elk
Didelphis virginiana Kerr	Virginia opossum
Erethizon dorsatus (Linnaeus)	North American porcupine
Glaucomys oregonensis (Arbogast et. al. 2017)	Humboldt's flying squirrel
Martes caurina (Merriam) *humboldtensis*	*coastal marten*
Odocoileus hemionus hemionus (Rafinesque)	black-tailed deer
Peromyscus maniculatus (Wagner)	deer mouse
Procyon lotor (Linnaeus)	raccoon
Rattus rattus (Linnaeus)	black rat

Sciurus griseus Ord	western gray squirrel
Sorex vagrans Baird	vagrant shrew
Tamias townsendii (Bachman)	Townsend's chipmunk
Tamiasciurus douglasii (Bachman)	Douglas' squirrel
Usus americanus Pallas	black bear
Amphibians and reptiles	
Ambystoma macrodactylum Baird	long-toed salamander
Anaxyrus boreas (Baird and Girard)	western toad
Charina bottae (Blainville)	rubber boa
Lithobates catesbeianus (Shaw)	American bullfrog
Pseudacris regilla (Baird and Girard)	Pacific chorus frog
Taricha granulosa (Skilton)	rough-skinned newt

Table 6.2—Focal wildlife habitats and associated information relevant for assessment of and adaptation to climate change

Ecosystem	Characteristic species	Habitat features	Exposure (based on MC2 projections)	Sensitivity	Adaptive capacity	Non-climate stressors	Adaptation options
Oak savanna/ woodland	Birds—acorn woodpecker, California scrub-jay, mountain quail, wild turkey Mammals—western gray squirrel. Herpetofauna—alligator lizard, garter snake spp., gopher snake, northern red-legged frog, Pacific tree frog, racer, rough-skinned newt, rubber boa	• Oak trees: mast-producing, abundant cavities, diverse canopy structure • Diverse spatial pattern: interspersion with savanna/ grassland.	• Slight increase. • This habitat currently occurs at the eastern edge of the assesment area.	Increased susceptibility to sudden oak death, increased frequency and severity of summer drought events, and increased fire frequency could increase oak mortality.	• Active management to maintain woodland structure may be feasible in some areas. • Oaks may expand owing to resilience to drought and potential for upslope range shift.	• Sudden oak death • Invasive species • Land-use change • Recreation • Wildfire	• 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). • Establish landowner partnerships to conserve and promote this habitat type.
Sitka spruce forest (fog zone)	Birds—Marbled murrelet Mammals—Humboldt's marten, red tree vole Herpetofauna—alligator lizard, clouded salamander, coastal giant salamander, coastal tailed frog, Dunn's salamander, ensatina, garter snake spp., gopher snake, northern red-legged frog, Pacific tree frog, rough-skinned newt, rubber boa, torrent salamander spp., western red-backed salamander	• Sitka spruce • Western hemlock • Structurally complex old-growth forests • High fungal diversity and abundance	• Large expansion of habitat favorable to subtropical habitat type similar to N. California coast.	• Decreased fog would increase stress on Sitka spruce. • Cold, wet springs may result in lower reproductive fitness and increased susceptibility to pathogens. • Marine influence will have unknown influence on moderating temperature and moisture.	• Older stands may be more resilient. • Number of snags and amount of coarse woody debris may increase.	• Disease • Invasive species • Recreation • Wildire	• Continue to promote development of late-seral conditions in managed forests.
Low-/mid-elevation forest (west side)	Birds—Anna's hummingbird, marbled murrelet, red-breasted sapsucker, spotted owl, Vaux's swift Mammals—fringed myotis, Humboldt's flying squirrel, North	• Western hemlock • Douglas-fir • Western redcedar • Bigleaf maple • Structurally complex old-growth forests	• Transition from moist temperate needleleaf forest to mix of subtropical and mixed conifer forest similar to N. California coast.	• Replacement of western hemlock and western redcedar with Douglas-fir • Loss of maple recruitment without cold stratification of seeds	• Older stands may be more resilient. • Upward range shifts for some species may be limited.	• Disease • Invasive species • Land-use change • Recreation • Wildfire	• Continue development of late-seral conditions in managed forests. • Promote shade-tolerant tree species (including western redcedar) following thinning.

	American porcupine, red tree vole, Roosevelt elk, sooty grouse Herpetofauna—alligator lizard, clouded salamander, coastal giant salamander, coastal tailed frog, Dunn's salamander, ensatina, garter snake spp., gopher snake, northern red-legged frog, Pacific tree frog, racer, rough-skinned newt, rubber boa, torrent salamander spp., western red-backed salamander	• Berry-producing shrubs including *Vaccinium* spp.	• Warm winter regime.	• Loss of endemic habitat types			
Low/mid elevation forest (east side)	Birds—Anna's hummingbird, red-breasted sapsucker, Sooty grouse, Vaux's swift Mammals—fringed myotis, Humboldt's flying squirrel, North American porcupine, red tree vole Herpetofauna—alligator lizard, clouded salamander, coastal giant salamander, coastal tailed frog, Dunn's salamander, ensatina, garter snake spp., gopher snake, northern red-legged frog, Pacific tree frog, racer, rough-skinned newt, rubber boa, torrent salamander spp., western red-backed salamander	• Western hemlock • Douglas-fir • Western hemlock • Bigleaf maple • Grand fir • Western redcedar • Incense cedar • Structurally complex old-growth forests	• Transition from moist temperate needleleaf forest to mix of subtropical and mixed conifer forest similar but than for the west side.	• Replacement of western hemlock, western redcedar. and grand fir with Douglas-fir. • Loss of western hemlock, especially at western edge of assessment area. • Loss of maple recruitment without cold stratification of seeds.	• Older stands may be more resilient. • Some species (e.g., grand fir) may shift upward.	• Disease • Invasive species • Land-use change • Recreation • Wildfire	• Continue development of late-seral conditions in managed forests. • Promote shade-tolerant tree species (including grand fir, western redcedar, and incense cedar) following thinning.
Coastal meadows and grasslands	Birds—rufous hummingbirds, Mammals—Roosevelt elk Herpetofauna—alligator lizard, garter	• Early blue violet • Native grasses and forbs	• More extreme weather events and warmer winters	• Some loss of habitat due to sea-level rise. • Possible conversion to forest in fog-dependent locations.	• Adaptability will be minimal without management intervention.	• Disease • Invasive species • Land-use change • Recreation	• Restore meadows to native grasses and forbs. • Restore habitat type to manage forest encroachment • Remove nonnative grasses and blackberries.

	snake spp., gopher snake, rubber boa, racer Invertebrates— coastal greenish-blue butterfly, Oregon silverspot butterfly						
Montane forest and meadows	Birds—gray-crowned rosy finch, rufous hummingbird, snow bunting Mammals—Humboldt's flying squirrel, Roosevelt elk Herpetofauna—alligator lizard, clouded salamander, coastal giant salamander, coastal tailed frog, Dunn's salamander, ensatina, garter snake spp., gopher snake, northern red-legged frog, Pacific tree frog, racer, rough-skinned newt, rubber boa, torrent salamander spp., western red-backed salamander Invertebrates—native butterflies and bumblebees, Oregon silverspot	• Noble fir • High-elevation rocky meadows	• More extreme precipitation events in winter, change in annual amount of moisture, more winter flooding, higher summer temperatures and evapotranspiration, more drought stress.	• Patches of noble fir and silver fir restricted or eliminated. • Loss of snowpack. • Loss of specialist bumblebees and butterflies owing to loss of high-elevation forbs. • Continued forest encroachment into meadows.	• Forest habitat may persist on some north-facing slopes.	• Disease • Invasive species • Land-use change • Recreation	• Restore habitat type to manage forest encroachment.
Aquatic and wetlands (lacustrine, palustrine, riverine, dune wetlands)	Birds—bald eagle, purple martin, rufous hummingbird, Mammals—American beaver, mountain beaver, Herpetofauna—alligator lizard, clouded salamander, coastal giant salamander, coastal tailed frog, Dunn's salamander, ensatina, garter snake spp., gopher snake, northern red-legged frog, Pacific tree frog, racer, rough-skinned newt, rubber boa,	• Wetland-associated habitats • Riparian areas dominated by hardwood communities	• More extreme weather events and warmer winters.	• More intense flooding (spring) and drought (summer). • Sea-level rise will reduce amount of dune wetlands.	• Fluvial processes will continue, compensating for altered water flow. • Redirection of stream and riverbed paths and erosion of hillslopes adjacent to waterways may not be desirable in some locations.	• Invasive species • Land-use change • Recreation	• Restore beavers to aquatic systems to increase water storage capacity. • Augment coarse woody debris in streams. • Increase efforts to restore degraded wetlands throughout watersheds.

	torrent salamander spp., western pond turtle, western red-backed salamander. Invertebrates—vernal pool fairy shrimp.						
Marine and estuarine (including dunes and beaches)	Birds—bald eagle, black oystercatcher, peregrine falcon, purple martin, red knot, western snowy plover Herpetofauna—northern red-legged frog, Pacific tree frog. Invertebrates—hairy-necked tiger beetle, hoary elfin butterfly	• Sea cliffs • Sandy beaches • Sand dunes • River estuaries	• Higher sea levels, warmer and drier conditions.	• Increased cliff erosion owing to sea-level rise and increase in weather volatility.	• A slight shift of habitat may occur inland as sea level rises.	• Invasive species • Recreation • Land-use change • Highways	• Remove nonnative vegetation from dunes, including European beachgrasses, gorse, and Himalayan blackberry. • Remove dikes in estuarine areas.
Dune shrub forest	Birds—Anna's hummingbird, varied thrush Mammals—Humboldt's marten, North American porcupine, white-footed vole Herpetofauna—alligator lizard, garter snake spp., gopher snake, Pacific tree frog, rough-skinned newt, rubber boa, racer, western toad	• Lodgepole pine • Dense shrub habitat	• Higher sea levels, warmer and drier conditions.	• Reduced habitat extent owing to sea-level rise.	• This habitat has limited capacity to adapt.	• Invasive species • Recreation • Land-use change • Highways	• Remove nonnative vegetation from dunes, including European beachgrasses, gorse, and Himalayan blackberry.

Table 7.1. Selected highly valued places for recreation in the OCAP assessment area

Name	Location	Unique or special values
Nestucca Bay National Wildlife Refuge	Pacific City	The largest of six national wildlife refuges on the Oregon Coast. Provides wintering habitat for the dusky Canada goose (*Branta canadensis occidentalis* Baird) (a species of concern). Protects a range of habitat types, including tidelands, coastal prairies, coastal bogs, and upland forests; these habitats support numerous species of waterfowl, songbirds, and birds of prey, along with coho salmon (*Oncorhynchus kisutch* Walbaum), estuarine mammals, and Oregon silverspot butterfly (*Speyeria zerene hippolyta* W. H. Edwards). Provides outstanding opportunities for birding and viewing other wildlife. Includes several short trails with scenic views.
Yaquina Head Outstanding Natural Area	Newport	A narrow coastal headland extending 1.5 km into the ocean. Features an interpretive center and the tallest lighthouse on the Oregon Coast (built in 1872). Tall basalt cliffs provide vantage points for scenic views and year-round whale watching. The southern shoreline is an excellent location for exploring tidepools. Provides spring nesting habitat for falcons and thousands of seabirds, while numerous shorebird species occupy the area throughout the year. Marine mammals can often be seen at low tide at the base of the Head.
Marys Peak Scenic Botanical Area	West of Corvallis	The tallest point in the Oregon Coast Range, with expansive views of the Oregon Cascades, Willamette Valley, and coastal mountains. Located near several Willamette Valley population centers. The area is well known for its distinctive plant communities. The top of the peak includes a large meadow and an unusual stand of noble fir. Excellent wildflower viewing opportunities are available in the spring and summer. Also provides a campground, hiking trails, and mountain biking trails. Snow-based recreation is possible in the winter.
Cape Perpetua Scenic Area	Yachats	Includes 1,100 ha of coastal habitat, including rocky shorelines and upland late seral forests. The Cape Perpetua headland is the highest car-accessible viewpoint on the Oregon Coast. Provides an interpretive center with field programs, a large campground, and a 42-km network of non-motorized, forested trails. Includes distinctive scenic features on the coastline: Devil's Churn, Cook's Chasm, and Thor's Well. Adjacent to the Cape Perpetua Marine Reserve. The trail network was originally built by the Civilian Conservation Corps. Evidence of human use in this area dates back at least 6,000 years.
Oregon Dunes National Recreation Area	Florence to Coos Bay	One of the largest temperate costal sand dune systems in the world. Covers 12,700 ha along 64 km of coastline. Features a large network of off-road vehicle trails and open sand riding areas. The area also provides beach access, dunes-adjacent campgrounds, scenic vistas, and non-motorized trails on the sand. Beachside areas support habitat for the snowy plover, and inland areas host a wide array of terrestrial species. The sand dunes near Reedsport are especially tall and expansive. Includes excellent opportunities to learn about sand dune ecology and the dune habitat.

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Table 7.2—Participation by visitors for whom this was their primary activity, Siuslaw National Forest, 2016

	Percent	*Number*	
Warm-weather activities	**62.0**	**926,900**	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. Although participation generally peaks in summer when schools are out and weather is warmest, the OCAP assessment area has year-round warm-weather activities due to its relatively mild climate and low elevations.
Hiking/walking	27.0	403,650	
Viewing natural features	26.2	391,690	
Developed camping	2.3	34,385	
Bicycling	1.0	14,950	
Other non-motorized	1.1	16,445	
Picnicking	0.9	13,455	
Primitive camping	0.3	4,485	
Backpacking	0	0	
Driving for pleasure	3.1	46,345	
Horseback riding	0.1	1,495	
Winter activities	**0.3**	**4,485**	Participation depends on the timing and amount of precipitation as snow and cold temperatures to support consistent snow coverage; inherently sensitive to climatic variability and interannual weather patterns.
Downhill skiing	0	0	
Snowmobiling	0.3	4,485	
Cross-country skiing	0	0	
Wildlife activities	**4.5**	**67,275**	Temperature and precipitation are related to habitat suitability through effects on habit (i.e., vegetation, productivity of food sources, water quantity and temperature [for aquatic species]), and species interactions. Disturbances (e.g., wildfire, invasive species, insect outbreaks) may affect the amount, distribution, and spatial heterogeneity of suitable habitat. For some species-specific activities (e.g., salmon fishing), altered seasonality and climate-related events (e.g., upwelling) may affect recreation patterns and/or availability of the activity.
Hunting	0.7	10,465	
Fishing	2.6	38,870	
Viewing wildlife	1.2	17,940	
Gathering forest products	**1.3**	**19,435**	Participation depends on the availability and abundance of target species (e.g., berries, mushrooms), which are related to patterns of temperature, precipitation, and snowpack. Disturbances may alter the availability and productivity of target species in current locations and affect opportunities for species dispersal.
Water-based activities	**0.2**	**2,990**	Participation requires sufficient water flows (in streams) and levels (in lakes). Water-based recreation is 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.
Non-motorized activities	0.2	2,990	
Motorized activities	0	0	
Other	**10.8**	**161,460**	
Relaxing	7.2	107,640	
Nature center activities	0.5	7,475	
Visiting historic sites	0.3	4,485	
Resort use	0	0	
Nature study	0.2	2,990	
Some other activity	2.6	38,870	
Motorized recreation	**21.7**	**324,415**	
OHV use	14.2	212,290	
Motorized trail activity	2.6	38,870	
Other motorized	4.4	65,780	
No activity reported	**0.2**	**2,990**	
Total (estimated)		**1,490,515**	

Table 7.3—Estimated total annual expenditures by visitors to Siuslaw National Forest

Spending category	Non-local spending		Local spending	
	Total annual expenditures	Spending by category	Total annual expenditures	Spending by category
	Dollars	*Percent*	*Dollars*	*Percent*
Motel	13,441,181	27.4	310,212	4.7
Camping	2,539,597	5.2	347,867	5.2
Restaurant	9,627,541	19.6	1,022,647	15.4
Groceries	6,565,845	13.4	1,549,671	23.3
Gas and oil	8,841,063	18.0	2,309,284	34.8
Other transportation	350,437	0.7	29,063	0.4
Entry fees	1,328,513	2.7	277,369	4.2
Recreation and entertainment	2,675,086	5.5	231,972	3.5
Sporting goods	1,273,312	2.6	387,471	5.8
Souvenirs and other expenses	2,433,442	5.0	173,980	2.6
Total	49,076,017		6,639,534	

Table 8.1—Nontimber forest products (NTFPs) with allowed harvest in the OCAP assessment area[a]

NTFP[b c]	US Forest Service	Bureau of Land Mgmt.	Oregon Dept. of Forestry
PLANTS			
Baltic rush (*Juncus balticus* Willd.)	X		
Beargrass. (*Xerophyllum tenax*)	-	X	X
Bigleaf maple (*Acer macrophyllim* Pursh)	X	X	
Bitter cherry (*Prunus emarginata* Dougl. Ex Hook)	X		
Black cottonwood (*Populus trichocarpa* Torr. & A. Gray ex. Hook.)		X	
Bleeding heart (*Dicentra Formosa* Andrews Walp.)		X	
Blue elderberry (*Sambucus cerulea* Raf.)		X	
Bracken fern (*Pteridium aquilinum* Gled. Ex Scop.)	X	X	X
California bay laurel (*Umbellurlaria californica* Hook. & Arn.) Nutt.)		X	
Cascara (*Frangula purshiana* (DC.) A. Gray ex J.G. Cooper)	X	X	X
Comm. Foxglove (*Digitalis purpurea* L.)	-	X	
Comm. Mullein (*Verbascum thapsus* L.)		X	
Currants (*Ribes spp.*)		X	
Deer fern (*Struthiopteris spicant* (L.) F.W.Weiss)	X		
Devil's club (*Oplopanax horridus* (Sm.) Miq.)		X	
Dogwood (*Cornus spp.*)		X	
Douglas-fir (*Pseudotsuga menzieii*)	X	X	
Douglas spirea (*Spiraea douglasii* Hook.)	X		
Engelmann spruce (*Picea engelmannii* Parry ex Engelm.)		X	
False lily-of-the-valley (*Maianthemum dilatatum* (Alph. Wood) A.Nelso & J.F.Macbr)	X		
False Solomon's seal (*Maianthemum racemosum* (L.) Link)	X		
Fern fiddleheads			X
Grand fir (*Abies grandis* (Douglas ex D. Don) Lindley)		X	
Green sedge (*Carex viridula* Michx.)	X		
Horsetail (*Equisetum arvense* L.)		X	
Huckleberry (*Vaccinium spp.*)	X	X	X
Mock orange (*Philadelphus lewisii* Pursh)		X	
Moss			X
Noble fir (*Abies procera* Rehder)		X	
Oregon grape (*Mahonia aquifolium* (Pursh) Nutt.)	X	X	X
Oregon iris (*Iris tenax* Dougl. Ex Lindl.)	X		
Oregon white oak (*Quercus garryana* Douglas ex Hook.)		X	
Oxeye daisy (*Leucanthemum vulgare* Lam.)	X		
Pacific madrone (*Arbutus menziesii* Pursh)		X	
Pacific rhododendron (*Rhododendron macrophyllum* D. Don & G. Don)	X	X	
Pacific silver fir (*Abies mabilis* Douglas ex J.Forbes)		X	
Pacific yew (*Taxus brevifolia* Nutt.)			X
Pearly everlasting (*Anaphalis margariacea* (L.) Benth. & Hook.f.)	X	X	
Queen Anne's lace (*Daucus carota* L.)	X		
Red alder (*Alnus rubra* Bong.)	X	X	X
Red elderberry (*Sambucus racemose* L.)		X	
Red flowering current (*Ribes sanguineum* Pursh)	X		
Sagebrush (*Artemisia spp.*)		X	
St. John's wort (*Hypericum perforatum* L.)		X	
Salal (*Gaultheria shallon* Pursh)	X	X	X
Salmonberry (*Rubus spectabilis* Pursh)	X		
Salt rush (*Juncus lesueurii* Bol.)	X		
Serviceberry (*Amelanchier spp.*)	-	X	
Shore pine (*Pinus contorta* Douglas)	X		
Sitka spruce (*Picea sitchensis* (Bong.) Carr.)	X		
Slough sedge (*Carex obnupta* L.H.Bailey)	X		
Snowberry (*Symphoricarpus spp.*)		X	
Subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.)		X	
Western columbine (*Aquilegia formosa* Fisch. Ex DC.)		X	
Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)	X	X	
Western larch (*Larix occidentalis* Nutt.)		X	
Western redcedar (*Thuja plicata* Donn ex D.Don)	X	X	
Western white pine (*Pinus monticola* Dougl. Ex D.Don)		X	
Western yarrow (*Achillea millefolium* L.)	X		
White fir (*Abies concolor* (Gordon) Lindley ex Hildebrand)		X	
Wild ginger (*Asarum caudatum* Lindl.)		X	
Wild onion (*Allium validum* S.Wats.)		X	
Wild strawberry (*Fragaria virginiana* Mill.)		X	
Willow (*Salix spp.*)	X	X	
Wood sorrel (*Oxalis oregana* Nutt.)	X		
Wood violet (*Viola odorata* L.)	X		
FUNGI			
Bolete	X	X	
Cauliflower mushroom (*Sparassis spp.*)	X	X	
Chanterelles (*Cantharellus spp.*)	X	X	
Chicken of the woods (*Laetiporus spp.*)	X	X	
Craterellus spp.	X	X	
Coral fungus (*Ramaria spp.*)	X	X	
Hedgehog mushroom (*Hydnum repandum* L.)		X	
Lobster mushroom (*Hypomyces lactifluorum* (Schwein.) Tul. & C.Tul.)	X	X	
Matsutake (*Tricholoma matsutake* (S.Ito & Imai) Singer)	X	X	
Morel (*Morchella spp.*)	X	X	
Mushrooms (unspecified)	X		X
Oregon white truffle (*Tuber oregonense* Trappe, Bonito & Rawlinson)		X	
Oyster mushroom (*Pleurotus ostreatus* (Jacq.) P.Kumm.)	X		

Incense cedar (*Calocedrus macrolepis* Kurz)		X		Sword fern (*Polystichum munitum* (Kaulf.) C.Presi)	X	X	X	Pigs ear (*Gomphus clavatus* (Pers.) Gray)	X		
Labrador tea (*Rhododendron columbianum* (Piper) Harmaja)	X			Thimbleberry (*Rubus parviflorus* Nutt.)	X			Quinine conk (*Laricifomes officinalis* (Vill) Kotl. & Pouzar)		X	
Lady fern (*Athyrium spp.*)	X	X		Twinberry (*Lonicera involucrate* (Richardson) Banks ex Spreng.)	X			Shaggy mane (*Coprunis comatus* (O.F. Müll.) Pers.)	X		
Licorice fern (*Polypodium glycyrrhiza* D.C. Eaton)	X			Twinflower (*Lonicera involucrate* (Richardson) Banks ex Spreng.)		X		Slippery jack (*Suillus luteus* (L.) Roussel)	X		
Lodgepole pine (*Pinus contorta* Douglas)		X		Vine maple (*Acer circinatum* Pursh)	X	X	X				
Manzanita (*Arctostaphylos spp.*)		X	X	Wax myrtle (*Myrica gale* L.)	X						

[a] Additional harvesting restrictions or conditions may exist depending on specific location, administrative unit, part harvested (e.g., bark), quantity harvested, species, conservation status, and whether the harvest is for commercial or personal use. Some land managers consider additional NTFPs upon request.
[b] NTFPs are presented primarily by common name to remain consistent with land manager listings. As such, some NTFP names represent individual species, whereas others represent a genus or a larger grouping (e.g., moss).
[c] Some land managers group NTFPs into special forest product categories without explicitly listing component species. These categories include poles, boughs, shrubs, foliage, cuttings, transplants, seeds, and seedlings. Therefore, not every allowable NTFP species may be represented in this table.

Table 8.2—Climate vulnerability considerations for harvesters of nontimber forest products (NTFPs) (adapted from Jones and Lynch [2002])

Harvester category	Motivations	Climate vulnerability considerations
Subsistence harvester	Harvesting is primarily for household consumption but may include small-scale trade and sale.	Some species will expand their ranges while others will contract. Increase competition with other harvester groups for species with diminishing ranges.
Cultural/ spiritual harvester	NTFP species and/or place that it grows is sacred/spiritual. The act of harvesting/ processing/consuming is a cultural/spiritual practice. Harvesting is part of stewardship relationship with a NTFP species and/or the place that it grows.	Some Native American groups hold treaty rights and/or other privileges to harvest traditional cultural NTFPs on ceded and/or ancestral lands. Harvesters may need to travel longer distances to find target species if species distribution shifts. Access may be lost if NTFP distribution shifts onto private lands or if land ownership becomes fragmented. Increased competition with other harvester groups for species with diminishing ranges.
Recreational harvester	Small-scale harvesting for pleasure. Berries and mushrooms most common. May be casual secondary activity associated with primary recreational pursuit such as hiking or camping.	Small-scale effects. Increased competition with other harvester groups for species with diminishing ranges.
Botanical medicine practitioner/ herbalist	Target species are plants and fungi used for medicine.	Some habitats may decrease (e.g., meadows, riparian), others may increase. New species may enter current habitats. Competition with commercial harvesters for species with diminishing ranges may increase.
Commercial harvester	Harvesting for sale or trade.	Economic motivations may result in unsustainable harvesting practices. May affect other harvester types owing to the large volume harvested. Could impart ecological benefits through removal of invasive or undesirable NTFPs.
Scientific harvester	Harvest for scientific study and research.	Controlled through research permits. Sustainable harvest studies can inform ecosystem management planning.

Table 8.3—Effects of climate change on culturally significant plants found in the OCAP assessment area

Species	Cultural value	Habitat	Climate change risk
Camas (*Camassia* spp.)	Harvested in the summer and typically pit-cooked, camas bulbs were an important staple food in the Pacific Northwest and were widely traded (Stevens et al. 2000).	Seasonally wet areas including meadows and rock gardens. Indigenous management employed burning to maintain meadow habitat.	Wet habitats are already limited. Altered seasonality could lead to earlier soil drying during growing season, further constricting habitat.
Beargrass (*Xerophyllum tenax*)	Leaves are harvested in the summer after the blooms have died. Primarily used in basketry and as elements of ceremonial head rolls, necklaces, and dance aprons (Anderson et al. 2015). Also has value as browse for deer and elk.	Found in many forest types throughout its range, it is located within pockets of high-elevation Pacific silver fir forests. It responds well to disturbances such as wildfire.	High-elevation areas are small and isolated in the Oregon Coast Range, leaving them vulnerable to colonization and replacement by low-elevation species as the climate warms. Populations could also increase in the short to medium term with new and larger openings related to disturbance.
Huckleberry/ blueberry (*Vaccinium* spp.)	An important traditional food harvested in late summer and dried for later use. Harvest time is a period of celebration by tribal people (Richards and Alexander 2006).	Occupy wet sites such as coastal fens as well as higher-elevation sites in the silver fir zone. Some species benefit from disturbance-caused openings (Chamberlain et al. 2018).	Occupies wet and high-elevation habitats. Changing climatic conditions could cause phenology mismatches with pollinators. More disturbance could increase colonization but reduce berry production.
Salal (*Gaultheria shallon*)	Berries serve as an important food source when dried and mashed into cakes for later use (Tirmenstein 1990).	Dominant shrub species found in many forest types. Commonly found in well-drained soils in the western hemlock and Sitka spruce zones.	Tolerance of diverse environmental conditions imparts high adaptive capacity. However, habitat suitability could decrease by the end of the 21st century (Prevéy et al. 2020a).
Beaked hazelnut (*Corylus cornuta* var. *californica* Marshall)	Stems and shoots are gathered in spring; nuts are gathered in late summer/early fall. Nuts are used for subsistence; stems and shoots are used in basketry, fish traps, and other products (Native Plants PNW 2016, Young-Mathews 2011).	Typically grows as an understory species in moist, well-drained soils in open forests and forest edges. Indigenous management included periodic burning.	Tolerance of diverse environmental conditions imparts high adaptive capacity. However, habitat suitability could decrease by the end of the 21st century (Prevéy et al. 2020a).

Table 8.4—Summary of metrics describing selected ecosystem services in Siuslaw National Forest (SIU) and Northwest Oregon (NWOR) and Coos Bay (CB) BLM Districts

Unit (Area, x1,000 hectares) \ Ecosystem Service	Timber Volume[a] (million board feet sold)	Non-timber Forest Products[b]: Christmas Trees (Permits)	Mushrooms (pounds)	Non-timber Wood/ Firewood (million board feet sold)	Decorative and Craft Plants (limbs, boughs, foliage, cones, etc. in pounds)	Transplants (number)	Carbon Stock[c] (metric tonnes per hectares)	Recreation[d] (visits x1,000)	Water Supply[e] (millions of cubic meters)
SIU (255)	36	257	44,664	4.3	2,972,240	1,673	405	1,495	4,138.4
NWOR (289)	109	29	127,996	0.25	573,589	3,220	487	1,526*	Unavailable
CB (130)	38	170	126,551	0.19	68,768	0	469	775	Unavailable

Sources:

[a] **Timber** volume sold in 2013–2018, from USFS Pacific Northwest Region and Northwest Oregon BLM natural resources staff.

[b] **Forest products** harvested in 2013–2018, from USFS Pacific Northwest Region and Northwest Oregon BLM natural resources staff.

[c] **Carbon** estimate for: (1) 2013, Siuslaw National Forest, from USDA FS (2015); and (2) 2013, BLM units, from BLM (2016).

[d] **Recreation** estimate for (1) 2016, Siuslaw National Forest, from USFS National Visitor Use Monitoring program; and (2) 2016, BLM Northwest Oregon District from data provided by their recreation staff (*Northwest Oregon BLM recreation is only for resource areas within the OCAP assessment area).

[e] **Water supply** estimate is mean annual renewable water supply for 1981 to 2010 (Brown et al. 2016).

Note: Graphics are public domain; tent graphic designed by Brgfx / www.freepick.com; water-drop graphic from www.vexels.com.

Table 8.5—Summary of anticipated responses to climate change for selected ecosystem services in the OCAP assessment area

Ecosystem Service	Anticipated Response to Climate Change	Sources of uncertainty	Where most applicable?
Timber	↑↓ Direct effects—temperature-driven productivity gains potentially offset by increased summer water deficits and drought stress in drier areas; warmer conditions favor hardwoods ↓ Indirect effects—increase in disturbance events and interactions among disturbance types	CO_2 fertilization, phenology, species interactions, invasives, model results	Moist forests
Christmas Trees	↓ Preferred fir species increasingly lose habitat at lower-elevation species migrate upwards	Model results (MC2 and GCMs), disturbance, changes to desired traits/quality	High-elevation areas within the study area
Mushrooms	↑↓ Key infomation gap is understanding how different taxa will respond to changing conditions, as well as relationship to their associate plant species. Generally warm and wetter conditions in the fall could benefit certain fungi species as well as those that prefer disturbed sites. Drier sites may experience lower productivity.	Disturbance size and severity, precipitation patterns.	Moist forests
Non-timber Wood	↑ Increased productivity from warmer growing season and potential for increase in hardwood component of coastal forests ↓ Disturbance	Disturbance, productivity (warming vs. water deficit)	Moist forests
Decorative and Craft Plants	↑↓ Disturbance related effects to habitat quality and species composition, but some species may benefit from more disturbance, habitat fragmentation could limit migration to suitable areas ↓ Increasing demand risks overharvest	Individual species response, phenology, invasives, changes to quality/valued traits	Varies with species preferred habitat
Transplants	↑↓ See decorative and craft plants	See above	See above
Carbon	↑↓ Dependent on balance of productivity gains to increased temperature and water deficit, amount and severity of disturbances, distribution of communities resilient to disturbance, changes in species composition, and changes to cycling within and transfer among forest carbon pools	Disturbance, precipitation patterns, decay rates, CO_2 fertilization and nutrtient cycling	Full study area
Recreation	↑ Increased length in shoulder season for warm-weather activities. Increased preference of coastal recreation as heat, fire, and smoke issues increase in the rest of the region ↓ Intensification of winter storms and sea-level rise leave recreation infrastucture vulnerable to flooding, landslides, and erosion	Extreme heat, fire/smoke effects on warm-weather and other activities	Recreation sites adjacent to water features
Water	↑↓ Timing and quantity: Increase in seasonality of precipitation could lead to late-summer shortfalls exacerbated by increased population and development ↓ Quality: Higher temperatures and sedimentation stresse fish and aquatic habitat as well as delivery and wastewater infrastucture of small municipalities with low adaptive capacity	Model results (VIC and GCMs), precipitation patterns	Full study area

Table 9.1—Adaptation options for hydrology and water resources in the OCAP assessment area

Sensitivity to climatic variability and change: Altered precipitation and sea-level rise will lead to changes in timing and volume of peak flows.

Adaptation Strategy / Approach: Increase resilience of depositional floodplains by increasing connectivity.

Tactic	**Specific Tactic – A**	**Specific Tactic – B**	**Specific Tactic – C**
	Reintroduce American beavers and make use of beaver dam analogs (BDAs)	Conduct land swaps/acquisitions to increase the scale and connectivity of floodplain restoration	Add roughness/large woody debris (LWD) to stream channels to slow streamflow and reduce erosion
Where can tactics be applied?	Degraded wetlands; low-gradient stream systems; intersections with tidal zones; spawning areas; high-use areas	Low-gradient depositional valleys with salmon habitat and complex private/public ownership; locations where private landowners are concerned about flooding	After wildfires when snags can fall in streambeds; depositional valleys; degraded aquatic habitat; areas where wood removal and splash damming took place; high-gradient, erosion-prone streams
Opportunities for implementation	Partnerships with non-governmental organizations (NGOs) and others (e.g., Oregon Water Resources Department, watershed groups, beaver coalition); overlap with Oregon Coho Salmon recovery plan; 2018 Farm Bill source water protection program	Funds from stewardship sales; work with local land trusts; collaboration with stewardship groups; Land and Water Conservation Fund; Great American Outdoors Act; collaboration with Job Corps	Implement in collaboration with Job Corps

Sensitivity to climatic variability and change: Altered timing and volume of peak flows may make infrastructure more vulnerable.

Adaptation Strategy / Approach: Increase resilience of transportation system to peak flows.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Upsize culverts where peak flows are expected to increase	Relocate, harden (storm proof), decommission, or hydraulically close vulnerable roads	Conduct post-fire restoration in watersheds with vulnerable infrastructure.
Where can tactics be applied?	High-elevation watersheds, fire-prone or burned areas; low-elevation crossings where tidal surge can increase flooding	Infrastructure in floodplains; infrastructure on unstable slopes; roads with undersized culverts that will not be used in the future; high-use roads and critical roads (emergency use, egress, etc.)	Vulnerable areas identified using the Burned Area Emergency Rehabilitation (BAER) process; high-use recreation sites; drinking-water source areas; unstable slopes; utility corridors (can prepare infrastructure pre-disturbance)

Table 9.1 (continued)—Adaptation options for hydrology and water resources in the OCAP assessment area

Opportunities for implementation	Oregon Watershed Enhancement Board; salmon recovery efforts, habitat restoration; BAER projects; timber sales (where feasible); NGO partnerships to improve infrastructure outside of national forests; KV Act retained receipts; Great American Outdoors Act (national asset management program); Oregon Department of Transportation Emergency Relief for Federally Owned Roads (ERFO), through Federal Highway Administration	Same opportunities as Specific Tactic A	Silver Jacket organizational approach; BAER projects; partnerships with watershed stewardship groups; partnerships with counties, cities; private landowners (e.g., Natural Resource Conservation Service. Environmental Quality Incentives Program); industrial forest landowners; cross-boundary management; potential Oregon Department of Environmental Quality (ODEQ) 303d funding

Sensitivity to climatic variability and change: Water quality may decrease because of increased stream temperatures, sedimentation, and algal blooms.
Adaptation Strategy / Approach: Protect or improve water quality for aquatic and human systems.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Increase shade in riparian areas in low-elevation streams (where stream temperature is expected to increase)	Restore riparian areas to reduce sediment inputs (e.g., modify harvest practices, conduct vegetation treatments, restore streamflow processes, disconnect roads, implement BDAs, create fire breaks)	Improve early warning systems and public health communication
Where can tactics be applied?	Where stream temperature is expected to increase; low-gradient depositional watersheds (use valley confinement algorithm to identify vulnerable locations)	Headwalls (headwaters, high-elevation watersheds); watersheds that provide drinking water; low-gradient depositional watersheds (use valley confinement algorithm to identify vulnerable locations)	USFS recreation sites and wells; private, undocumented wells (widespread); freshwater lakes, reservoirs, slack water, swimming areas, beaches; where traditional foods and harvesting occur
Opportunities for implementation	Salmon habitat restoration; Job Corps; watershed councils	Use landslide risk map to identify vulnerable locations; develop partnerships with watershed groups	Existing monitoring efforts; Oregon Health Administration; ODEQ; monitoring with citizen science; algal blooms (use CyAN app); tribal partnerships; NGO partnerships

Table 9.2—Adaptation options for fisheries and watersheds in the Oregon Coast Adaptation Partnership assessment area

Sensitivity to climatic variability and change: Increased flood frequency, higher peak flows, lower summer flows, and warming stream temperatures may alter habitat quality and reduce survival.

Adaptation Strategy / Approach: Increase habitat resilience and access to upstream habitat refugia (summer thermal refugia and winter flow refugia) by restoring stream and floodplain structure and processes.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Remove or replace barriers (e.g., culverts, tide gates) to increase connectivity to allow fish to move to other areas when wildfires occur	Introduce or maintain beaver habitat by incorporating BDAs	Restore stream channels to allow for floodplain connectivity so that beavers can establish dams to provide fish and macroinvertebrate habitat
Where can tactics be applied?	Forest-wide; prioritize near areas with high intrinsic potential, lower in the network, areas with low fire risk or high resistance to fire, streams with low gradients, and small, cold tributaries; areas with lower low-flows where connectivity of water remains; areas that may support recolonization by fish (lakes, estuaries, side channels, other tributaries)	Low-gradient areas where beaver food is available; Prescribed Burn Risk Assessment Tool can be used to identify these locations; locations that are conducive to BDAs	Main-stem rivers; river floodplains
Opportunities for implementation	Salmon Super Highway; atershed councils; Soil and Water Conservation Districts (SWCDs); USFS work with engineers (deferred maintenance); Natural Resources Conservation Service (NRCS); Oregon Department of Transportation (ODOT); Oregon Department of Fish and Wildlife (ODFW); Oregon Water Resources Department	Same opportunities as Specific Tactic A	Same opportunities as Specific Tactic A

Table 9.2 (continued)—Adaptation options for fisheries and watersheds in the OCAP assessment area

Sensitivity to climatic variability and change: Changes to estuaries and lower flows in rivers will affect key habitats for fishes, especially for those that use estuaries to transition to the ocean.
Adaptation Strategy / Approach: Increase habitat connectivity for fishes using estuaries to allow more habitat while they transition.

	Specific Tactic – A	Specific Tactic – B	Specific Tactic – C
Tactic	Remove tide gates and allow flooding to occur on federal lands, thus increasing the amount of water held on land and creating winter habitat	Not identified	Not identified
Where can tactics be applied?	Tide gate locations; floodplains that provide critical habitat		

Sensitivity to climatic variability and change: Increased flood frequency, higher peak flows, and lower summer flows will affect the ability of fishes to use limited floodplain habitats and access coastal lakes.
Adaptation Strategy / Approach: Increase habitat connectivity by reducing stressors caused by roads and infrastructure in the floodplain or by dams on coastal lakes.

	Specific Tactic – A	Specific Tactic – B	Specific Tactic – C
Tactic	Increase floodplain habitat by decommissioning roads and maintaining access to coastal lakes	Not identified	Not identified
Where can tactics be applied?	Areas where roads are vulnerable or in disrepair; roads and crossings that restrict habitat connectivity		

Sensitivity to climatic variability and change: Sedimentation and stream temperature will increase following wildfires, which will likely occur more frequently with climate change.

Adaptation Strategy / Approach: Reduce sedimentation associated with erosion, wildfire, and trails, while increasing connectivity to allow fish movement.

	Specific Tactic – A	Specific Tactic – B	Specific Tactic – C
Tactic	Develop natural fire breaks; manage timber to achieve mosaic pattern of fire severity for both wildfire and prescribed fire (pre fire)	Identify areas near fish habitat that are more important than other locations to limit post-fire timber harvest (outside of riparian areas and high-risk landslide areas) (post fire)	Restore riparian areas to increase canopy diversity and to encourage fire breaks and shading as well as control invasive plant populations; promote wider spacing of shade-providing trees and reduce fuel loading (thin/harvest dense stands)

Table 9.2 (continued)—Adaptation options for fisheries and watersheds in the OCAP assessment area

Where can tactics be applied?	Fire-prone areas; riparian areas with critical habitat; timber, fuels, and restoration projects	Recently burned areas; spawning habitats; coldwater refugia	Fire-prone areas; riparian areas with critical habitat; timber, fuels, and restoration projects

Sensitivity to climatic variability and change: Sedimentation and stream temperature will increase after wildfires, which will likely occur more frequently with climate change.

Adaptation Strategy / Approach: Improve or expand fish habitat and increase connectivity to allow fish movement.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Place large wood in lower-gradient areas from headwaters to main stem to catch sediment; focus on road network, areas without deposition/sediment-limited areas (pre and post fire)	Remove or replace barriers (e.g., culverts, tide gates) to increase connectivity, allowing fish to move to other areas when fires occur (pre fire)	Design crossings in anticipation of areas prone to debris that transport materials up and over road; remove roads that are subject to debris flows install large, non-plastic culverts to remain resilient (pre and post fire)
Where can tactics be applied?	Lower-gradient areas from headwaters to main-stem rivers, especially areas with high intrinsic potential for wood placement	Forest wide; prioritize areas that have high intrinsic potential for wood placement, that are lower in the network, that have lower fire risk or high resistance to fire, and that have a low gradient; target areas that may support recolonization by fish (lakes, estuaries, side channels, other tributaries)	Use modeling to identify areas of high risk for high debris flow/landslides (e.g., Net Map)

Table 9.3—Adaptation options for forest vegetation in the OCAP assessment area

Sensitivity to climatic variability and change: Increased warming, drought, and wildfire will reduce tree vigor and increase susceptibility to insects and pathogens, with increased potential for extensive outbreaks, particularly invasive insects and pathogens.

Adaptation Strategy / Approach: Manage for adaptive capacity and enhance as much diversity on the landscape as possible (e.g. increase tree vigor by managing for proper stand densities; use monitoring and adaptive management approaches, including aerial detection surveys, Forest Inventory and Analysis (FIA) data, and potentially Lidar).

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**	**Specific Tactic – D**
Tactic	Use Maximum Stand Density models, which incorporate climate, soils, and other factors, to set stocking levels	Implement silvicultural treatments that promote stand and landscape diversity	Use monitoring to identify regeneration failures, noticeable declines, and widespread mortality; implement adaptive management approaches in response	Implement pre-commercial thinning where appropriate (e.g., following post-fire regeneration)
Where can tactics be applied?	Old plantations; stands under 80 years old (much of Siuslaw NF is late-successional reserves); prioritize based on areas expected to undergo loss of fog	Plantation areas on Mt. Hebo, including places with off-site trees; prioritize based on areas expected to undergo loss of fog	Plantation areas on Mt. Hebo, including places with off-site trees.	Prioritize based on areas expected to undergo loss of fog.
Opportunities for implementation	Western Wildlands Environmental Threat Assessment Center (WWETAC) partnership	Knutson-Vandenberg Act (K-V/K2) funds potentially applicable	Potential to implement an Adaptive Silviculture for Climate Change site in this area.	Stewardship-retained receipts for restoration work; K-V/K2 funds

Sensitivity to climatic variability and change: Area burned and length of the fire season will increase with climate change.
Adaptation Strategy / Approach: Strategically reduce fire risk, considering fire-severity regime, ignition sources, burning conditions, and resources and values at risk (e.g., weather-driven fire events, smaller fires).

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Promote Firewise practices, home hardening, and defensible space in the wildland-urban interface (WUI) and around communities	Increase public education about fire risks, red flag warnings, and air quality	Reduce human-caused ignitions, including in infrastructure, through outreach to recreationists and collaboration with partners
Where can tactics be applied?	Near WUI and communities; USFS infrastructure (recreation sites); Cascade Head Experimental Forest (includes residences)	In the northern portion of Siuslaw NF where private property is interspersed	Near WUI and communities; anywhere people congregate or there is infrastructure; campgrounds, dispersed camping areas; during deer hunting season (late summer to early fall)

Table 9.3 (continued)—Adaptation options for forest vegetation in the OCAP assessment area

Opportunities for implementation	Oregon State University (OSU) Extension (fire outreach)	OSU Extension (fire outreach)	OSU Extension (fire outreach)

Sensitivity to climatic variability and change: Opportunities for invasive plant species establishment may increase with climate change (e.g., gorse, Scotch broom, false brome).
Adaptation Strategy / Approach: Limit introductions, prevent establishment and spread, and limit where invasive species grow.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Implement early detection and rapid response and target species that threaten high-value resources	Communicate with the public about reducing the role of humans, equipment, and ornamental escapes as vectors	Include invasive species prevention measures in all projects
Where can tactics be applied?	Areas adjacent to private property and areas that receive high visitation	Areas adjacent to private property	All projects (e.g., timber sales, culvert replacements, trail work, new trailheads, recreation facilities)
Opportunities for implementation	USFS retirees; Clackamas County Dump Stoppers; Southern Oregon Grouse Project SWCDs; county weed boards.	USFS retirees, Clackamas County Dump Stoppers; peer-to-peer networking/influencing; OHV and other recreation groups; Southern Oregon Gorse Project SWCDs; county weed boards	Funding from vegetation projects or from partners

Sensitivity to climatic variability and change: Greater frequency of intense winter wind and rainstorms, resulting in blowdown, flooding, and debris flows (especially in sandstone geology).

Adaptation Strategy / Approach: Develop a better understanding of risks associated with wind events, including whether management interventions are feasible.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Identify which topographic positions and stand characteristics are most vulnerable to wind events (e.g., use fine-scale wind modeling to investigate specifics)	Manage stand density for wind firmness; maintain lower height-to-diameter ratios (e.g., keep below 70).	Update Late-Successional Reserve Assessment objectives for risk reduction related to wind
Where can tactics be applied?	Most areas, across large landscapes	Species with shallower root systems (western hemlock, western redcedar, Sitka spruce) are most susceptible; consider prioritizing based on the presence of stem or root decay; prioritize based on results from Tactic A	Forest-wide where there are landscape restoration efforts (e.g., late-successional reserves); results from Tactic A can inform Tactic C

Table 9.3 (continued)—Adaptation options for forest vegetation in the OCAP assessment area

Opportunities for implementation	Partnership with WWETAC; wind grids for past and future (from USFS Office of Sustainability and Climate); integrate with fire modelling; work with a climatologist; pre- and post-fire events; Landtrender; use windthrow data where available; Aerial Detection Survey data (windthrow polygons)	Include measures to improve wind firmness in all projects	In advance of forest plan revision

Table 9.4—Adaptation options for non-forest vegetation in the OCAP assessment area

Sensitivity to climatic variability and change: Higher temperatures and an altered precipitation regime in the Coast Range may increase stress for some montane plant communities, including rare plants.

Adaptation Strategy / Approach: Build long-term resilience, build understanding of systems, and mitigate disturbance.

	Specific Tactic – A	Specific Tactic – B	Specific Tactic – C
Tactic	Improve/initiate long-term monitoring	Build resilience (e.g., sow native seed mixes); protect sensitive areas near recreation areas (e.g., limit access, designate special interest areas, use signage and education); plant native species in undisturbed areas)	Implement early detection and rapid response for invasive species, using a range of treatment options; educate recreationists on how to limit invasive introductions and spread
Where can tactics be applied?	Rare montane meadow locations, especially existing restoration projects (e.g., Marys Peak)	Disturbed meadow surfaces, especially near recreation sites, horse trails, and areas with OHV activity	Disturbed areas; target oxeye daisy (*Leucanthemum vulgare* Lam.) and nonnative pasture grasses
Opportunities for implementation	Partnerships with cities (e.g., City of Corvallis) and tribes	Native plant societies with volunteers; Marys Peak Alliance; Xerces Society; Willamette Valley NRCS Plant Materials Program (Center for Seed Rearing); Coffee Creek native seed operation; tribes	USFS recreation programs; high schools (citizen involvement); tribes; Institute for Applied Ecology (IAE) and partners; biocontrol program through USFS Forest Health Protection; Agricultural Research Service

Sensitivity to climatic variability and change: Higher temperatures and reduced fog may increase stress for some coastal plant communities, including rare plants.

Adaptation Strategy / Approach: Build long-term resilience, build understanding of systems, and mitigate disturbance.

	Specific Tactic – A	Specific Tactic – B	Specific Tactic – C
Tactic	Improve/initiate long-term monitoring	Build resilience (e.g., sow native seed mixes); protect sensitive areas near recreation areas (e.g., limit access, designate special interest areas, use signage and education); plant native species in undisturbed areas)	Implement early detection and rapid response for invasive species, using a range of treatment options; educate recreationists on how to limit invasive introductions and spread; consider biocontrol
Where can tactics be applied?	Coastal headlands, slope meadows	Disturbed meadow surfaces, especially near recreation sites, horse trails, and areas with OHV activity	Disturbed areas; target oxeye daisy and nonnative pasture grasses
Opportunities for implementation	Partnerships with Oregon State Parks and local tribes	Native plant societies with volunteers; Marys Peak Alliance; Xerces Society; Willamette Valley NRCS Plant Materials Program (Center for Seed Rearing); Coffee Creek native seed operation; tribes	USFS recreation programs; high schools (citizen involvement); tribes; IAE and partners; biocontrol program through USFS Forest Health Protection; Agricultural Research Service

Table 9.4 (continued)—Adaptation options for non-forest vegetation in the OCAP assessment area

Sensitivity to climatic variability and change: Climate change stressors cross boundaries, creating increased need for different landowners to collaborate**.**

Adaptation Strategy / Approach: Increase coordination among adjacent jurisdictions (federal agencies, state agencies, tribes, NGOs).

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Formalize partnerships (agreements)	Enhance existing collaboratives and develop new ones if needed	
Where can tactics be applied?	Meadow and wetland area restoration	Special habitat focus with an "all lands" approach	
Opportunities for implementation	Interagency agreements among USFS, BLM, ODFW, and tribes; cost-sharing strategies; Good Neighbor Authority	Interagency agreements among USFS, BLM, ODFW, and tribes; cost-sharing strategies; Good Neighbor Authority; NRCS, SWCDs; Collaborative Forest Landscape Restoration Program funding	

Sensitivity to climatic variability and change: Altered precipitation regime (more rain, less snow) in the Coast Range may facilitate woody vegetation encroachment in montane meadows.

Adaptation Strategy / Approach: Manage woody vegetation to retain meadows where feasible.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Monitor vegetation and related environmental variables (e.g., soil moisture)	Remove woody vegetation (cutting, goats)	
Where can tactics be applied?	Marys Peak, Grass Mountain, Prairie Mountain	Meadow edges	
Opportunities for implementation	Partnerships with BLM, City of Corvallis, IAE, and tribes	BLM; City of Corvallis; IAE; Oregon Hunters Association; Rocky Mountain Elk Foundation; tribes; integrate removal efforts into timber sales; seek stream restoration projects that could benefit from large wood	

Table 9.5—Adaptation options for wildlife habitat in the OCAP assessment area

Sensitivity to climatic variability and change: Altered timing of precipitation, drought, loss of fog, increased flooding events, snow melt, and rising sea level will reduce plant productivity, increase tree mortality, shift plant species composition, and alter wildlife habitat in forests, riparian areas, wetlands, meadows, estuaries, and beaches.
Adaptation Strategy / Approach: Restore and improve water-holding capacity of focal habitats; promote connectivity of focal habitats.

	Specific Tactic – A	Specific Tactic – B	Specific Tactic – C	Specific Tactic – D
Tactic	Promote and protect high-elevation refugia	Look at stream grade and plant composition to identify appropriate locations for beavers and areas with resilient native plant communities (for beaver habitat)	Reintroduce beavers to improve water-holding capacity of aquatic systems	Form relationships with private landowners to implement projects that promote connectivity (purchase land when relevant)
Where can tactics be applied?	North-facing slopes for noble fir on Marys Peak, Grass Mountain, Prairie Mountain, Little Grass Mountain, Monmouth Peak, and Mt. Hebo; meadow plant communities	Freshwater and brackish aquatic systems	Freshwater and brackish aquatic systems	Adjacent private landowners, inholdings
Opportunities for implementation	Stewardship groups and partnerships with private landowners and other agencies to preserve noble fir in the appropriate places; reduce (non-noble fir) tree encroachment in meadows	In areas where beavers and other wildlife-specific needs are incorporated in riparian and aquatic habitat restoration plans	ODFW	Land acquisition team (accept submissions, prioritize); Land and Water Conservation Fund (LWCF)

Sensitivity to climatic variability and change: Increased temperatures will cause shifts in plant and wildlife species ranges, reduce habitat for temperature-sensitive wildlife, and alter plant phenology and species interactions (e.g., predation, competition, timing of available food resources).
Adaptation Strategy / Approach: Develop a better understanding of implications of expected range shifts of plant and animal species, including interactions between native and nonnative species; identify situations where transitions are appropriate and shape transitions where feasible and appropriate.

	Specific Tactic – A	Specific Tactic – B	Specific Tactic – C	Specific Tactic – D
Tactic	Look at vegetative composition of edge habitats and enhance edge habitats, allowing for wildlife dispersal into these areas	Allow some beneficial nonnative animal and plant species, while removing other nonnative invasive plant species to address shifts in phenology; replace nonnatives with better adapted native species when feasible	Monitor phenology of flowers and berries, how it relates to temperature and moisture, and relationships to native pollinators	Ensure abundance of microhabitats that may be able to provide refugia under a range of weather conditions

Table 9.5 (continued)—Adaptation options for wildlife habitat in the OCAP assessment area

Where can tactics be applied?	May be applicable in some focal areas; where oak woodlands are expanding; edges of monoculture plantations; edge habitats that can connect isolated habitats of concern (e.g., between two isolated meadows) to avoid isolated island populations; edge habitats on Mt. Hebo and Mary's Peak	Likely applicable across all habitat types; Oregon silverspot butterfly on Hebo Ranger District; other opportunities to promote native plants (e.g., common yarrow [Achillea millefolium L.])	Meadows (likely differences between coastal meadows and montane meadows due to different soil conditions and precipitation patterns); coastal shrub areas; Sitka spruce and dune system, especially in areas that produce berries; places near Remote Automated Weather Station (RAWS) data stations for monitoring of seasonal weather	High-elevation meadows: promote shrubs and driplines of trees as pollinator habitats (rather than removing all shrubs and trees as had previously been common practice); dune-shrub habitat

Sensitivity to climatic variability and change: Changing frequency and extent of wildfire, insect outbreaks, and diseases may lead to loss of late-successional forest, altered structure and heterogeneity of other forest successional stages, reduction in habitat connectivity and distribution, and increased spread of invasive species.

Adaptation Strategy / Approach: Maintain resilience of old-growth forests and increase resilience of plantation forests.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Protect interior old-growth forests	Protect old and larger trees from insects and disease	Increase structural and biological diversity of plantation forests
Where can tactics be applied?	Old-growth forests that are vulnerable to disturbance; fuel management projects	Old-growth forests that are vulnerable to disturbance	Fuel management projects; timber sales; reforestation efforts; during land management plan revision

Table 9.6—Adaptation options for recreation in the OCAP assessment area

Sensitivity to climatic variability and change: Sea-level rise, higher high-tide lines, shifts in precipitation, and extreme storm surges will result in some coastal areas becoming unusable, damaging recreation infrastructure and access roads.

Adaptation Strategy / Approach: Incorporate climate change vulnerability as a component of sustainable recreation planning.

	Specific Tactic – A	Specific Tactic – B	Specific Tactic – C	Specific Tactic – D
Tactic	Improve understanding of which sites are vulnerable to flooding caused by extreme precipitation events	Consider climate change vulnerability in project designs and strategic investment decisions; favor investments in sites that will be more resilient	For sites deemed to be vulnerable, explore decommissioning, redesign, or shifting investments elsewhere	Emphasize alternate recreational locations and opportunities; manage expectations when notifying the public about sites that become unavailable
Where can tactics be applied?	Following a large-scale recreation site analysis	Features located near streams or lakes or at low elevations may be especially vulnerable; project-level decisions	Features located near streams or lakes or at low elevations may be especially vulnerable	Sites that may become unavailable due to flooding, storm surges, high tides, and sea-level rise
Opportunities for implementation	Forest-wide recreation site analysis; 5-year infrastructure plan; public engagement opportunities	Project submissions for National Assessment Management Program; 5-year infrastructure plan	Project submissions for National Assessment Management Program; 5-year infrastructure plan	Coordinate messaging with other agencies, including Oregon State Parks, Oregon Coast Visitors Association, and county parks

Sensitivity to climatic variability and change: Increased temperatures in the fall and spring will result in increased use during the shoulder seasons.

Adaptation Strategy / Approach: Increase management flexibility and capacity for managing recreation resources to meet shifting demands.

	Specific Tactic – A	Specific Tactic – B	Specific Tactic – C	Specific Tactic – D
Tactic	Develop creative budget strategies to support longer and overlapping use seasons	Coordinate with other recreation providers to be more strategic about which opportunities are offered, especially in the shoulder seasons	Communicate with the public (including social media) about what is open, what is closed, and safety concerns specific to the shoulder seasons	Add language to concessionaire contracts and special-use permits to allow for seasonal flexibility
Where can tactics be applied?	Forest-wide	Forest-wide	Forest-wide	Forest-wide
Opportunities for implementation	Grants from the state; partnership opportunities with Youth Corps, correctional crews, and trail volunteer organizations; expand fee program; pursue additional grant funding, partnerships, and opportunities for new fees	Oregon State Parks, Oregon Coast Visitors Association (OCVA); county parks; BLM; recreation-site analysis can inform strategic decisions	OCVA; Facebook; Twitter; traditional press releases	Concessionaires; special-use permittees; during permit renewals and when issuing new permits

Table 9.6 (continued)—Adaptation options for recreation in the OCAP assessment area

Sensitivity to climatic variability and change: Increased wildfire frequency and extent will result in closures of sites and/or districts, fire restrictions, and changes in use patterns (e.g., recreationists coming from inland areas where fire and smoke are prevalent).

Adaptation Strategy / Approach: Facilitate resilience to wildfire through proactive planning and preparation.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**	**Specific Tactic – D**
Tactic	Coordinate with other recreation providers and national forest units to ensure a consistent response to fire risk and consistent messaging	Communicate with the public about fire risks and their implications for recreational access, including closures and fire restrictions, using social media and other outlets	Consider the potential for increased summer demand and interactions with other climatic vulnerabilities during recreation planning	Establish tentative plans for rapid responses to wildfire and hazard tree removal in transportation corridors, high-use recreational areas, and campgrounds
Where can tactics be applied?	Pre-season coordination between recreation staffs on different units; implementation during fire events or when risks are elevated	Pre-season messaging with the public about fire risks and responses, thus managing expectations; messaging during the fire season to inform public about closures and restrictions	Recreation site analysis; National Access Management Program (NAMP) process	Pre-season coordination with ODOT, counties, law enforcement, search-and-rescue; implementation following fire and wind events
Opportunities for implementation	Partnerships with Oregon State Parks, OCVA, county parks, BLM, and other Oregon national forests	Partnerships with OCVA, social media, website; ensure good signage in recreation sites	Recreation site analyses; NAMP process	Partnerships with ODOT, counties, law enforcement, search-and-rescue; BAER

Table 9.7—Adaptation options for ecosystem services in the OCAP assessment area

Sensitivity to climatic variability and change: Altered disturbance patterns and habitat quality may affect sensitive plant and animal species that provide first foods and other non-timber forest products (NTFPs).

Adaptation Strategy / Approach: Collaborate with tribes to integrate traditional ecological knowledge (TEK) into management of culturally sensitive species.

	Specific Tactic – A	Specific Tactic – B	Specific Tactic – C
Tactic	Identify and map critical areas for culturally sensitive species (e.g., camas, rushes); monitor populations over time (with tribes)	Protect areas of historical and anticipated future distribution for culturally sensitive species; consider acquiring land that may provide habitat in the future (e.g., wetlands, higher elevations)	Work with tribes to explore effects of traditional plant management techniques for culturally sensitive species; identify practices that increase species resilience; develop best management practices.
Where can tactics be applied?	Estuaries, wet prairies; cultural sites that are co-located with culturally sensitive species	Estuaries, wet prairies; cultural sites that are co-located with culturally sensitive species	Projects involving camas, huckleberries, salmon, lampreys, and other culturally important foods
Opportunities for implementation	Build on existing partnerships to work with tribes; emphasize co-ownership and protect privacy	LWCF	Create new partnerships and build on existing partnerships

Sensitivity to climatic variability and change: Altered hydrologic and disturbance regimes will affect the amount, seasonal distribution, and quality of water for municipal and ecosystem uses.
Adaptation Strategy / Approach: Protect areas that provide key hydrologic ecosystem services.

	Specific Tactic – A	Specific Tactic – B	Specific Tactic – C
Tactic	Protect low-lying wetlands and estuaries to increase resilience to changes in hydrology and sea-level rise; review and improve zoning where possible (to prevent development of wetlands and estuaries)	Protect sole-source aquifers from salinization, overuse, and pollution; protect areas of dunes where surface water connects with the aquifer	Increase communication about water quality issues in lakes and reservoirs (e.g., algal blooms, bacteria)
Where can tactics be applied?	Low-lying wetlands and estuaries	Water sources near Florence, Coos Bay, and North Bend	Well users; recreationists (fishing, swimming)
Opportunities for implementation	Land acquisition; communicate importance of existing undeveloped land; partnerships with counties and cities on land-use planning	Special-use permits can potentially be used to motivate protection	Enhance existing monitoring efforts; develop partnerships with DEQ and ODFW

Table 9.7 (continued)—Adaptation options for ecosystem services in the OCAP assessment area

Sensitivity to climatic variability and change: Pollinators may be increasingly vulnerable to climate change effects, including diminished habitat and phenology mismatches.
Adaptation Strategy / Approach: Enhance pollinator habitat on federal lands and near federal facilities.

	Specific Tactic – A	Specific Tactic – B	Specific Tactic – C

Tactic	Develop a checklist to consider pollinator services in planning, project analysis, and decision making; direct USFS units to improve pollinator habitat by increasing native vegetation (through Integrated Pest Management) and by applying pollinator-friendly, forest-wide best management practices and seed mixes	Establish pollinator gardens	Establish a reserve of native seed mixes including pollinator-friendly plants that are available, affordable, and effective; develop revegetation guidelines that incorporate menu-based seed mixes by habitat type (e.g., species that are good for pollinators) and are delineated by empirical or provisional seed zones
Where can tactics be applied?	Sensitive habitats and species; plant communities vulnerable to climate change	Pollinators Pathways Project	Pollinators Pathways Project; incorporate TEK in pollinator management

Sensitivity to climatic variability and change: Altered timing, availability, and distribution of NTFPs caused by shifts in phenology, disturbance, and habitat quality, potentially leading to conflicting uses among tribal, recreational, and commercial uses, and possibly to more human impacts on resources.
Adaptation Strategy / Approach: Ensure equitable access and sustainable supply of NTFPs for resource users while maintaining ecological function.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**	**Specific Tactic – D**
Tactic	Increase information on NTFP ecologies, harvest dynamics, stewardship practices, and market dynamics through data collection and research	Better integrate NTFPs into forest planning; use silvicultural prescriptions that enhance suitable conditions through canopy openings and appropriate stand structure, prescribed fire, and meadow management	Determine the abundance and distribution of NTFPs that meet needs of different user groups; manage harvest levels to ensure sustainable supplies	Identify areas of particular importance to NTFPs and monitor population health, reproductive success, and age distribution of target species; assess viability and redirect use away from vulnerable areas
Where can tactics be applied?	All habitat types; thinning projects, prescribed fire, invasive species management, other management projects	Upland forest, wetlands, meadows, dune ecosystems, estuaries, and other special habitats	Popular harvest areas	Popular harvest areas and other special habitats
Opportunities for implementation	Partnerships with NTFP user groups, tribes, and universities	Forest and project-level planning	Partnerships with NTFP user groups, tribes, and universities	Partnerships with NTFP user groups, tribes, and universities

Table 9.7 (continued)—Adaptation options for ecosystem services in the OCAP assessment area

Sensitivity to climatic variability and change: Expected population growth in local communities will likely increase development pressure and demand for ecosystem services, interacting with potential increases in climate-influenced hazards and creating stress for regional infrastructure.

Adaptation Strategy / Approach: Increase planning, cross-jurisdictional coordination, and communication in preparation for climate-influenced acute (e.g., extreme events) and chronic (e.g., development, effects on water) stresses.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**	**Specific Tactic – D**
Tactic	Identify sensitive roads; improve communication among jurisdictions and responsible parties for the regional road network	Communicate with resource users so they have realistic expectations for access; restrict access in some cases (e.g., with a permit system)	Increase communication among agencies to guide users to safe or alternative recreation sites if preferred sites are unavailable	Proactively acknowledge cumulative effects across land ownerships and modify management accordingly
Where can tactics be applied?	In valley bottoms; along Highway 101 and other coastal roads	Areas with hazards and overuse	Areas with hazards and overuse	Northern spotted owl (*Strix occidentalis caurina* Merriam) sites; sites with botanical species of concern; areas with high fire risk (adjacent to WUI); watersheds of concern
Opportunities for implementation	Build on preparations for earthquakes and tsunamis; natural hazard mitigation planning (state and county level); hazard information from Oregon Department of Geology and Mineral Industries	Websites, apps, social media	Websites, apps, social media	Reduce fire risk; communicate with landowners and encourage collaboration

Figures

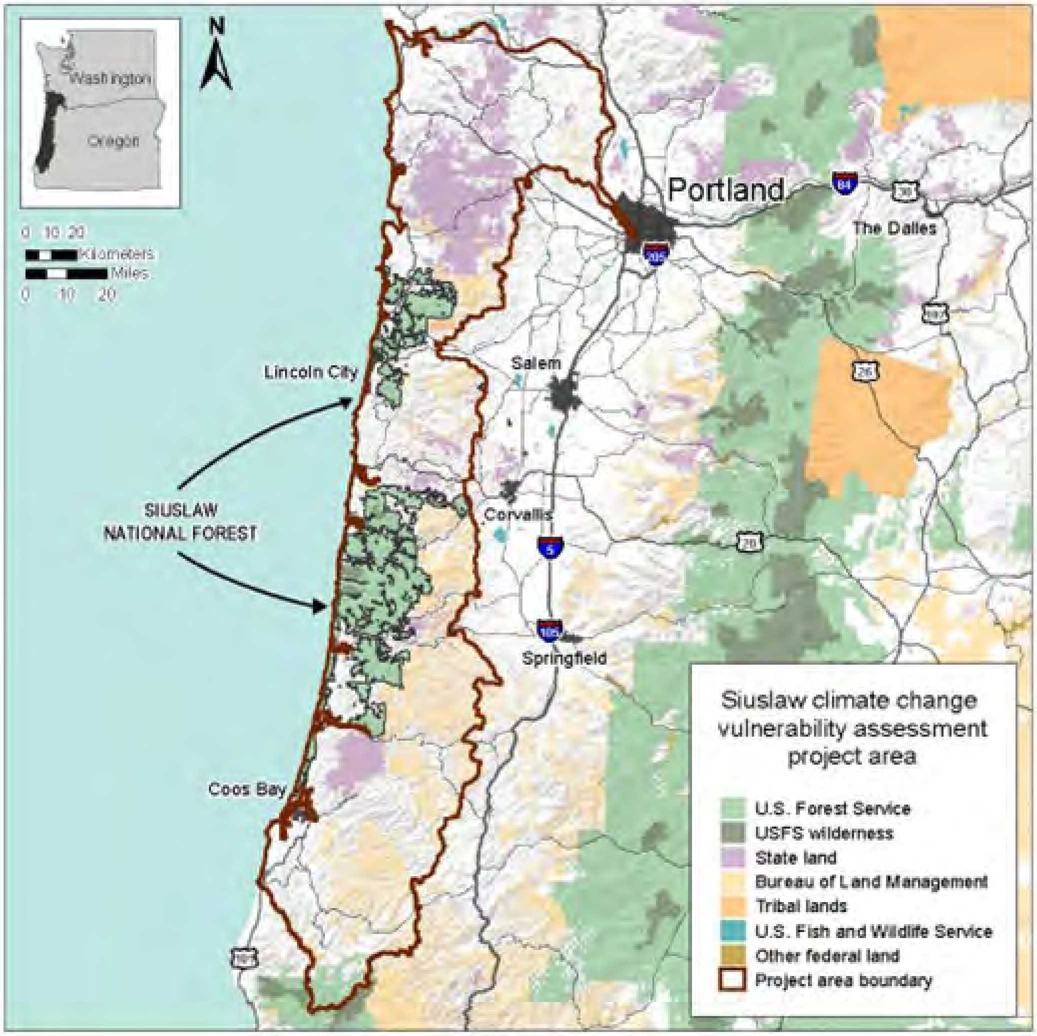


Figure 1. Oregon Coast Adaptation Partnership assessment area.

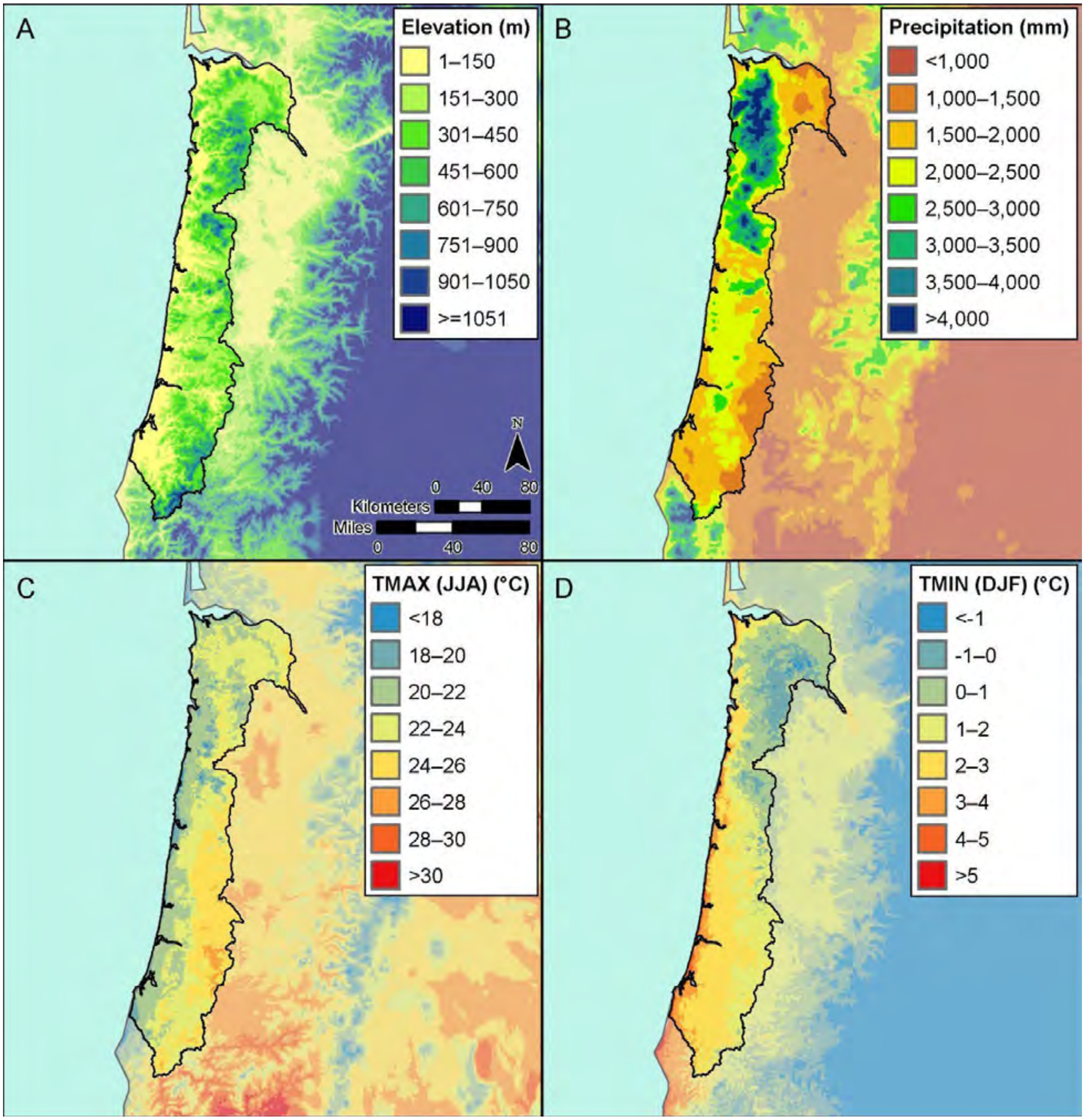


Figure 2.1—Oregon Coast Adaptation Partnership (OCAP) assessment area elevation and climate 1970-1999. PRISM data (Daly et al. 2001) were used to plot elevation (m) (A), mean annual precipitation (B), mean daily maximum temperature (TMAX) for June-July-August (C), and mean daily minimum temperature (TMIN) for December-January-February (D). The OCAP region and National Forest boundaries are overlaid.

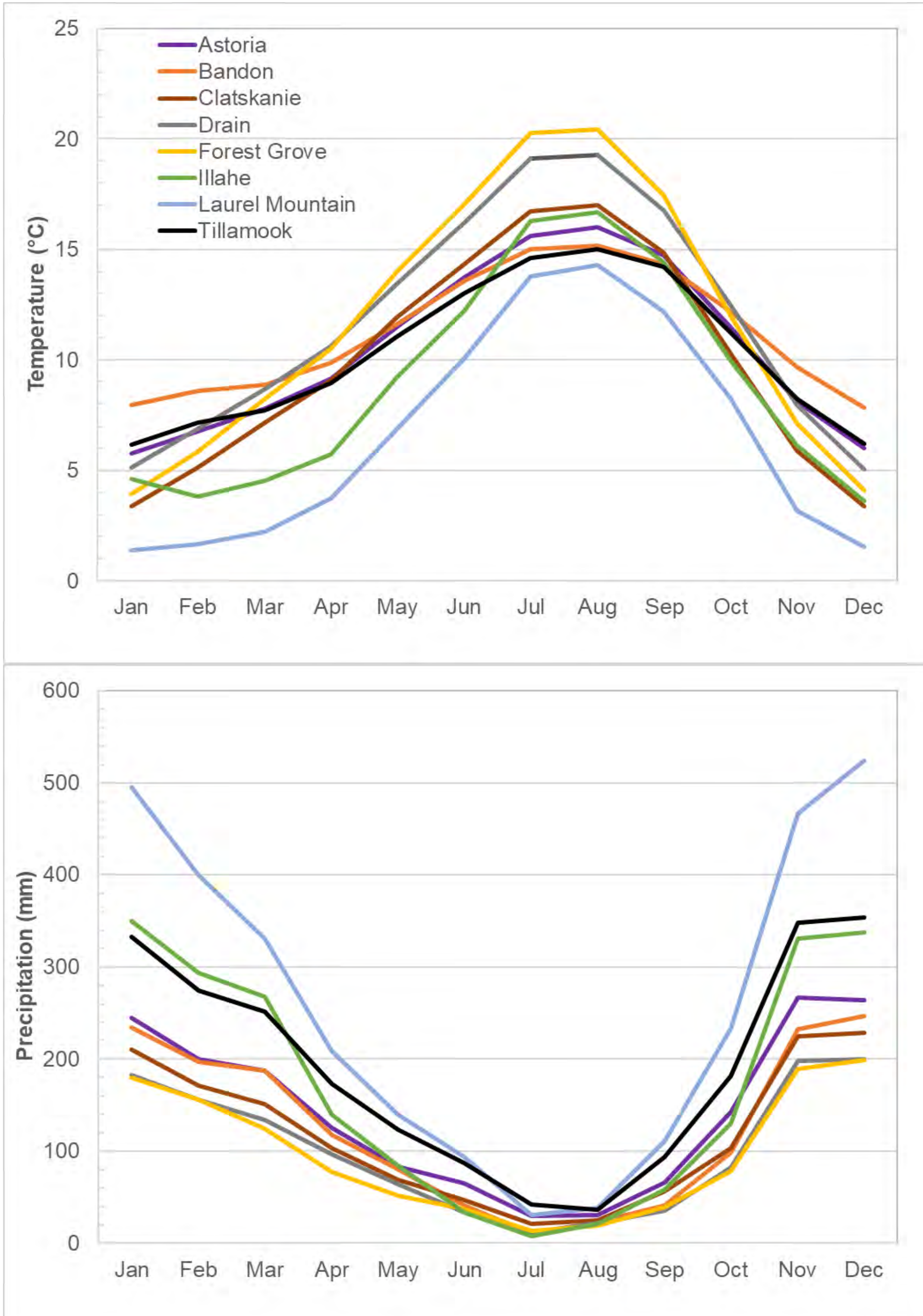


Figure 2.2—Mean monthly temperature and precipitation for selected locations within the OCAP assessment area. The monthly mean data are from the Western Region Climate Center (WRCC) and cover the period 1971–2000.

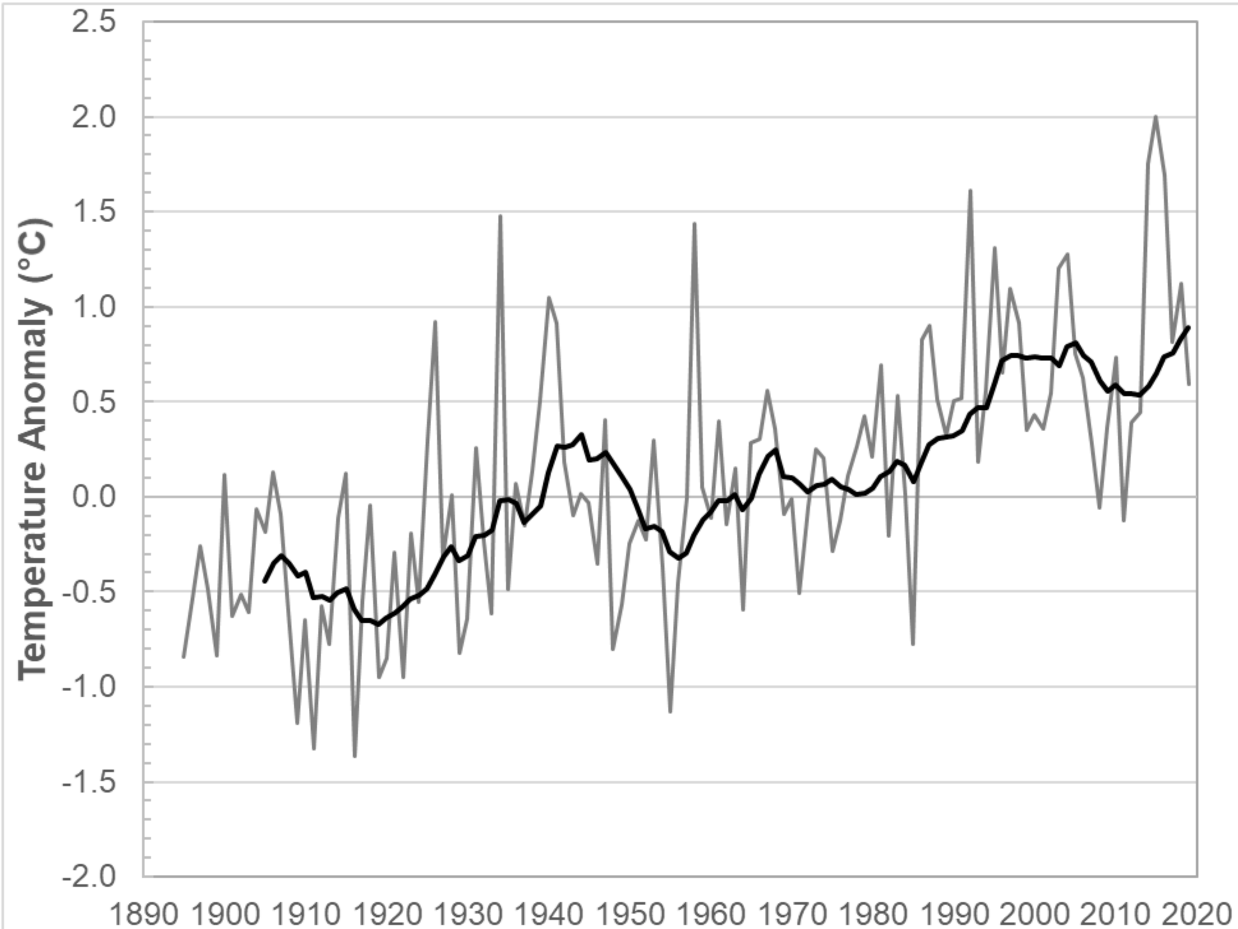


Figure 2.3—United States Historical Climate Network (USHCN) mean annual temperature anomaly (1901–2000 mean baseline) with an 11-year moving average filter applied. Note that the temperature time-series represents the mean of the 10 USHCN stations evaluated.

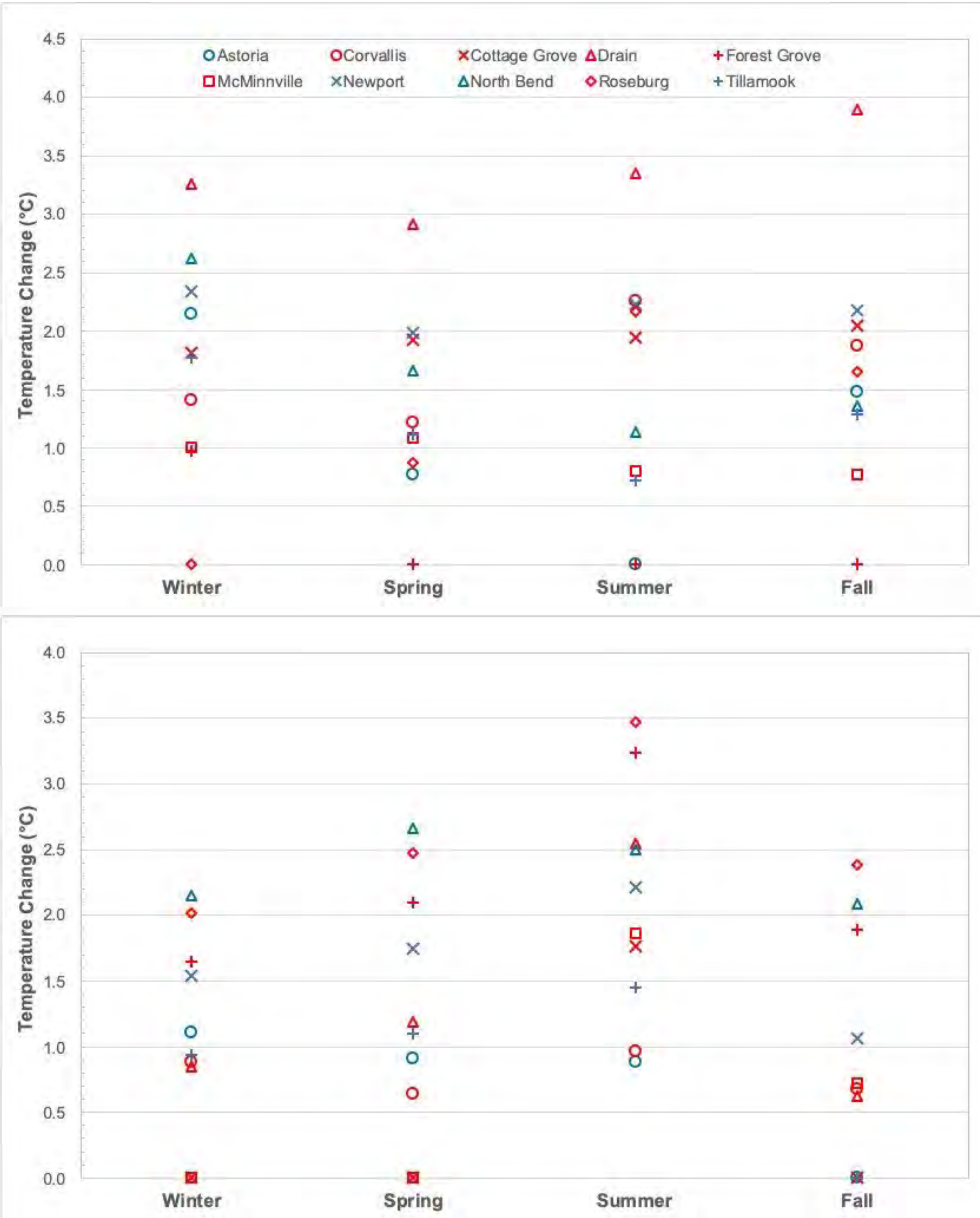


Figure 2.4—Maximum (A) and minimum (B) temperature change by season for each of the evaluated United States Historical Climate Network stations. Note that blue and red symbols represent coastal and inland locations, respectively.

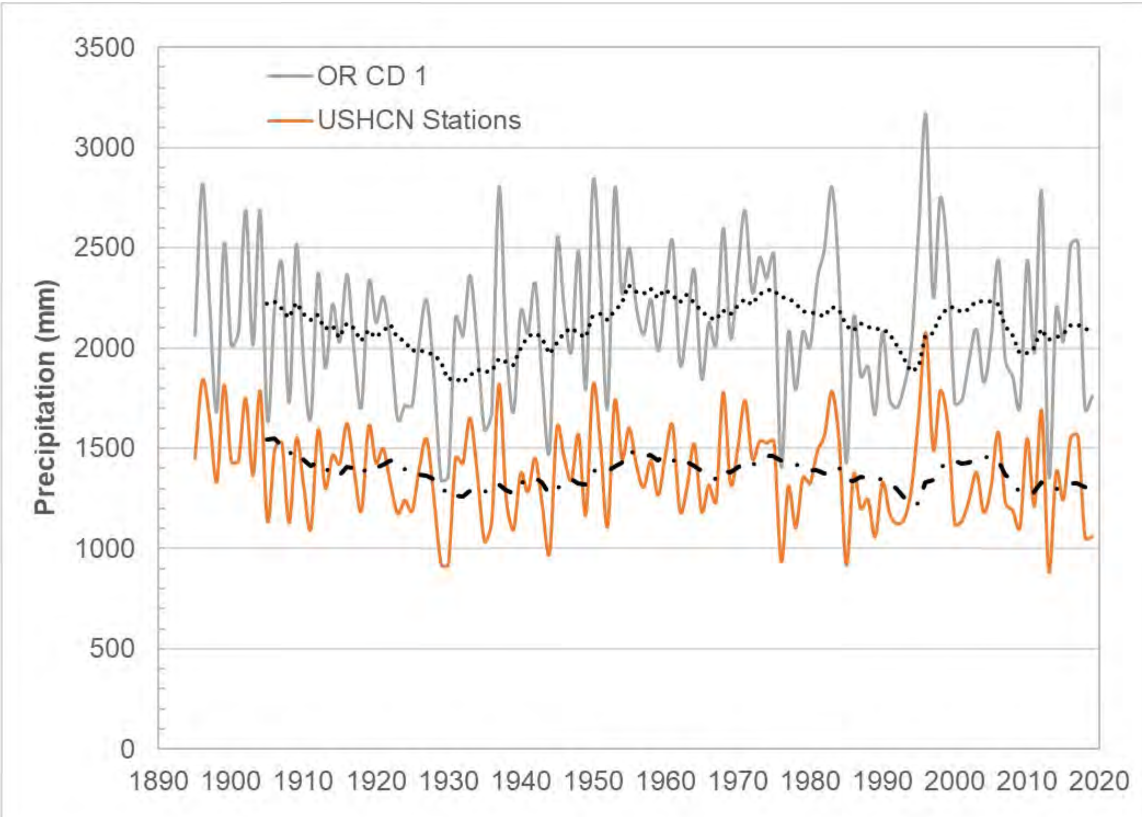


Figure 2.5—Historical annual precipitation for the OCAP assessment area. Historical values were derived from Oregon Climate Division 1 and the mean of ten United States Historical Climate Network stations within or proximate to the region. An 11-year moving average was applied to each dataset.

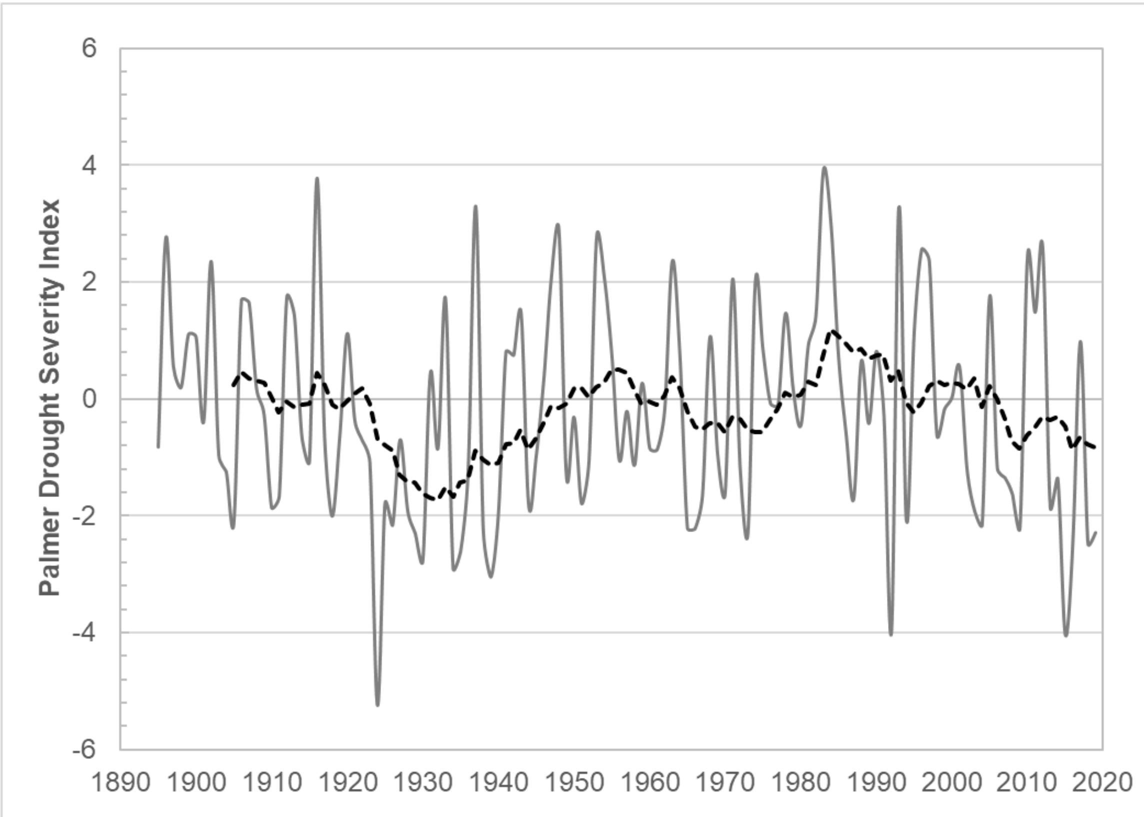


Figure 2.6—Historical summer (June-August) Palmer Drought Severity Index (PDSI) for Oregon Climate Division 1–Coastal Area. The dashed line represents an 11-year moving average.

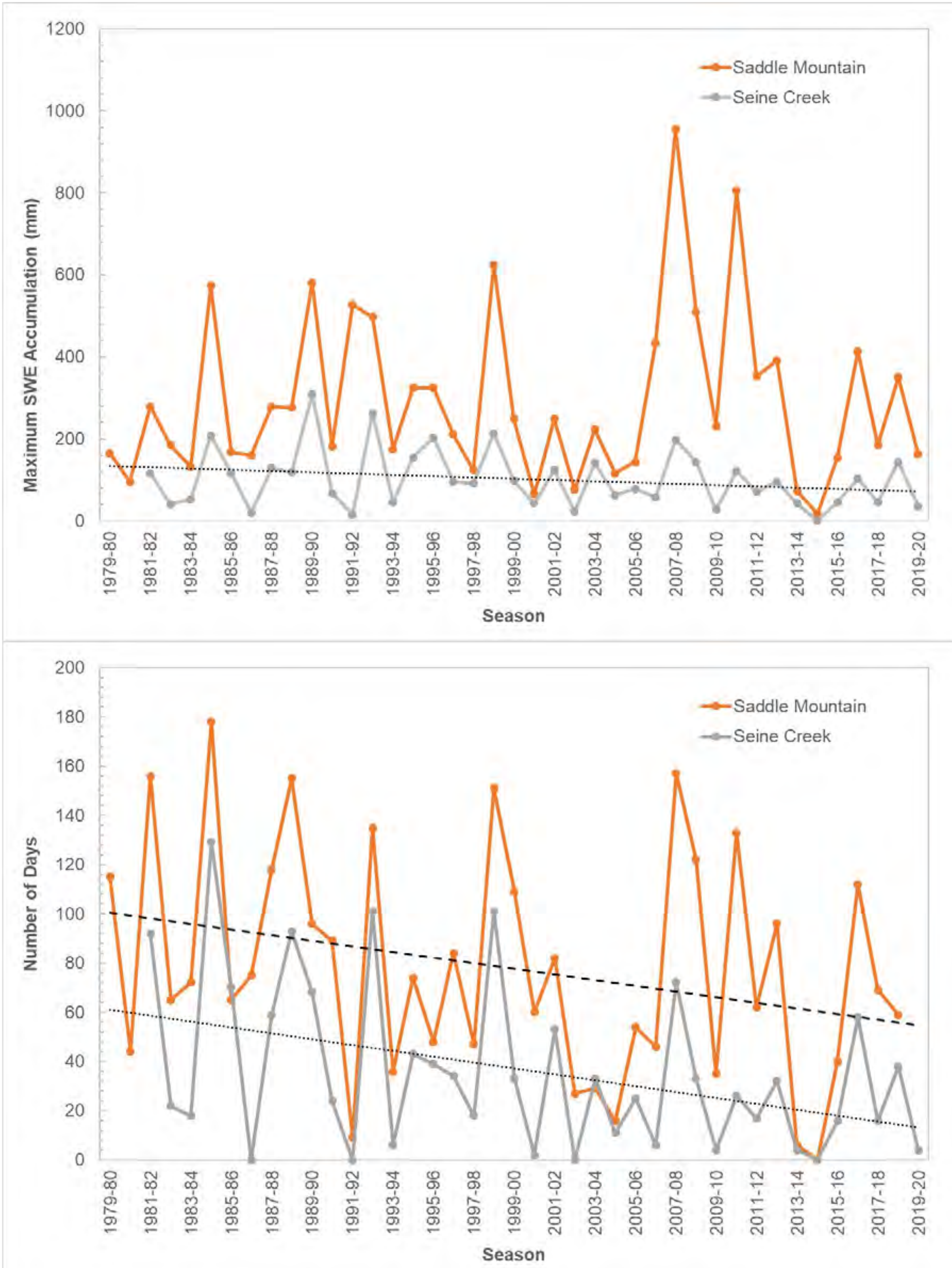


Figure 2.7—Maximum snow water equivalent (SWE) accumulation (A) and number of days with snow cover (≥ 25 mm) (B) at Saddle Mountain and Seine Creek from the SNOTEL network.

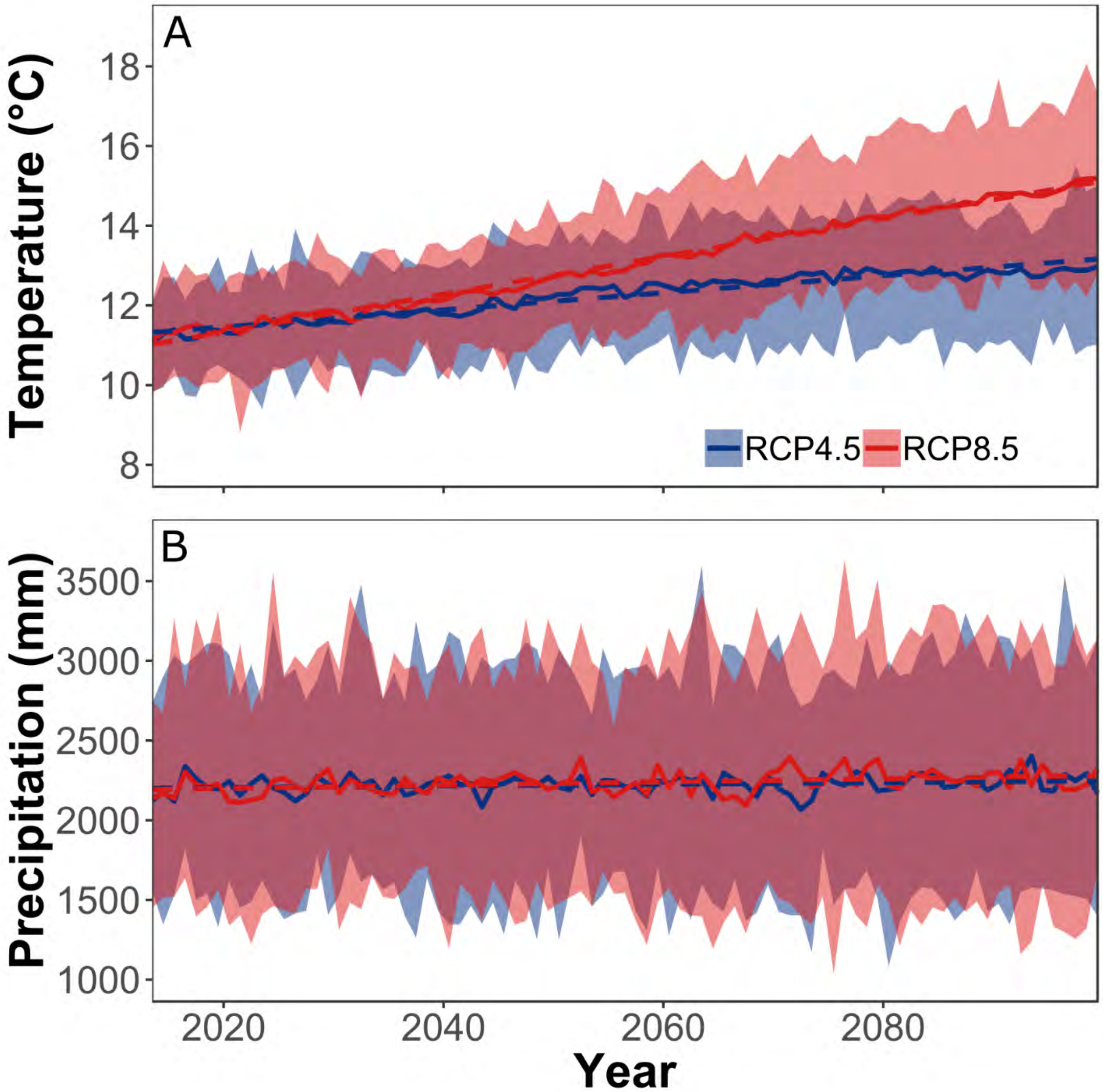


Figure 2.8—A comparison of RCP 4.5 and RCP 8.5 climate change scenarios for the OCAP assessment area. Projected annual temperature (A) and precipitation (B) were calculated from 30 global climate models in the NASA NEX-DCP30 downscaled climate dataset (Thrasher et al. 2013, van Vuuren et al. 2011).

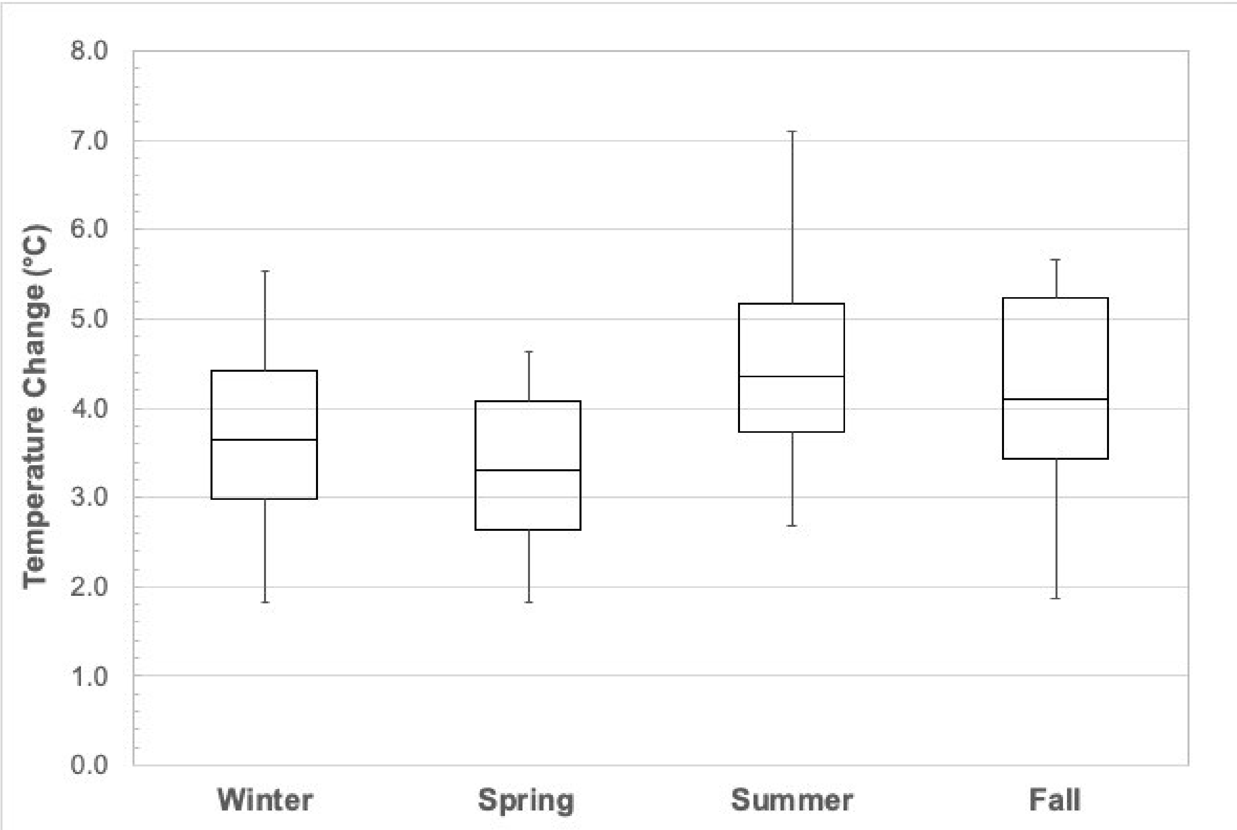


Figure 2.9—Box-and-whisker plots of seasonal temperature change for the 30 global climate models evaluated. The center line within each box represents the median, the bottom of the box represents the first quartile, and the top of the box represents the third quartile. The “whiskers” represent the minimum and maximum values.

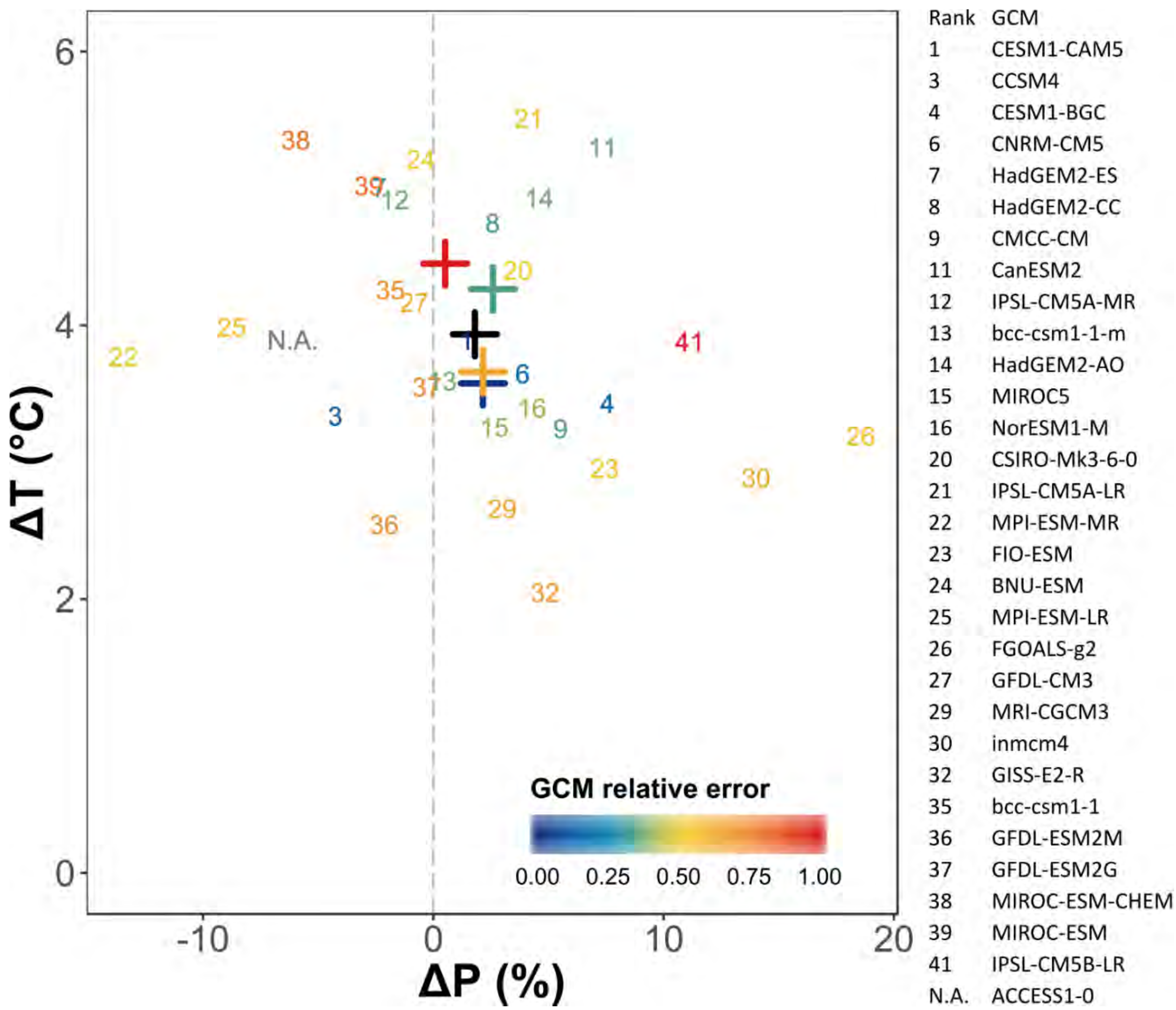


Figure 2.10—Projected change in mean annual temperature (ΔT) and average annual precipitation (ΔP) from 30 global climate models (GCMs) from 1970–1999 to 2070–2099 for the OCAP assessment area. ΔT and ΔP were calculated using the NASA NEX-DCP30 climate dataset (Thrasher et al. 2013). GCMs are ranked according to model skill for simulating historical climate of the Pacific Northwest region (Rupp et al. 2013). The GCMs are color coded per quartile of model skill: blue, green, yellow, and red colors represent quartiles of ranking from the highest to the lowest, respectively. Plus (+) symbols are the means of each quartile group of GCMs using the same color coding. The black plus symbol represents the mean of the entire 30-member set.

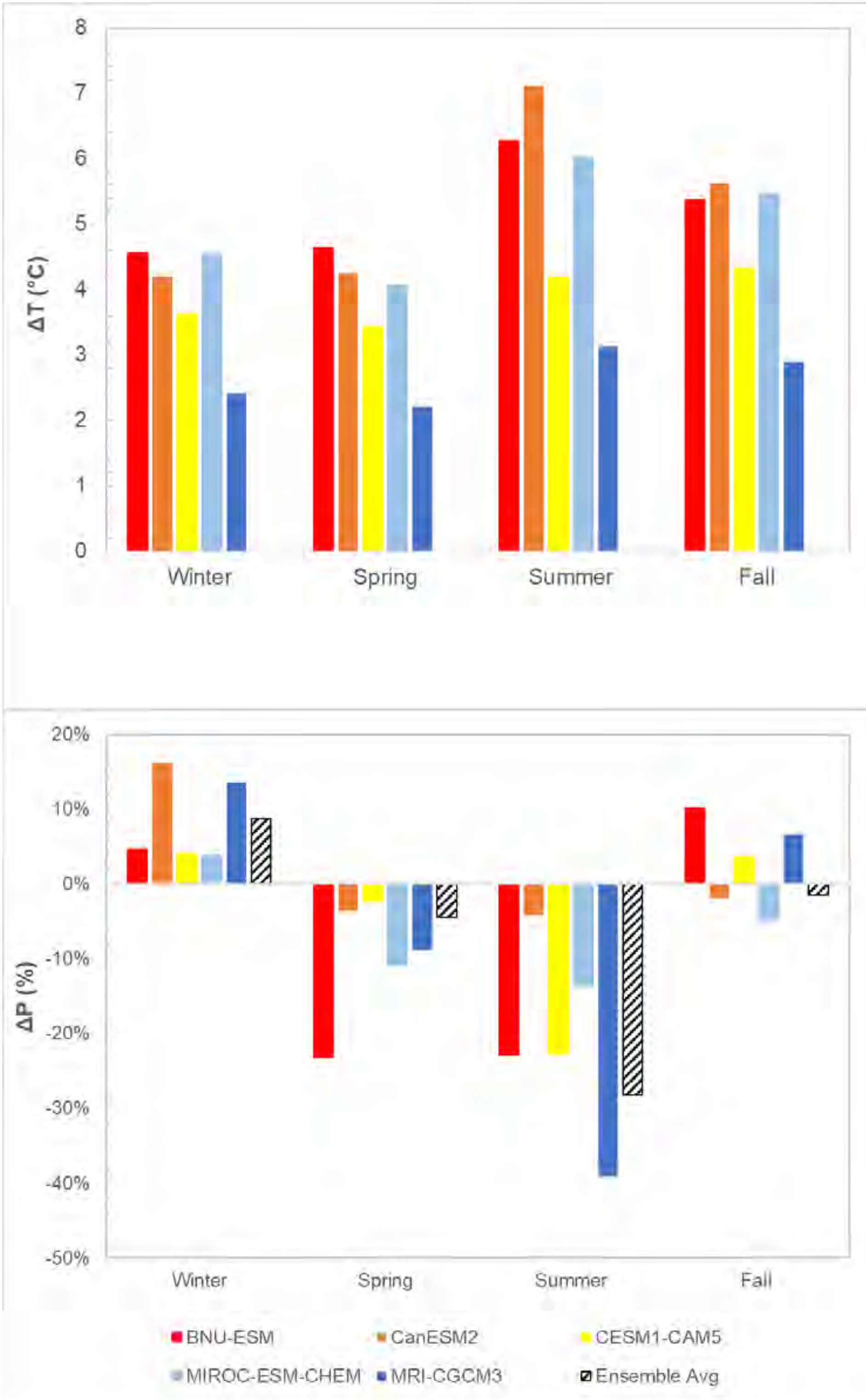


Figure 2.11—Projected change in seasonal mean temperature (top) and precipitation (bottom) under the RCP 8.5 climate change scenario (van Vuuren et al. 2013) for five selected global climate models. Future projections were calculated from the NASA NEX-DCP30 downscaled climate dataset (Thrasher at al. 2013).

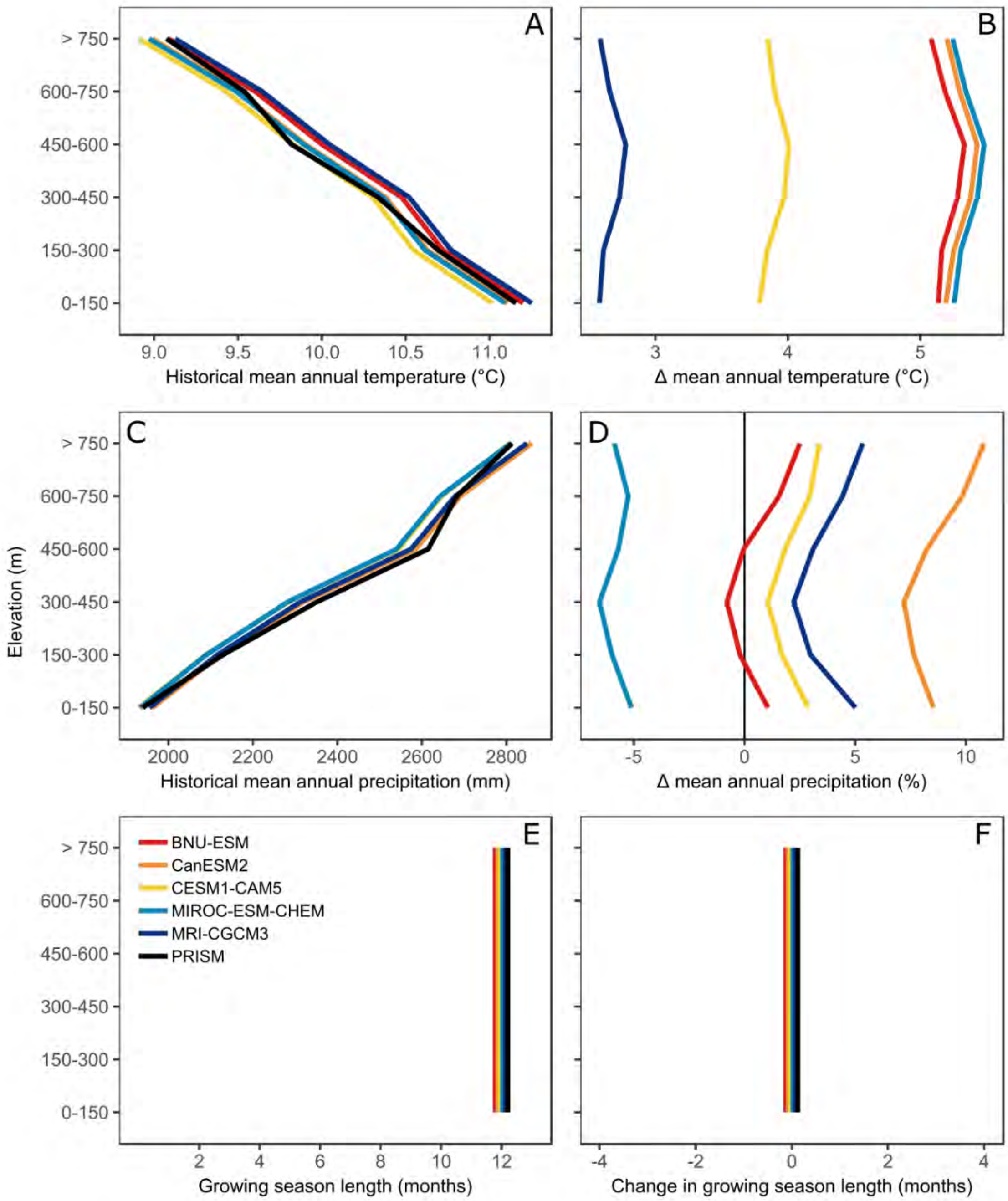


Figure 2.12—Historical mean annual temperature (A), and projected change (B); historical mean annual precipitation (C), and projected change (D); and historical growing season length (E), and projected change (F) for the OCAP assessment area for five selected global climate models. The historical period is 1970–1999, and changes were calculated for 2070–2099 relative to the historical period. Historical values were calculated from PRISM (Daly et al. 2001), and future projections were calculated from the NASA NEX-DCP30 downscaled climate dataset (Thrasher et al. 2013) for the RCP 8.5 climate change scenario (van Vuuren et al. 2013). The OCAP assessment area was divided into elevation bands in 150-m increments. Datasets used provide monthly averages, and growing season length was calculated by counting months with average monthly temperature above 0 °C.

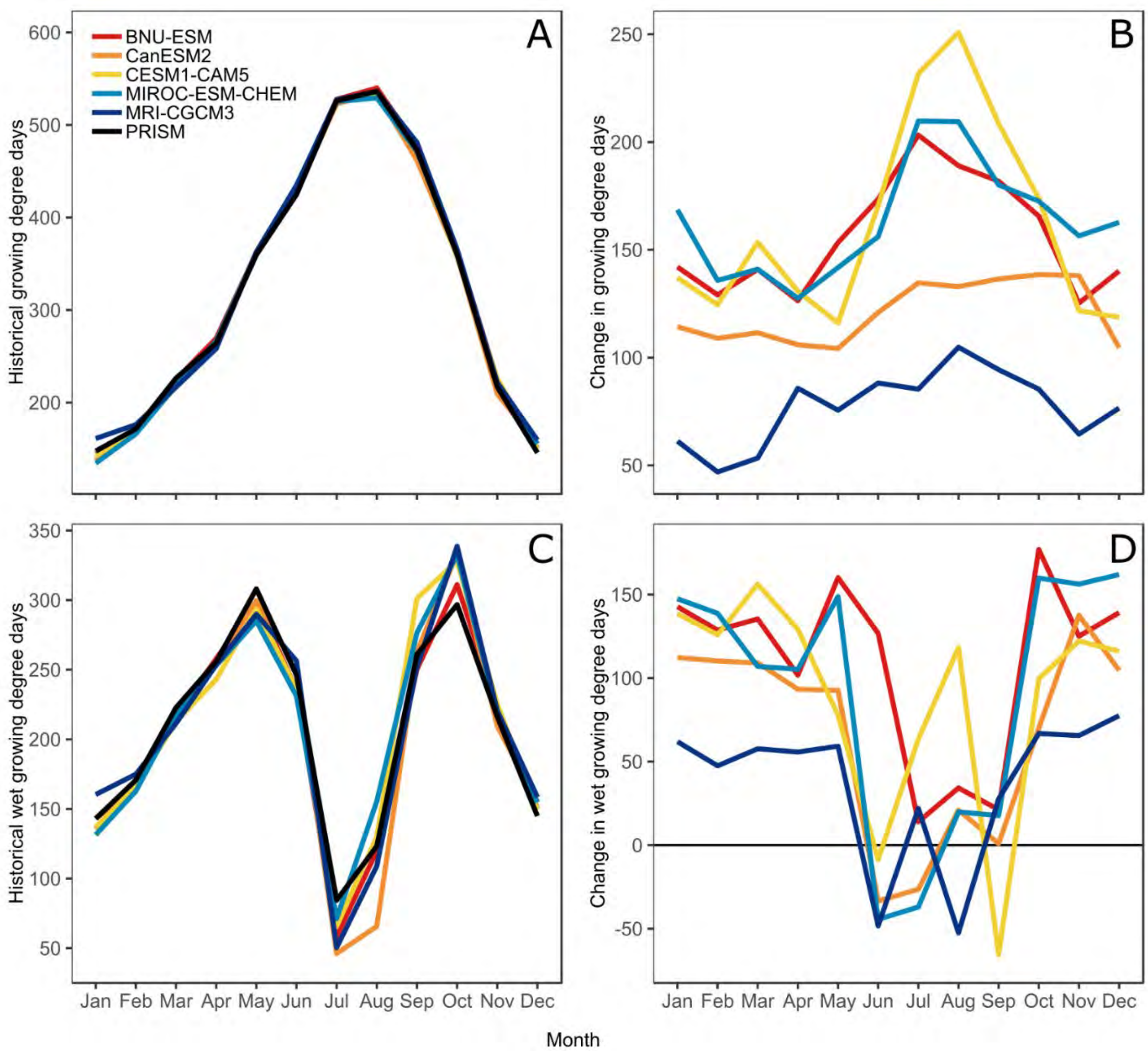


Figure 2.13—Monthly growing degree-days (GDD) (A, B) and wet growing degree-days (WGDD) (C, D) by elevation for five selected global climate models (GCM) for the OCAP assessment area. Historical values (A, C) for GDD and WGDD were calculated from PRISM data (Daly et al. 2001) for 1970–1999, and NASA NEX-DCP30 downscaled climate data (Thrasher et al. 2013) for 2070–2099 (B, D), under the RCP 8.5 emission scenario (van Vuuren et al. 2013). We used a temperature threshold of 0 °C. For precipitation, the threshold was set to the average May precipitation for 1970–1999.

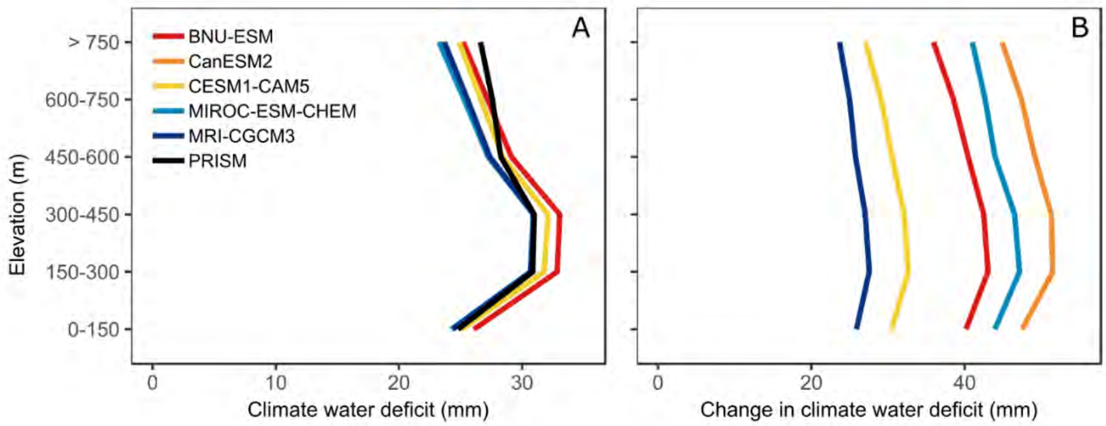


Figure 2.14—Climatic water deficit (CWD) for 1970–1999 (A) and projected change in CWD by 2070–2099 based on the five selected global climate models (B) for the OCAP assessment area. CWD values were calculated from potential evapotranspiration (PET) and actual evapotranspiration (AET) calculated by the MC2 dynamic global vegetation model. Future values represent RCP 8.5 climate change scenario (van Vuuren et al. 2013).

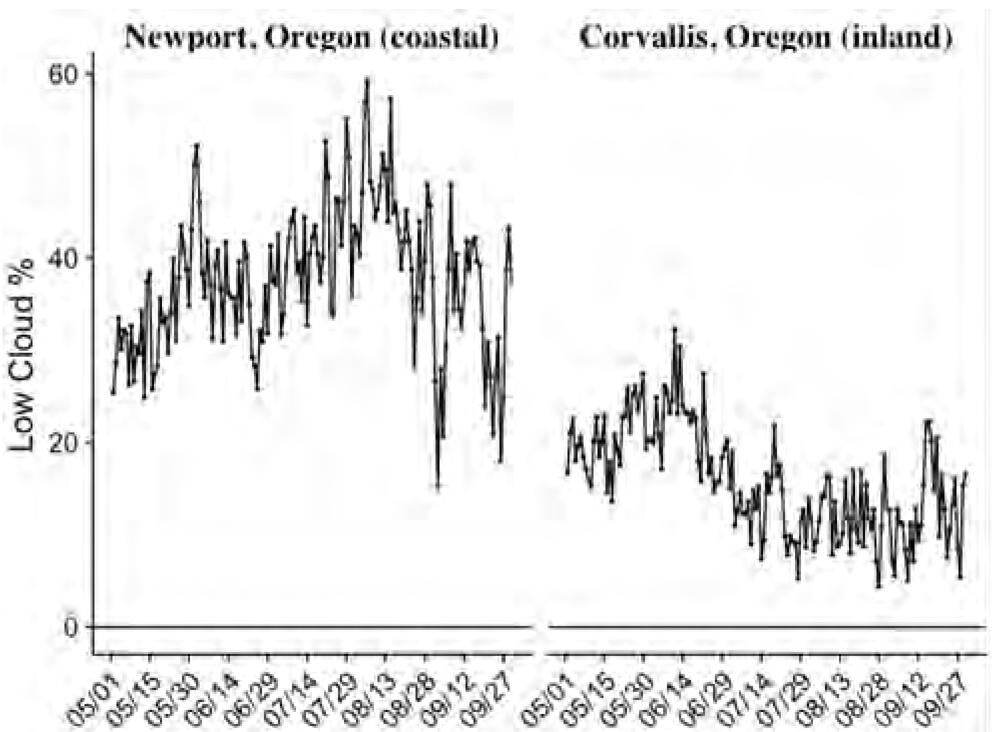


Figure Box 2.1—Average daily summertime low cloud frequency recorded at a coastal airport (Newport, Oregon) and an inland airport (Corvallis, Oregon), 1996–2017 (Iowa Environmental Mesonet 2019). Daily low-cloud frequency is defined as the percentage of total hourly airport observations over each 24-hour period that meet two criteria: cloud cover exceeding 50 percent and a cloud base height at or below 2000 m.

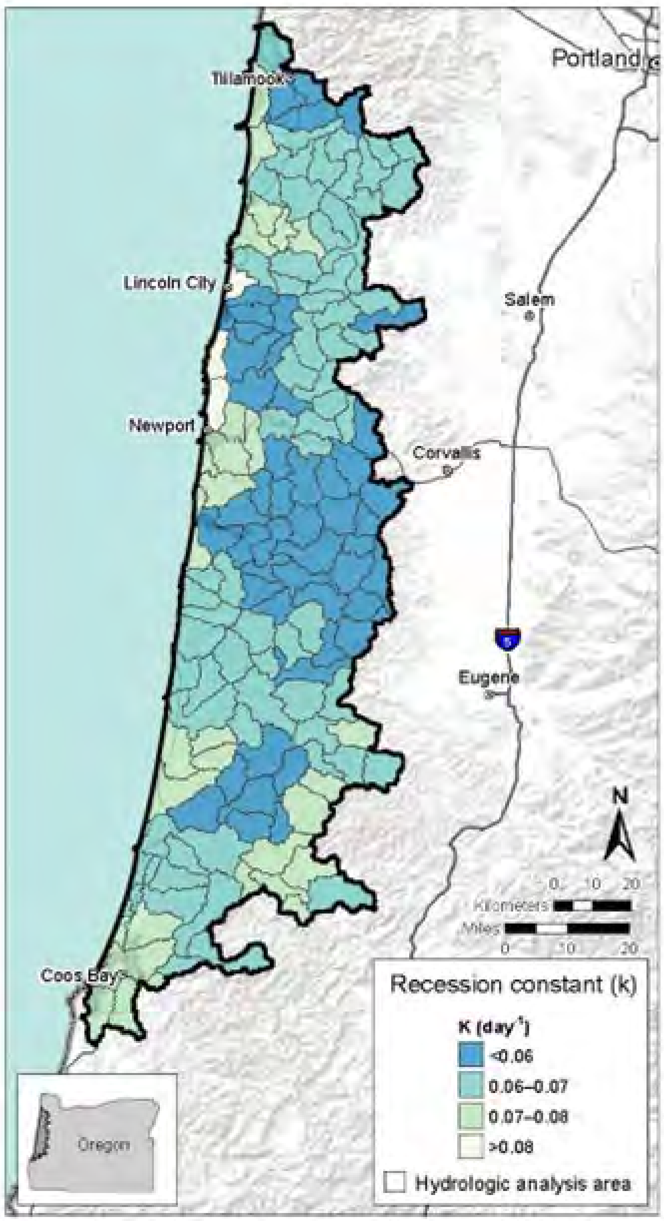


Figure 3.1—Relative geologic storage of water and "drainage efficiency" across the OCAP assessment area. The inverse of the k value (i.e., 1/k) is the number of days required for the flow rate to fall to 1/e from an "initial" flow rate (e is Euler's number used in natural logarithms and has a value of about 2.7.). Following Safeeq et al. (2013), watersheds with k values below 0.065 are groundwater-dominated, slow-draining systems; watersheds with k values above 0.065 are fast-draining systems with shallow subsurface-water storage.

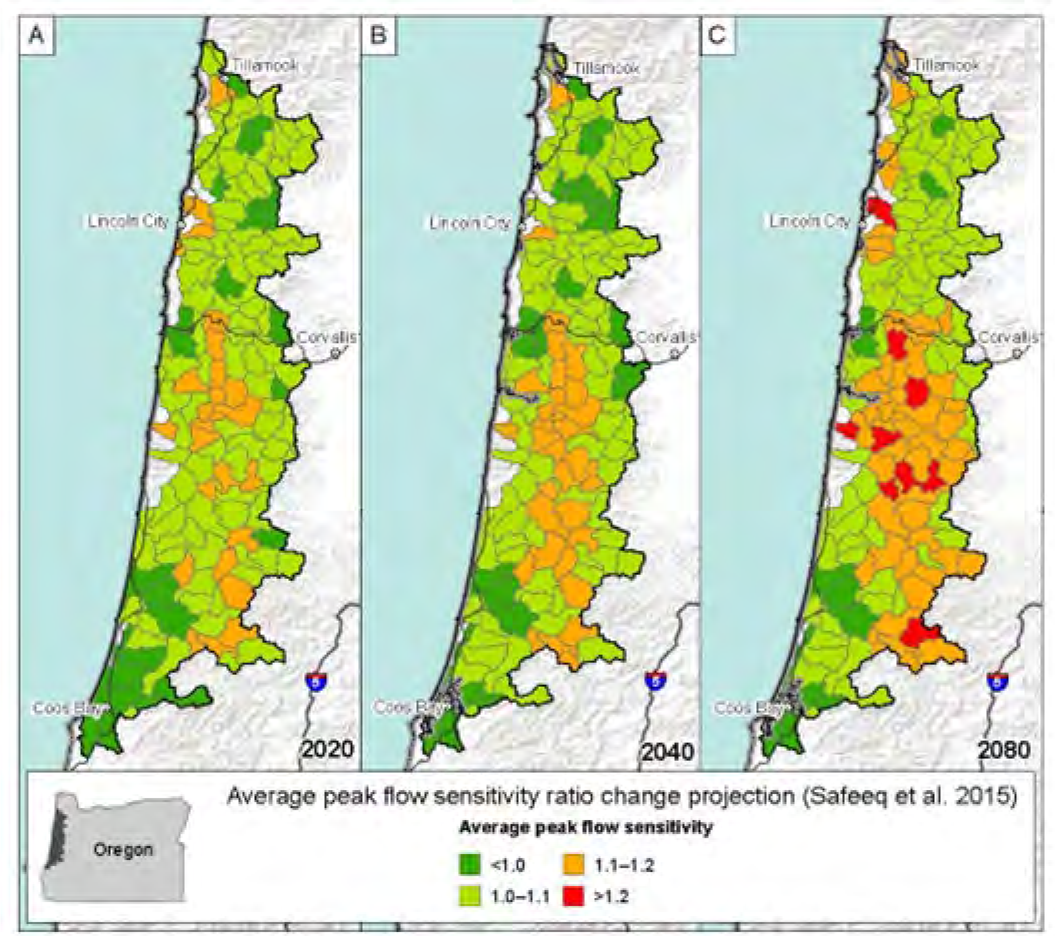


Figure 3.2—Average change in peak streamflow sensitivity for watersheds in the OCAP assessment area. Sensitivity ratios are based on calculations described in Safeeq et al. (2015). Small increases in the peak flow sensitivity ratio indicate watersheds where there is low sensitivity to changes in peak flows; larger increases in the sensitivity ratio indicate an increased capacity for watersheds to experience shifts in peak streamflows.

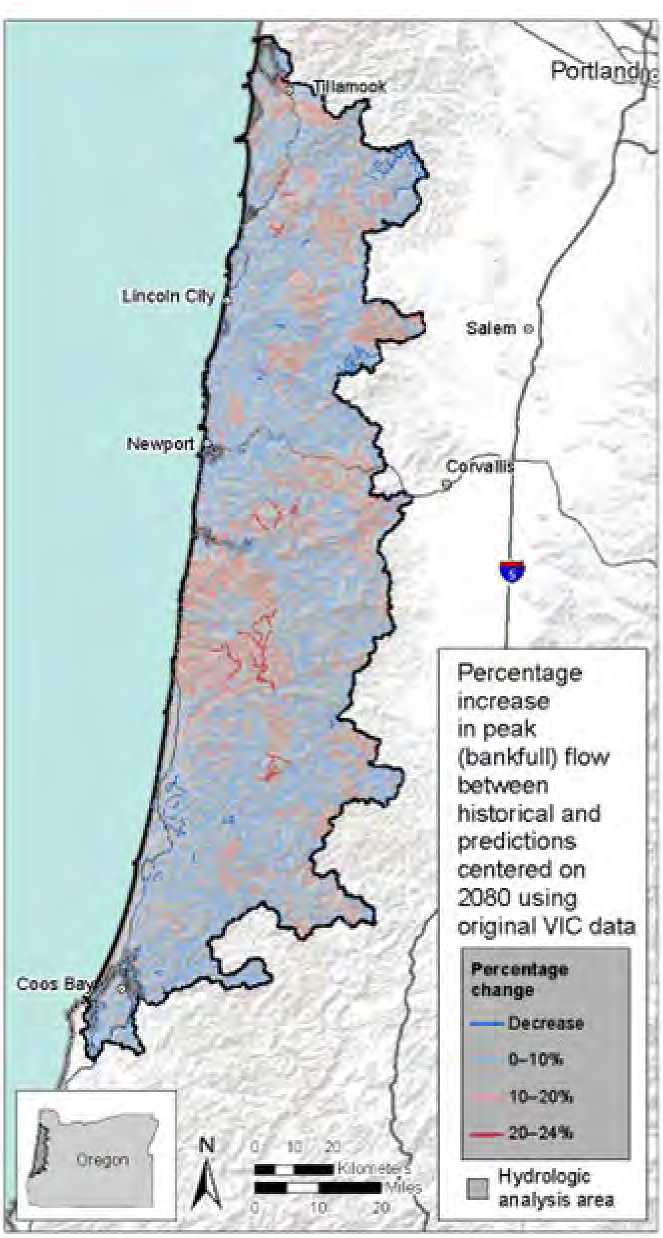


Figure 3.3—Projected increase in peak flows between a historical period (1970–1999) and the 2080s under the A1B greenhouse gas emission scenario. Projections are based on Variable Infiltration Capacity (VIC) model projections of surface-water input changes filtered by the geologically-based unit hydrograph.

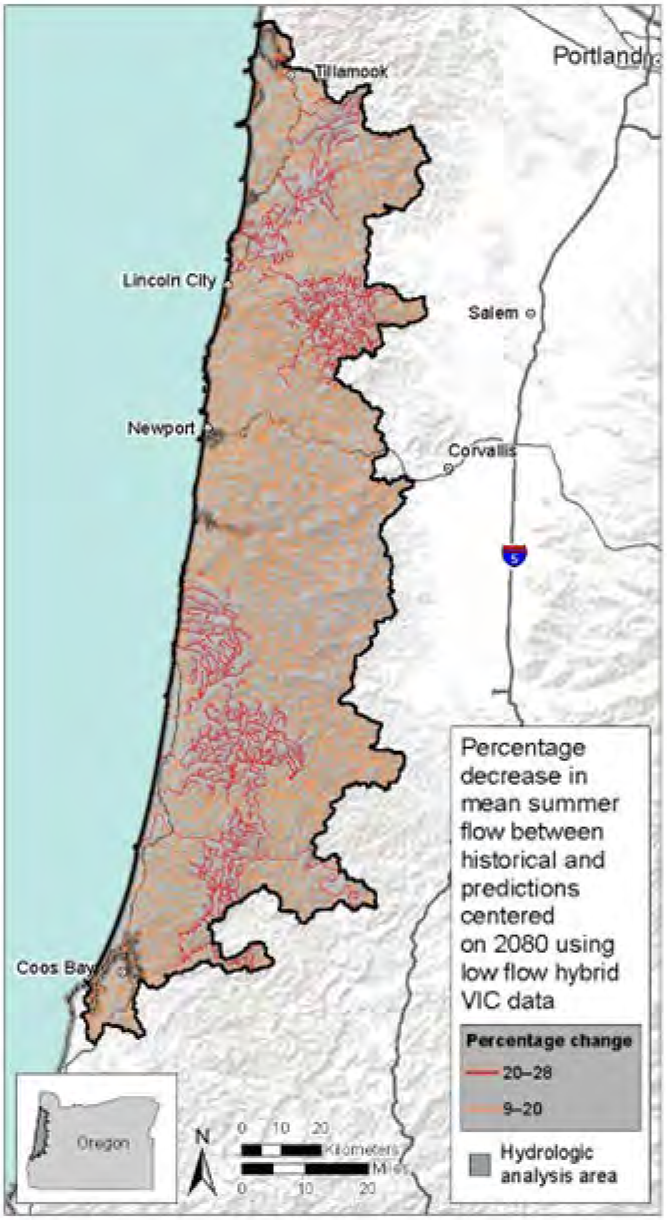


Figure 3.4—Projected decrease in low flows between a historical period (1970–1999) and the 2080s under the A1B greenhouse gas emission scenario. Projections are based on Variable Infiltration Capacity (VIC) model projections of surface-water input changes filtered by the geologically-based unit hydrograph (Safeeq et al. 2013, Tague and Grant 2009).

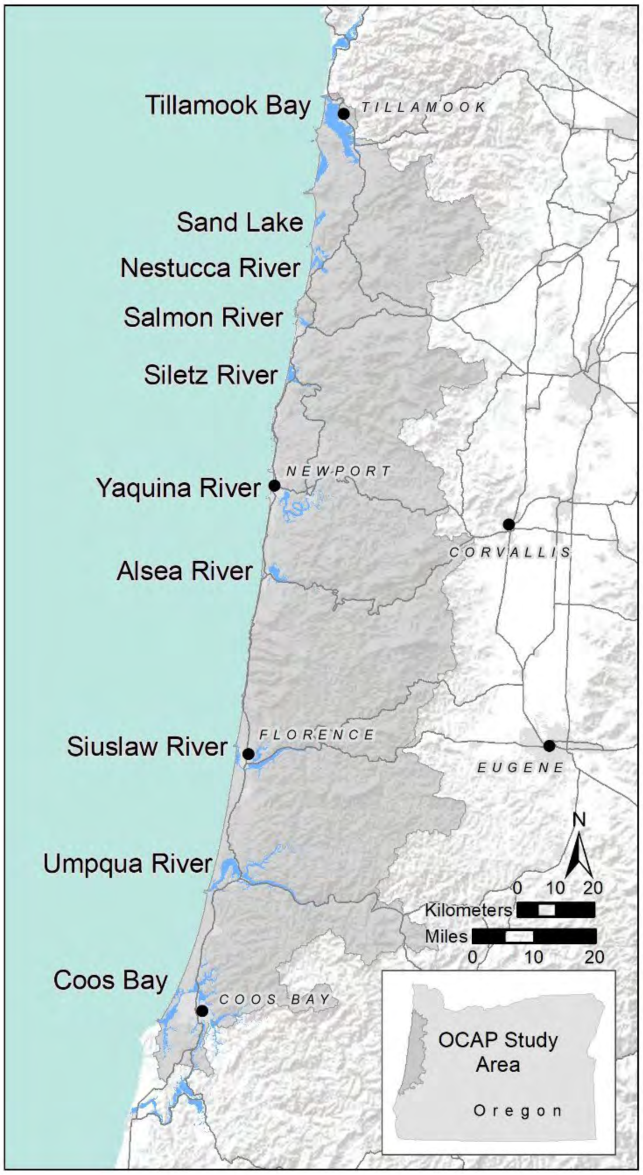
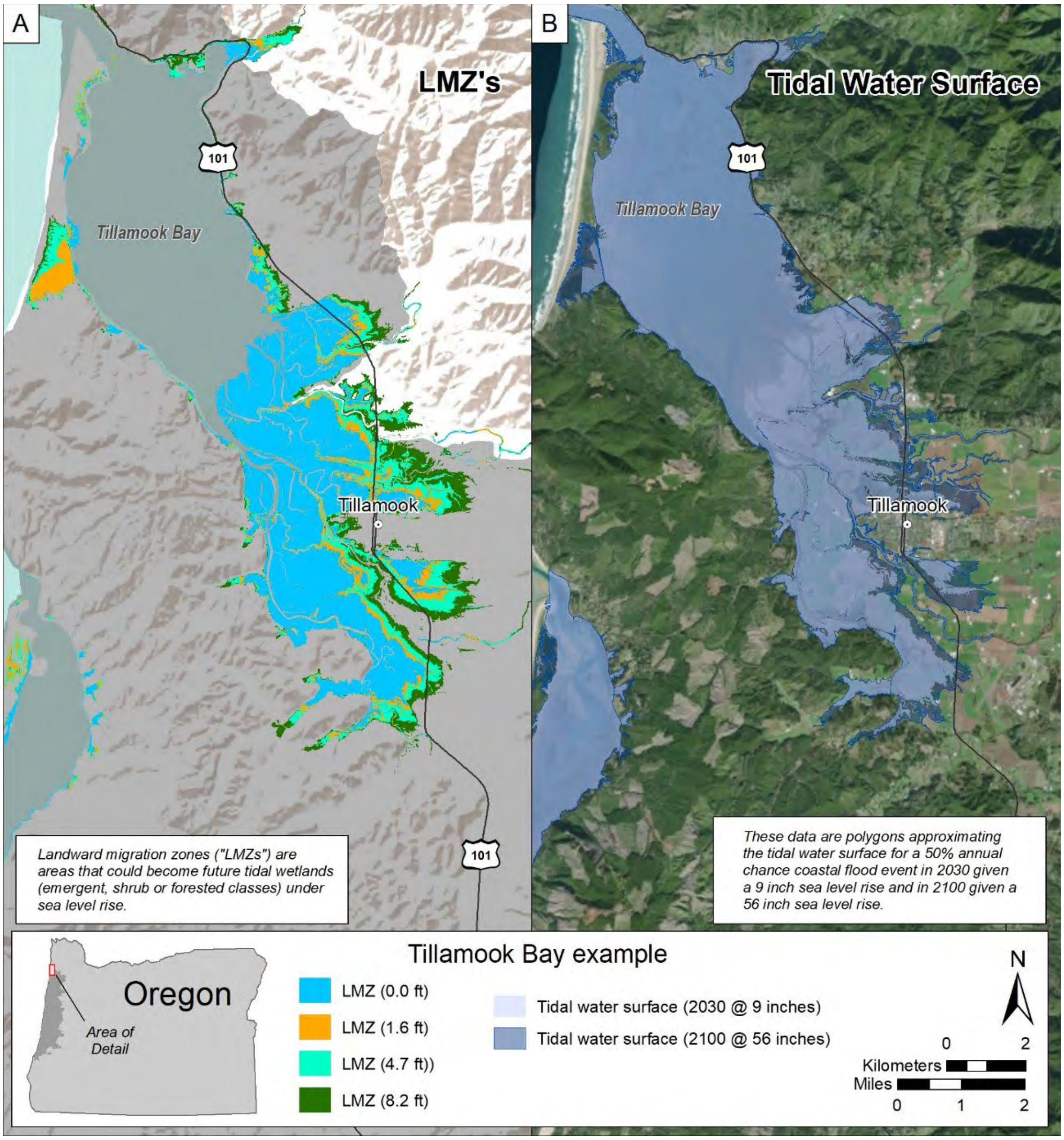
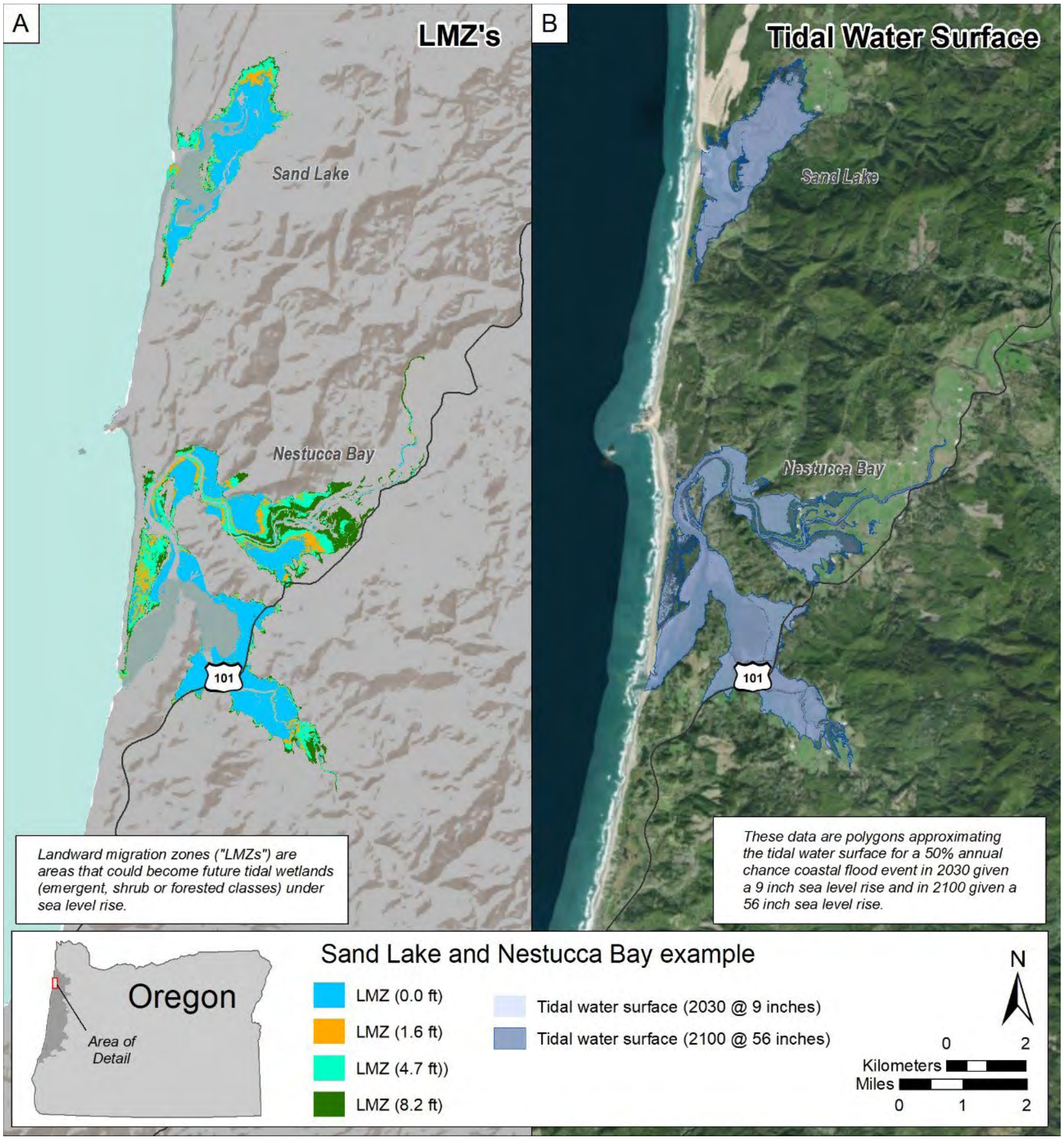
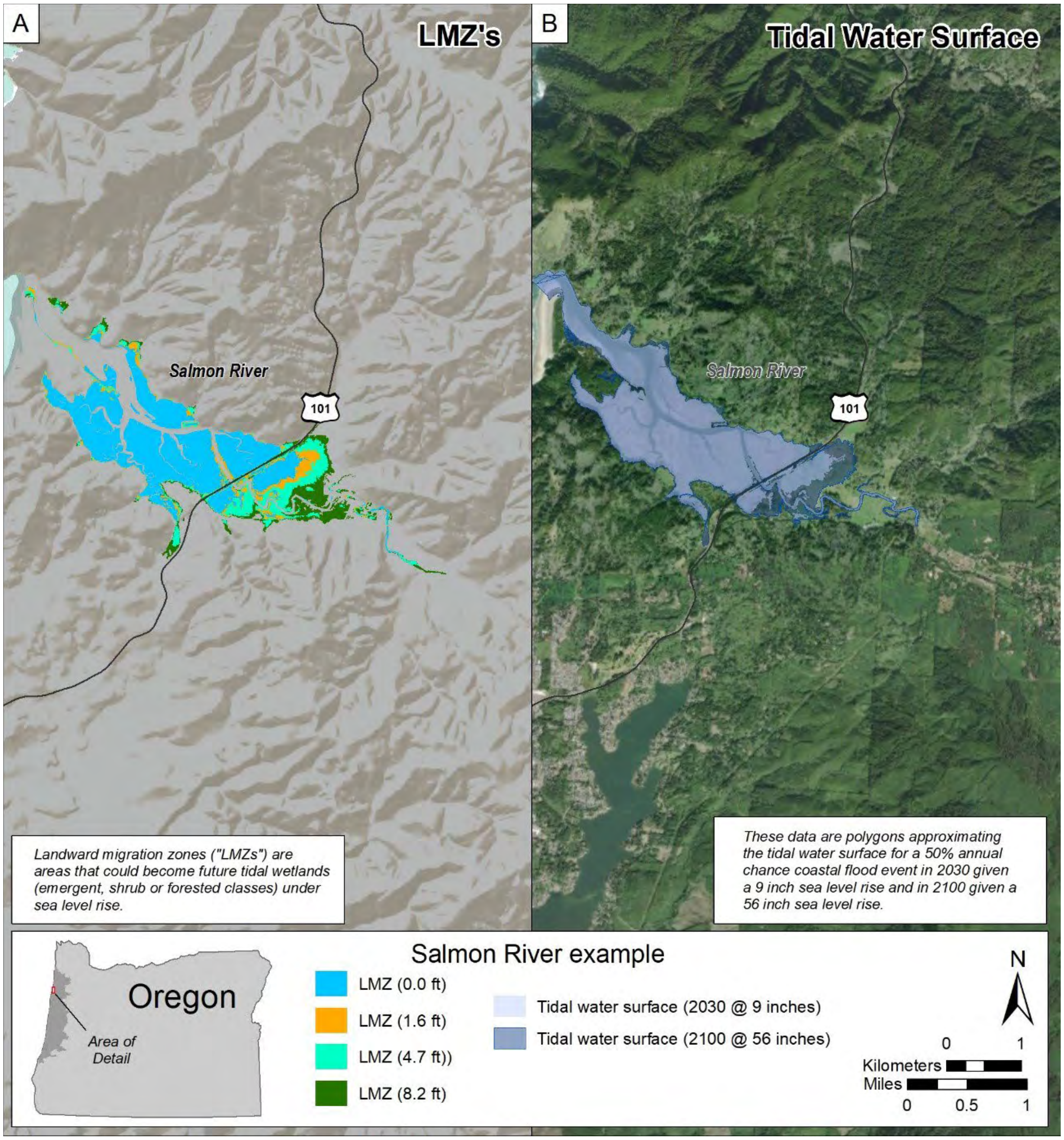
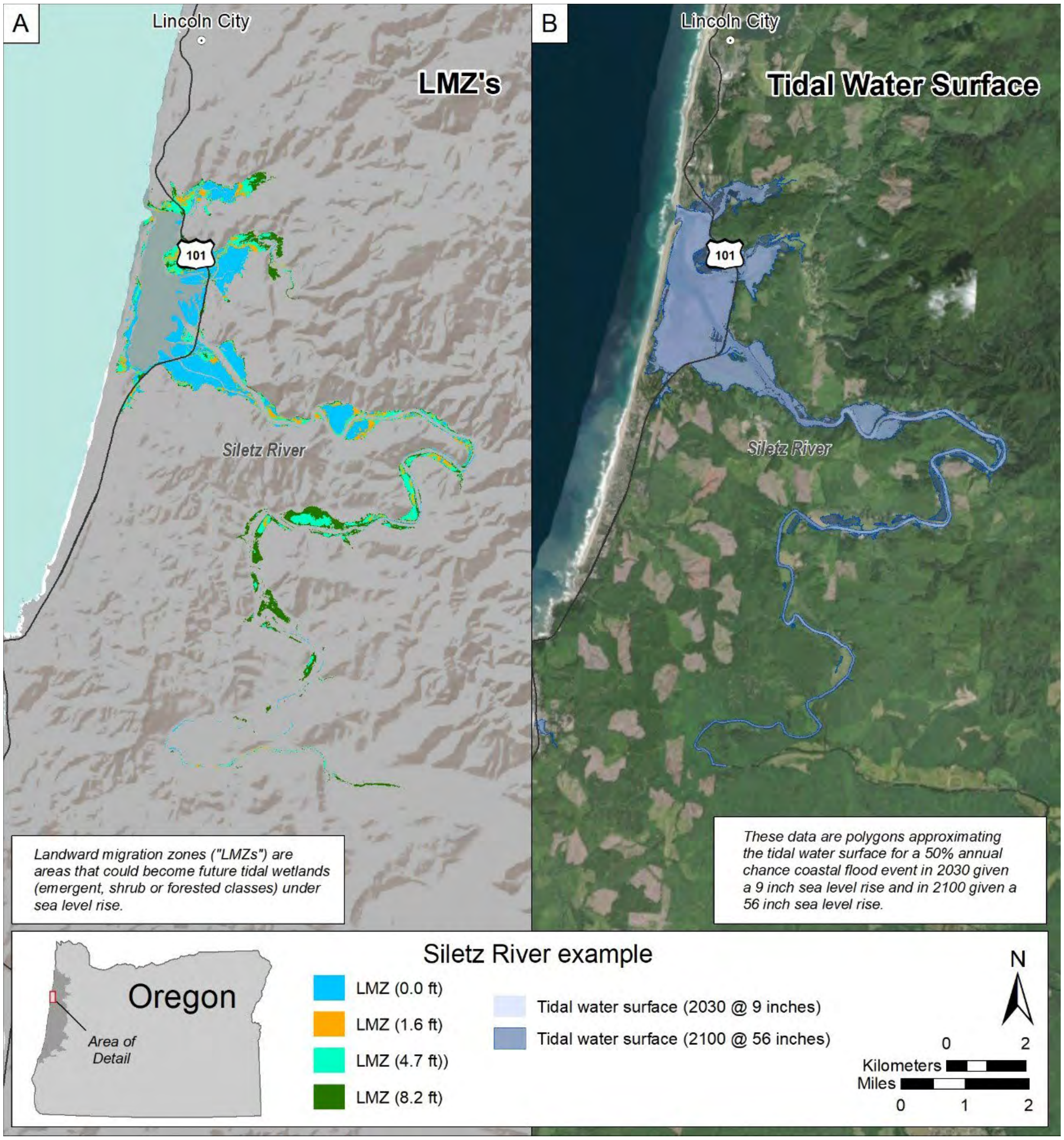


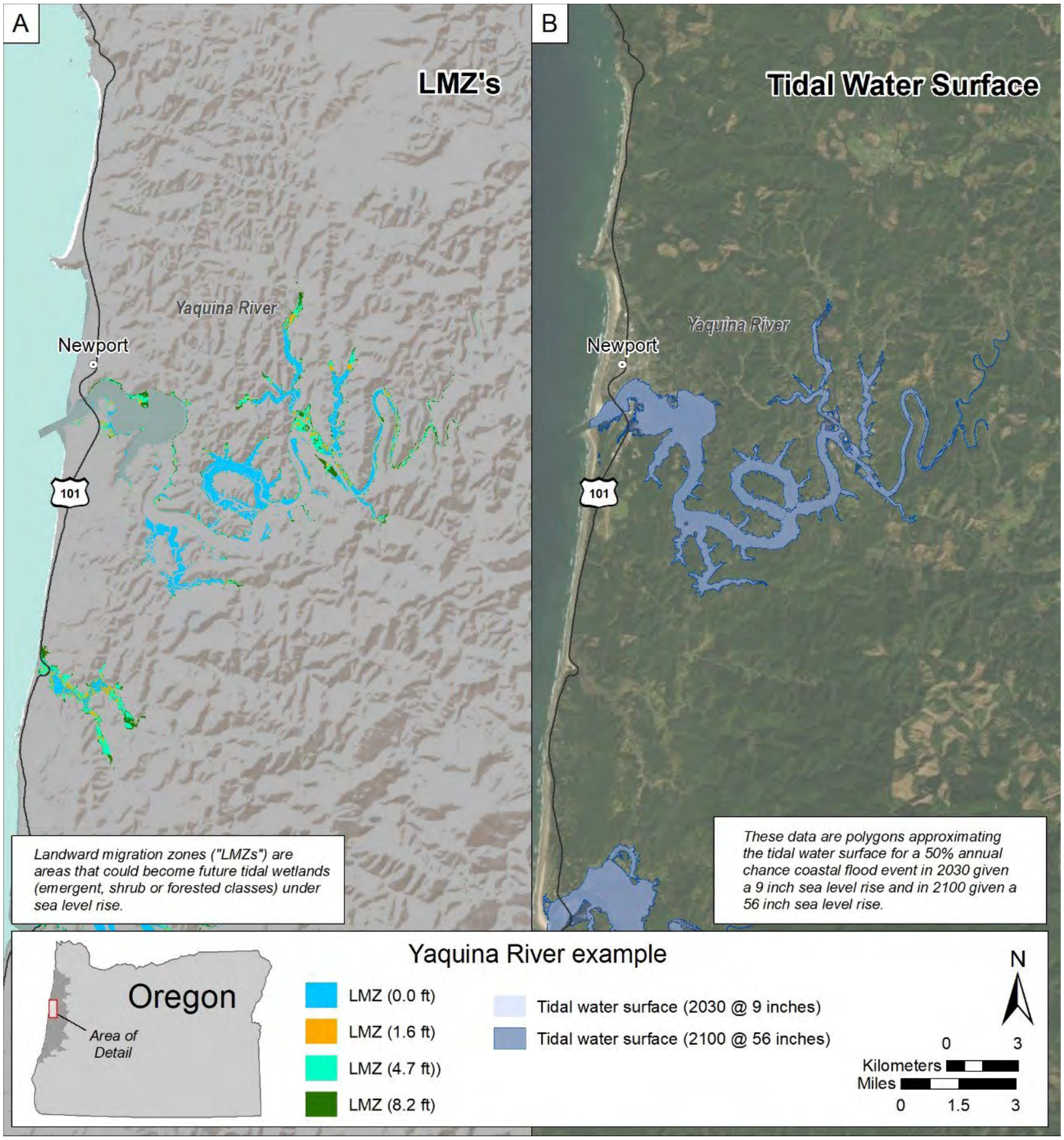
Figure 3.5—Ten estuaries draining from the Oregon Coast Range into the Pacific Ocean are included in the OCAP assessment area.

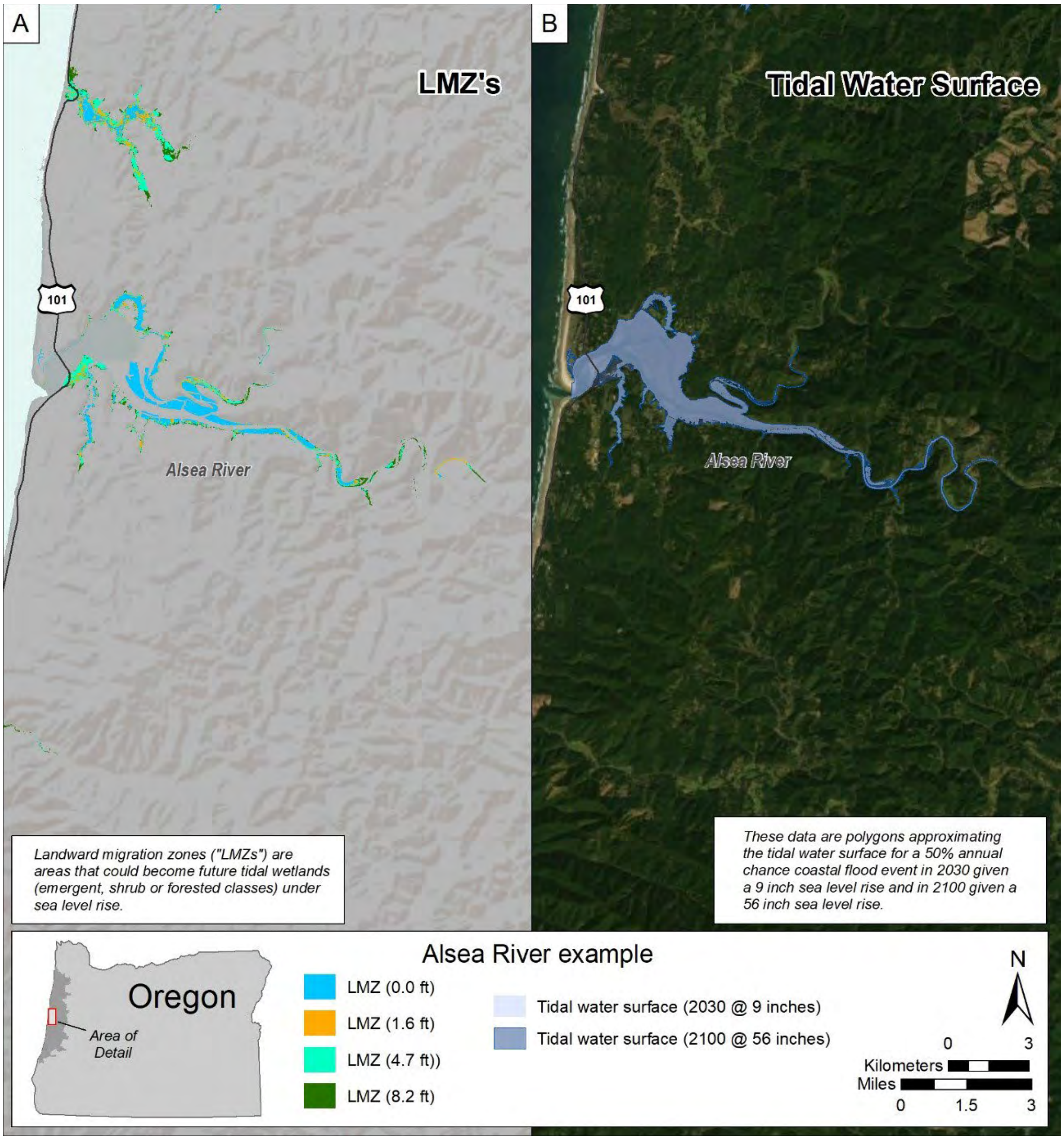

A
LMZ's
B
Tidal Water Surface
101
Tillamook Bay
Tillamook
Landward migration zones ("LMZs") are areas that could become future tidal wetlands (emergent, shrub or forested classes) under sea level rise.
These data are polygons approximating the tidal water surface for a 50% annual chance coastal flood event in 2030 given a 9 inch sea level rise and in 2100 given a 56 inch sea level rise.
Tillamook Bay example
Oregon
Area of Detail
LMZ (0.0 ft)
LMZ (1.6 ft)
LMZ (4.7 ft))
LMZ (8.2 ft)
Tidal water surface (2030 @ 9 inches)
Tidal water surface (2100 @ 56 inches)
N
Kilometers 0 2
Miles 0 1 2

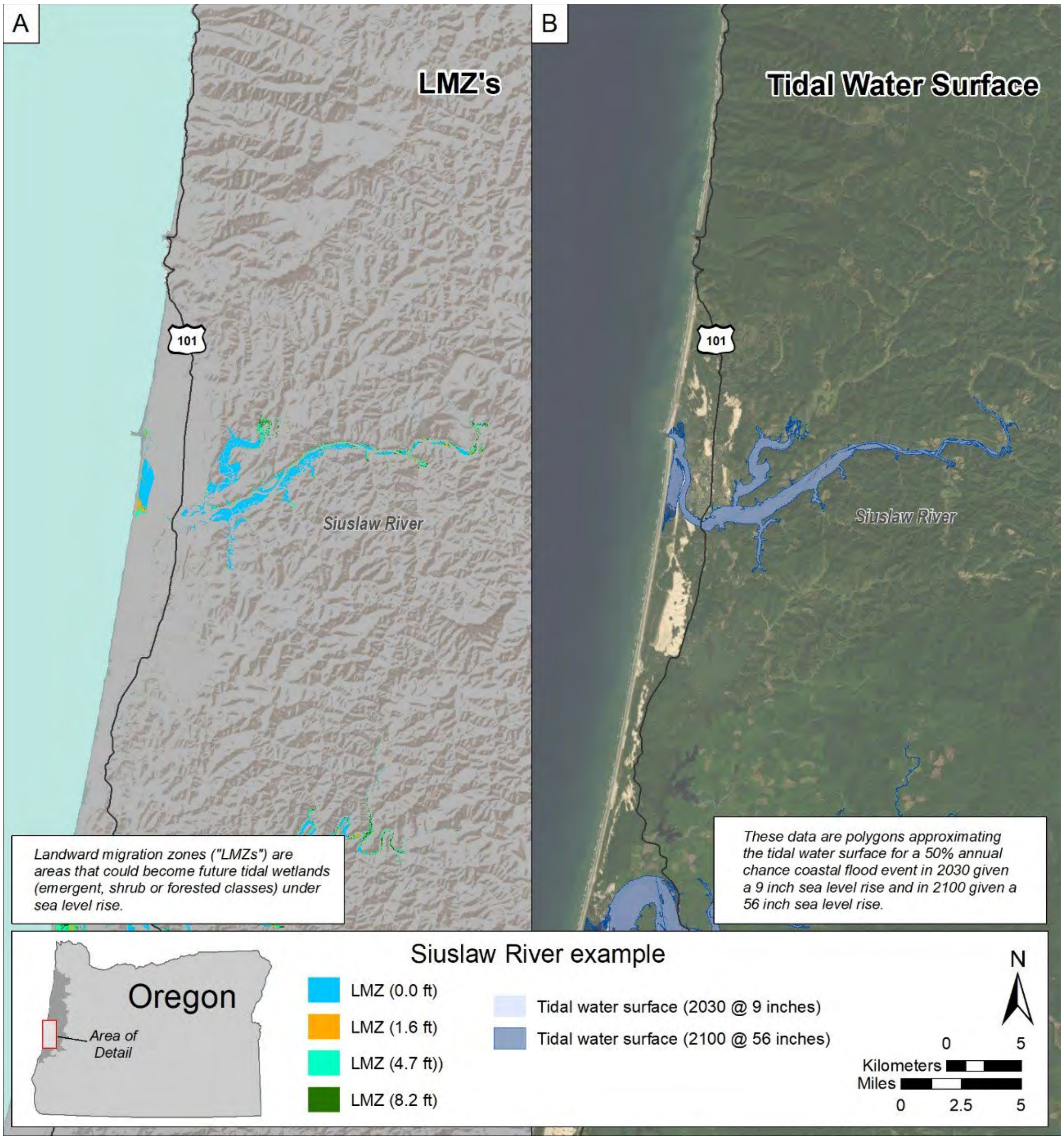

A
LMZ's
Sand Lake
Nestucca Bay
101
Landward migration zones ("LMZs") are areas that could become future tidal wetlands (emergent, shrub or forested classes) under sea level rise.
B
Tidal Water Surface
Sand Lake
Nestucca Bay
101
These data are polygons approximating the tidal water surface for a 50% annual chance coastal flood event in 2030 given a 9 inch sea level rise and in 2100 given a 56 inch sea level rise.
Oregon
Area of Detail
Sand Lake and Nestucca Bay example
LMZ (0.0 ft)
LMZ (1.6 ft)
LMZ (4.7 ft))
LMZ (8.2 ft)
Tidal water surface (2030 @ 9 inches)
Tidal water surface (2100 @ 56 inches)
N
Kilometers
0
2
Miles
0
1
2

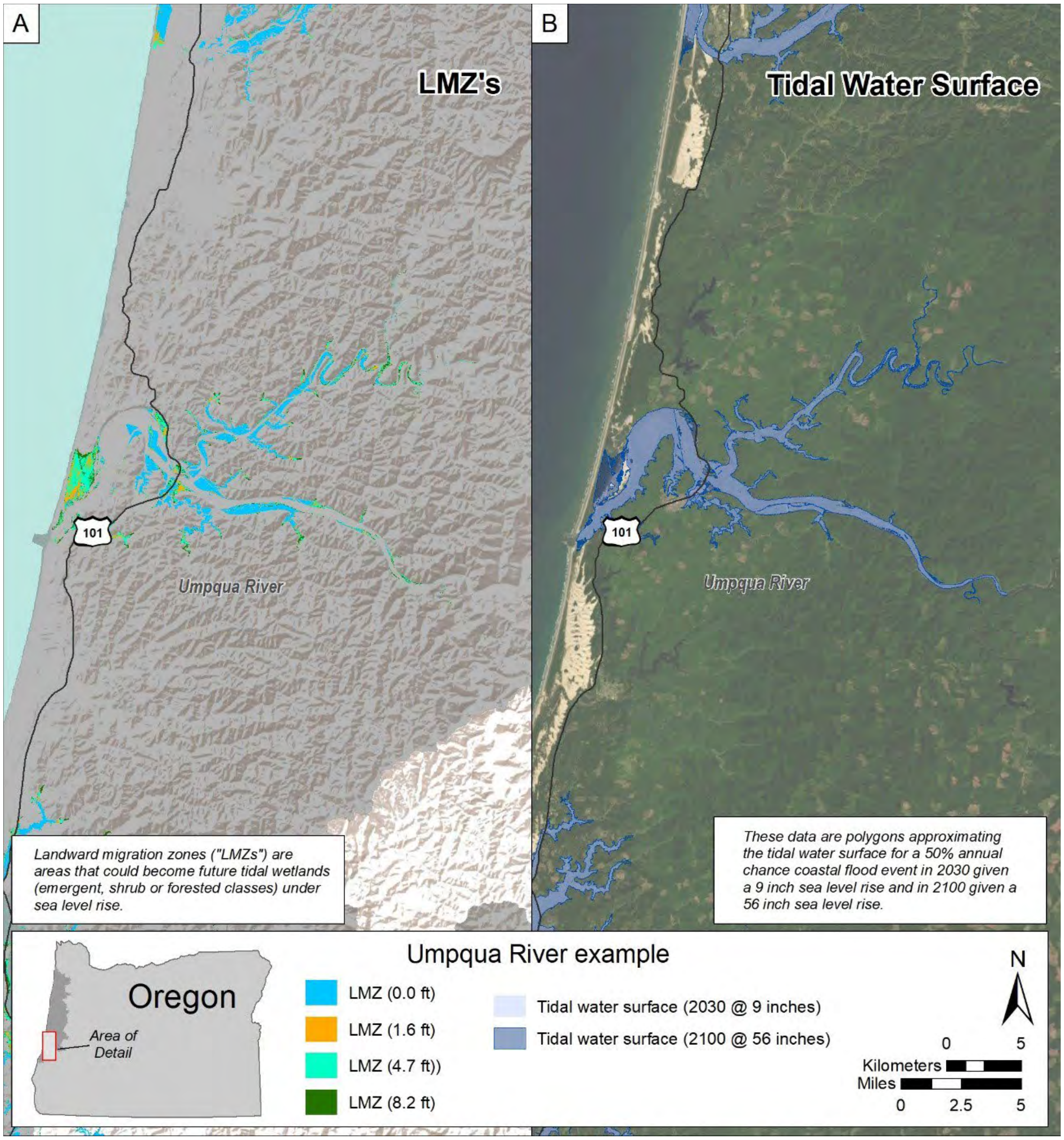

A
LMZ's
B
Tidal Water Surface
Salmon River
101
Salmon River
101
Landward migration zones ("LMZs") are areas that could become future tidal wetlands (emergent, shrub or forested classes) under sea level rise.
These data are polygons approximating the tidal water surface for a 50% annual chance coastal flood event in 2030 given a 9 inch sea level rise and in 2100 given a 56 inch sea level rise.
Salmon River example
Oregon
Area of Detail
LMZ (0.0 ft)
LMZ (1.6 ft)
LMZ (4.7 ft))
LMZ (8.2 ft)
Tidal water surface (2030 @ 9 inches)
Tidal water surface (2100 @ 56 inches)
N
0
1
Kilometers
Miles
0
0.5
1


A
Lincoln City
LMZ's
101
Siletz River
Landward migration zones ("LMZs") are areas that could become future tidal wetlands (emergent, shrub or forested classes) under sea level rise.
B
Lincoln City
Tidal Water Surface
101
Siletz River
These data are polygons approximating the tidal water surface for a 50% annual chance coastal flood event in 2030 given a 9 inch sea level rise and in 2100 given a 56 inch sea level rise.
Siletz River example
Oregon
Area of Detail
LMZ (0.0 ft)
LMZ (1.6 ft)
LMZ (4.7 ft))
LMZ (8.2 ft)
Tidal water surface (2030 @ 9 inches)
Tidal water surface (2100 @ 56 inches)
N
0
2
Kilometers
Miles
0
1
2


A
LMZ's
B
Tidal Water Surface
Yaquina River
Newport
101
Yaquina River
Newport
101
Landward migration zones ("LMZs") are areas that could become future tidal wetlands (emergent, shrub or forested classes) under sea level rise.
These data are polygons approximating the tidal water surface for a 50% annual chance coastal flood event in 2030 given a 9 inch sea level rise and in 2100 given a 56 inch sea level rise.
Yaquina River example
Oregon
Area of Detail
LMZ (0.0 ft)
LMZ (1.6 ft)
LMZ (4.7 ft))
LMZ (8.2 ft)
Tidal water surface (2030 @ 9 inches)
Tidal water surface (2100 @ 56 inches)
N
0
3
Kilometers
Miles
0
1.5
3


A
LMZ's
101
Alsea River
Landward migration zones ("LMZs") are areas that could become future tidal wetlands (emergent, shrub or forested classes) under sea level rise.
B
Tidal Water Surface
101
Alsea River
These data are polygons approximating the tidal water surface for a 50% annual chance coastal flood event in 2030 given a 9 inch sea level rise and in 2100 given a 56 inch sea level rise.
Oregon
Area of Detail
Alsea River example
LMZ (0.0 ft)
LMZ (1.6 ft)
LMZ (4.7 ft))
LMZ (8.2 ft)
Tidal water surface (2030 @ 9 inches)
Tidal water surface (2100 @ 56 inches)
N
0
3
Kilometers
Miles
0
1.5
3


A
LMZ's
101
Siuslaw River
Landward migration zones ("LMZs") are areas that could become future tidal wetlands (emergent, shrub or forested classes) under sea level rise.
B
Tidal Water Surface
101
Siuslaw River
These data are polygons approximating the tidal water surface for a 50% annual chance coastal flood event in 2030 given a 9 inch sea level rise and in 2100 given a 56 inch sea level rise.
Oregon
Area of Detail
Siuslaw River example
LMZ (0.0 ft)
LMZ (1.6 ft)
LMZ (4.7 ft))
LMZ (8.2 ft)
Tidal water surface (2030 @ 9 inches)
Tidal water surface (2100 @ 56 inches)
N
0 5
Kilometers
Miles
0 2.5 5


A
LMZ's
101
Umpqua River
Landward migration zones ("LMZs") are areas that could become future tidal wetlands (emergent, shrub or forested classes) under sea level rise.
B
Tidal Water Surface
101
Umpqua River
These data are polygons approximating the tidal water surface for a 50% annual chance coastal flood event in 2030 given a 9 inch sea level rise and in 2100 given a 56 inch sea level rise.
Umpqua River example
Oregon
Area of Detail
LMZ (0.0 ft)
LMZ (1.6 ft)
LMZ (4.7 ft))
LMZ (8.2 ft)
Tidal water surface (2030 @ 9 inches)
Tidal water surface (2100 @ 56 inches)
N
0 5
Kilometers
Miles
0 2.5 5

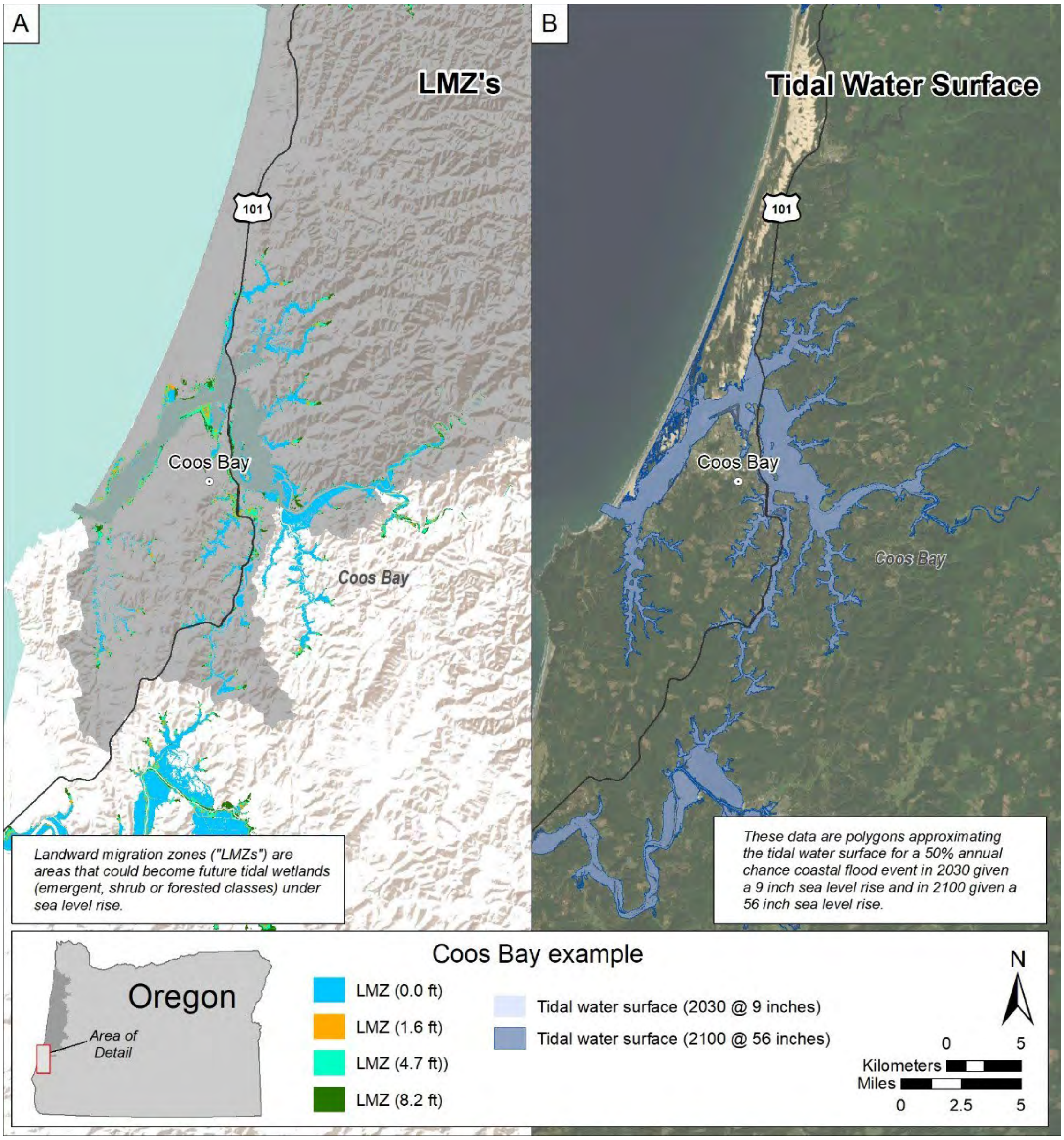


Figure 3.6—Potential areas of landward migration for vegetation under different tidal inundation scenarios are presented for each of the 10 estuaries present in the Oregon Coast Adaptation Partnership assessment area. Landward migration zones (LMZ) associated with mean sea-level increases of 0 m, 0.48 m, 1.42 m, and 2.5 m are presented (A). Also presented is the projected tidal water surface for a 50 percent annual chance of coastal flood even in 2030 given a 22.9-cm rise in sea level, and in 2100 given a 142.25-cm rise in sea level (B). All LMZ models were developed by Brophy and Ewald (2017), and tidal water-surface scenarios were developed by OCMP (2017).

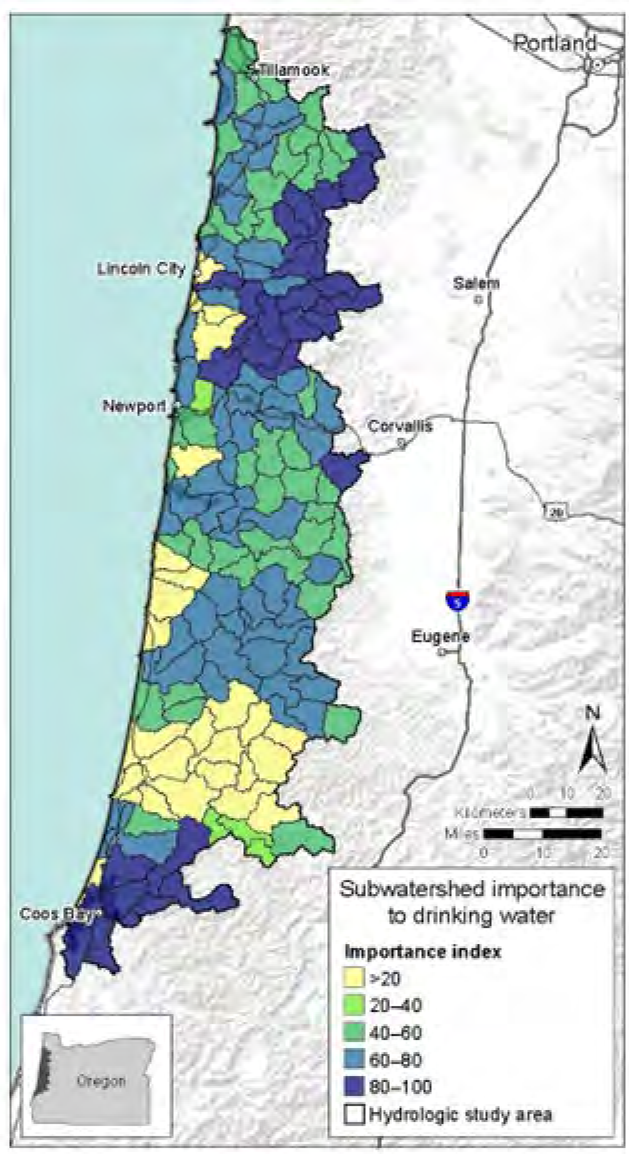


Figure 3.7—An index of the relative importance of each subwatershed to surface drinking water. The closer a subwatershed is to the downstream intake and the more people an intake serves, the higher the importance index (F2F2 2018).

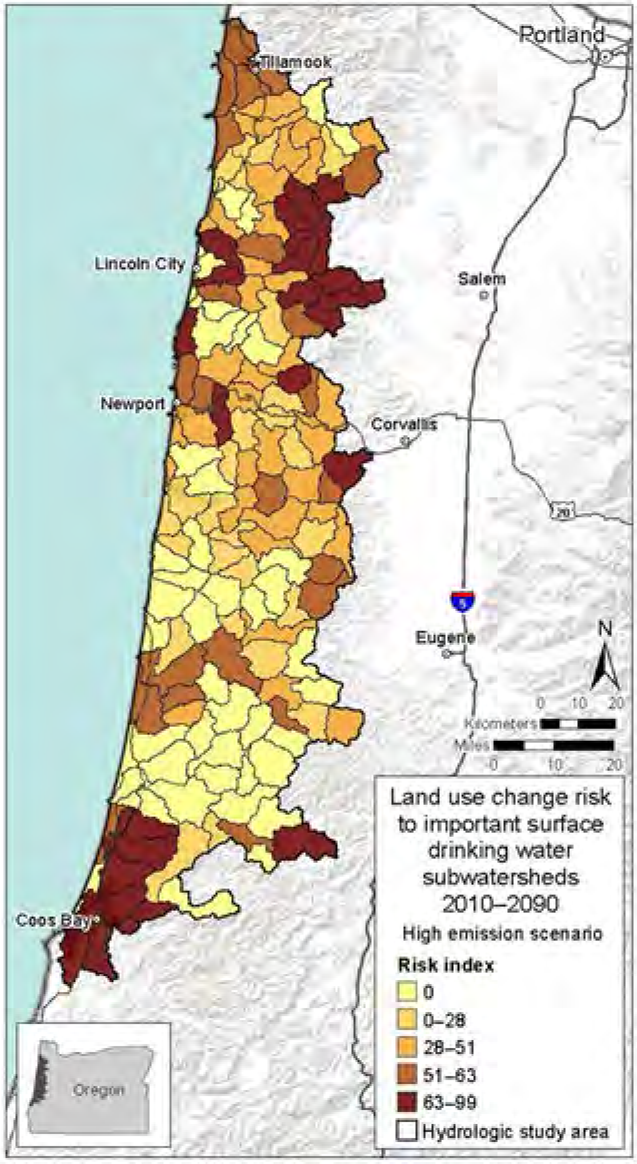


Figure 3.8—Forest 2 Faucets 2.0 risk of land-use change to important surface-water watersheds, 2010–2090 (RCP 8.5 emission scenario). Development risk is evaluated using ICLUS Land Use data, which models land-use change based on socioeconomic and climate scenarios at 10-year intervals (F2F2 2018).

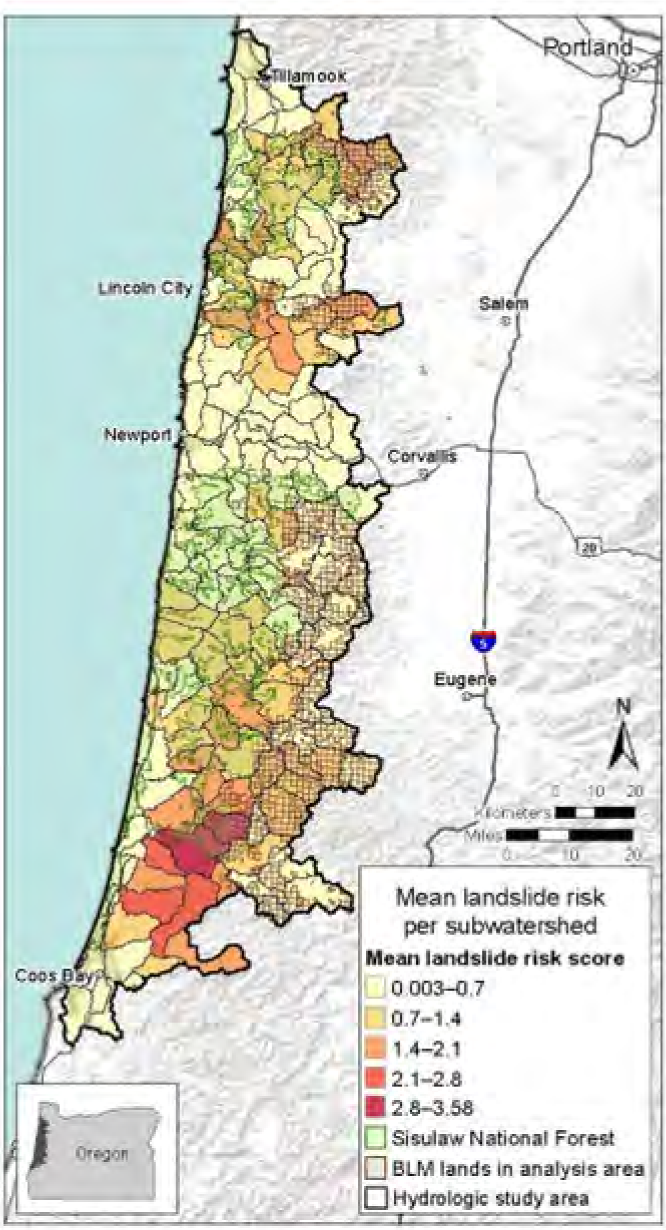


Figure 3.9—Mean landslide risk index by subwatershed (Hydrologic unit code 12) with an overlay of Siuslaw National Forest and Bureau of Land Management lands. Subwatersheds with higher risk scores overlap with Siuslaw National Forest lands and important areas for surface water (table 3.8, fig. 3.8). Data are derived from 2019 Aquatic and Riparian Effectiveness Monitoring Program (AREMP) landslide risk analyses.

Figure 3.10—The Oregon Dunes National Recreation Area dunal aquifer boundary largely overlaps with Siuslaw National Forest lands, where hydrologically interconnected lakes, freshwater emergent wetlands and ponds, and freshwater forest/shrub wetlands are dominant. The North Bend/Coos Bay Water Board holds a special-use permit to draw from the aquifer-well locations shown here. Dunal aquifer data are from EPA 2019.

Figure 3.11—The dunal aquifer boundary for Florence, Oregon, with overlaying Siuslaw National Forest lands and hydrologically interconnected lakes, freshwater emergent wetlands and ponds, and freshwater forest/shrub wetlands. The aquifer is designated by the U.S. Environmental Protection Agency as a sole-source aquifer because it supplies at least 50 percent of drinking water and there is no “reasonable alternative” source (e.g., in the case of contamination or depletion) (EPA 2018b). Dunal aquifer data are from EPA (2019).

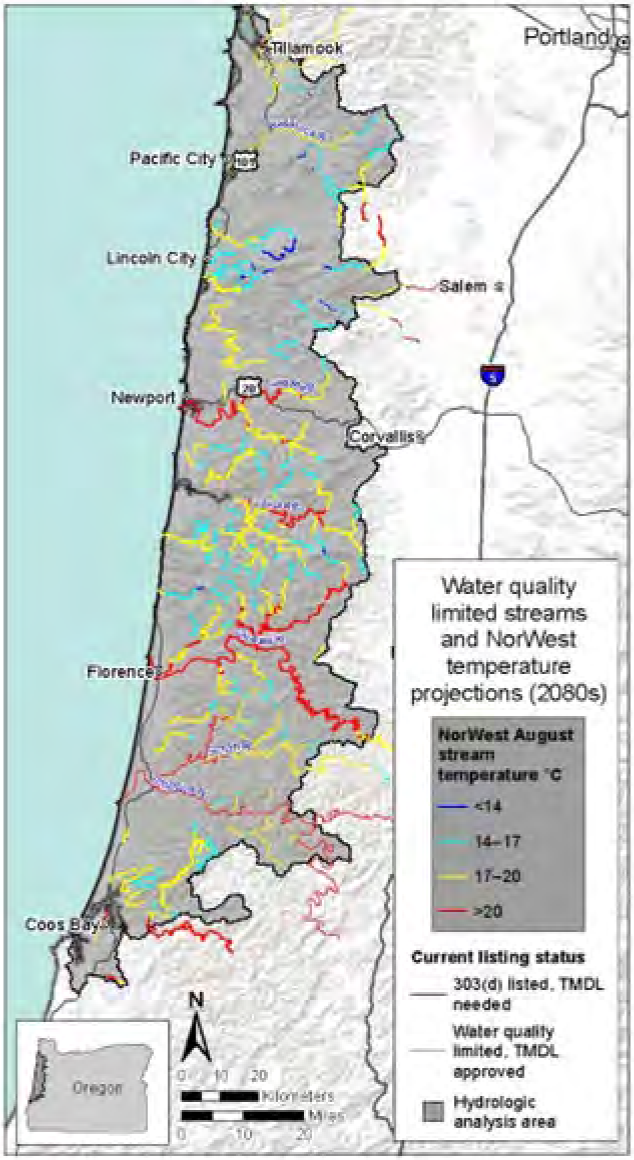


Figure 3.12—Projected stream temperature (2080s under the A1B greenhouse gas emission scenario; Isaak et al. [2017]) for currently impaired streams. Streams already designated as 303(d) impaired but without total maximum daily loads (TMDLs) are indicated with thicker line widths. Streams with approved TMDLs are indicated with narrower line widths.

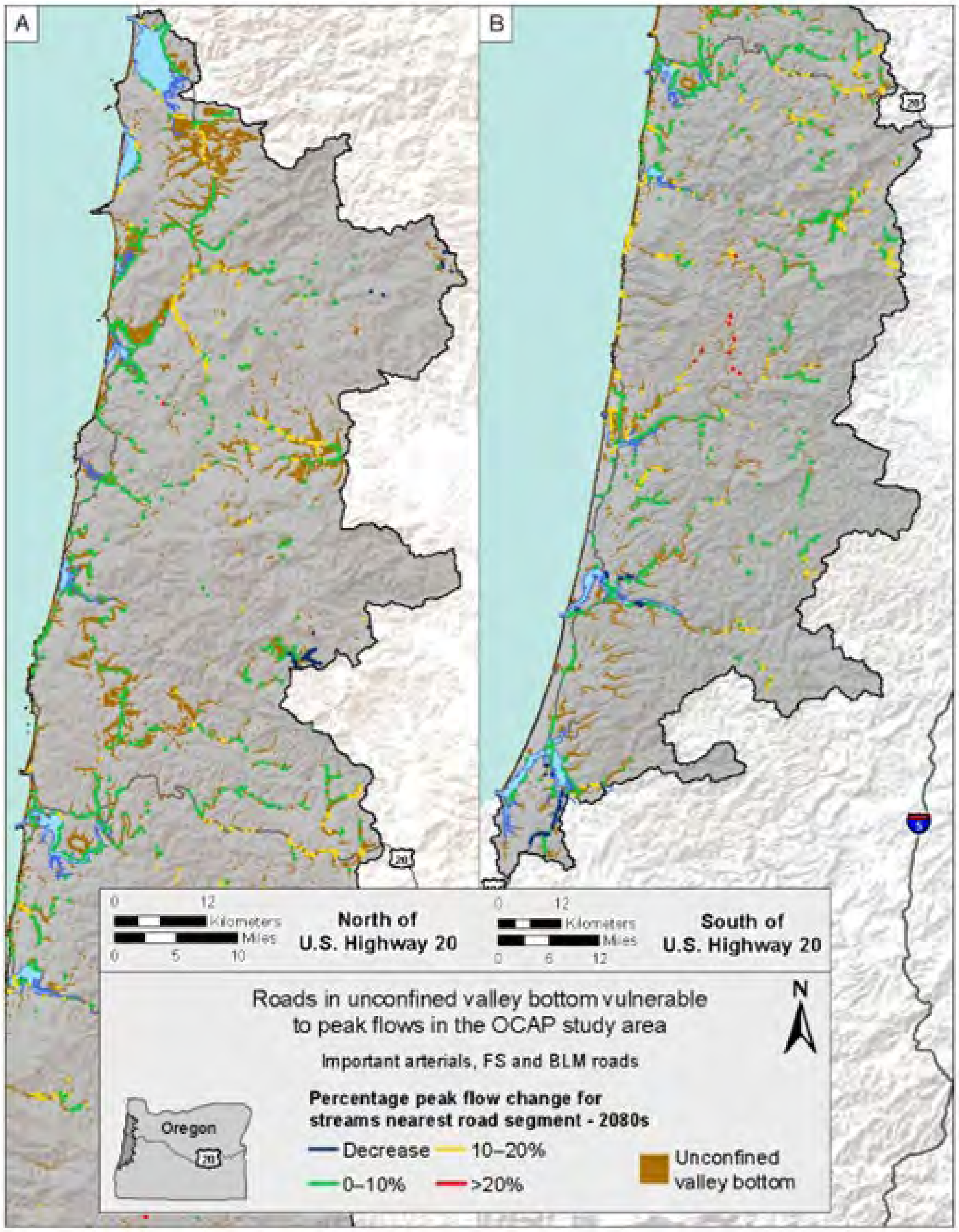


Figure 3.13—Vulnerability of roads in unconfined valley-bottom locations to peak flows in the OCAP assessment area. Map A depicts the assessment area north of U.S. Highway 20 and Map B the assessment area south of U.S. Highway 20 (Nagel et al. 2014).

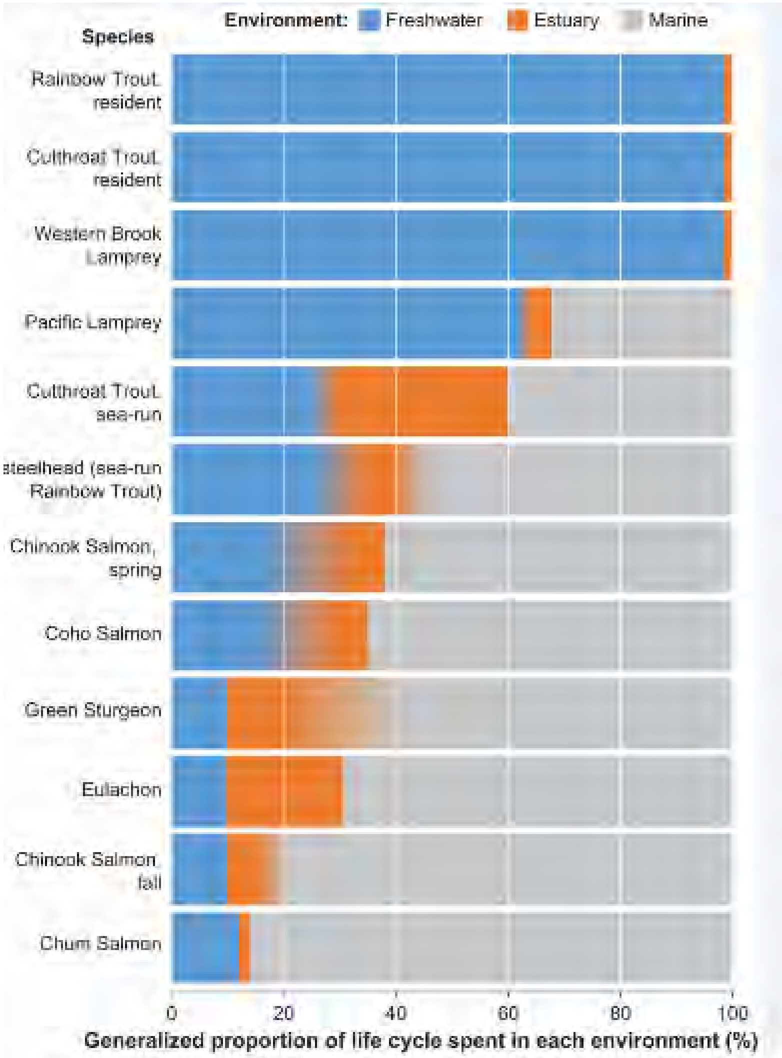


Figure 4.1—Generalized proportion of the life cycle of focal fishes in freshwater, estuary, and marine environments. Trout and lampreys occupy freshwater during their lifetime more than sturgeon, eulachon, and salmon.

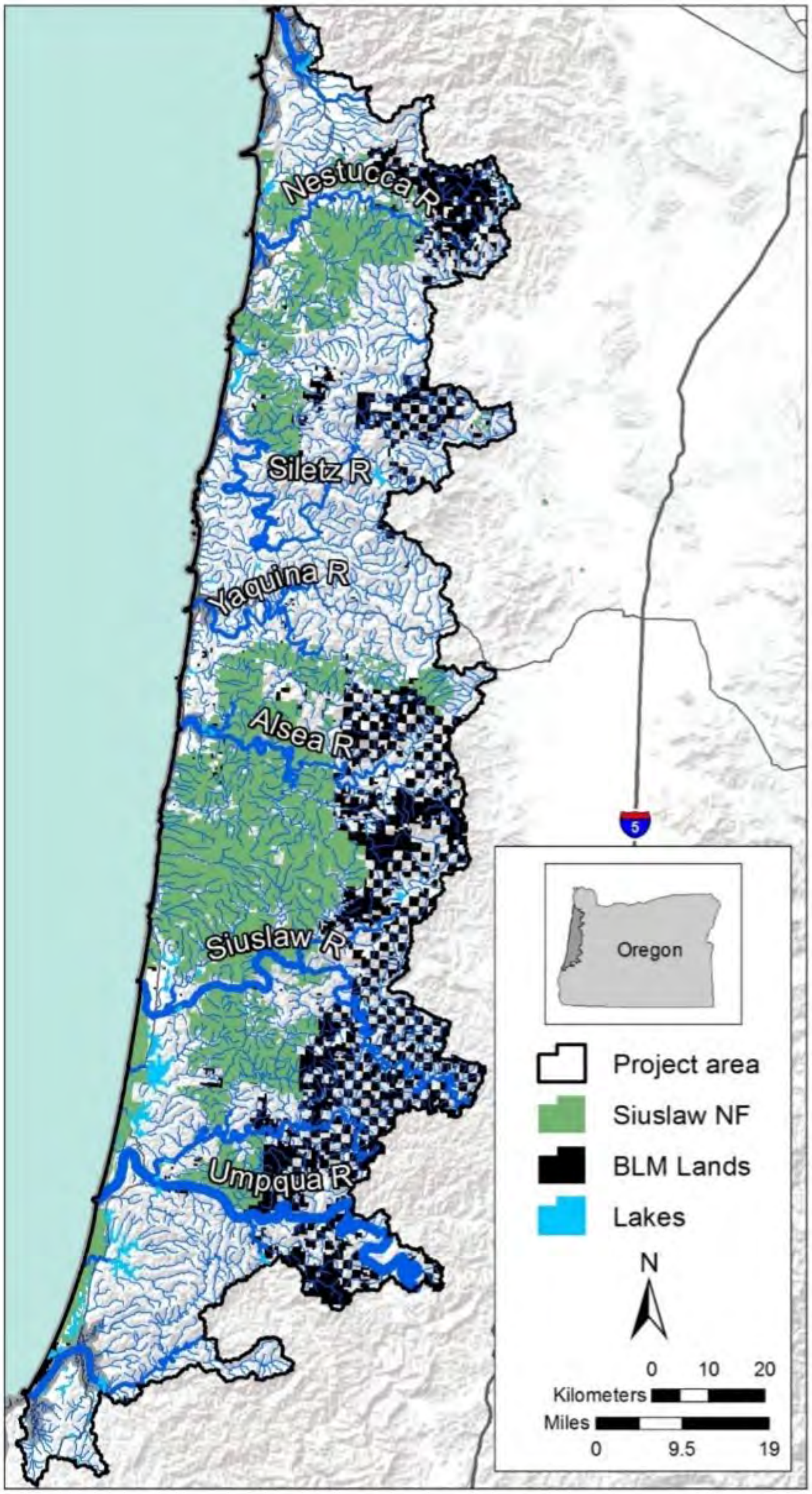


Figure 4.2—Network of 7,911 stream km in the OCAP assessment area, showing land ownership and major rivers.

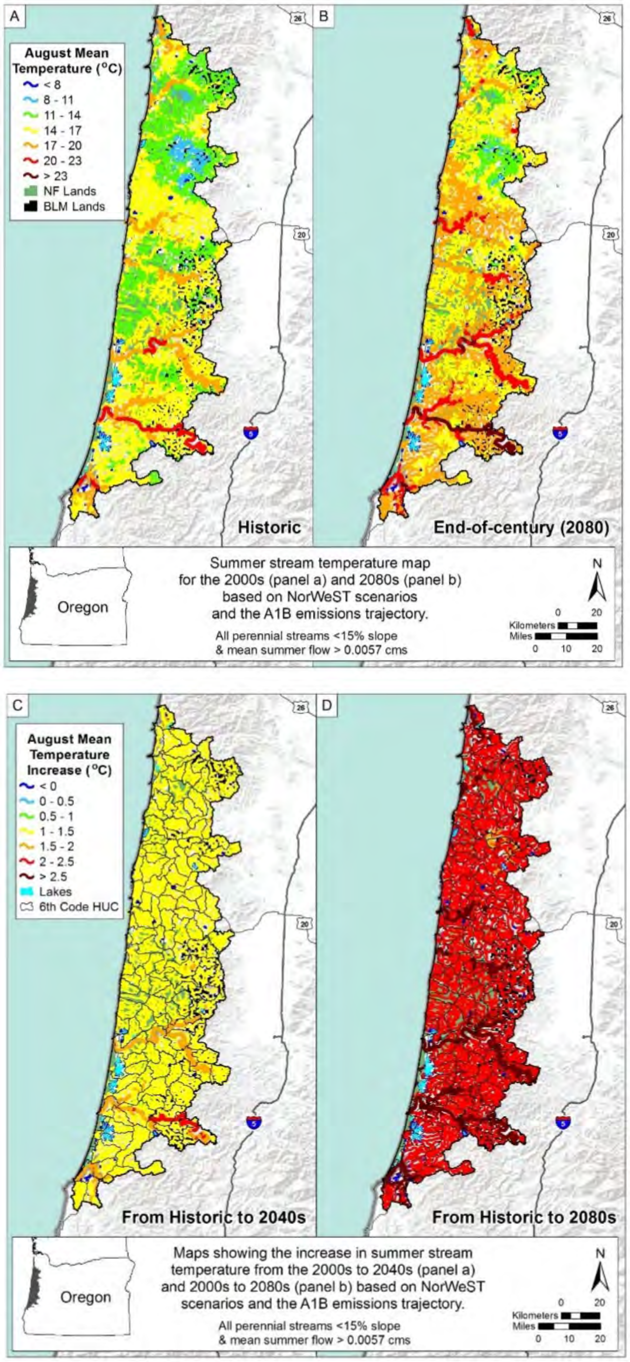


Figure 4.3—Scenarios depicting mean August stream temperatures across the 7,911 km of streams in the OCAP assessment area during a baseline period (A: 2000s) and late 21st century period (B: 2080s). Panels C and D show future temperature increases relative to the baseline period (future increases are summarized in Appendix A by 6th code HUC boundaries that are shown as small black polygons). 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).

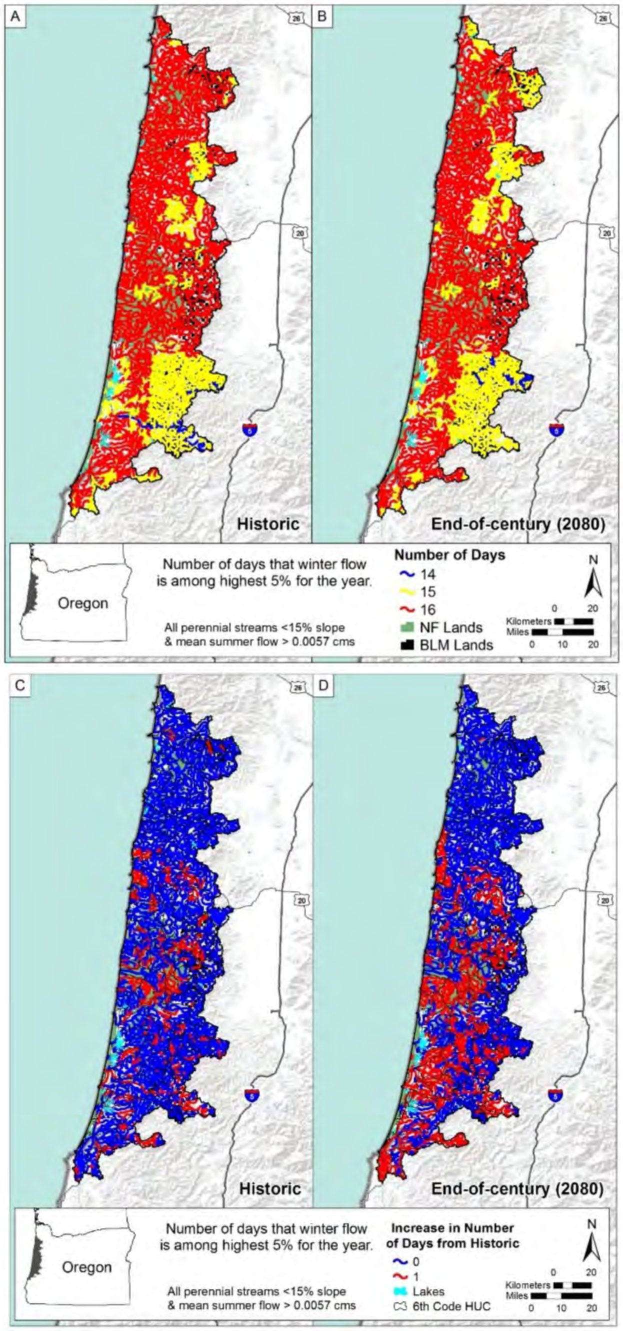


Figure 4.4—Scenarios depicting the number of days with high flows during the winter across the 7,911 km of streams in the analysis area during a baseline period (A: 2000s) and late 21st century period (B: 2080s). Panels C and D show future flow changes relative to the baseline period (future increases are summarized in Appendix A by 6th code HUC boundaries that are shown as small black polygons). ArcGIS shapefiles with reach-scale predictions 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).

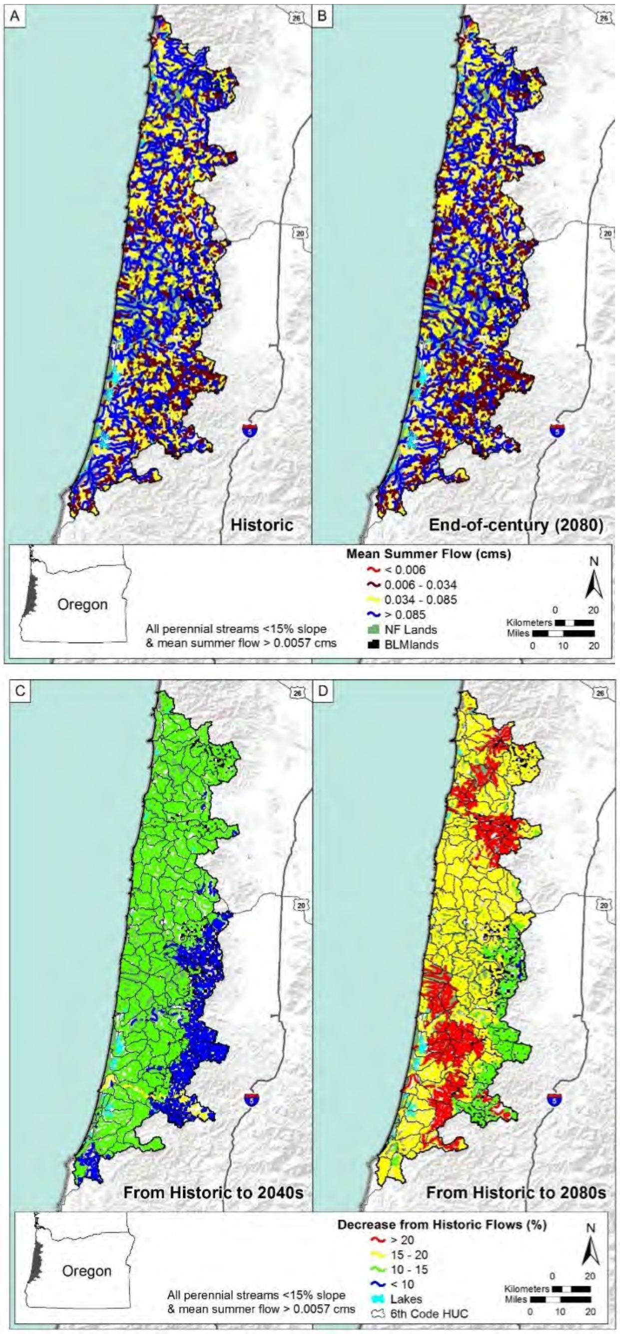


Figure 4.5—Scenarios depicting mean summer flows across the 7,911 km of streams in the assessment area during a baseline period (A: 2000s) and late 21st century period (B: 2080s). Panels C and D show future flow changes as percentages relative to the baseline period (future increases are summarized in Appendix A by 6th code HUC boundaries that are shown as small black polygons). ArcGIS shapefiles with reach-scale predictions 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).

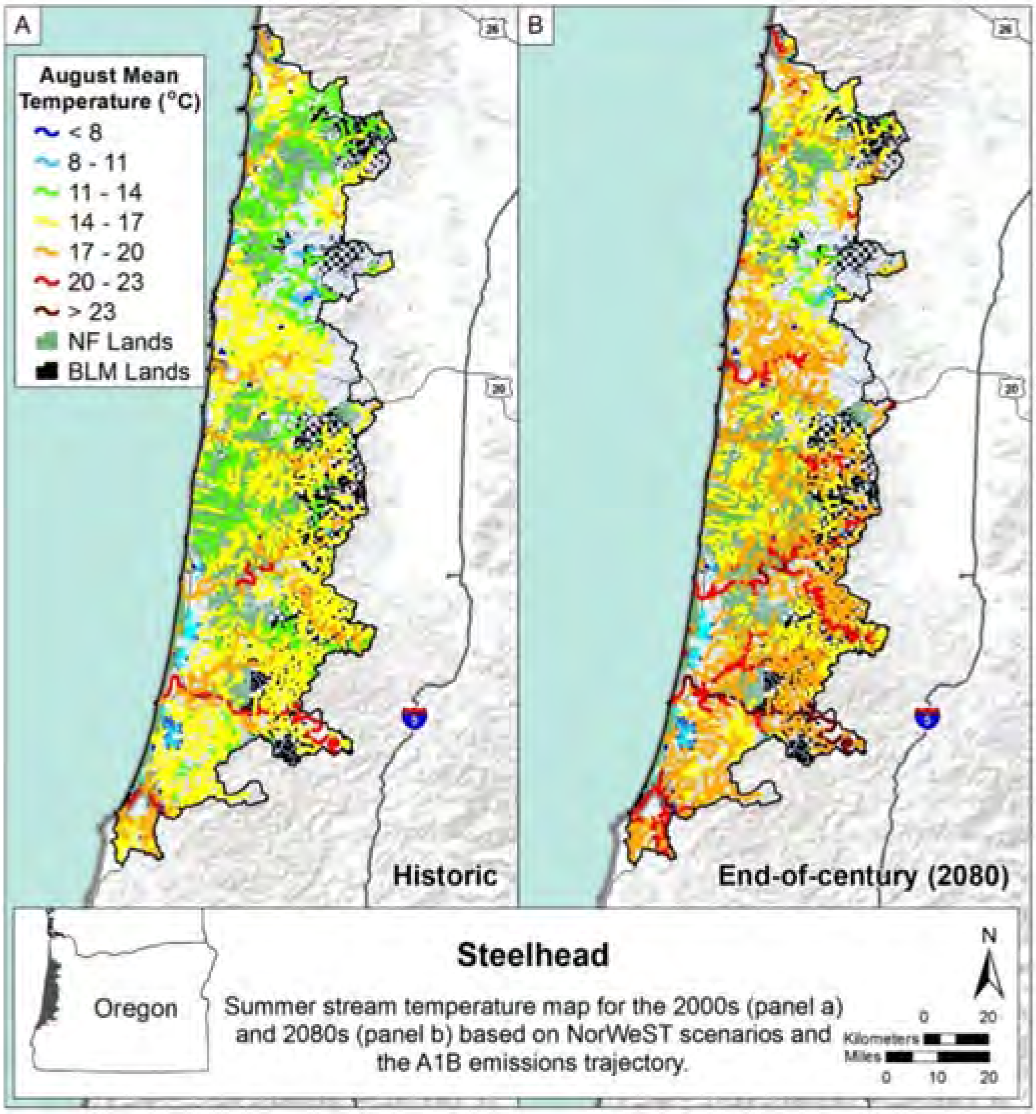


Figure 4.6—Summer stream temperatures in steelhead habitats during the historical baseline period of the 2000s (panel A) and a future projection for the 2080s (panel B) based on NorWeST scenarios and the A1B emission trajectory.

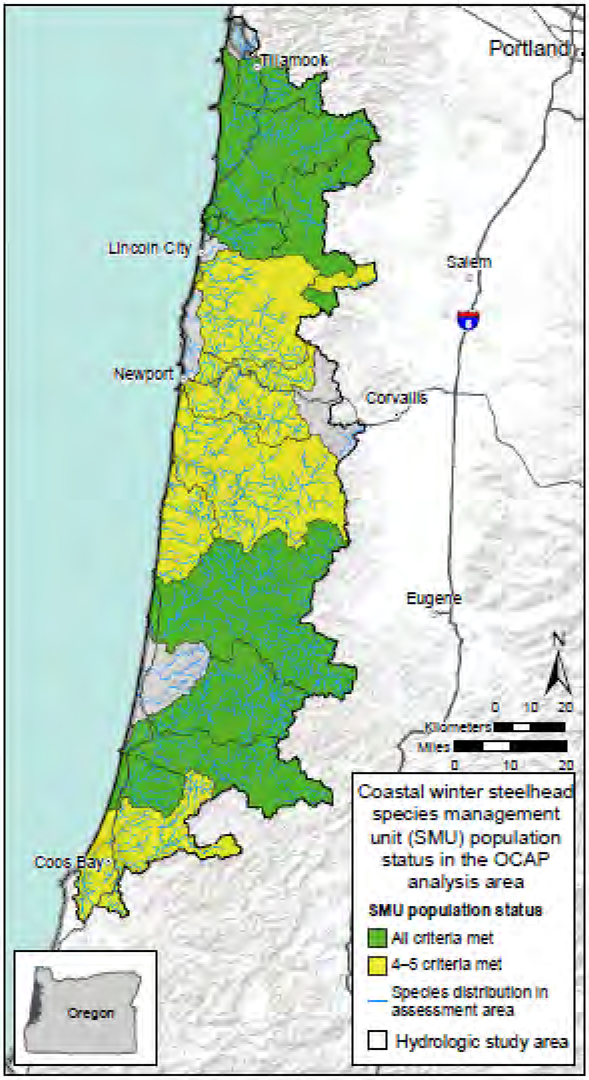


Figure 4.7—Status of coastal Oregon populations of winter steelhead based on ODFW criteria related to distribution, abundance, productivity, reproductive independence, and hybridization.

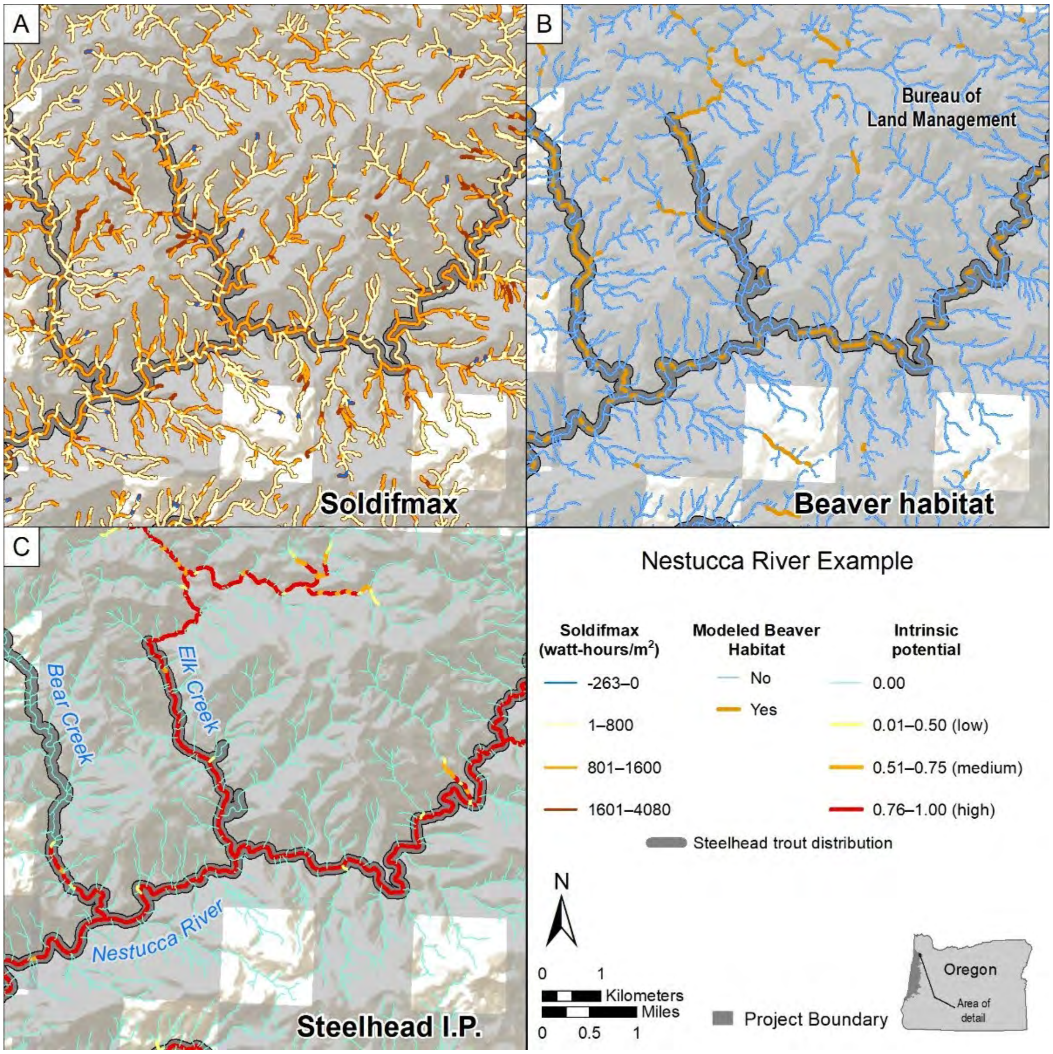


Figure 4.8—Steelhead distribution (shown in dark gray) in simulated streams of the Nestucca River, with future projection of effectiveness of riparian vegetation on water temperature (using soldifmax metric; panel A), presence of beaver habitat (panel B), and habitat potential (panel C) based on NetMap analyses.

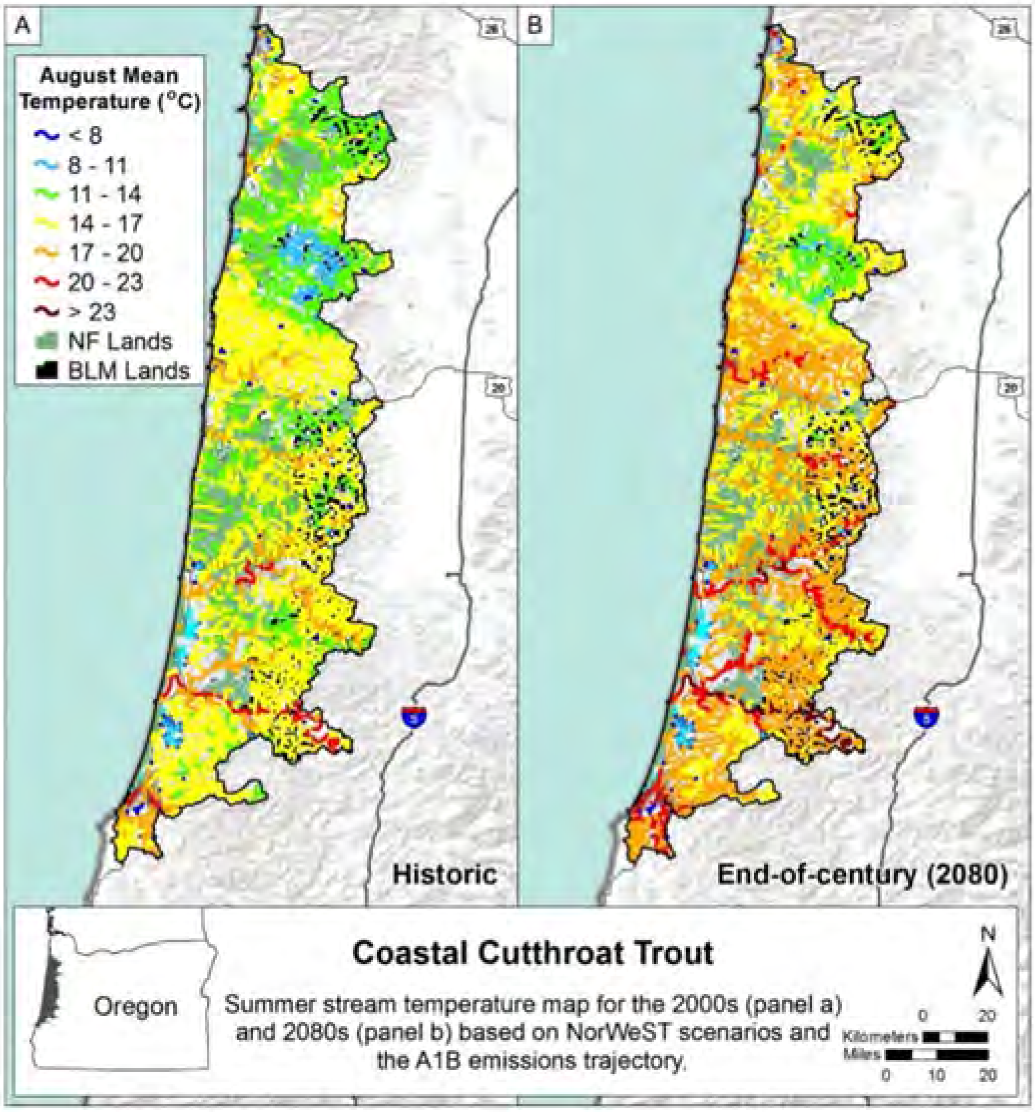


Figure 4.9—Summer stream temperatures in coastal cutthroat trout habitats during the historical baseline period of the 2000s (panel A) and a future projection for the 2080s (panel B) based on NorWeST scenarios and the A1B emission trajectory.

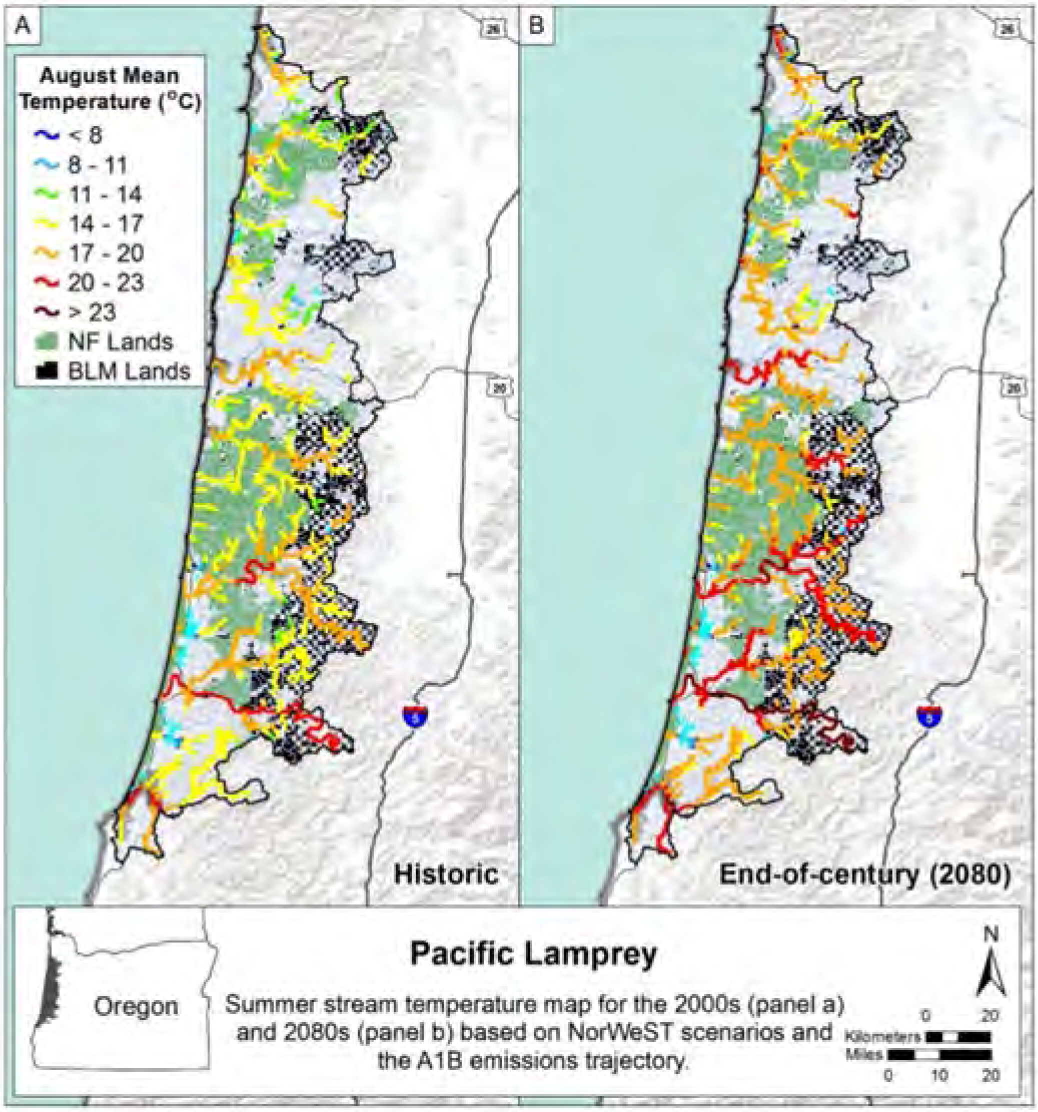


Figure 4.10—Summer stream temperatures in Pacific lamprey habitats during the historical baseline period of the 2000s (panel A) and a future projection for the 2080s (panel B) based on NorWeST scenarios and the A1B emission trajectory.

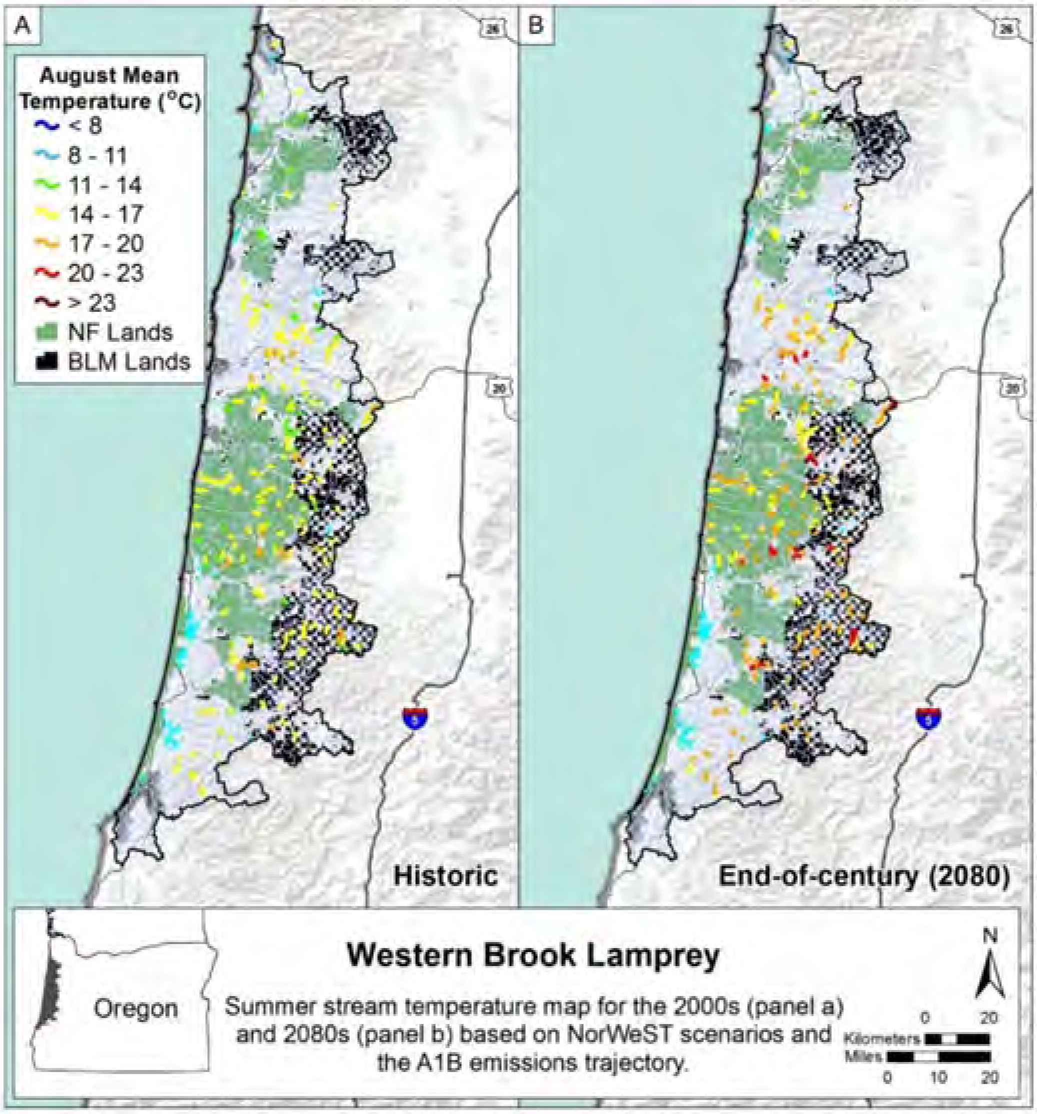


Figure 4.11—Summer stream temperatures in western brook lamprey habitats during the historical baseline period of the 2000s (panel A) and a future projection for the 2080s (panel B) based on NorWeST scenarios and the A1B emission trajectory.

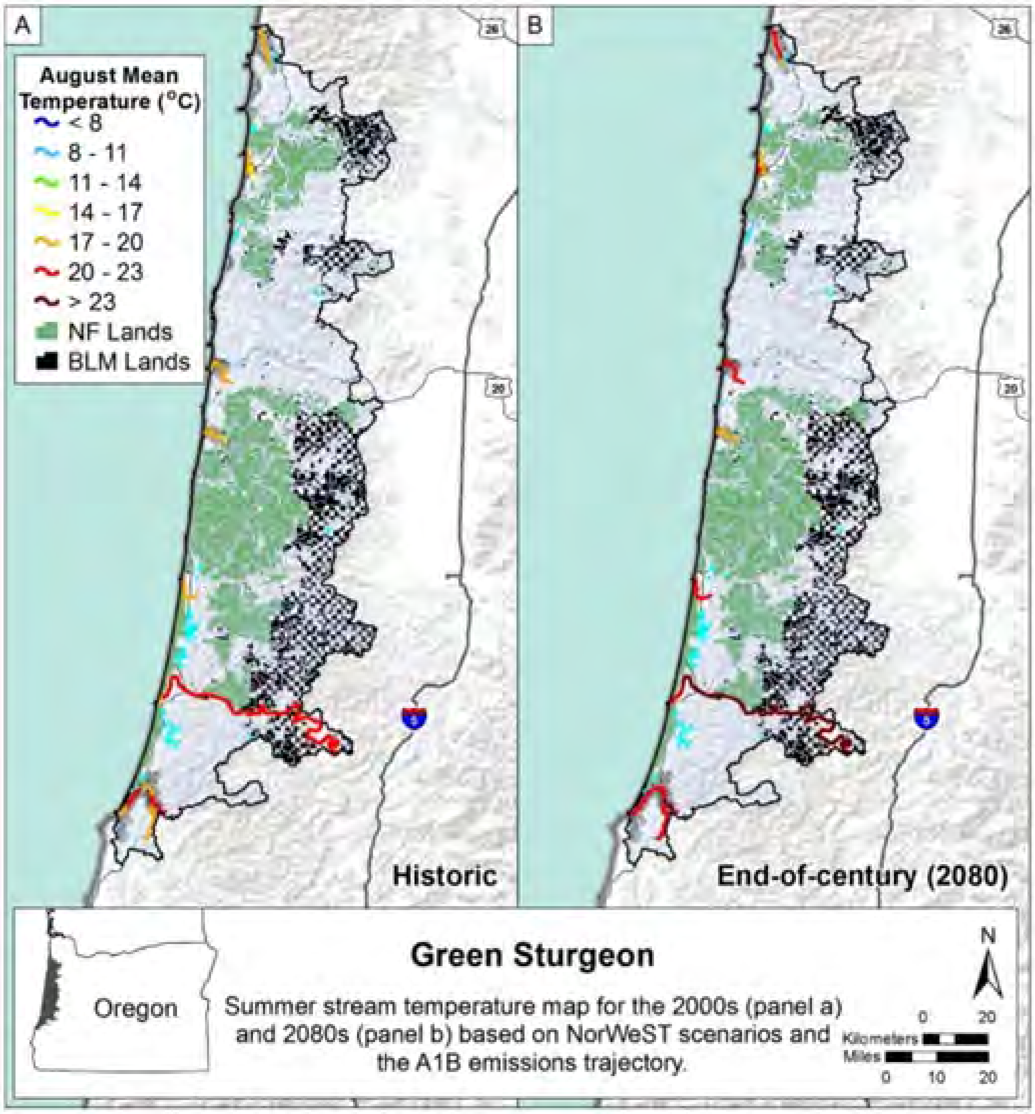


Figure 4.12—Summer stream temperatures in green sturgeon habitats during the historical baseline period of the 2000s (panel A) and a future projection for the 2080s (panel B) based on NorWeST scenarios and the A1B emissions trajectory.

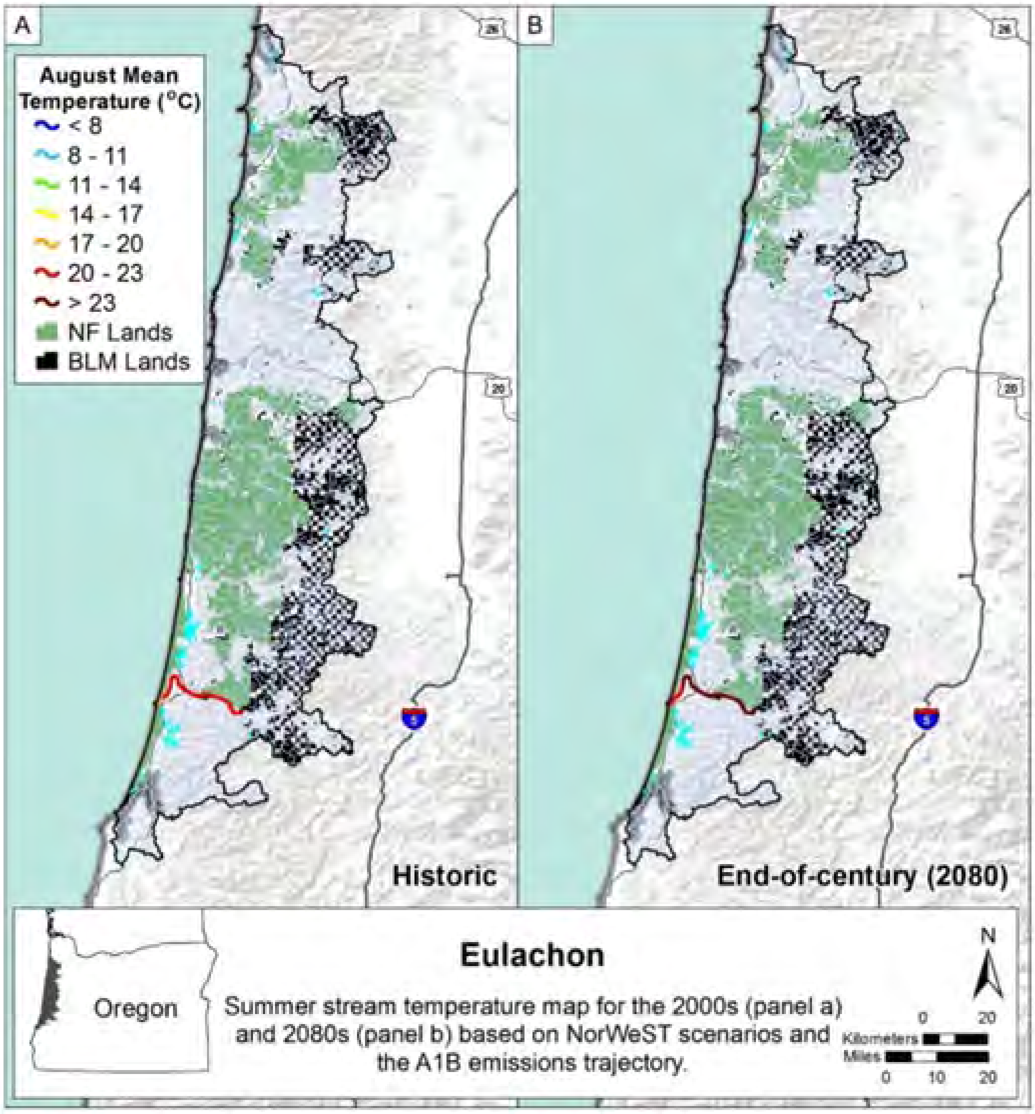


Figure 4.13—Summer stream temperatures in eulachon habitats during the historical baseline period of the 2000s (panel A) and a future projection for the 2080s (panel B) based on NorWeST scenarios and the A1B emission trajectory.

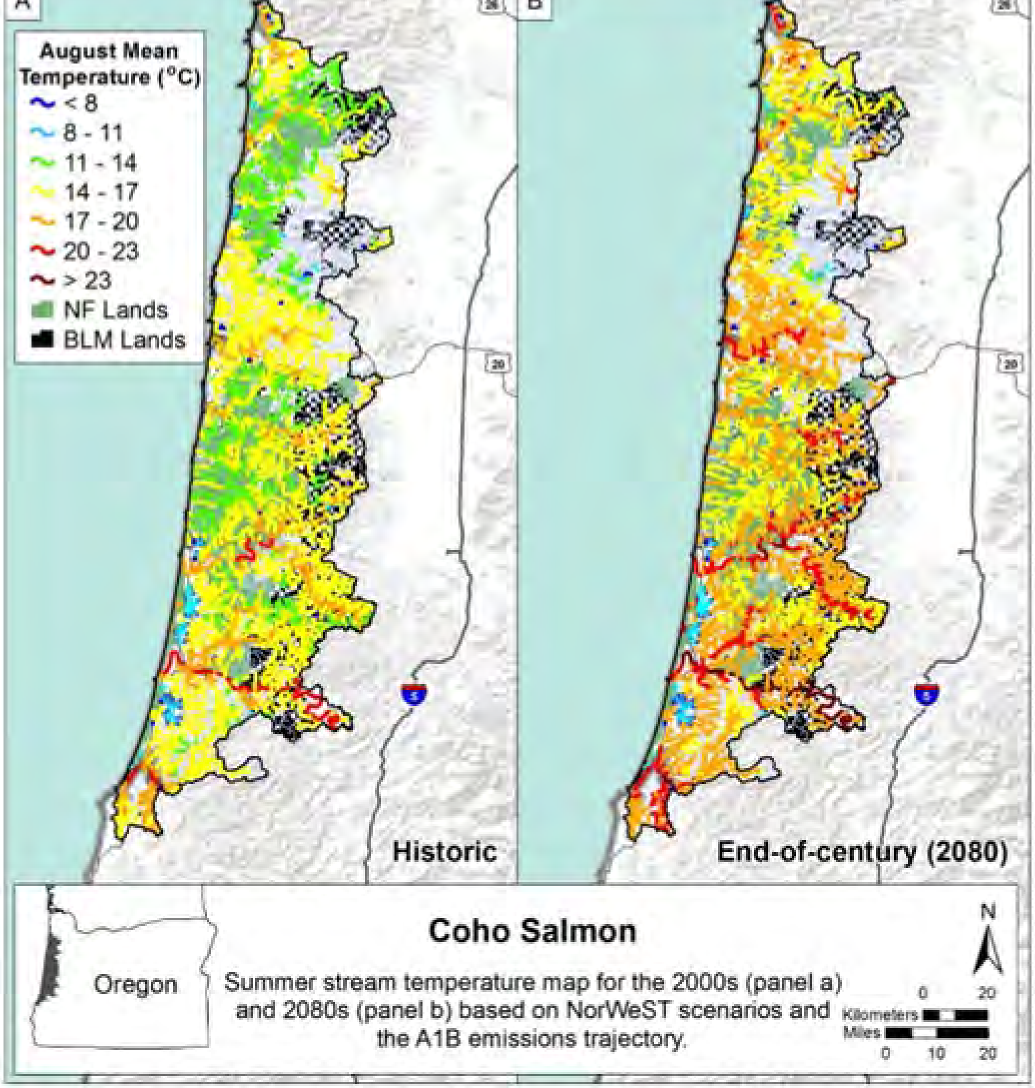


Figure 4.14—Summer stream temperatures in coho salmon habitats during the historical baseline period of the 2000s (panel A) and a future projection for the 2080s (panel B) based on NorWeST scenarios and the A1B emission trajectory.

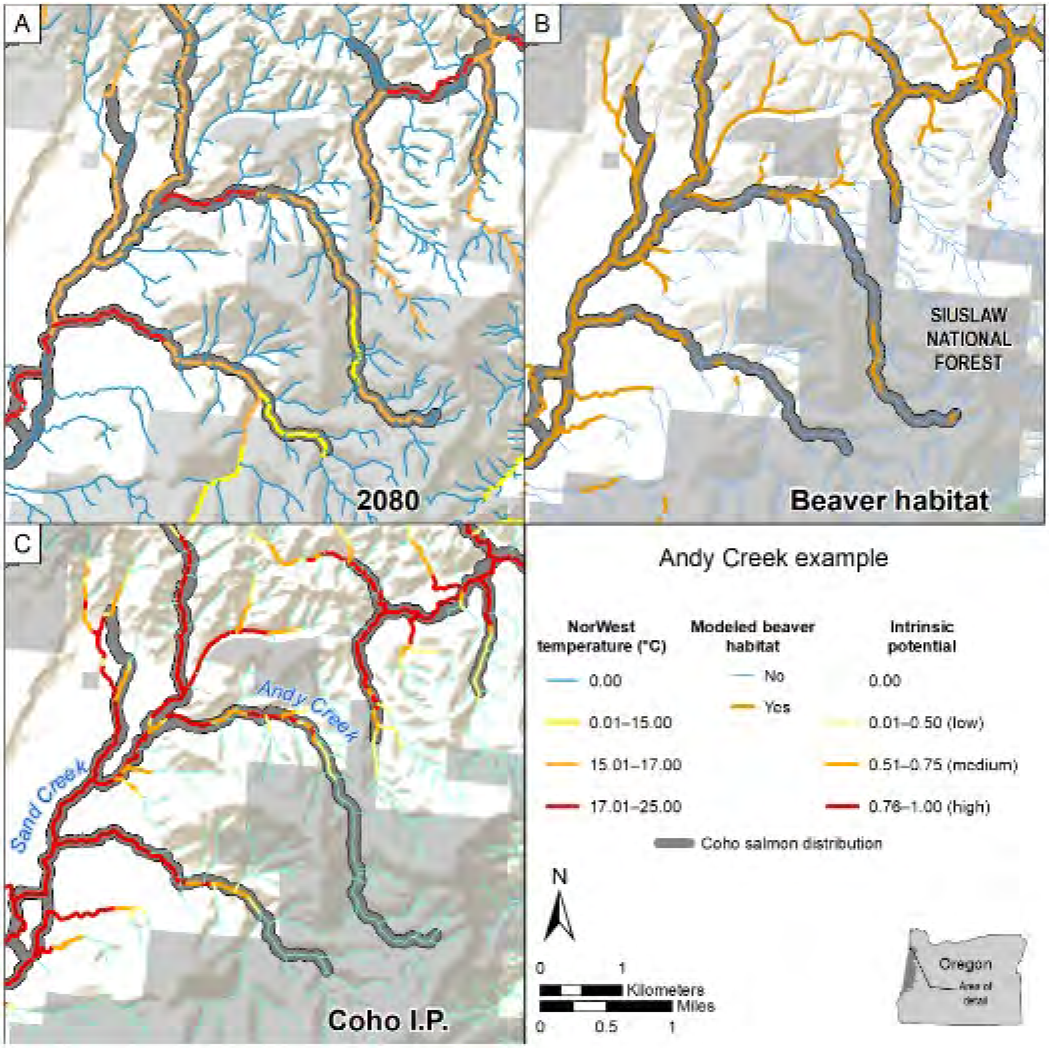


Figure 4.15—Coho salmon distribution (shown in dark gray) in simulated streams of Sand Creek and Andy Creek, with future projection for the 2080s from a composite average of 10 global climate models for the western United States (panel A), presence of beaver habitat (panel B), and habitat potential (panel C) based on NetMap analyses.

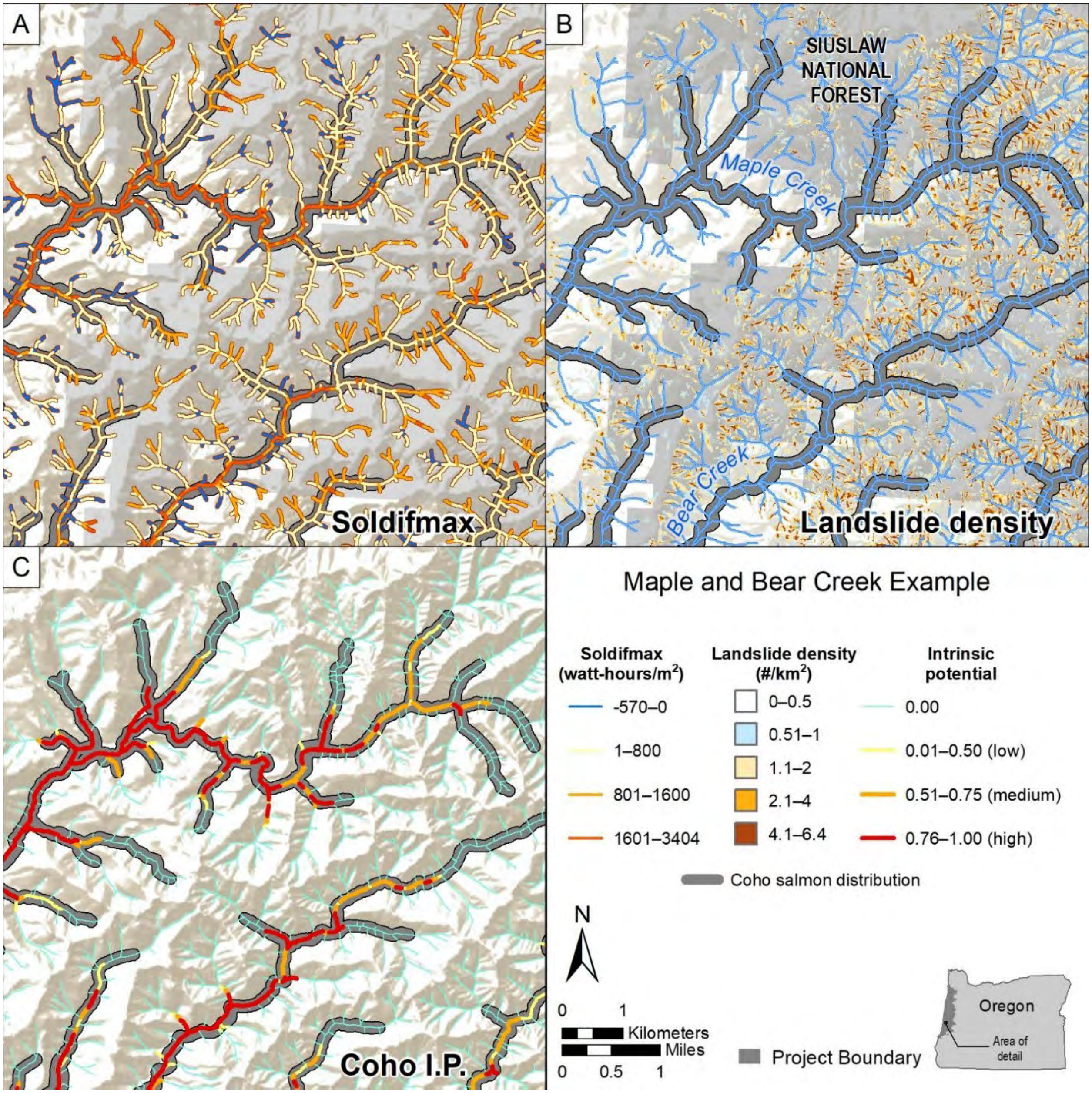


Figure 4.16—Coho salmon distribution (shown in dark gray) in simulated streams of Maple Creek and Bear Crees, with effectiveness of riparian vegetation on water temperature (using soldifmax metric; panel A), landslide density (panel B), and habitat potential (panel C) based on NetMap analyses.

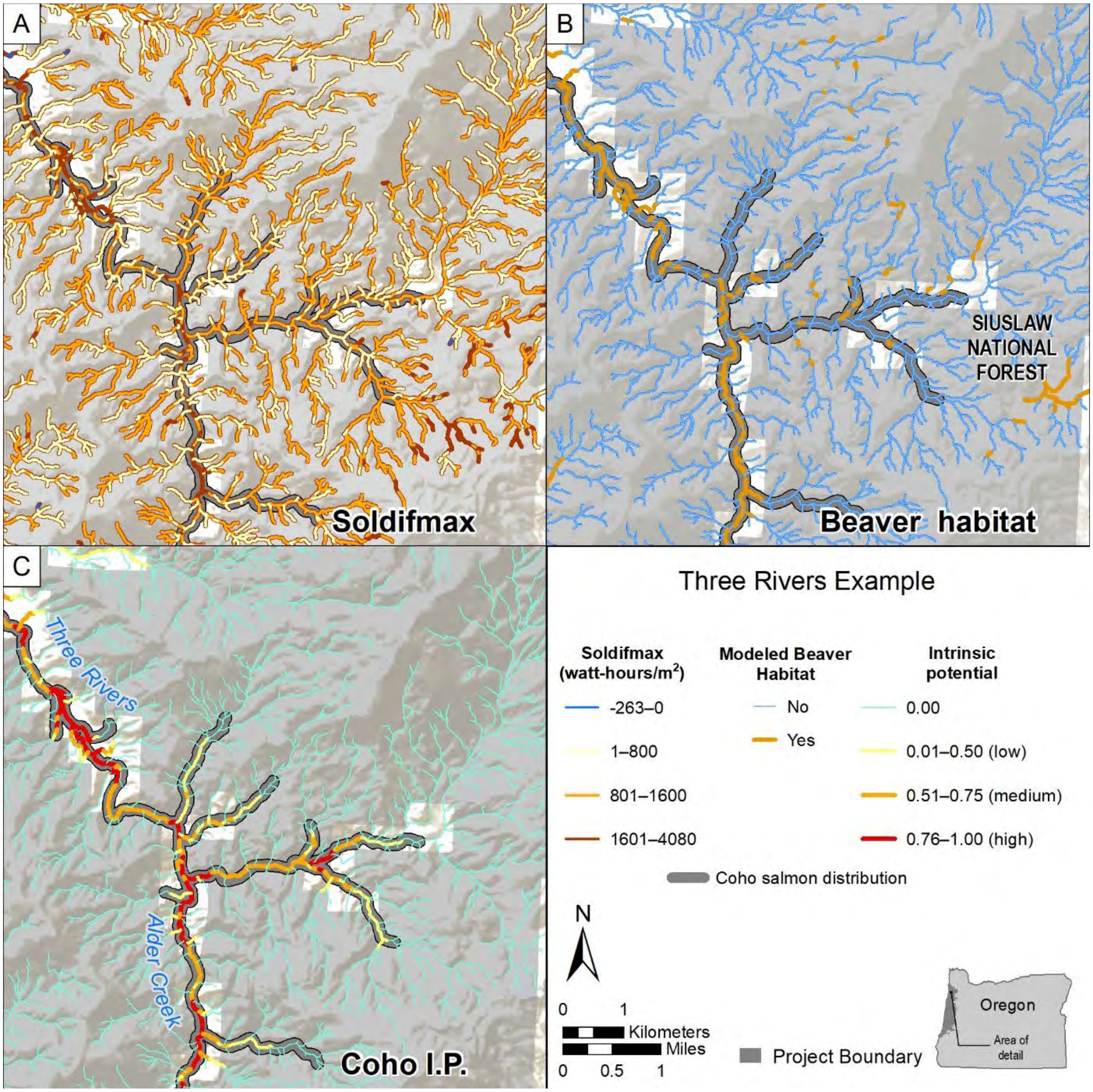


Figure 4.17—Coho salmon distribution (shown in dark gray) in simulated streams of Three Rivers, with effectiveness of riparian vegetation on water temperature (using soldifmax metric; panel A), presence of beaver habitat (panel B), and habitat potential (panel C) based on NetMap analyses.

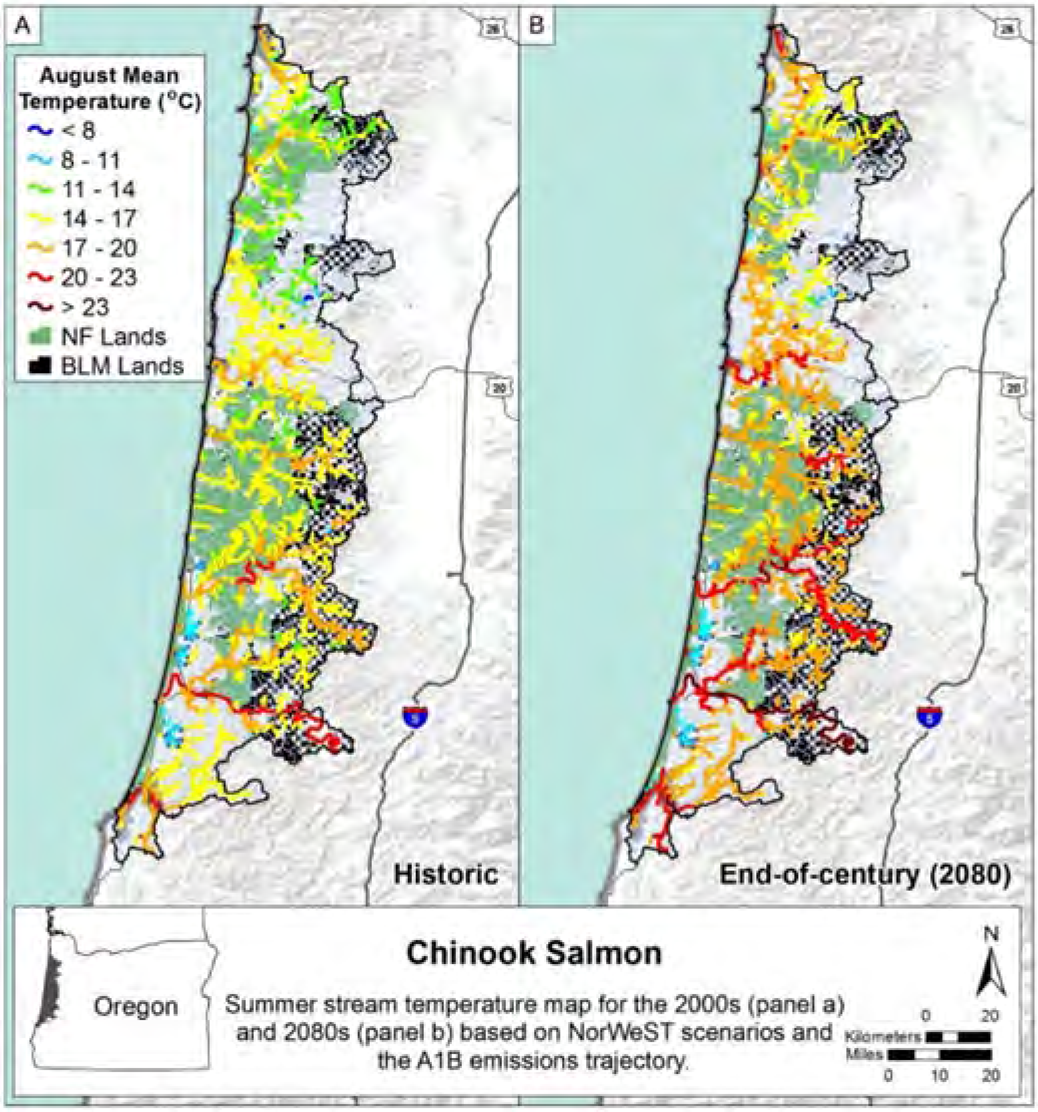


Figure 4.18—Summer stream temperatures in Chinook salmon habitats during the historical baseline period of the 2000s (panel A) and a future projection for the 2080s (panel B) based on NorWeST scenarios and the A1B emission trajectory.

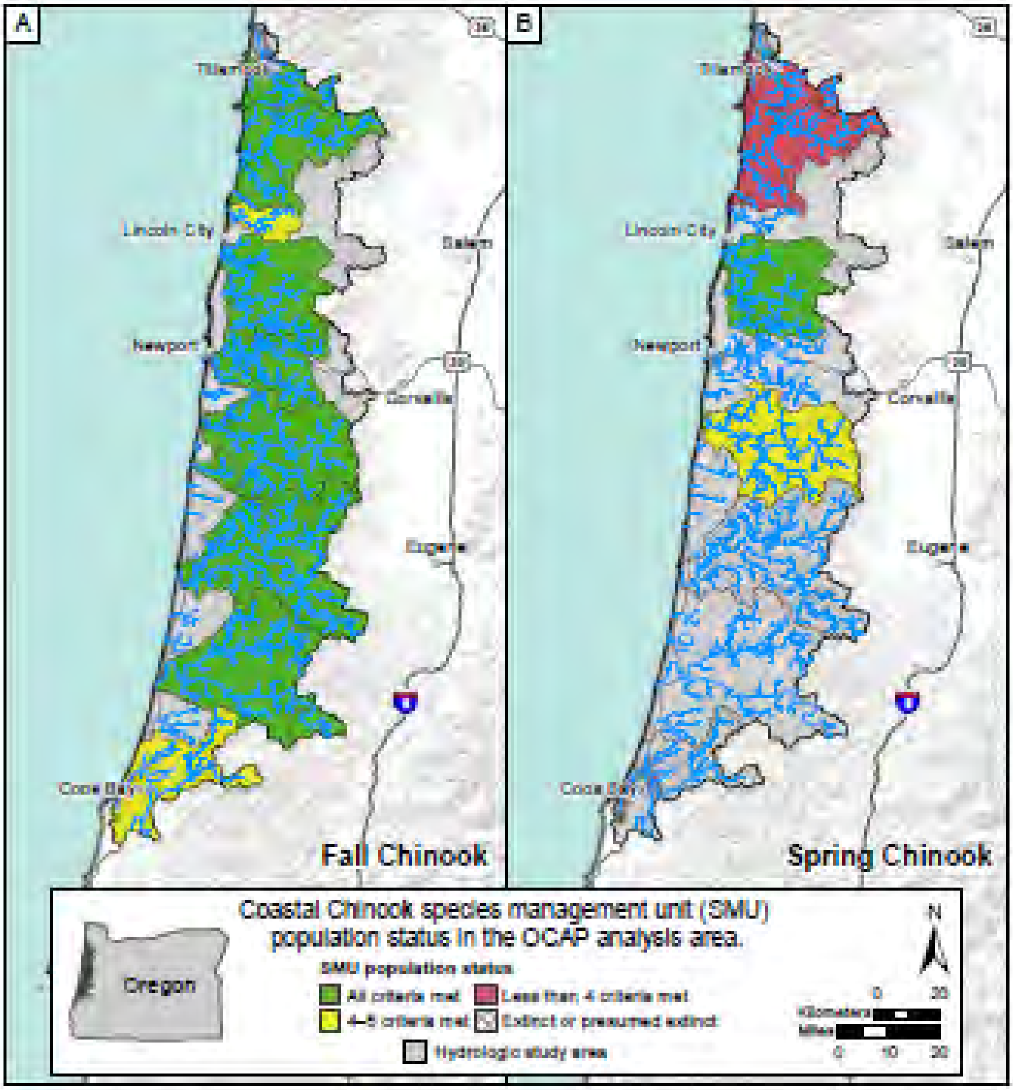


Figure 4.19—Status of coastal Oregon populations of fall and spring Chinook salmon based on ODFW criteria related to distribution, abundance, productivity, reproductive independence, and hybridization.

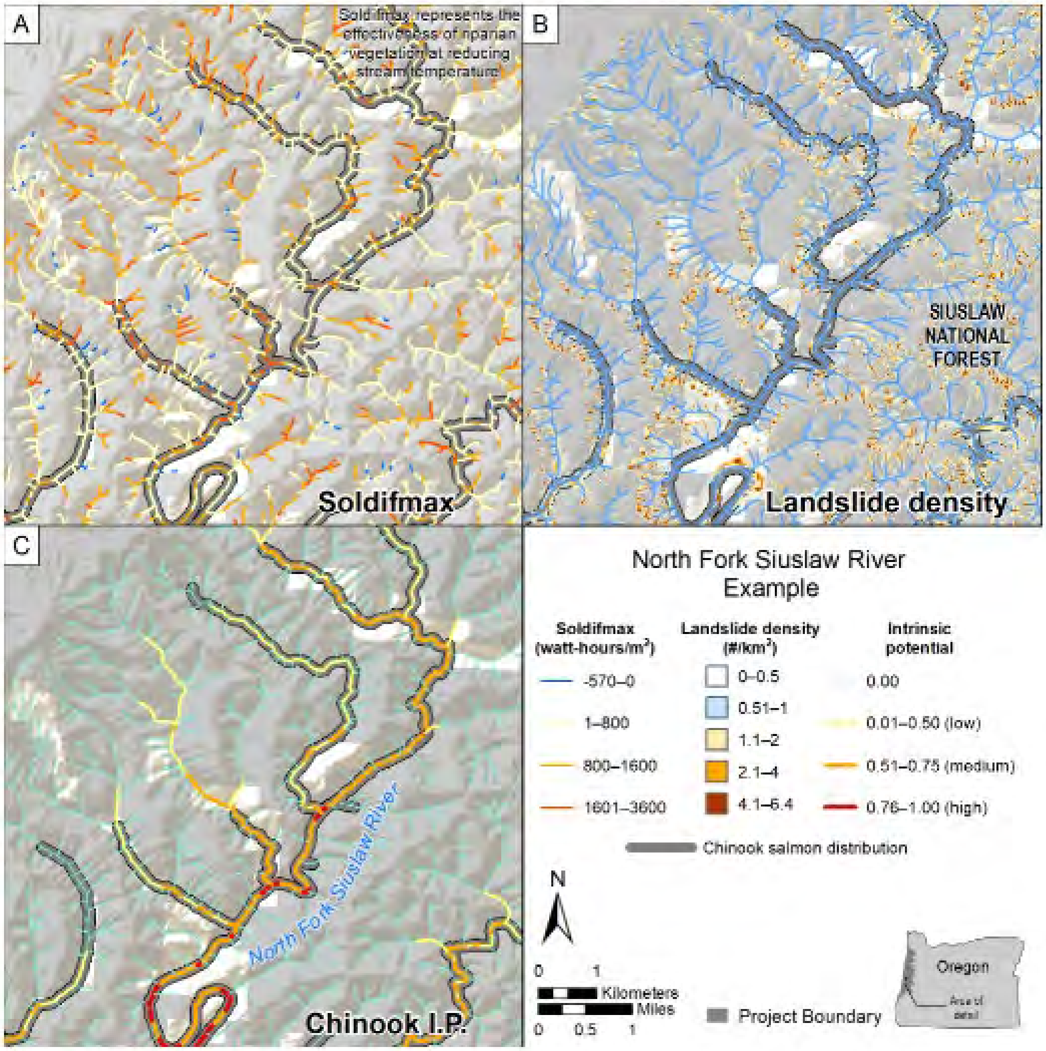


Figure 4.20—Chinook salmon distribution (shown in dark gray) in simulated streams of the North Fork Siuslaw River, with effectiveness of riparian vegetation on water temperature (using soldifmax metric; panel A), landslide density (panel B), and habitat potential (panel C) based on NetMap analyses.

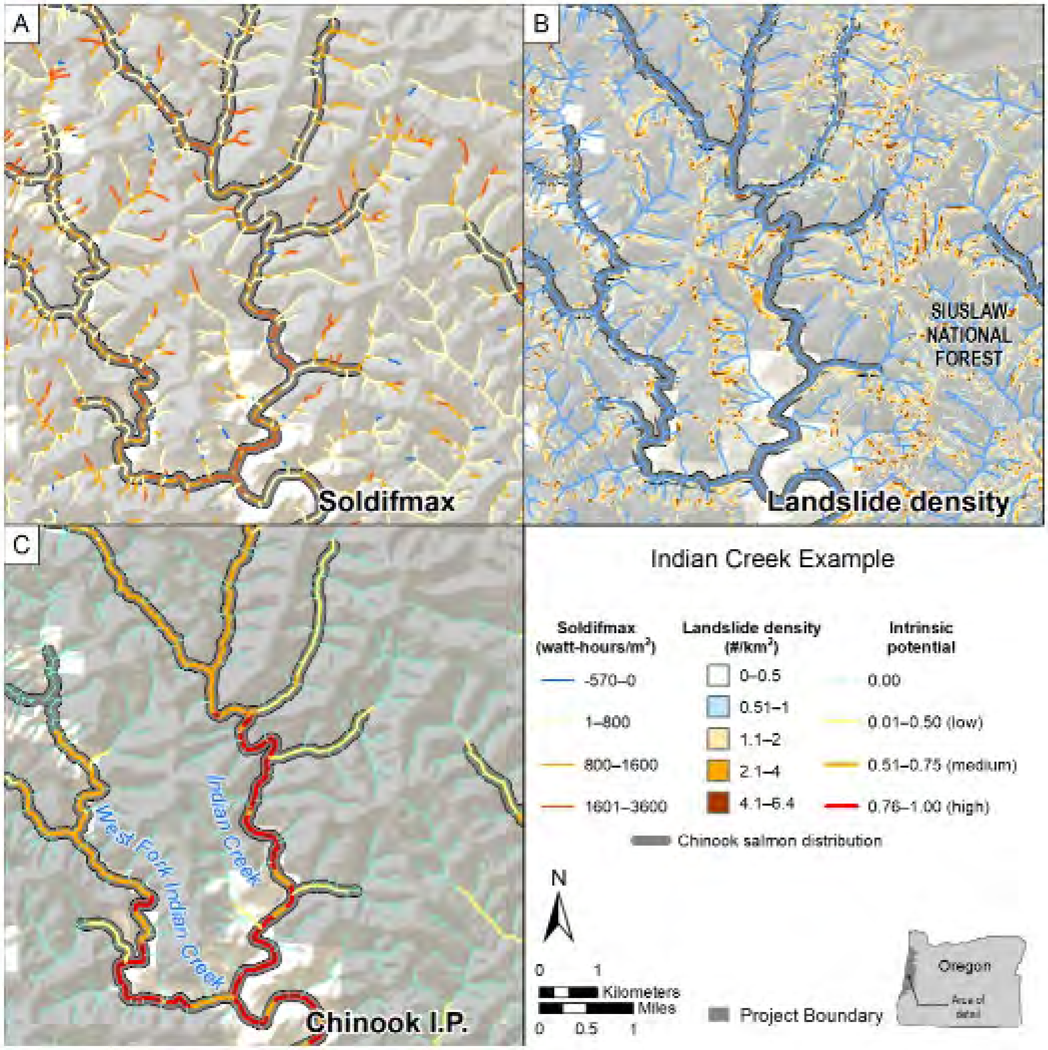


Figure 4.21—Chinook salmon distribution (shown in dark gray) in simulated streams of Indian Creek, with effectiveness of riparian vegetation on water temperature (using soldifmax metric; panel A), landslide density (panel B), and habitat potential (panel C) based on NetMap analyses.

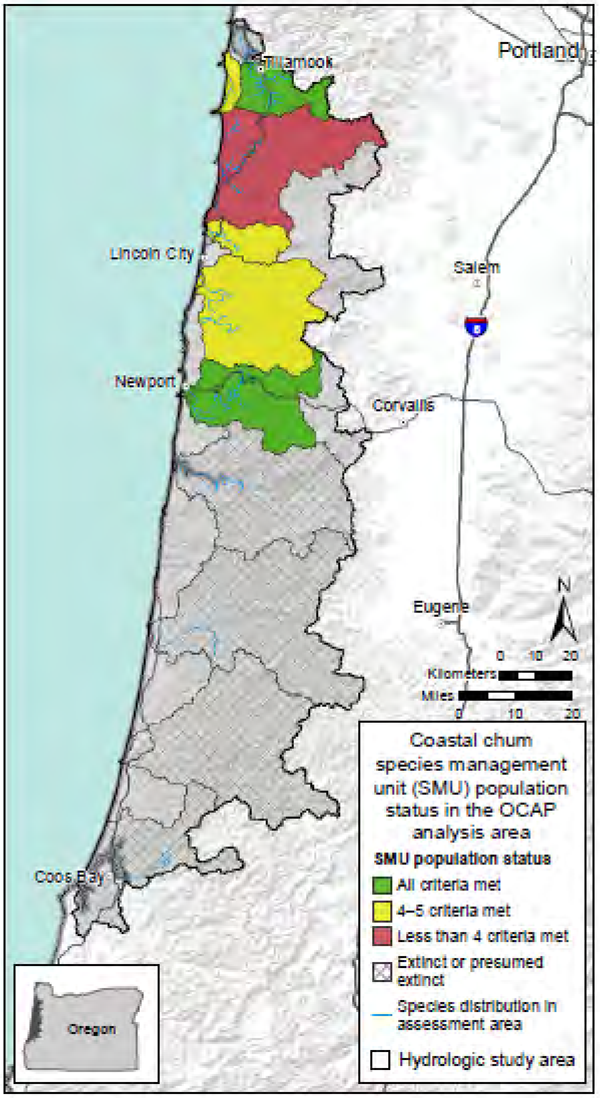


Figure 4.22—Status of coastal Oregon populations of chum salmon based on ODFW criteria related to exist, distribution, abundance, productivity, reproductive independence, and hybridization.

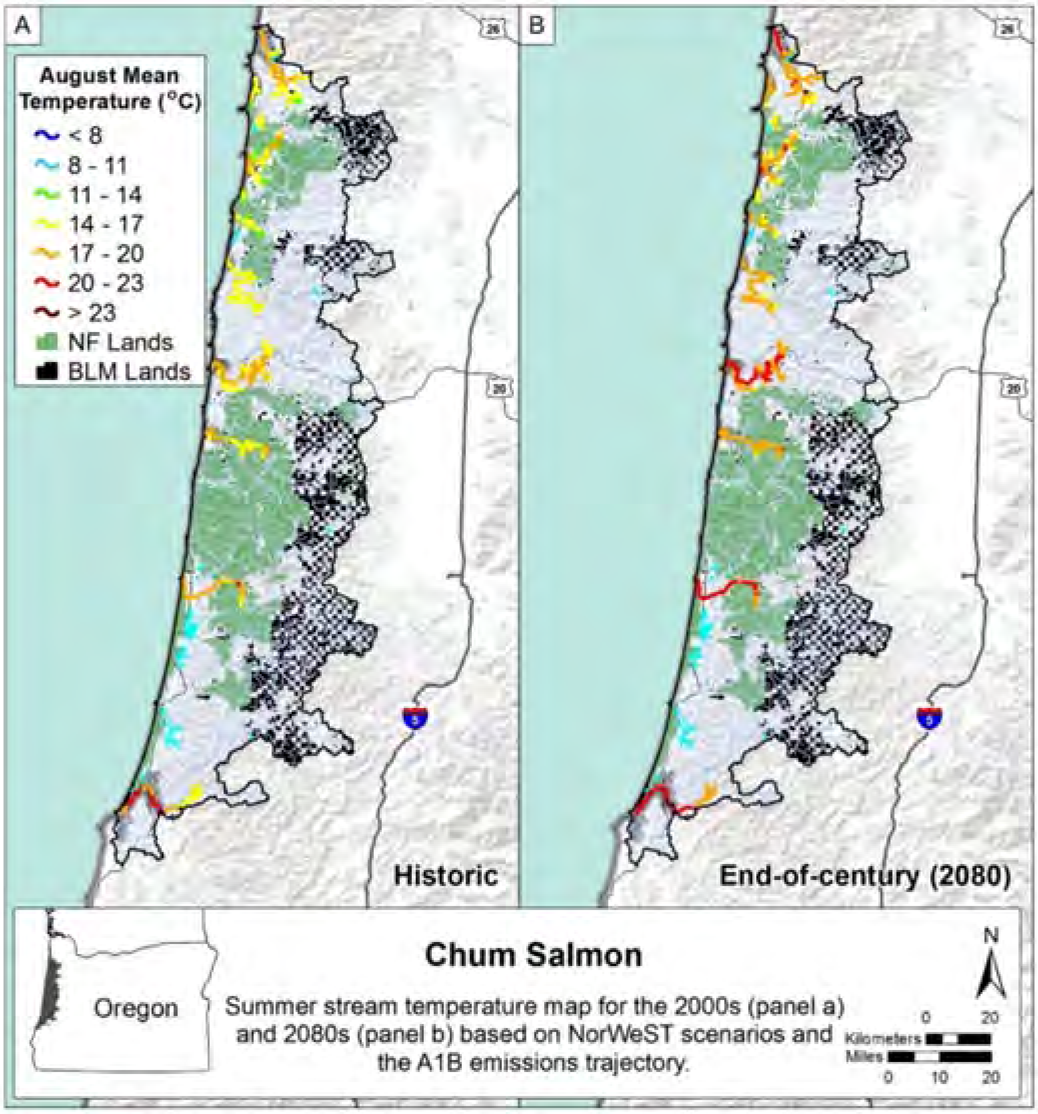


Figure 4.23—Summer stream temperatures in chum salmon habitats during the historical baseline period of the 2000s (panel A) and a future projection for the 2080s (panel B) based on NorWeST scenarios and the A1B emission trajectory.

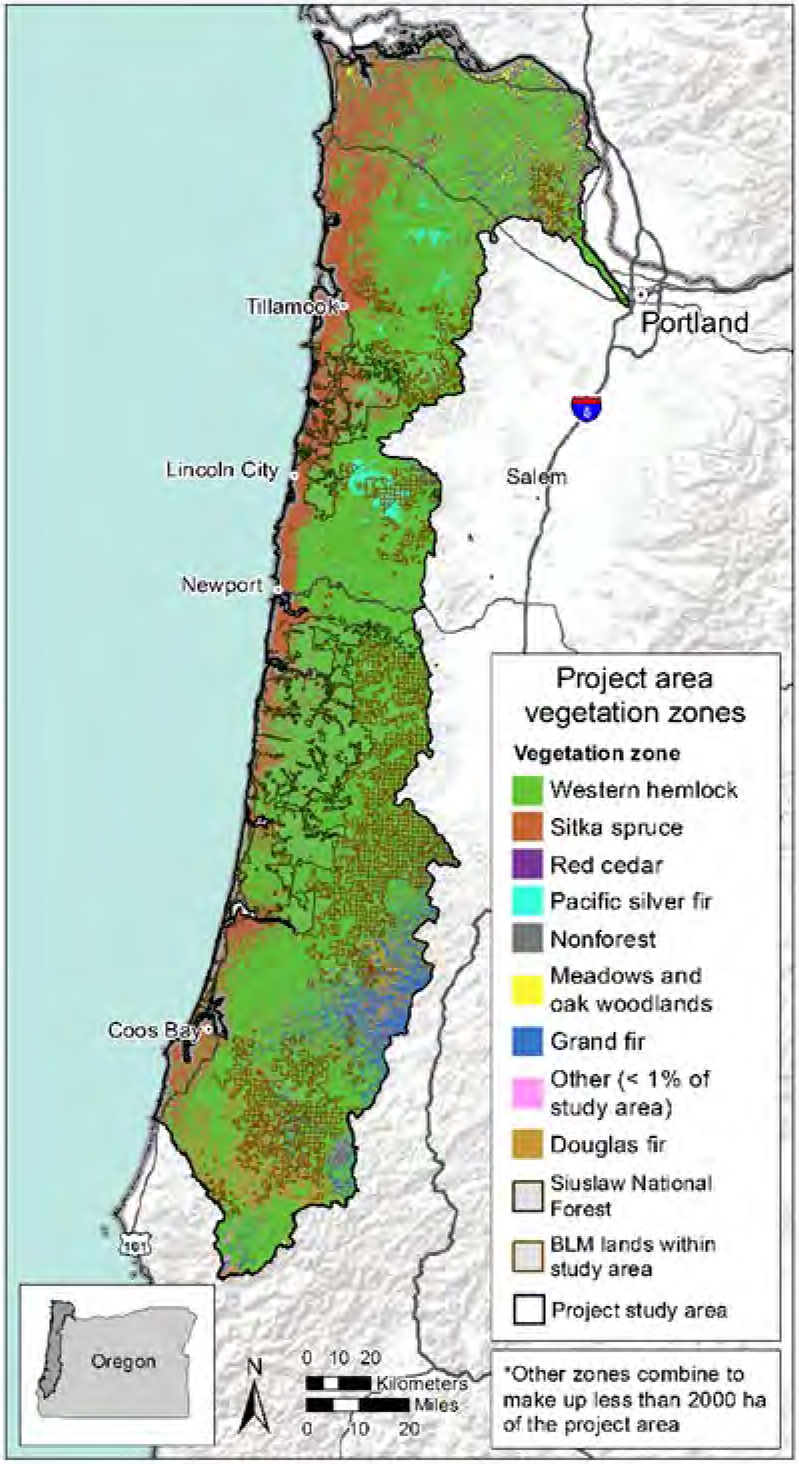


Figure 5.1—Geographic distribution of vegetation zones across the OCAP assessment area. Data are from https://www.ecoshare.info/category/gis-data-vegzones.

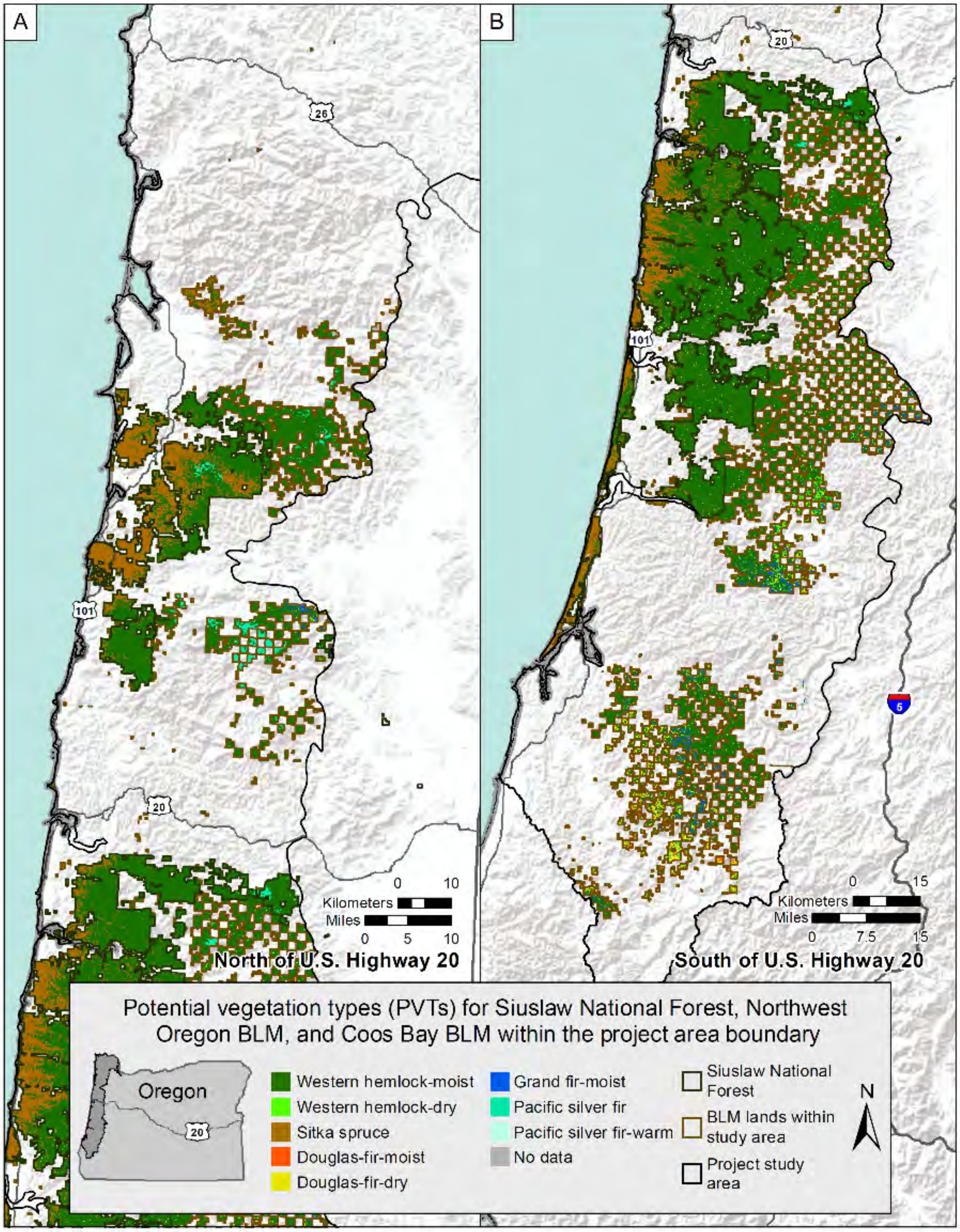


Figure 5.2—Geographic distribution of vegetation across study units in the OCAP assessment area. Panel A depicts study units north of U.S. Highway 20; panel B depicts study units south of U.S. Highway 20. Data are from https://www.ecoshare.info/category/gis-data-vegzones.

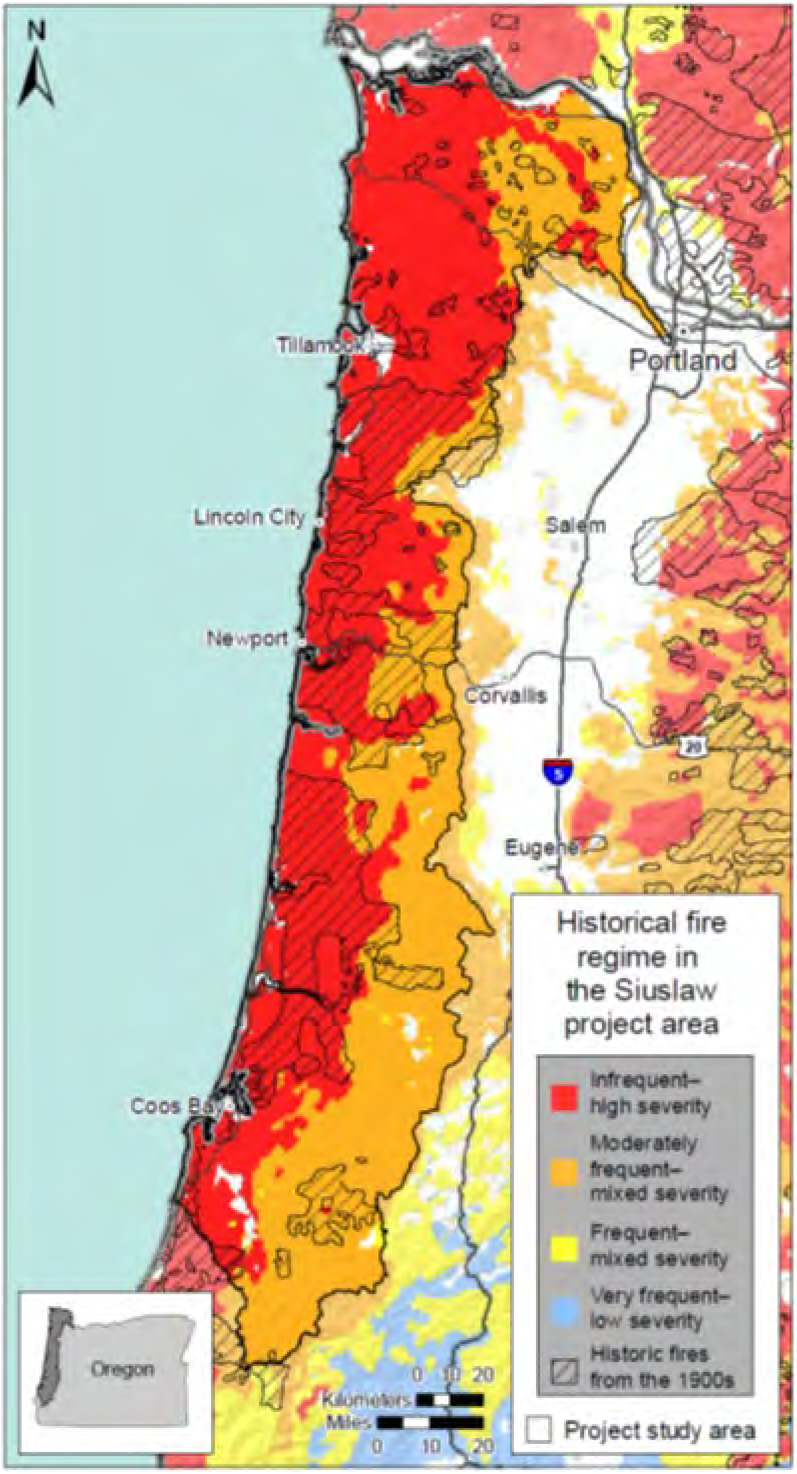


Figure 5.3—Historical fire regimes and perimeters of large fires from the early 1900s for the OCAP assessment area. Fire regime map follows Spies et al. (2018). Historical fire perimeters are from Thompson and Johnson (1900) and Plummer et al. (1902).

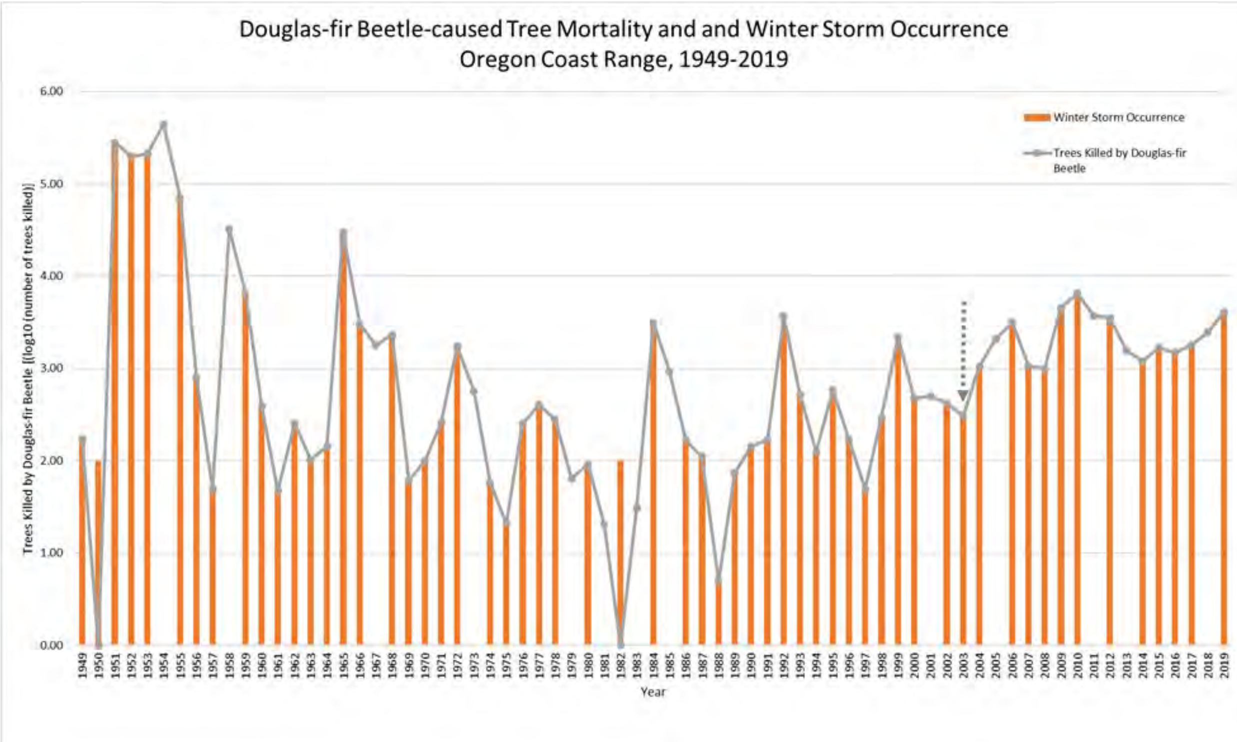


Figure 5.4—Annual Douglas-fir beetle-caused tree mortality in the Oregon Coast Range and winter storm occurrence, 1949 to 2019. Mortality data compiled from the annual Oregon and Washington Aerial Insect and Disease Survey (ADS) and historical reports are displayed as $\log_{10}$ (number of trees killed). The trees-killed value is arbitrarily set at zero for 1950 because ADS data are unavailable, and historical document narratives indicate low levels of Douglas-fir beetle-caused mortality. The occurrence of one or more notable storm events during October (previous year) through March of the associated year are indicated by solid bars; the height of the bar has been matched to the tree mortality value to facilitate association with the year of occurrence and does not indicate relative storm severity or abundance. Storm occurrence during an extremely low mortality year is assigned an arbitrary value of 2 to make it visible on the graph. Storm types include windstorms, snowstorms, ice storms, rainstorms and flood events. Winter storm data were compiled from a number of sources including Storm King (The Pacific Northwest's Biggest Storms 1950-2004), Taylor and Hatton (1999), coastal Oregon counties Natural Hazards Mitigation Plans, FEMA Oregon Disaster Declaration Database, NOAA Storms and Unusual Weather Phenomena reports (Storm Data publications), and USFS Forest Health Protection historical reports. The dotted arrow indicates a change in Oregon and Washington ADS technology beginning in 2003, when digital sketch mapping was implemented and a new ADS minimum mapping standard adopted, lowering the minimum number of dead trees triggering creation of a mortality data record from a cluster of five trees to a single individual tree.

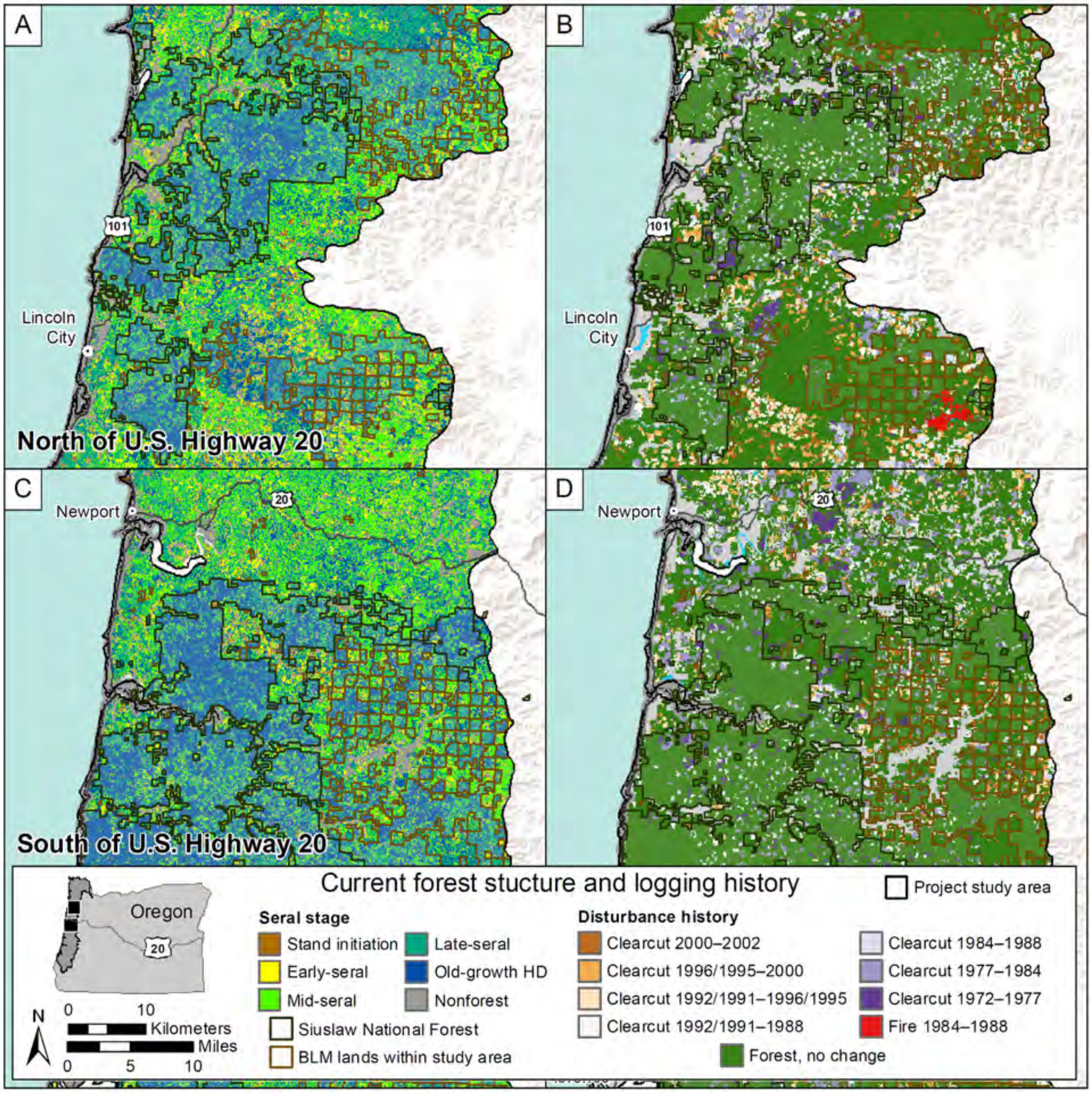


Figure 5.5—Current (2012) structural conditions in the OCAP assessment area. Clearcuts from 1972 to 2004 are in purple in the figure on the left, with darker purple corresponding to older clearcuts. On the right, late-successional and old-growth conditions are represented by darker blue, with early-seral conditions in orange and mid-seral conditions in green.

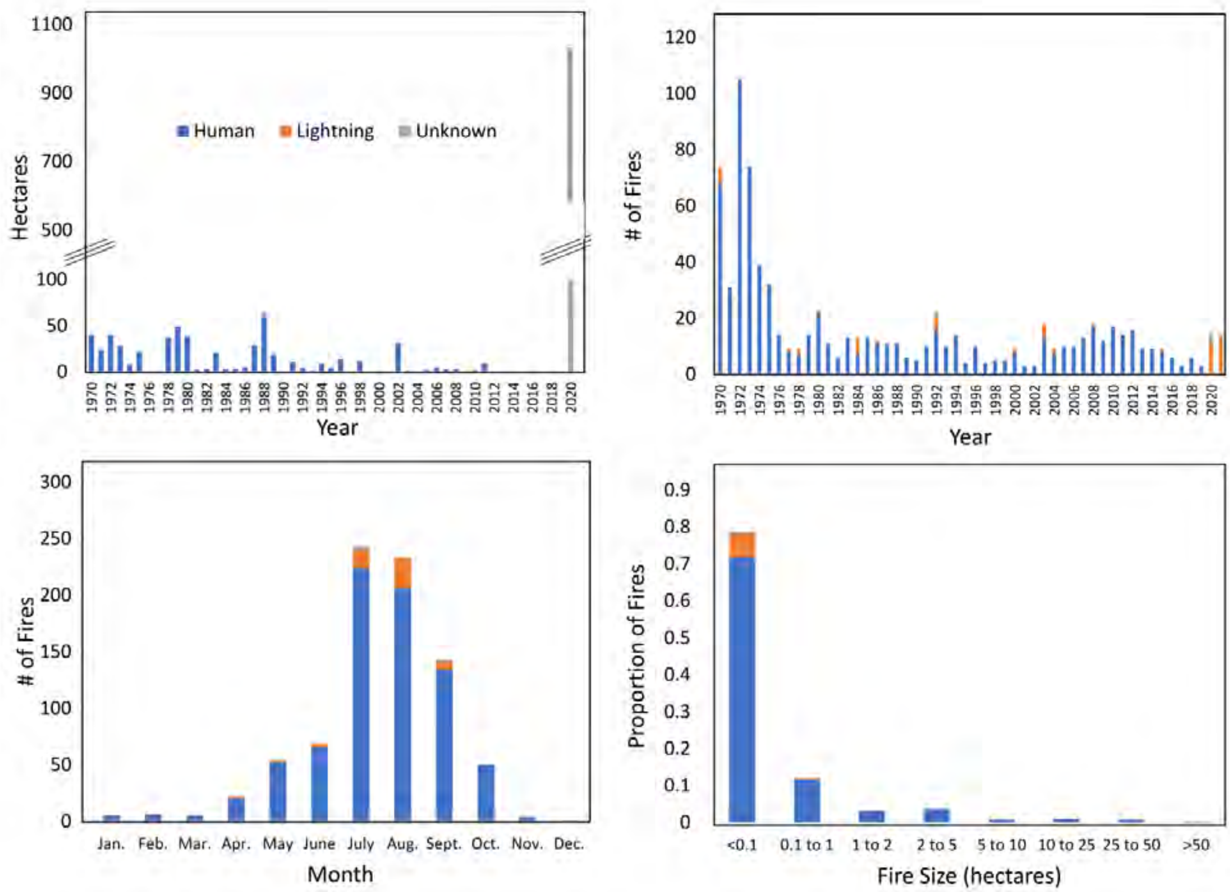


Figure 5.6—Patterns of area burned (top left), fire occurrence (top right), month (bottom left), and fire size (bottom right), in the OCAP assessment area from 1970 to 2022.

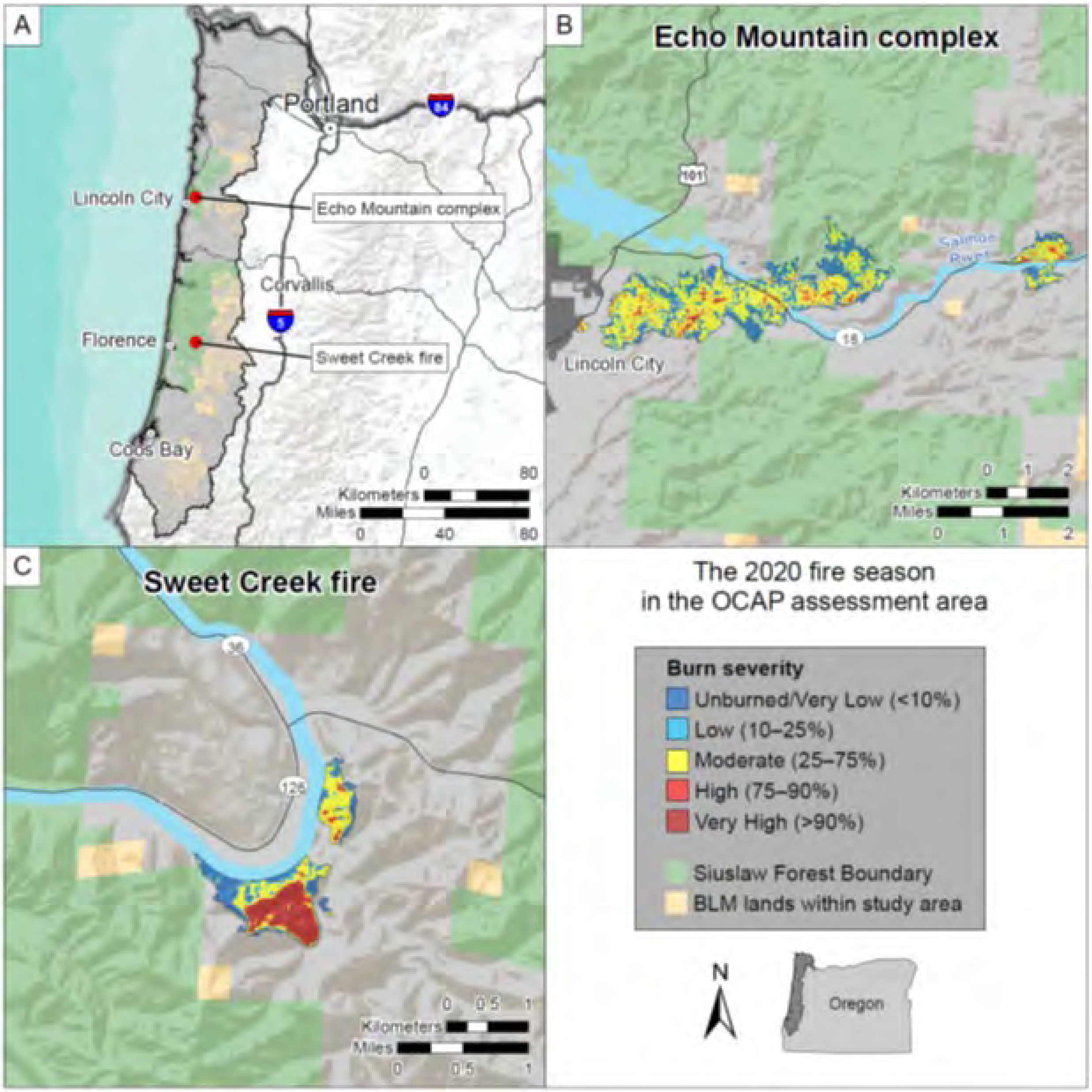


Figure 5.7—Patterns of burn severity in the 2020 Coast Range fires. Burn severity is based on the percent basal area mortality predicted from the relativized change in the normalized burn index, following Adelges et al. (2017).

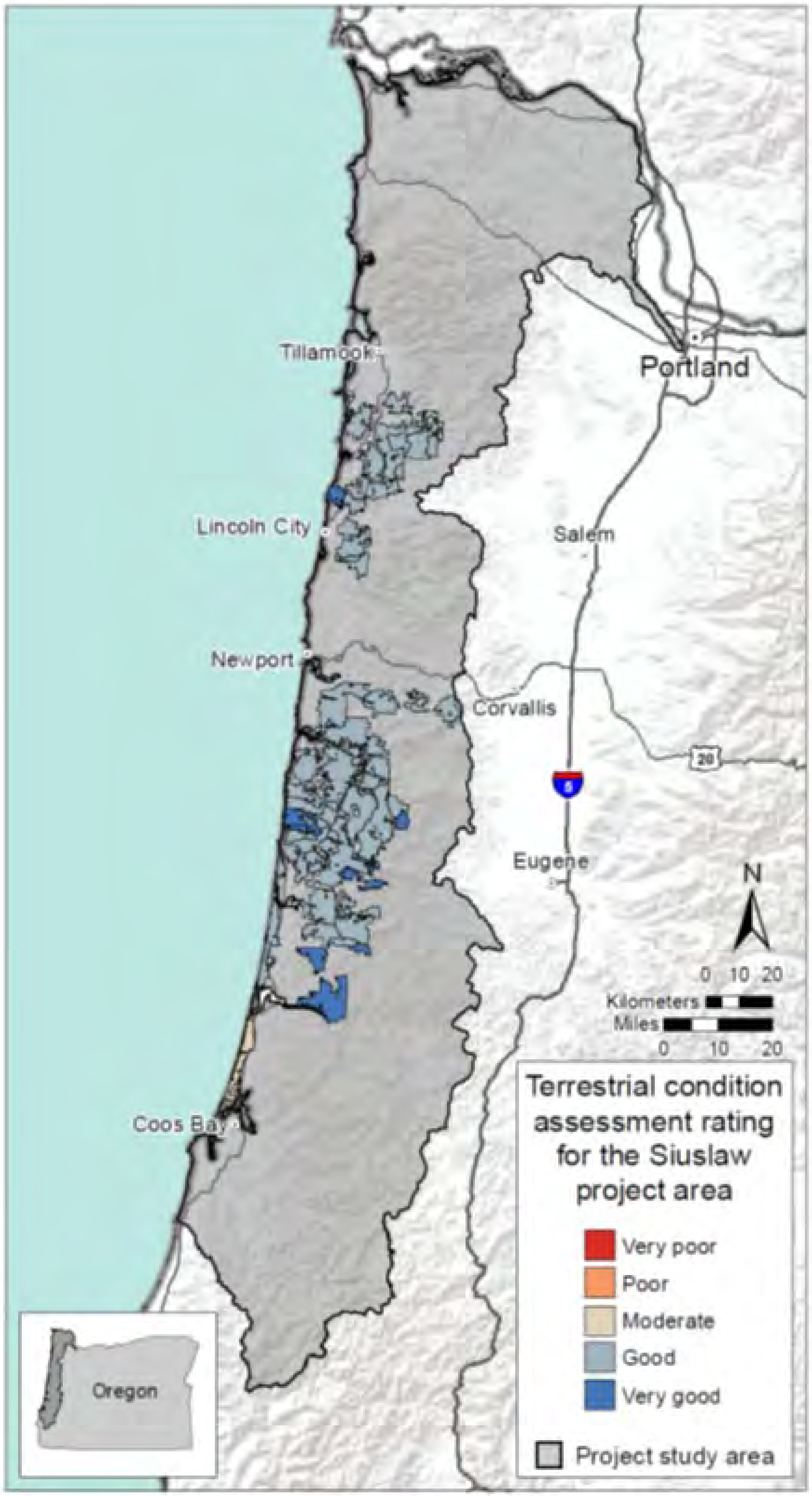


Figure 5.8—Terrestrial condition assessment rating for national forests in the OCAP assessment area. Data are from Cleland et al. (2017).

Figure 5.9—Positive forest vulnerability index (FVI) values (p-value <0.05) for September in the OCAP 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).

Figure 5.10—Potential soil drought stress in the OCAP assessment area (July–September). Data are from Ringo et al. (2018).

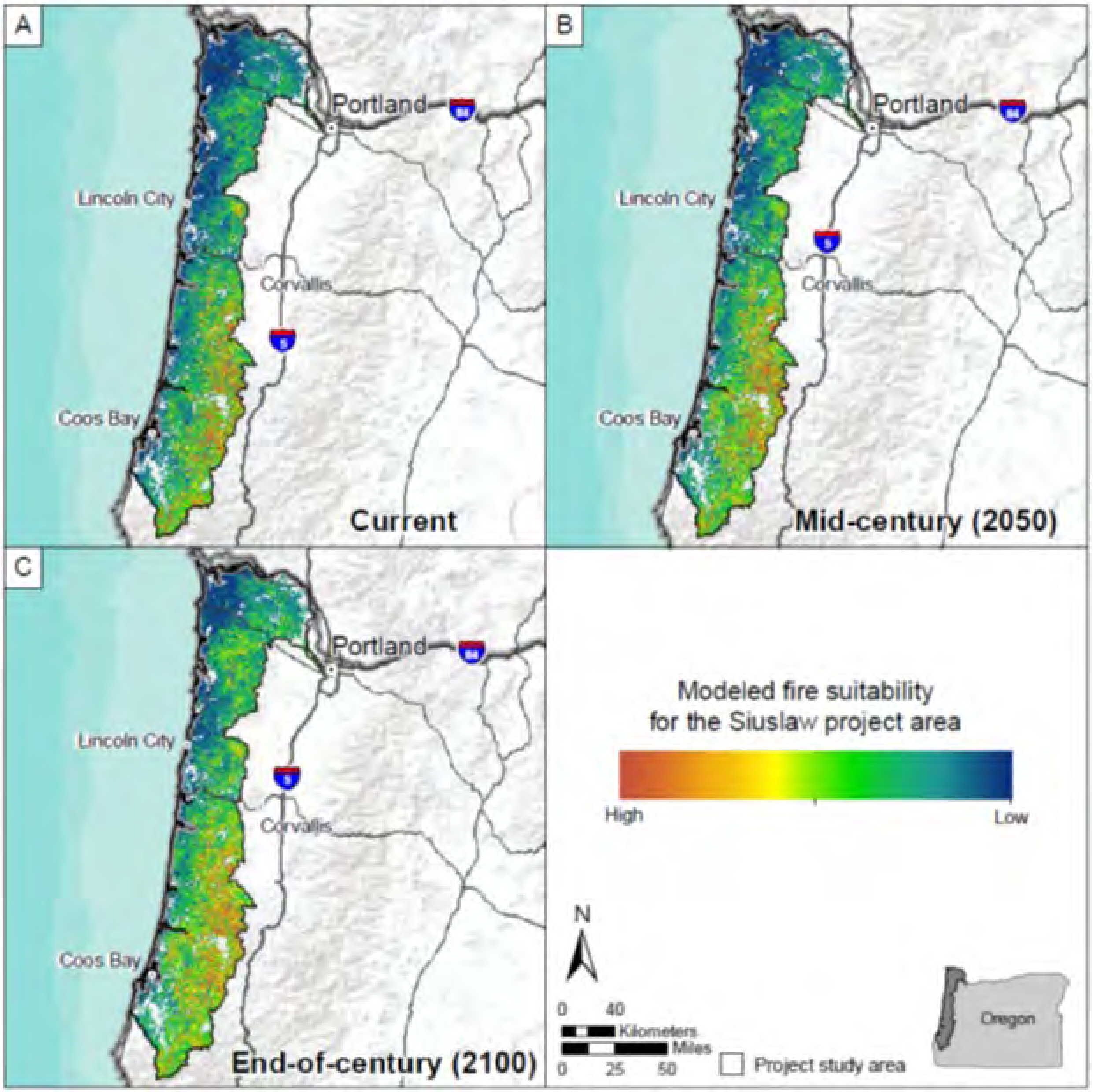


Figure 5.11—Modeled environmental suitability for large forest fires under current climate (2010) and projected future climate at the middle (2050) and end of the century (2100), both as projected under Representative Concentration Pathway 8.5. Modeling methods follow Davis et al. (2017).

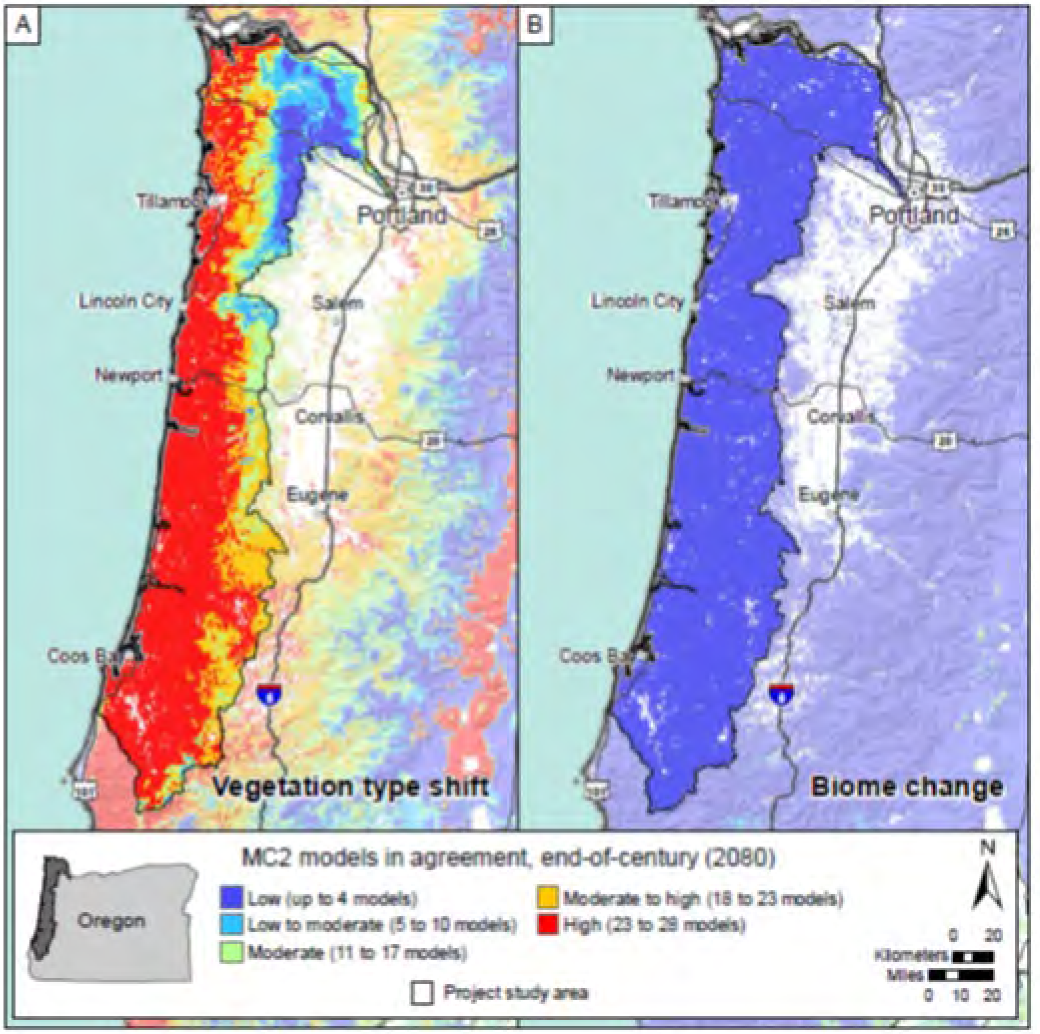


Figure 5.12—MC2 model agreement (among 28 climate scenarios) at the end of the century (2080) for simulated change in vegetation type (A) and simulated change in biome (e.g., forest to woodland or shrubland to grassland) (B).

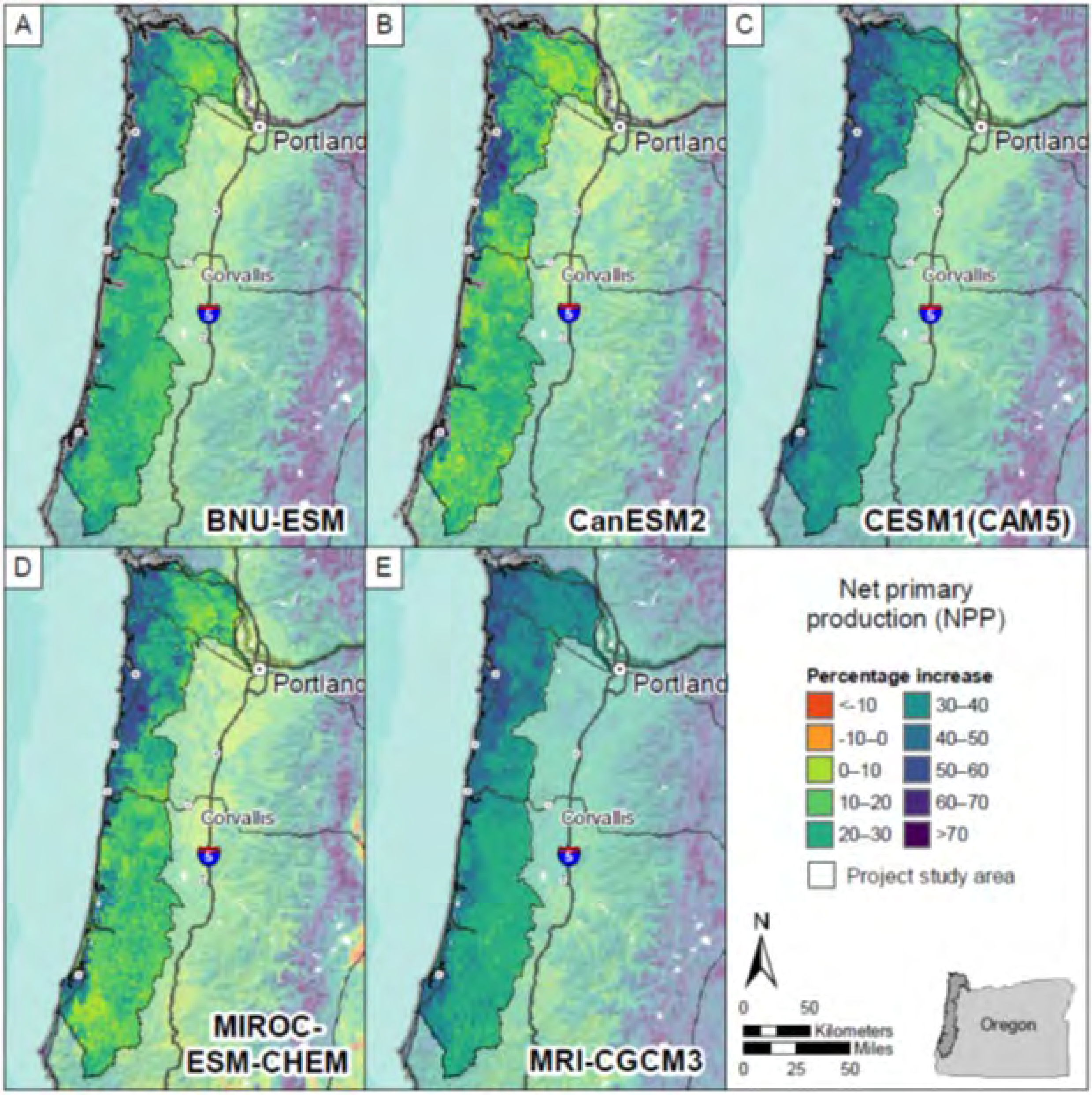


Figure 5.13—Percent change in net primary production as simulated by MC2 for the end of the century under five future climate scenarios (from five global climate models). The CESM1(CAM5) model is a top performer for the Pacific Northwest, with output similar to the model ensemble mean. CanESM2 represents the "hot-wet" extreme, BNU-ESM “hot,” MIROC-EMS-CHEM "hot-dry", and MRI-CGCM3 "warm" (less warming than the hot extremes).

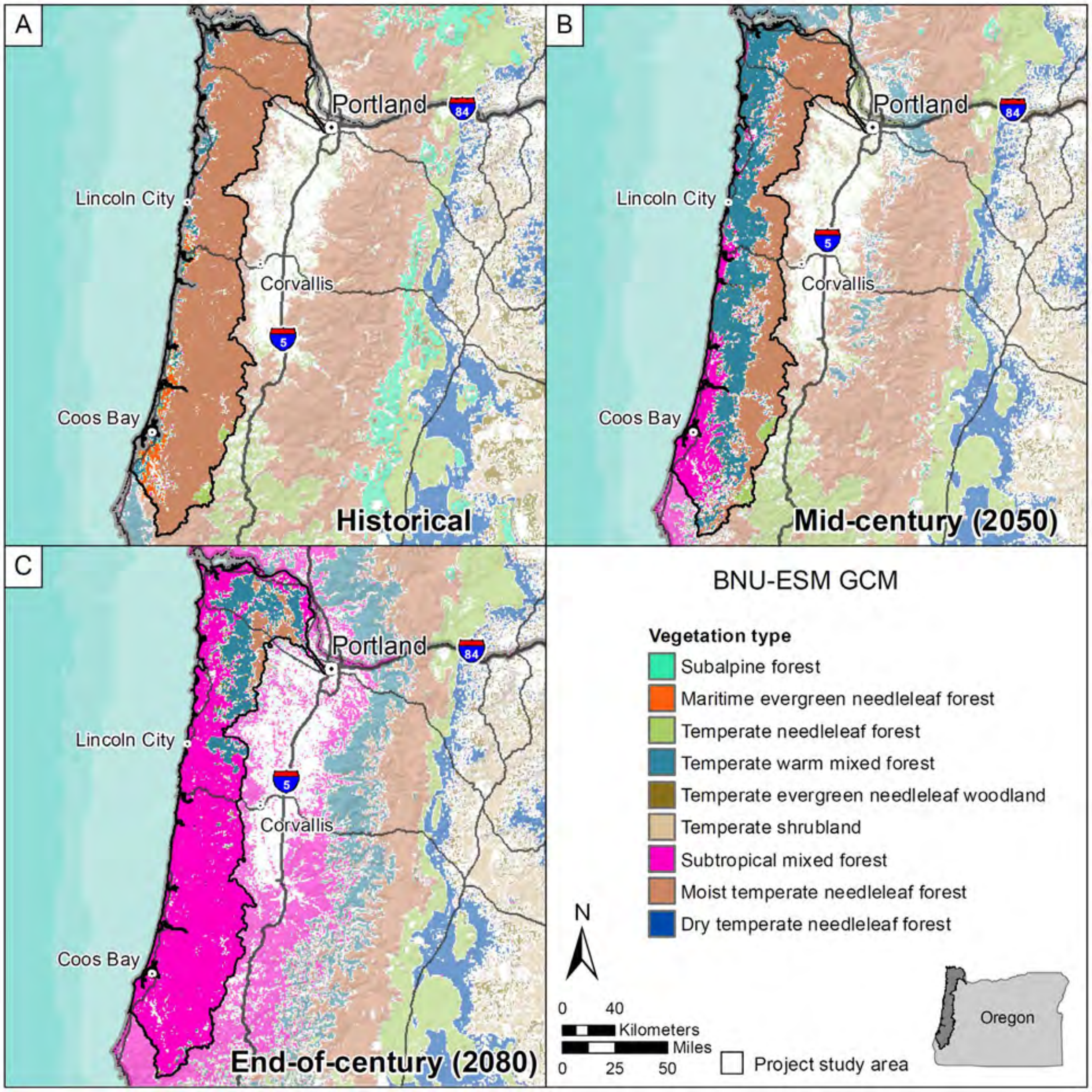


Figure 5.14—Vegetation types for the OCAP assessment area for the historical period, mid-century and end of century, as simulated by MC2 under the BNU-ESM global climate model (GCM) scenario for RCP 8.5. This model projects changes in temperature and precipitation that represent the "hot" extreme of higher-performing models for the Pacific Northwest (Rupp et al. 2013).

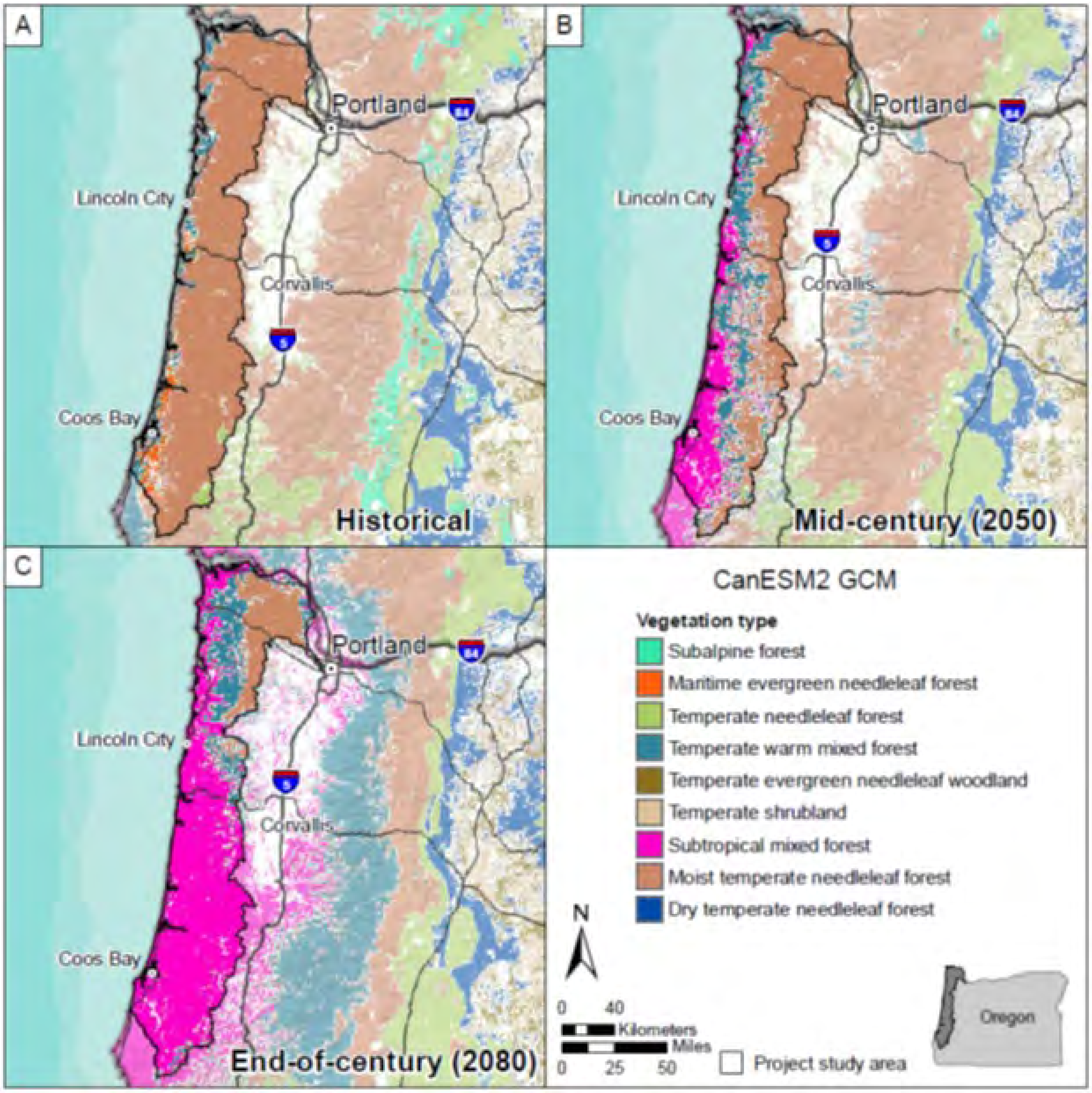


Figure 5.15—Vegetation types for the OCAP assessment area for the historical period, mid-century and end of century, as simulated by MC2 under the CanESM2 global climate model (GCM) scenario for RCP 8.5. This model projects changes in temperature and precipitation that represent the "hot-wet" extreme of higher-performing models for the Pacific Northwest (Rupp et al. 2013).

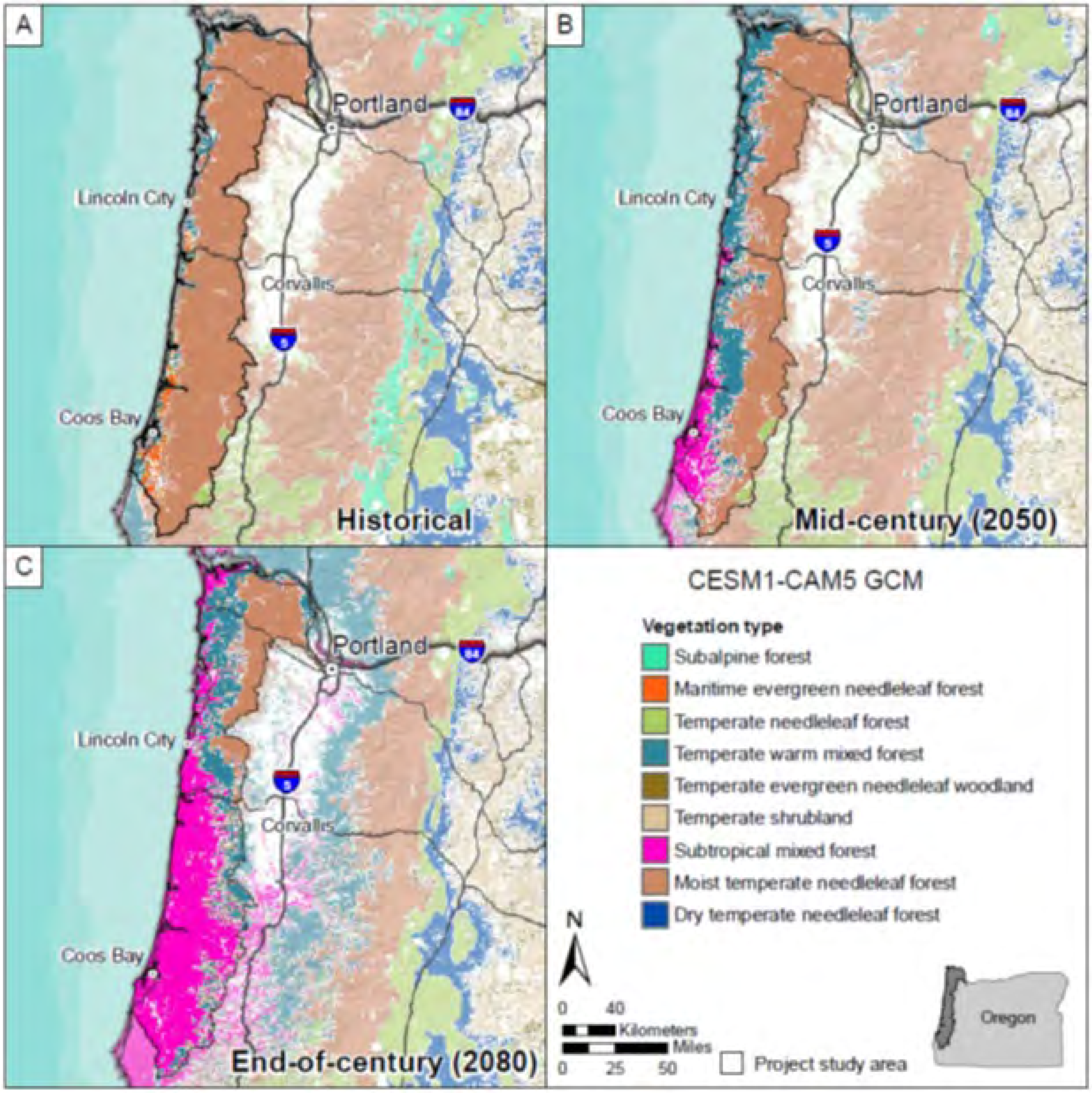


Figure 5.16—Vegetation types for the OCAP assessment area for the historical period, mid-century and end of century, as simulated by MC2 under the CESM1(CAM5) global climate model (GCM) scenario for RCP 8.5. This model is a highly ranked model for the Pacific Northwest (Rupp et al. 2013), with projected changes in temperature and precipitation similar to the ensemble mean ("average/best scenario").

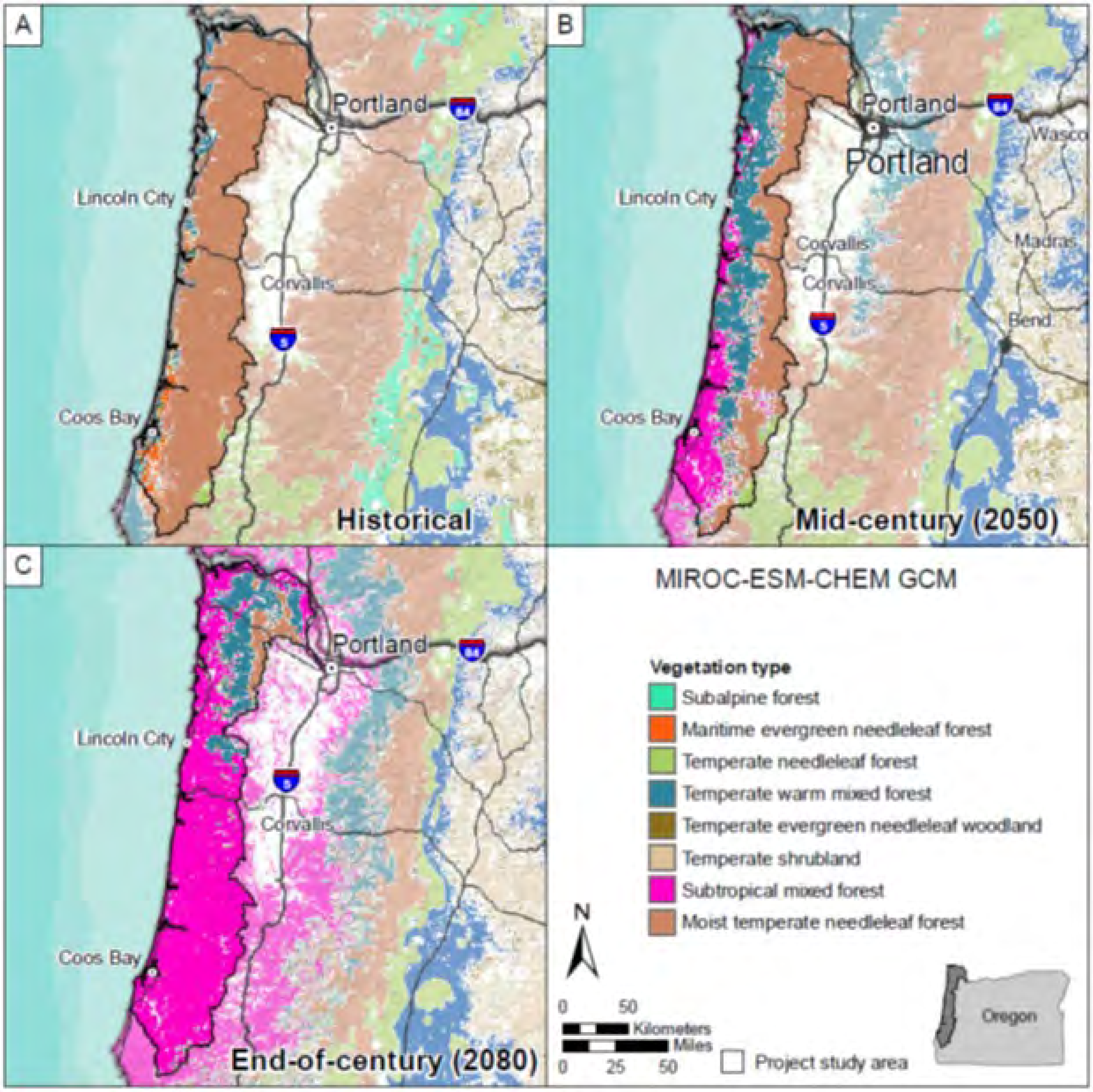


Figure 5.17—Vegetation types for the OCAP assessment area for the historical period, mid-century and end of century, as simulated by MC2 under the MIROC-EMS-CHEM global climate model (GCM) scenario for RCP 8.5. This model projects changes in temperature and precipitation that represent the “hot-dry” extreme of higher-performing models for the Pacific Northwest (Rupp et al. 2013).

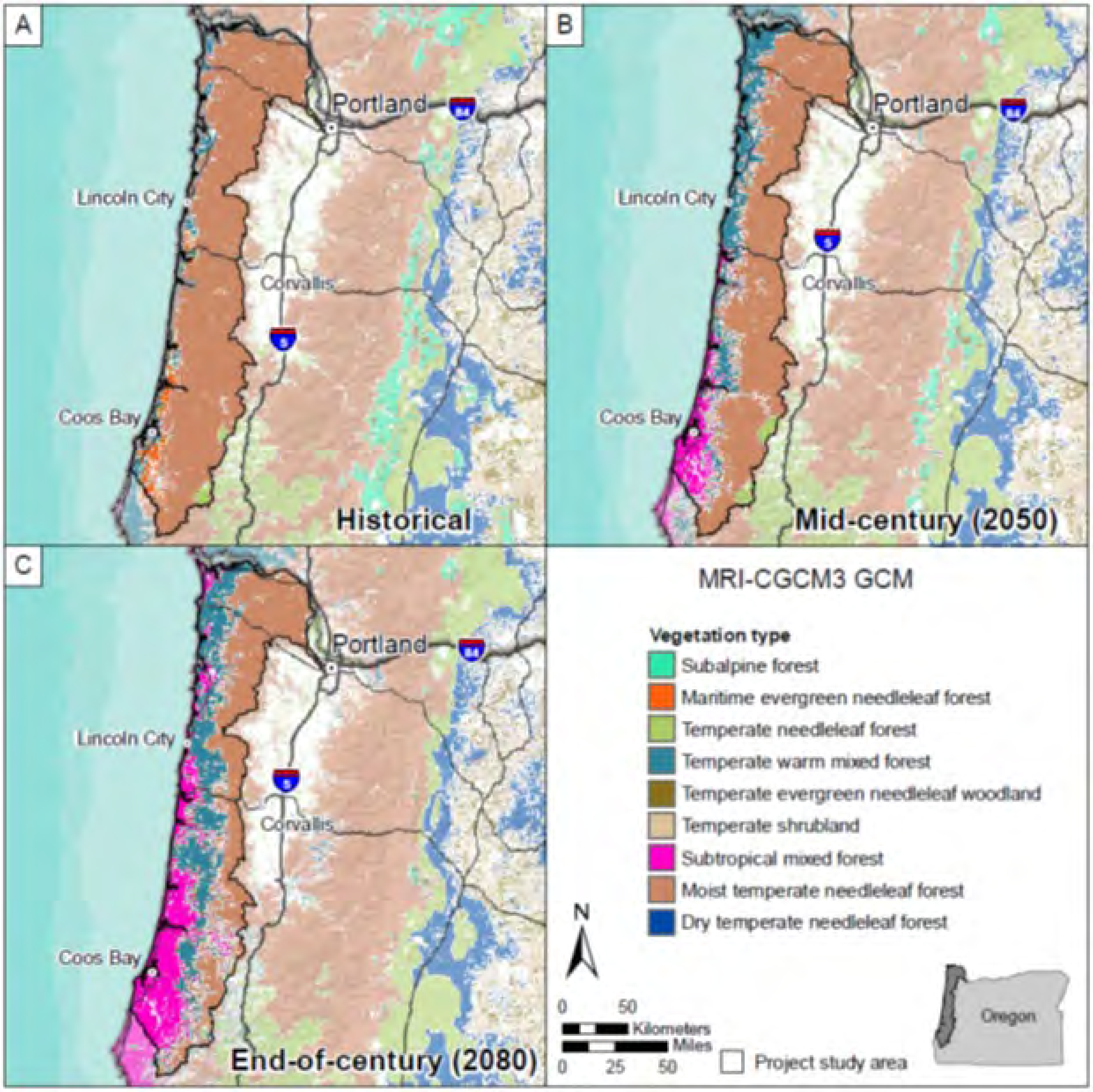


Figure 5.18—Vegetation types for the OCAP assessment area for the historical period, mid-century and end of century, as simulated by MC2 under the MRI-CGCM3 global climate model (GCM) scenario for RCP 8.5. This model projects changes in temperature and precipitation that represent the "warm" (less warming than hot) but not wet extreme of higher-performing models for the Pacific Northwest (Rupp et al. 2013).

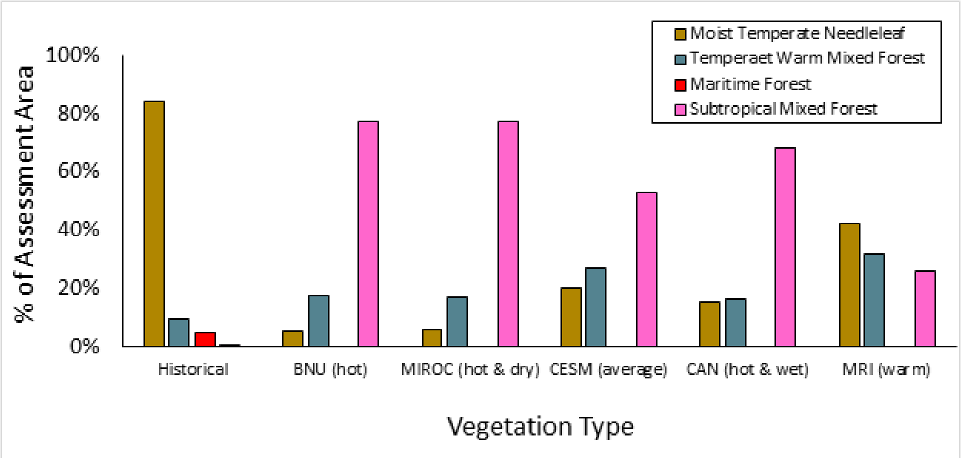


Figure 5.19—Proportion of different vegetation types for the OCAP assessment area for the historical period and end of century, as simulated by MC2 under five global climate model scenarios for RCP 8.5. Differences between the historical period and mid-century were minimal and thus are not shown.

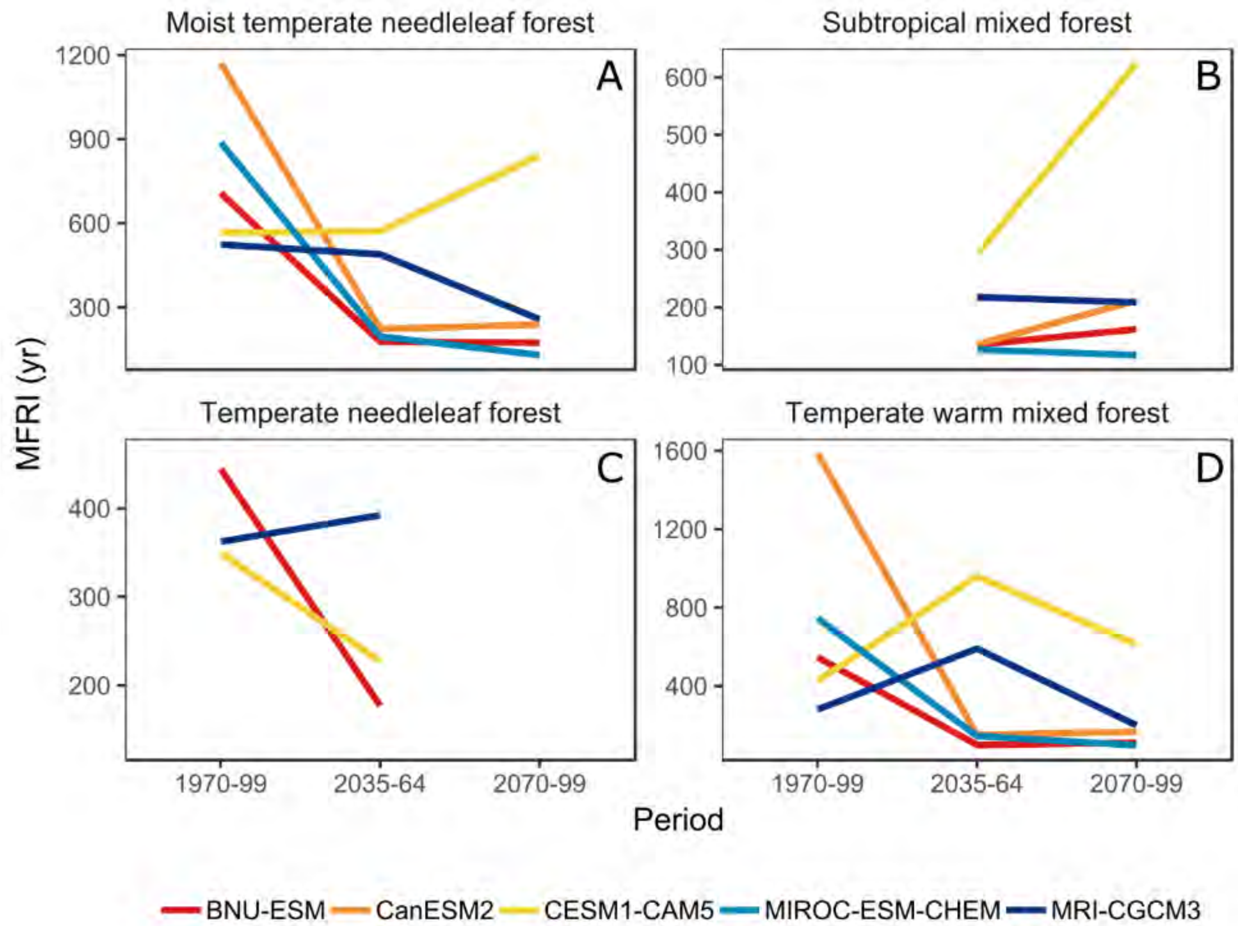


Figure 5.20—Projected mean fire-return interval (MFRI) in years for the historical (1970–1999), mid-century (2035–2064), and end of century (2070–2099) time periods for relevant MC2 vegetation types and global climate model scenarios in the OCAP assessment area. Note differences in scale for the y-axes.

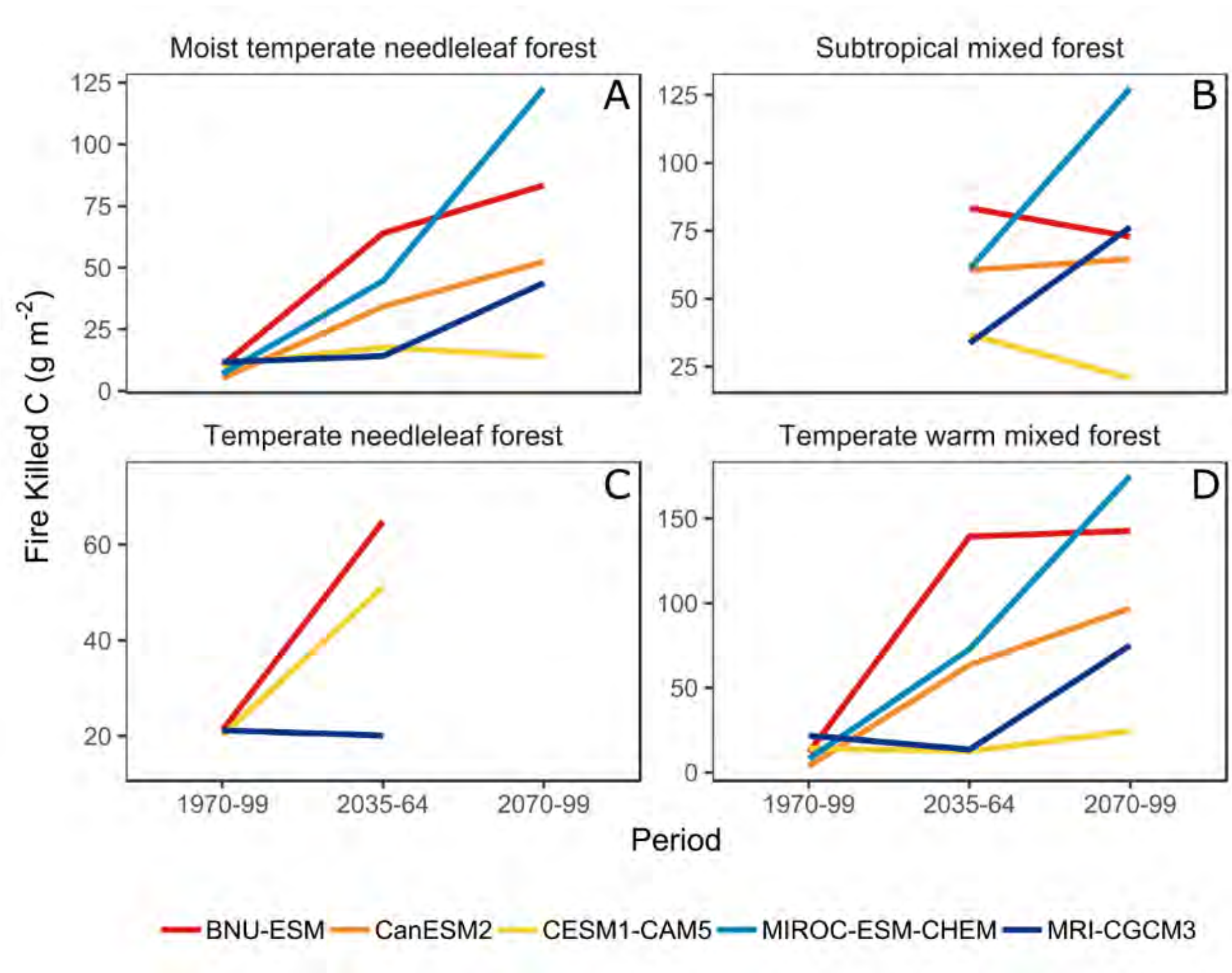


Figure 5.21—Projected fire severity (in fire-killed carbon in g m^{-2}) for the historical (1970-1999), mid-century (2035–2064), and end of century (2070–2099) time periods for relevant MC2 vegetation types and global climate model scenarios in the OCAP assessment area. Note differences in scale for the y-axes.

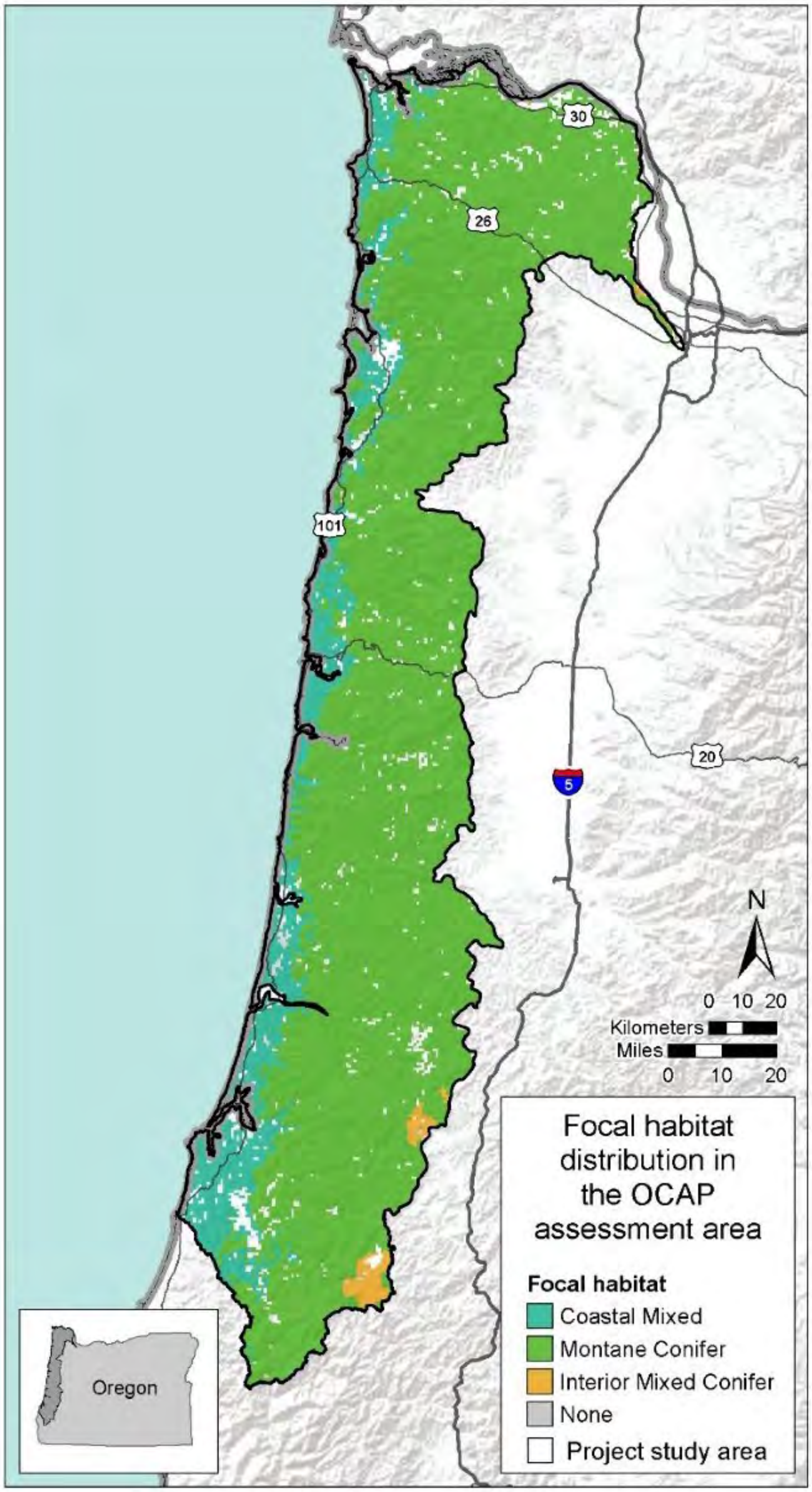


Figure 6.1—Distribution of vegetation types within the OCAP assessment area based on historical MC2 projections.

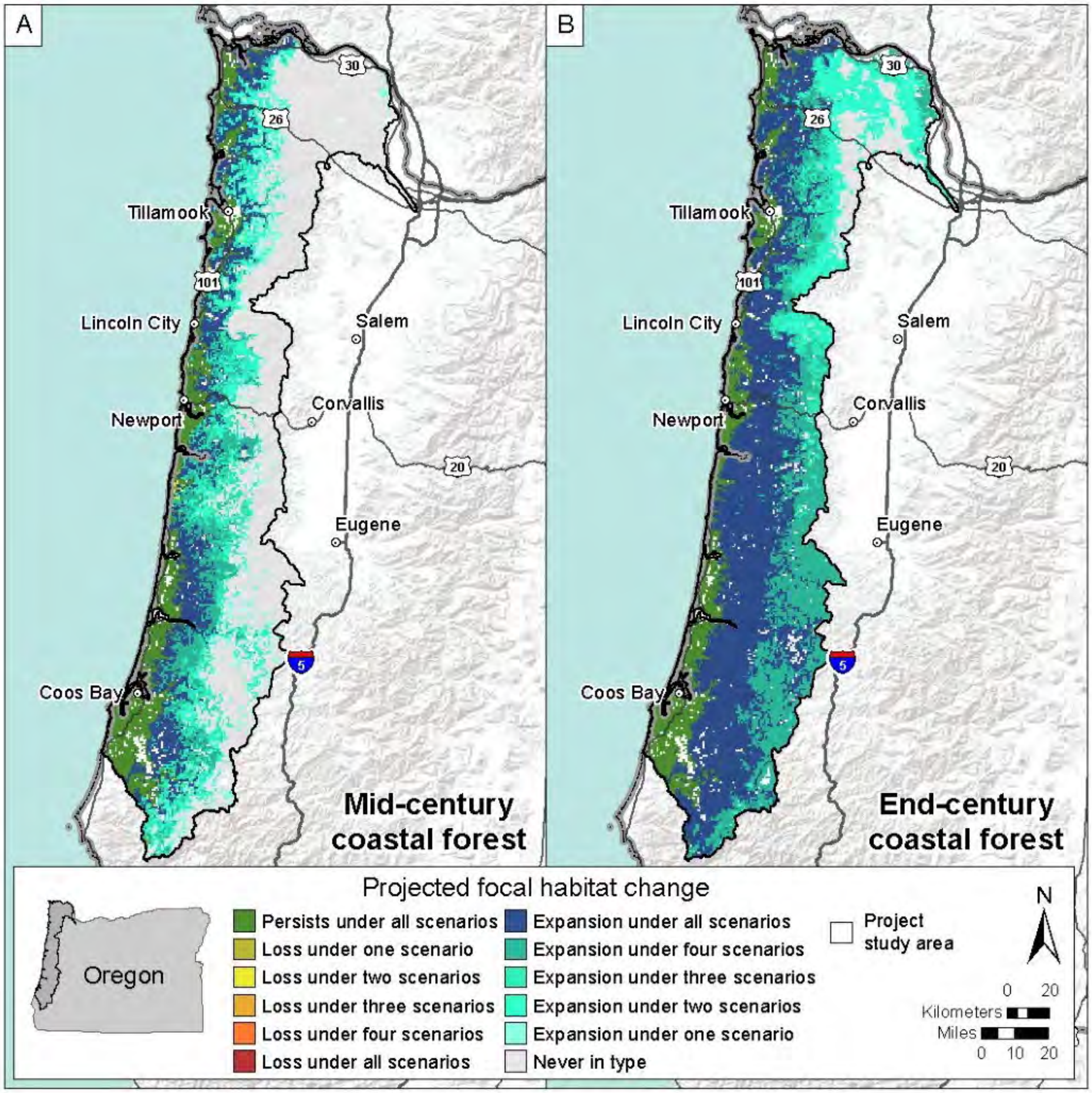


Figure 6.2—Consensus change maps from MC2 projections based on five climate change scenarios—Coastal Mixed Forest Vegetation Type.

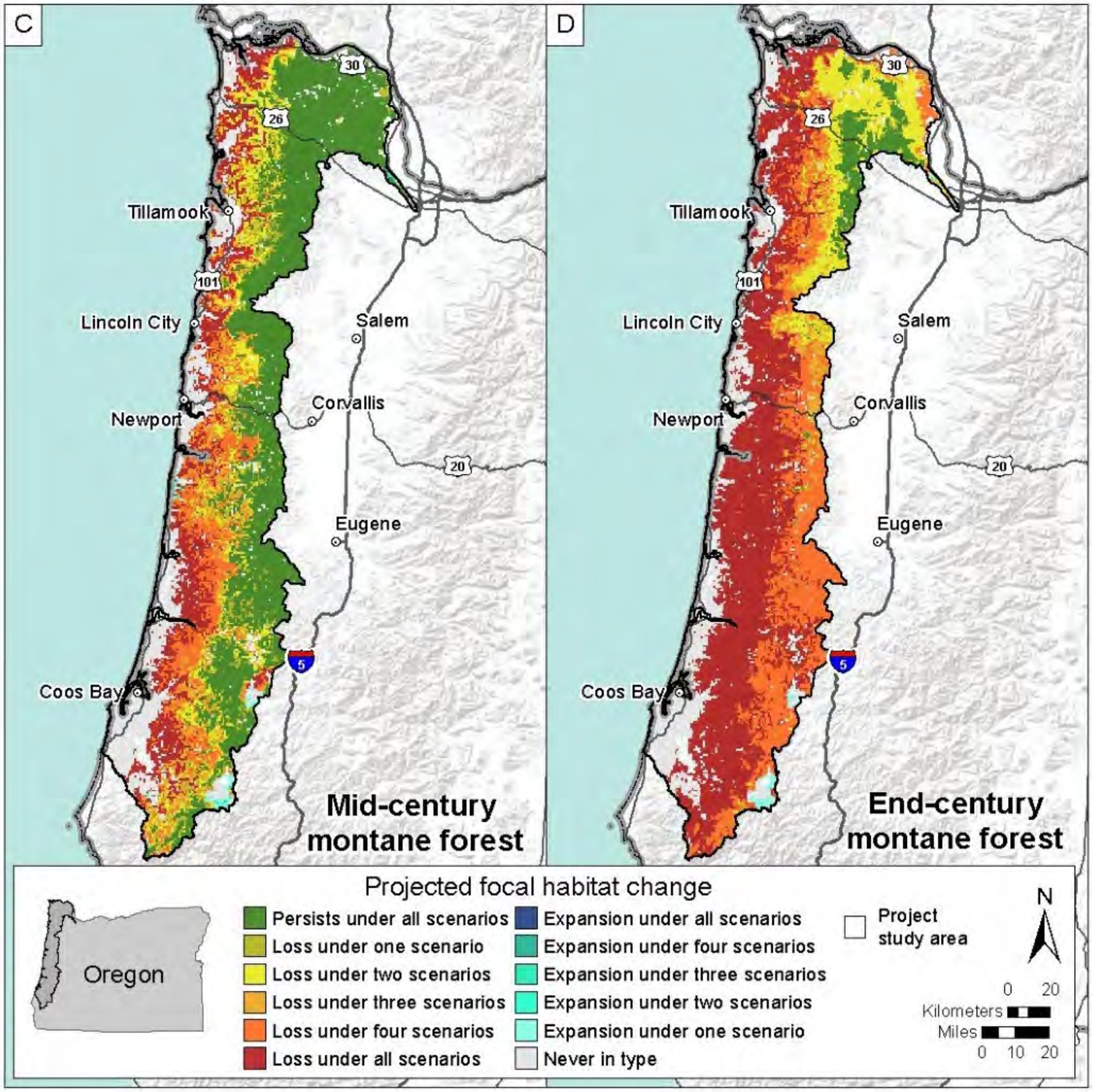


Figure 6.3—Consensus change maps from MC2 projections based on five climate change scenarios—Montane Conifer Forest Vegetation Type.

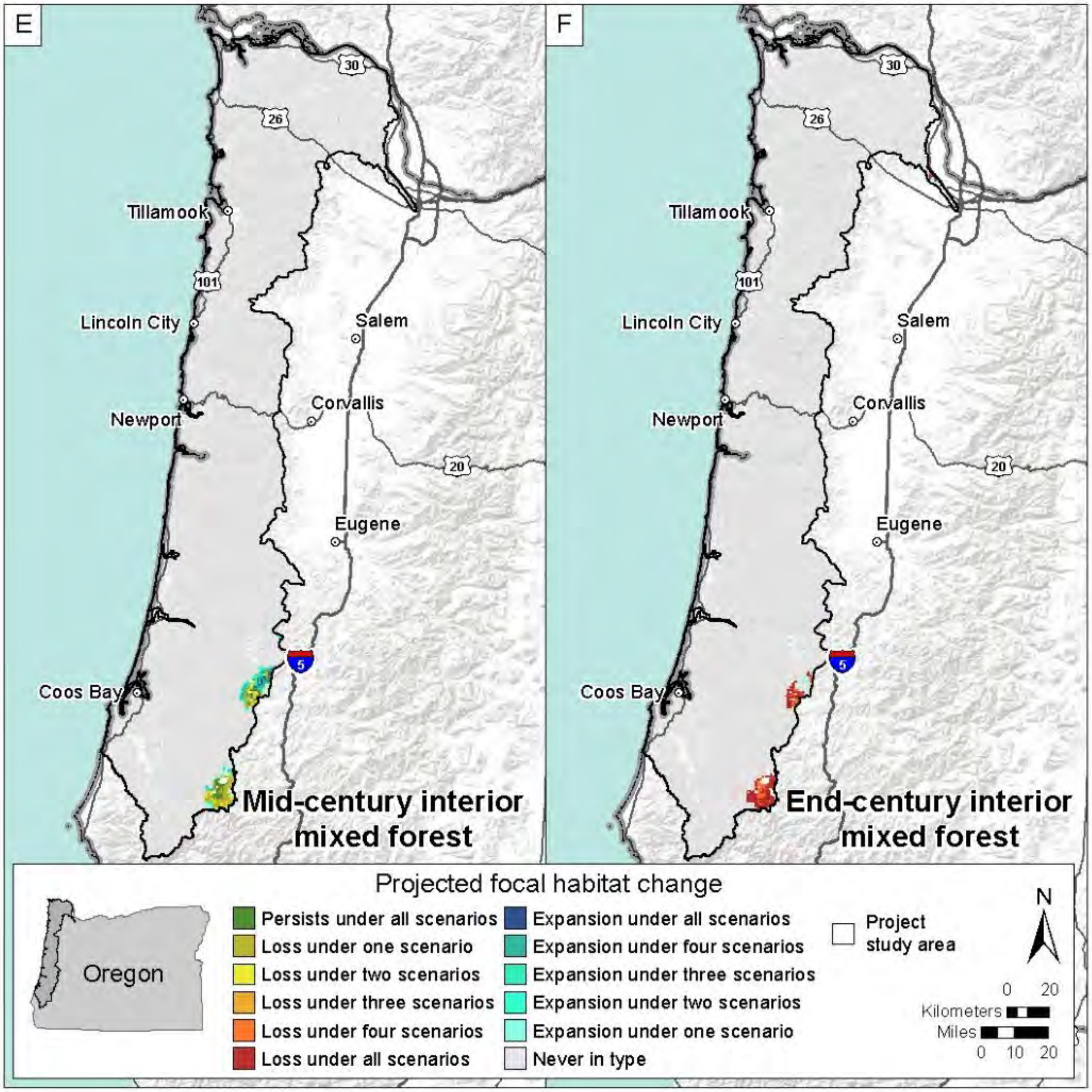


Figure 6.4—Consensus change maps from MC2 projections based on five climate change scenarios—Interior Mixed Forest Vegetation Type.

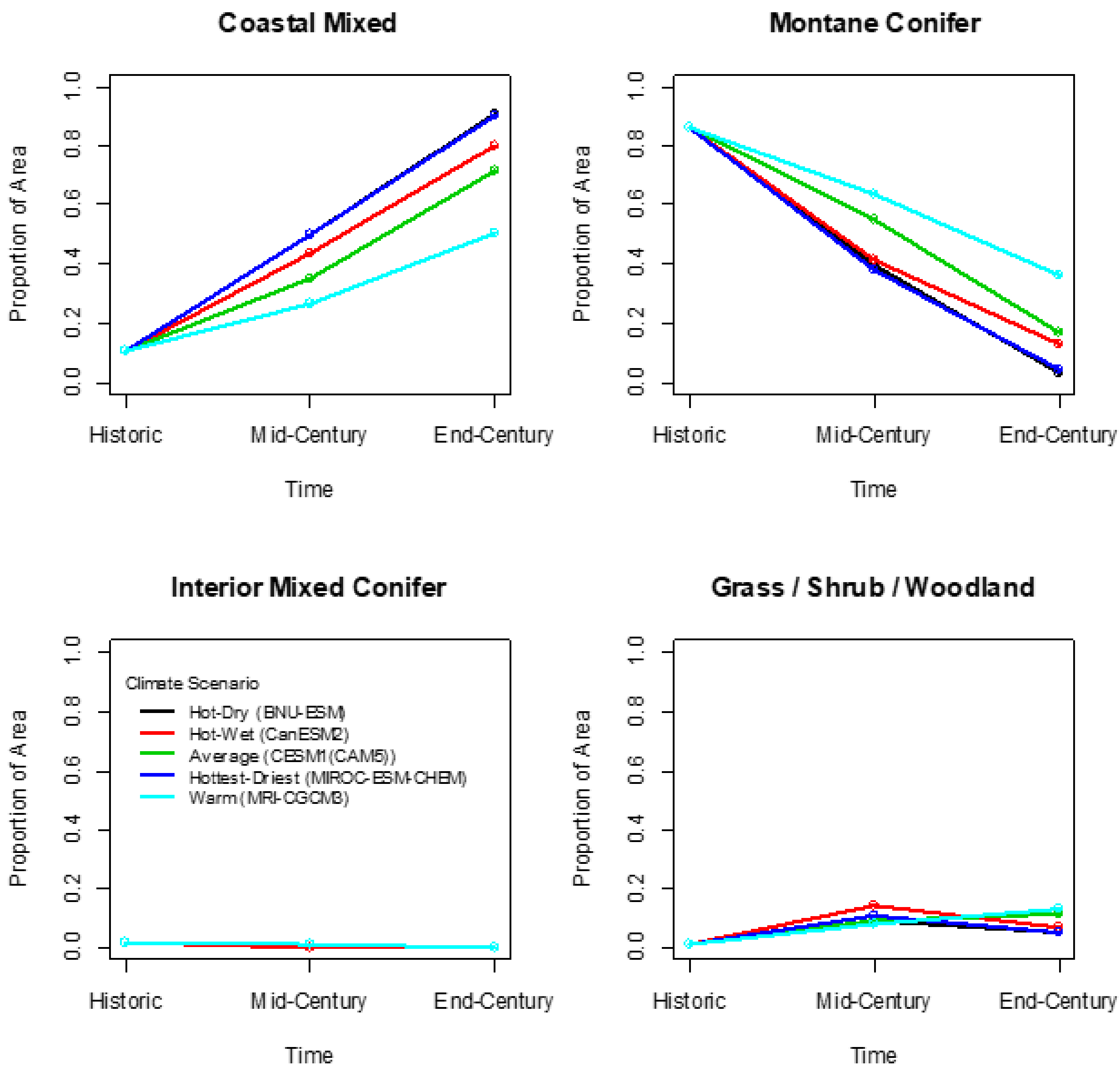


Figure 6.5—Modeled proportion of the OCAP assessment area encompassed by four vegetation types from MC2 projections of historic, mid-century, and end-century conditions from the five climate change scenarios included in the consensus change maps (see legend in Interior Mixed Conifer box).

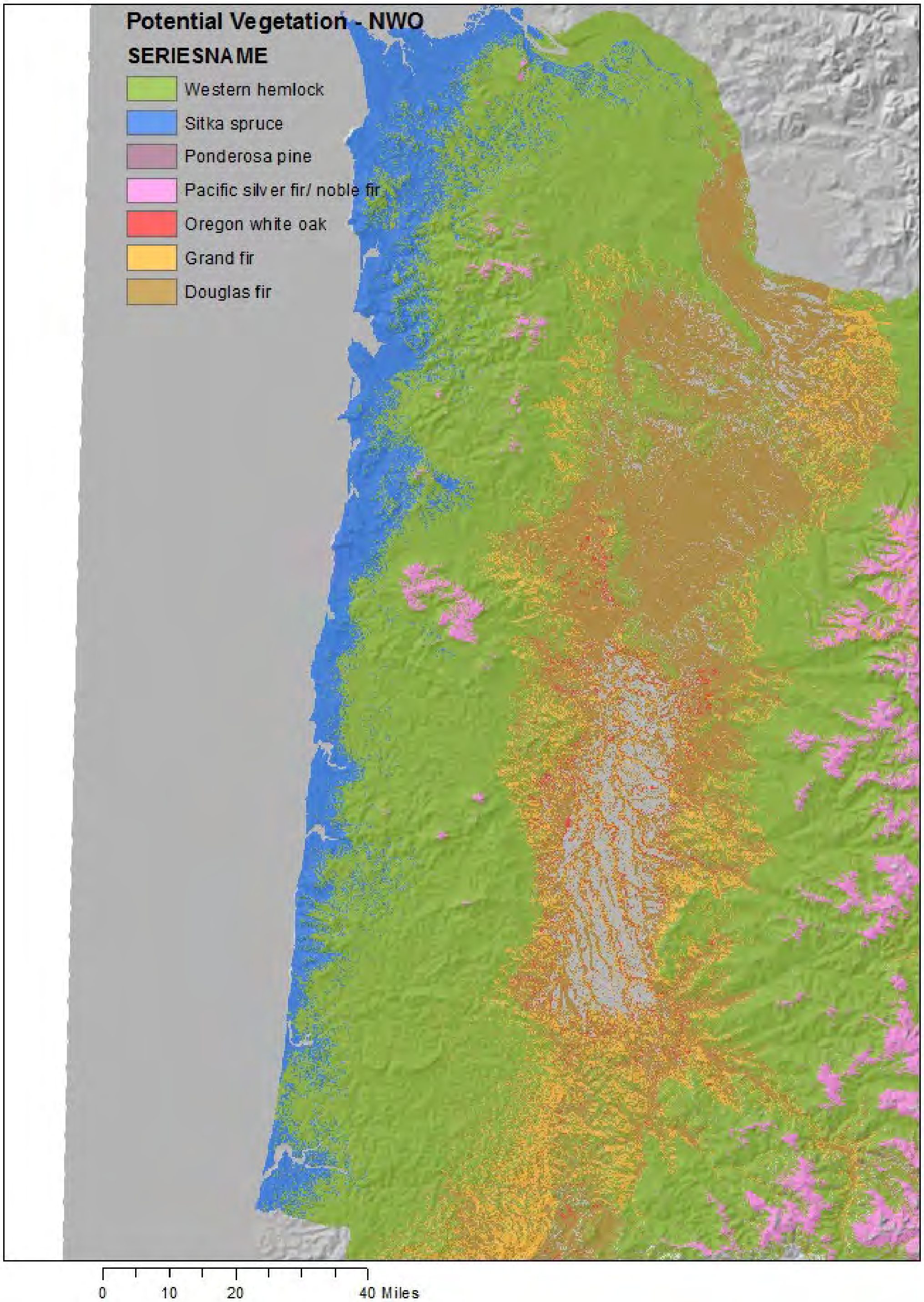


Figure 6.6—Potential vegetation series map for the OCAP assessment area.

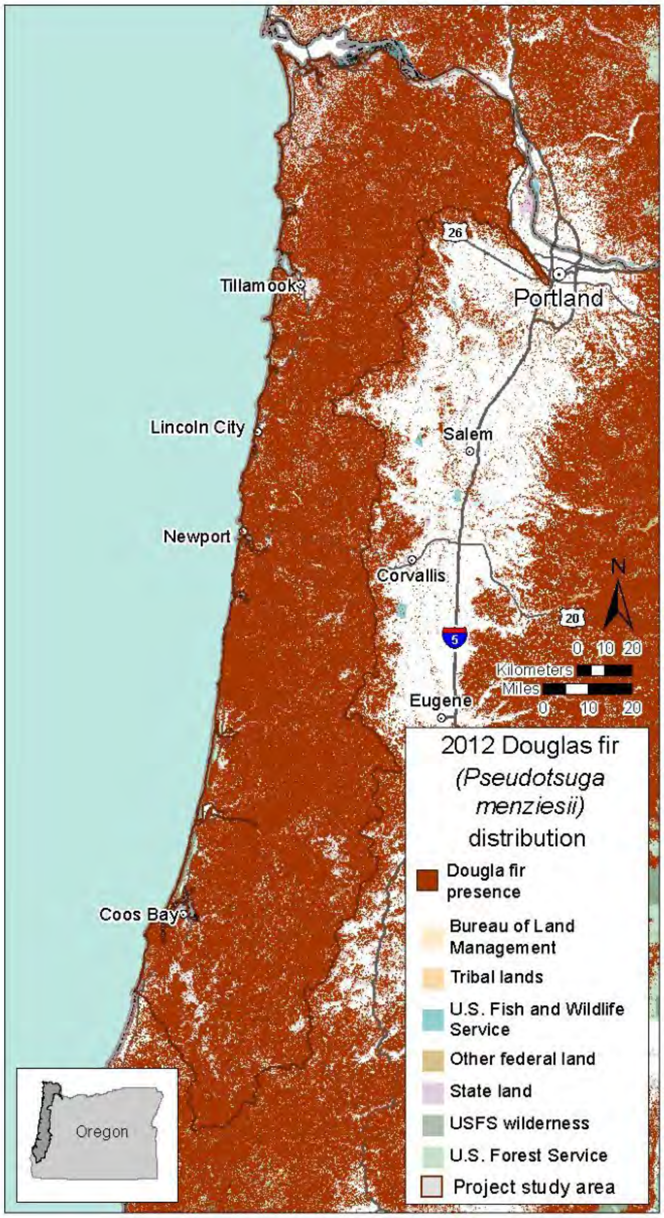


Figure 6.7—Current distribution of Douglas-fir in the OCAP assessment area.

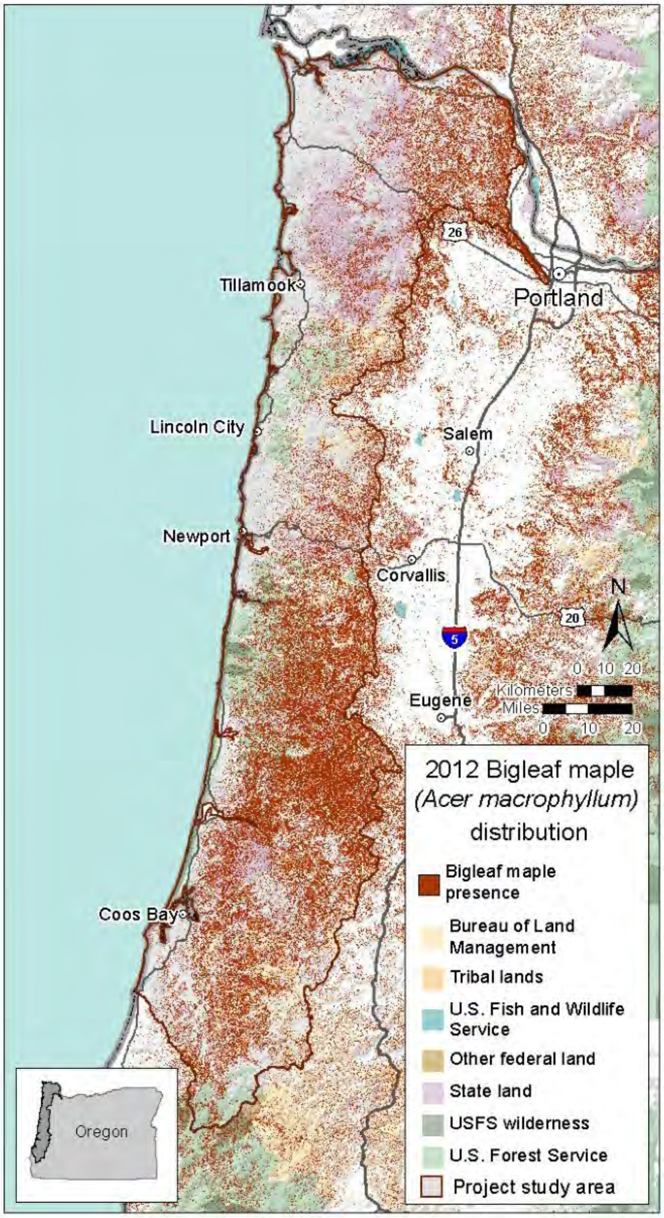


Figure 6.8—Current distribution of bigleaf maple in the OCAP assessment area.

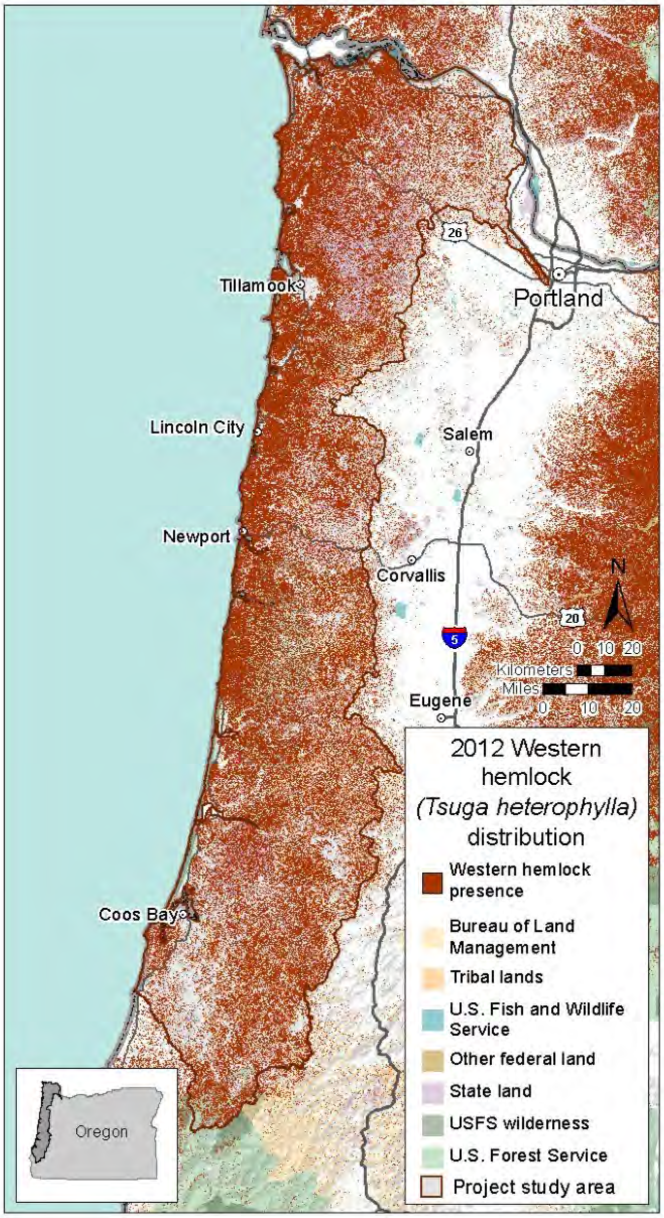


Figure 6.9—Current distribution of western hemlock in the OCAP assessment area.

Figure 6.10—Current distribution of grand fir in the OCAP assessment area.

Figure 6.11—Current distribution of western redcedar in the OCAP assessment area.

Figure 6.12—Current distribution of Pacific madrone in the OCAP assessment area.

Figure 6.13—Current distribution of incense cedar in the OCAP assessment area.

Figure 6.14—Current distribution of Sitka spruce in the OCAP assessment area.

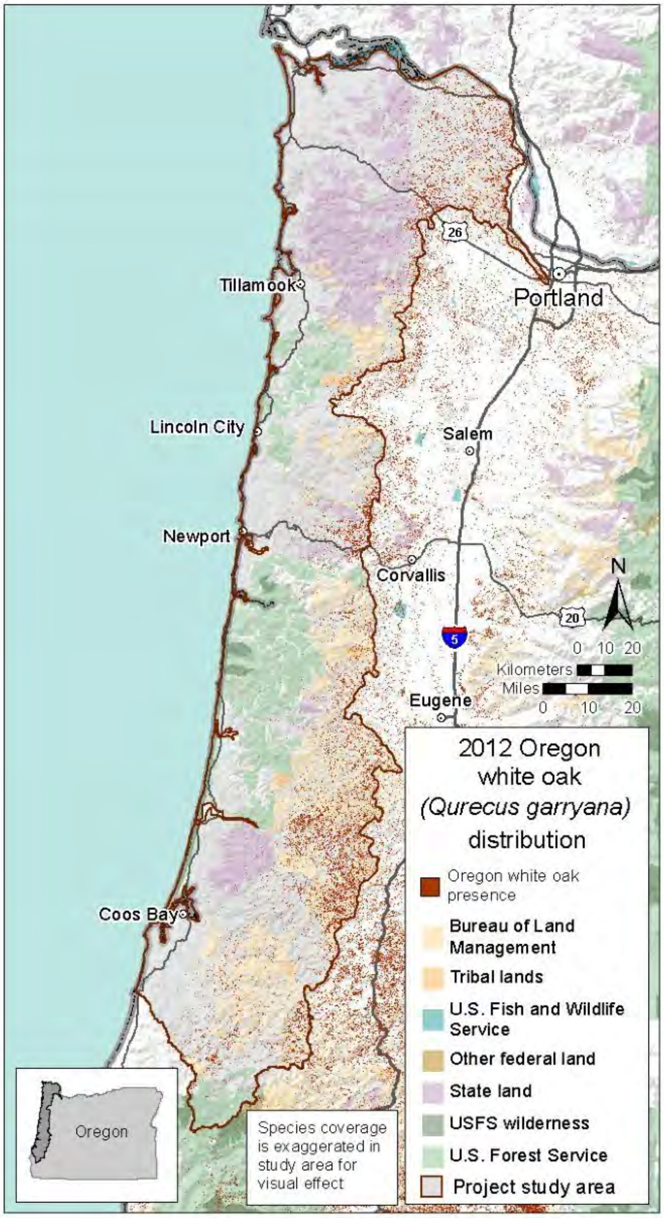


Figure 6.15—Current distribution of Oregon white oak in the OCAP assessment area.

Figure 6.16—Current distribution of noble fir in the OCAP assessment area.

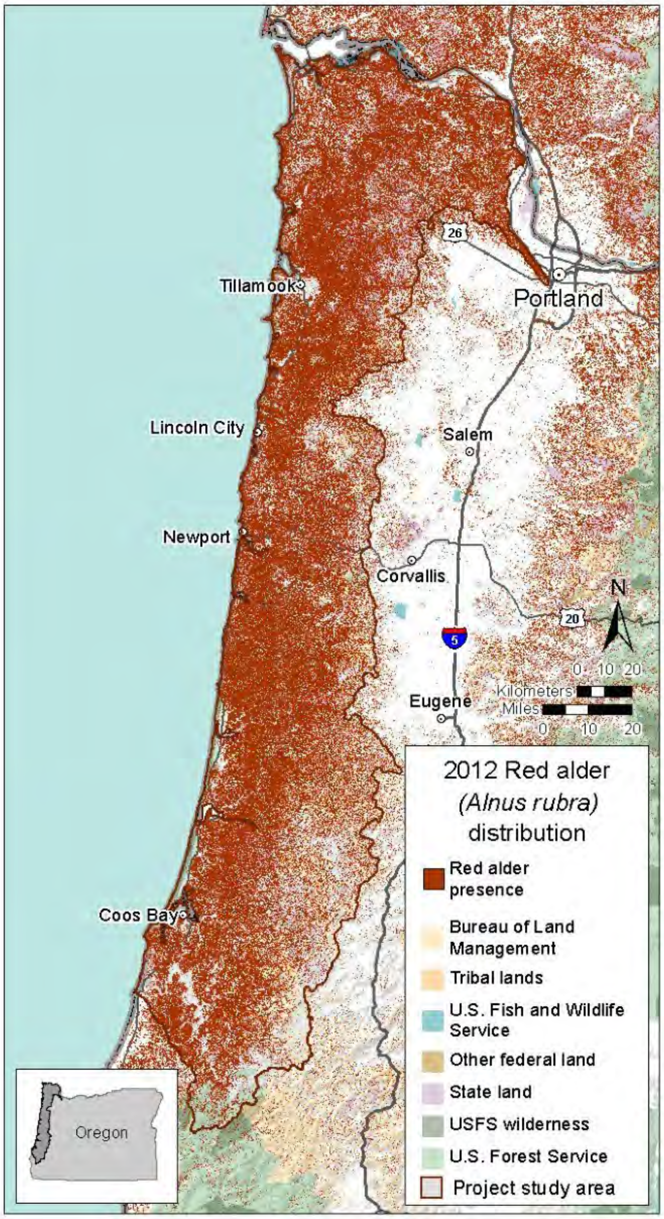


Figure 6.17—Current distribution of red alder in the OCAP assessment area.

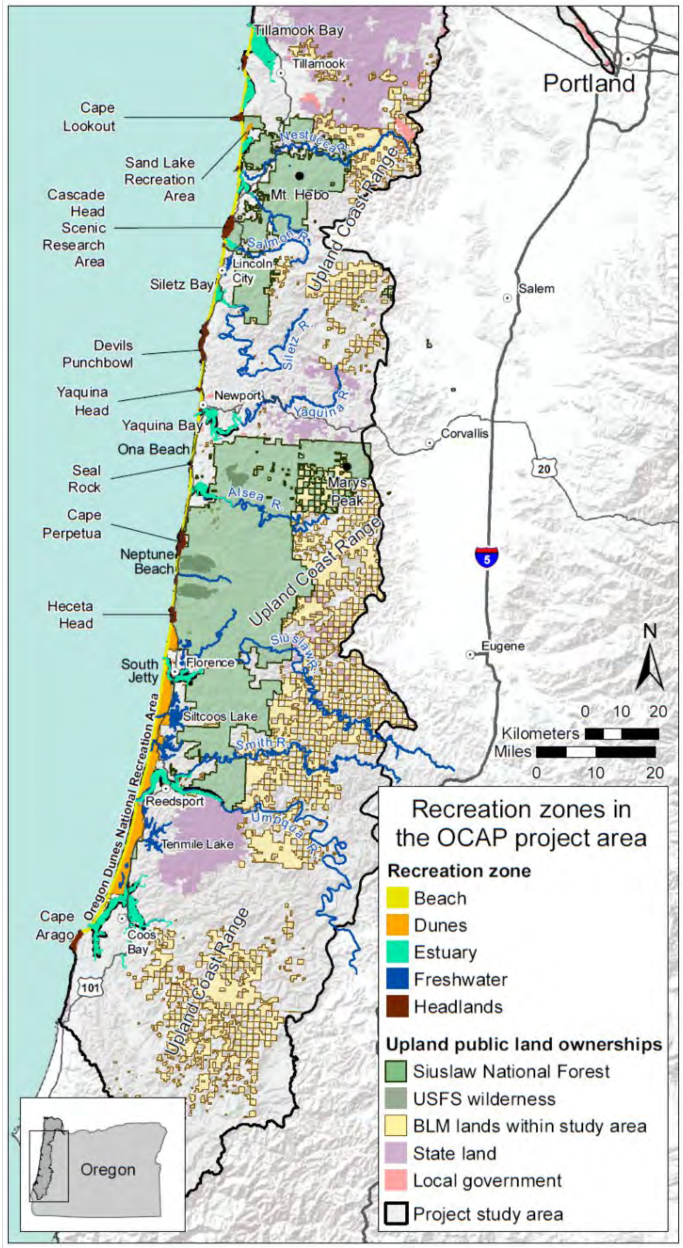


Figure 7.1—Geographic zones in the OCAP assessment area. Everything in the assessment area that is not designated as a "recreation zone" is considered the "upland zone."

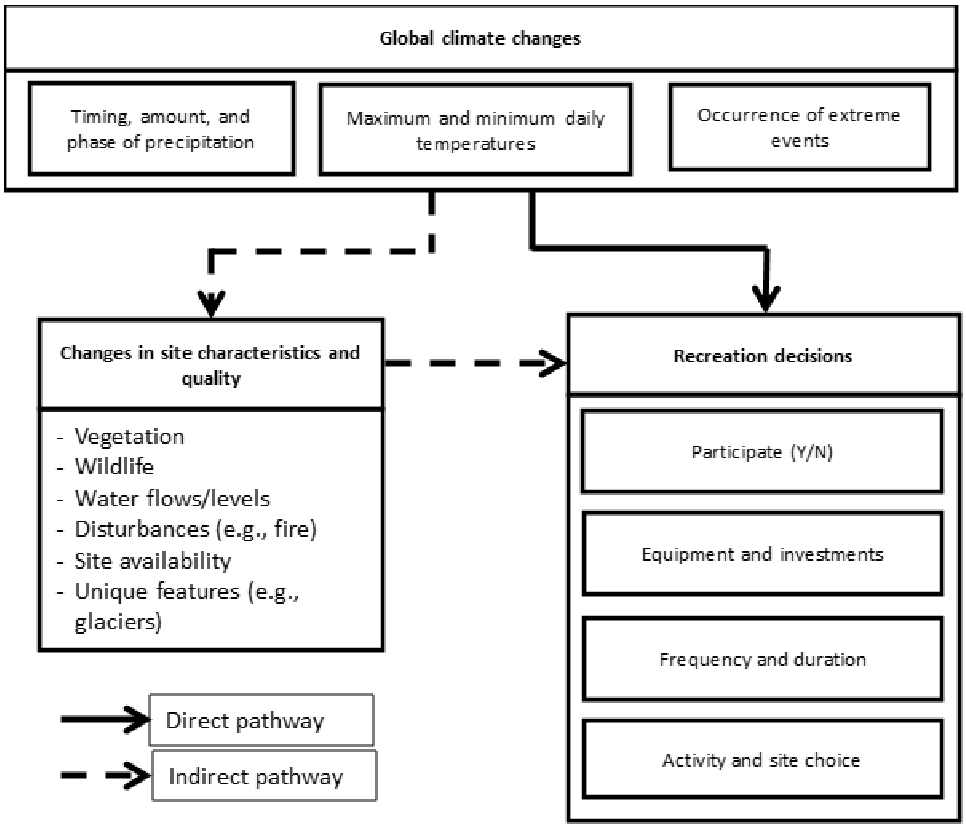


Figure 7.2—Direct and indirect effects of climate on recreation decisions (from Hand and Lawson 2018).

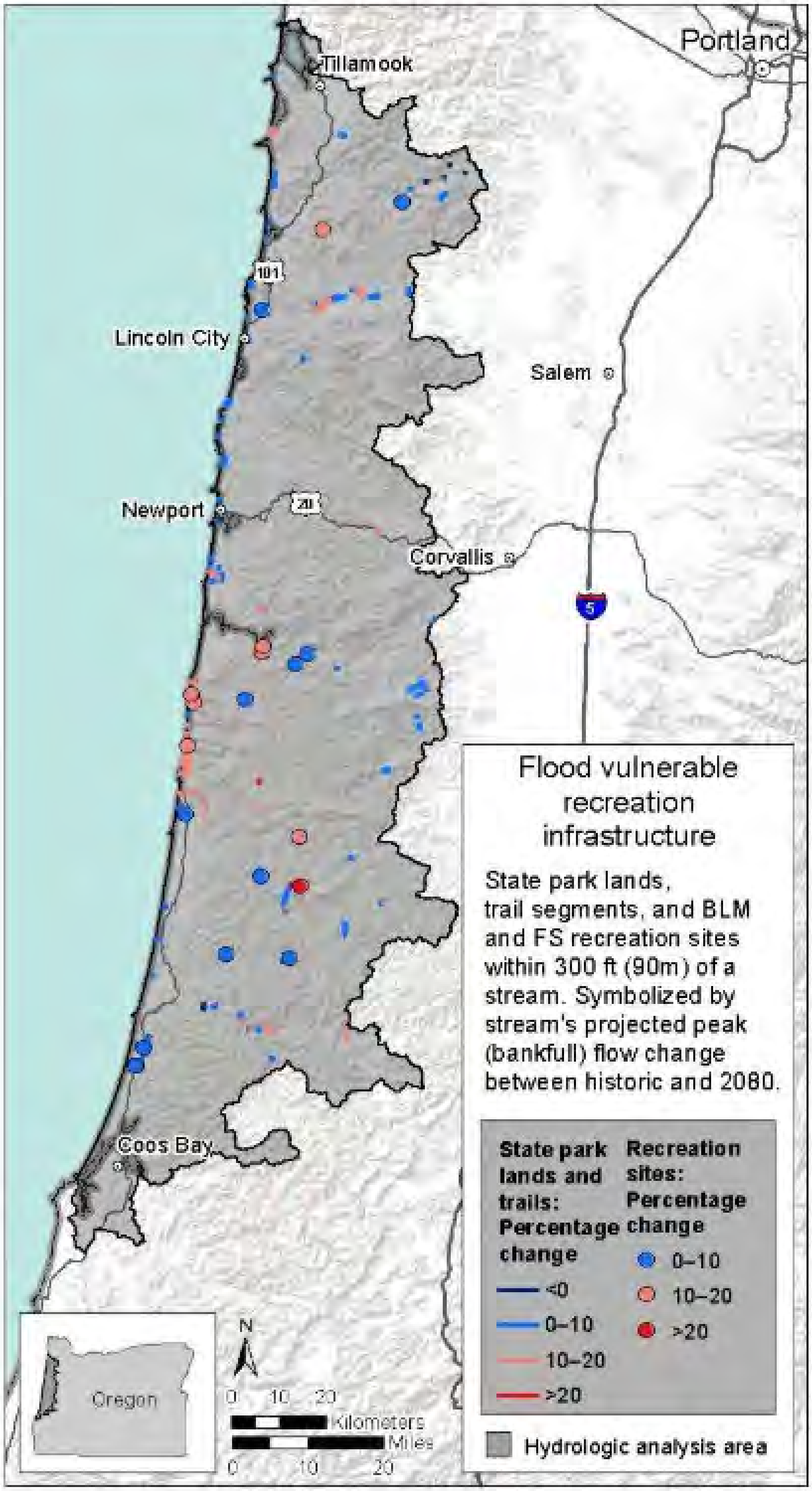


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Figure 7.3—Recreation infrastructure vulnerable to flooding in the OCAP assessment area.

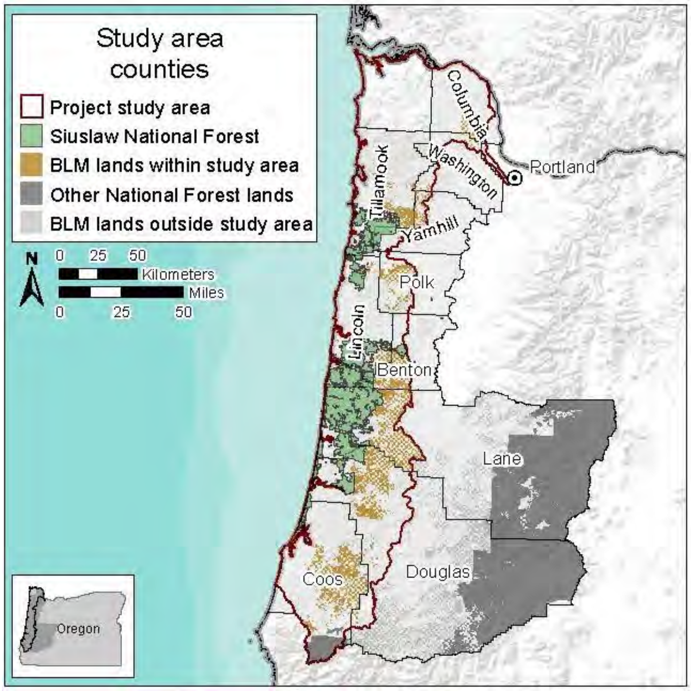
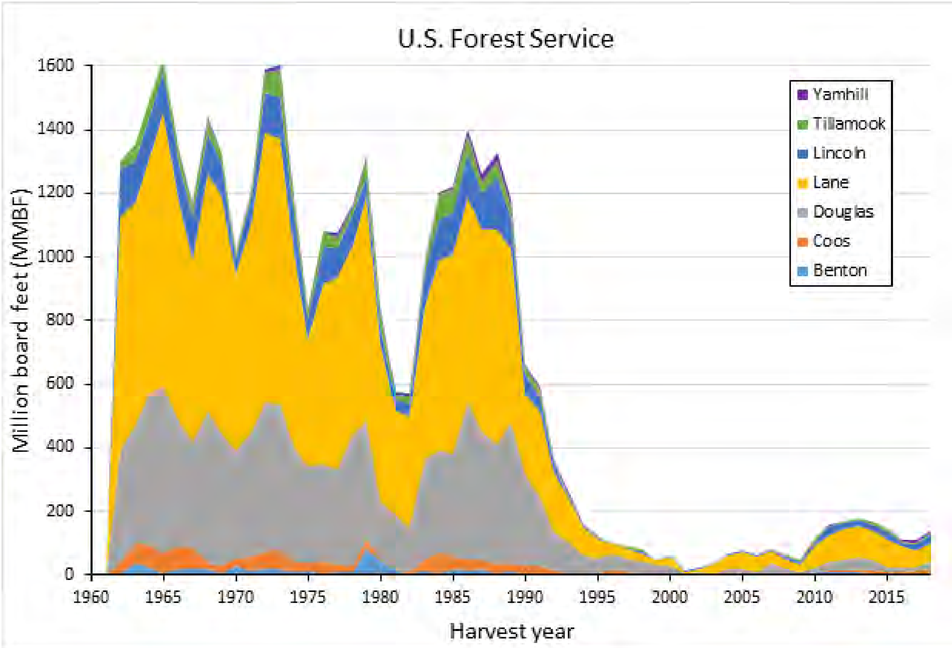


Figure 8.1—The OCAP assessment area, showing USFS and BLM lands.



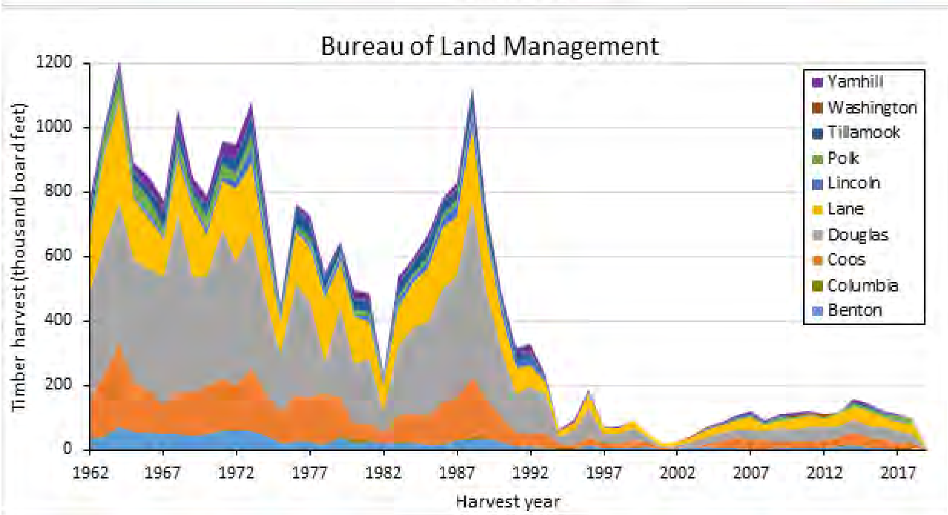


Figure 8.2—Annual timber output from lands managed by the (a) U.S. Forest Service and (b) Bureau of Land Management for counties in the OCAP assessment area, 1962–2018. Douglas and Lane Counties contain large areas of federal lands outside the assessment area. Source: Oregon Department of Forestry annual harvest reports for the State of Oregon.

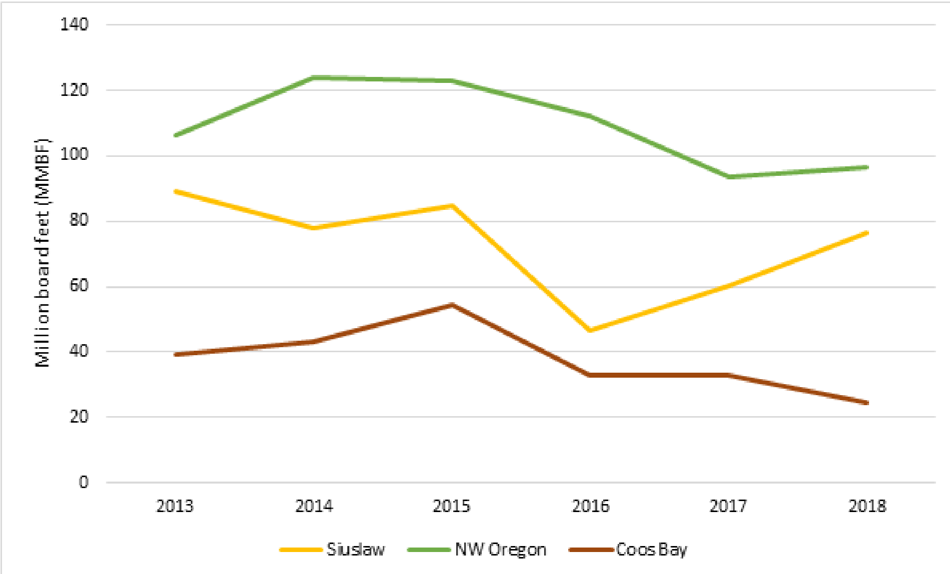


Figure 8.3—Annual saw timber harvest for Siuslaw National Forest and Bureau of Land Management Northwest Oregon and Coos Bay Districts, 2013–2018.

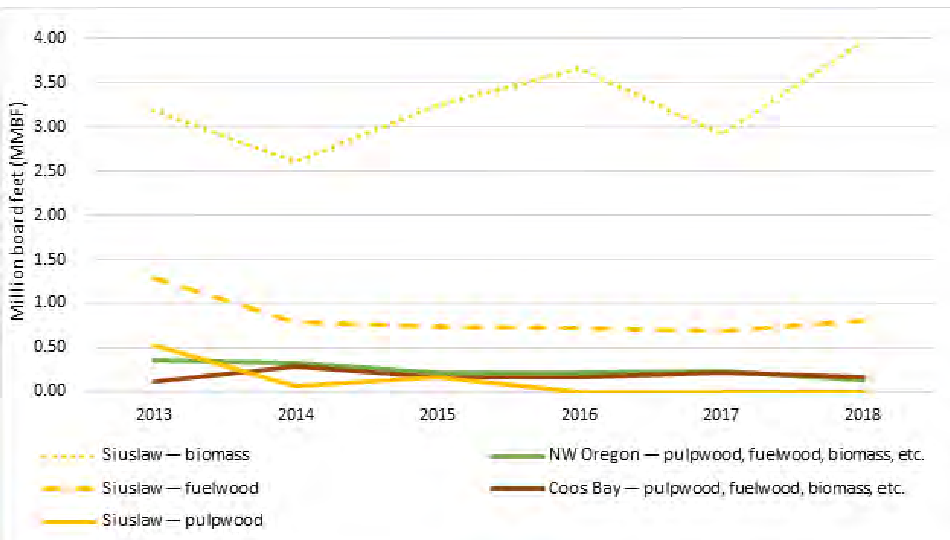


Figure 8.4—Annual output of non-saw timber wood products for federal units in the OCAP assessment area, 2013–2018.

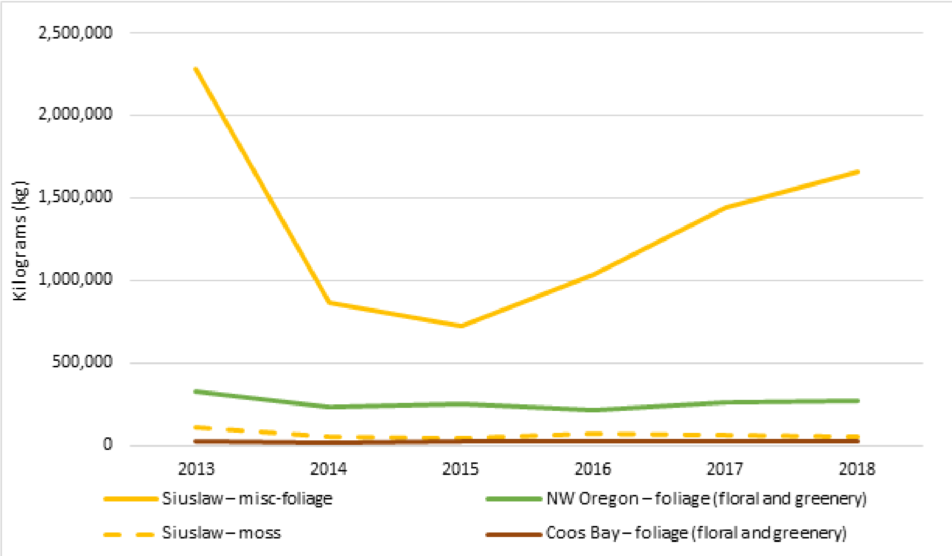


Figure 8.5—Annual output of foliage categories for federal units in the OCAP assessment area, 2013–2018.

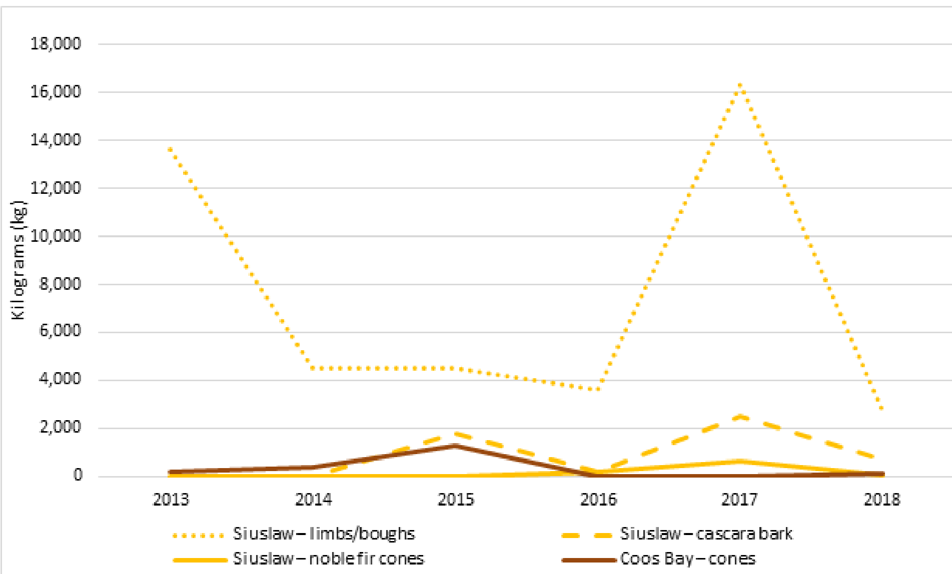


Figure 8.6—Annual output of small-scale non-timber forest products for federal units in the OCAP assessment area, 2013–2018.

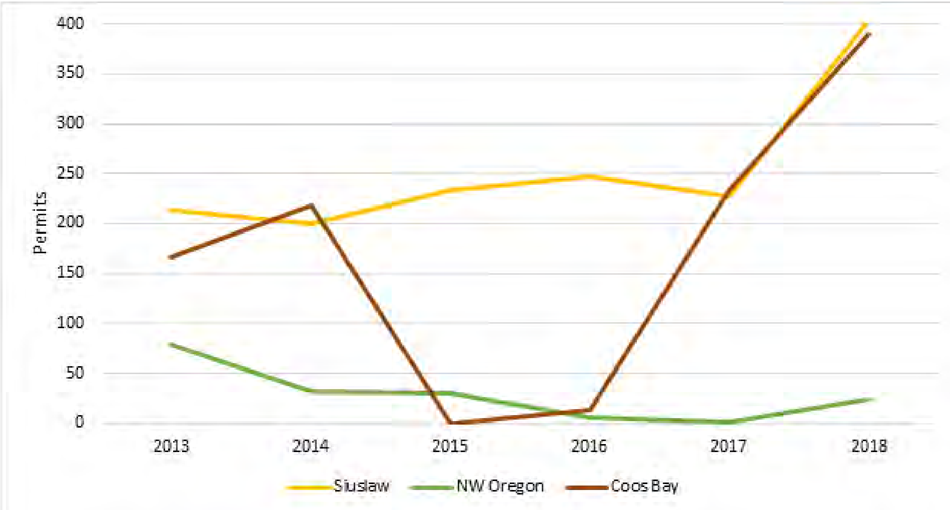


Figure 8.7—Annual permits issued for Christmas trees for federal units in the OCAP assessment area, 2013–2018.

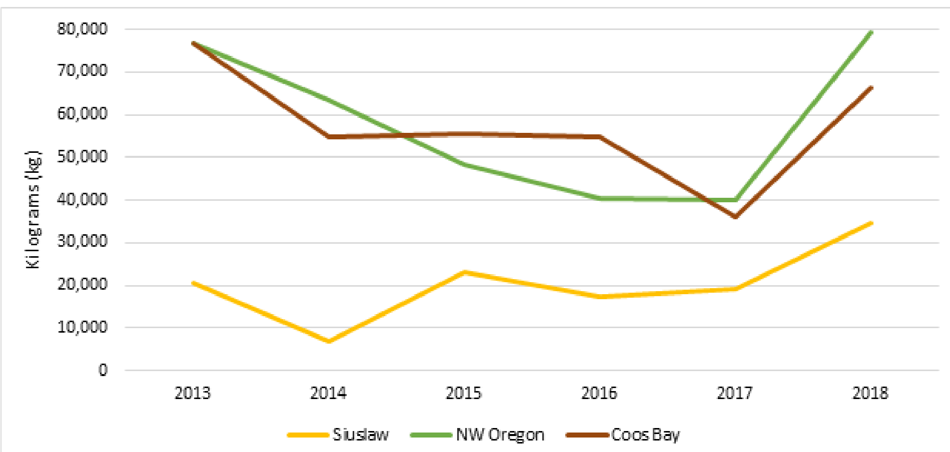


Figure 8.8—Annual output of mushrooms for federal units in the OCAP assessment area, 2013–2018.

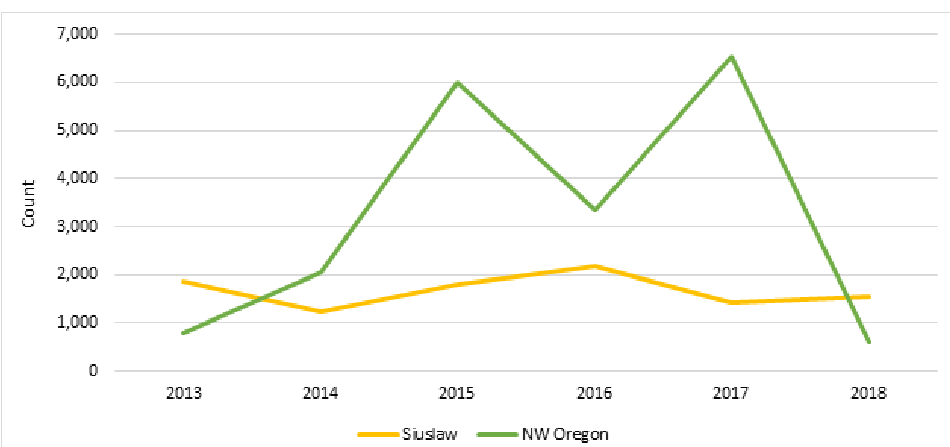


Figure 8.9—Annual output of transplants for federal units in the OCAP assessment area, 2013–2018.

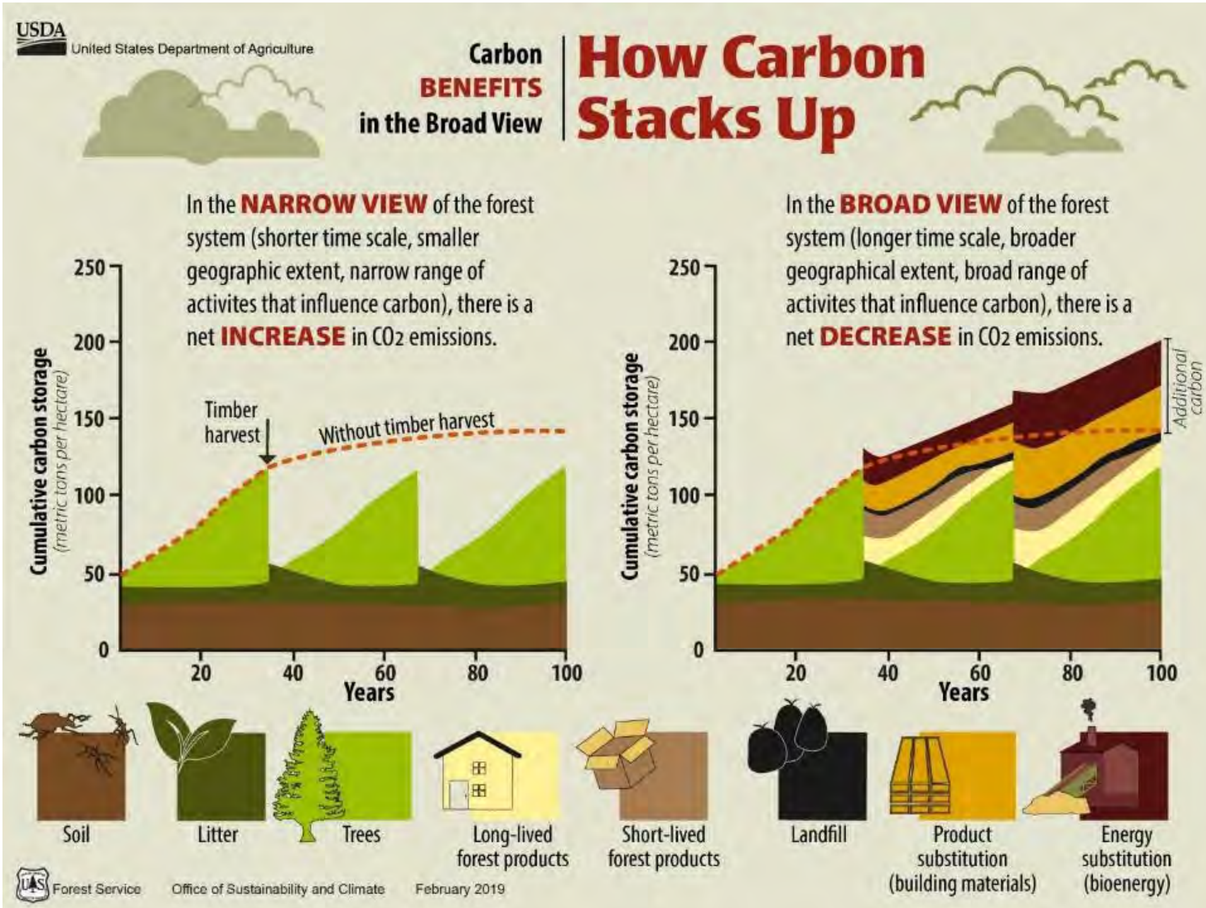


Figure 8.10—Carbon balance from a hypothetical forest management project, in which the forest is harvested every 40 years from land that started with low forest carbon stocks. The dashed line represents the amount of forest carbon with no harvesting. The figure on the left considers only carbon in the physical forest system. The figure on the right considers the whole forest system and illustrates how harvested forests can continue to accrue carbon over time when accounting for forest regrowth, carbon stored in wood products in use and landfills, and product and biomass energy substitution (also counted as stored carbon). Figure is adapted from McKinley et al. (2011).

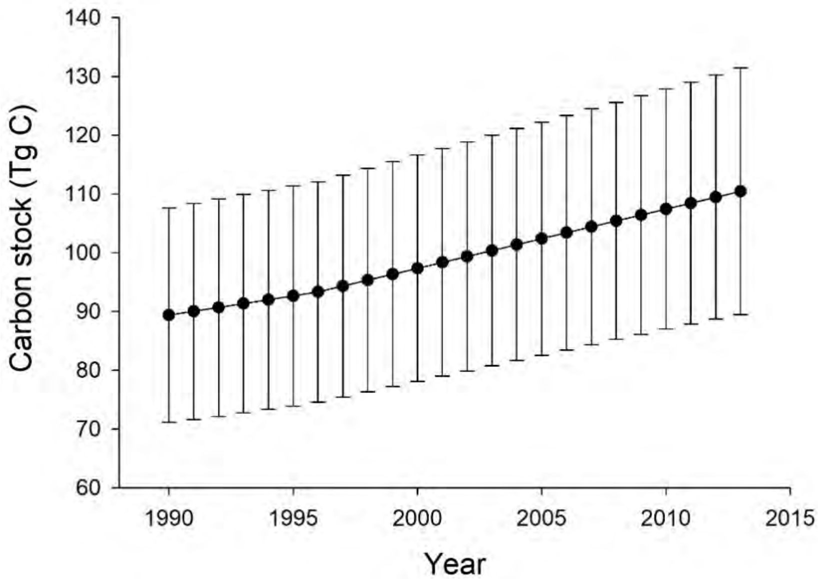


Figure 8.11—Estimated total forest ecosystem carbon stocks in teragrams for Siuslaw National Forest, 1990–2013. Estimates are bounded by 95 percent confidence intervals.

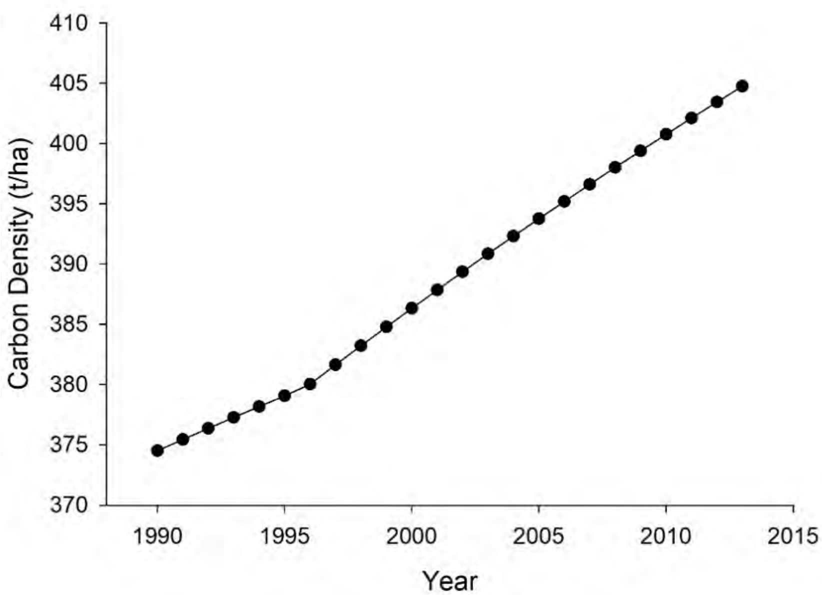


Figure 8.12—Carbon density of Siuslaw National Forest, 1990–2013.

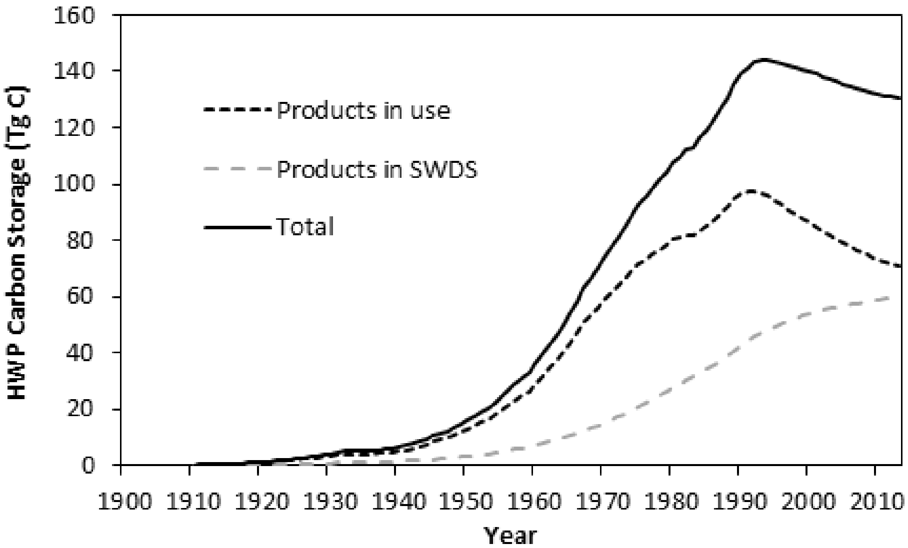


Figure 8.13—Cumulative total carbon stored in harvested wood products (HWP) manufactured from timber from national forests in the USFS Pacific Northwest Region. Carbon in HWP includes products that are still in use and carbon stored at solid waste disposal sites (SWDS), including landfills and dumps (Butler et al. 2014).

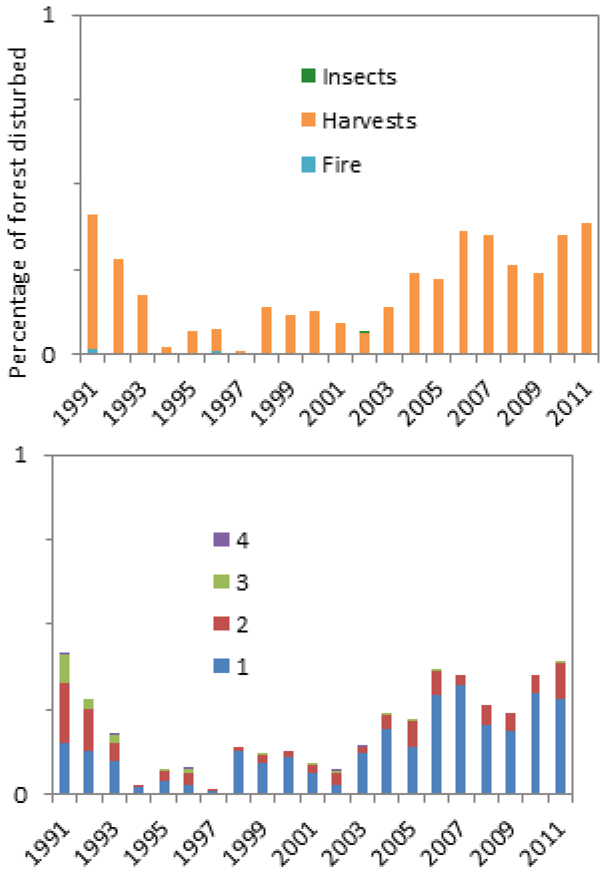


Figure 8.14—Percentage of forested area disturbed from 1991 to 2011 in Siuslaw National Forest by disturbance type (left panel), and magnitude classes (right panel), characterized by percentage change in canopy cover: 0–25% (1), 26–50% (2), 51–75% (3), 76–100% (4).

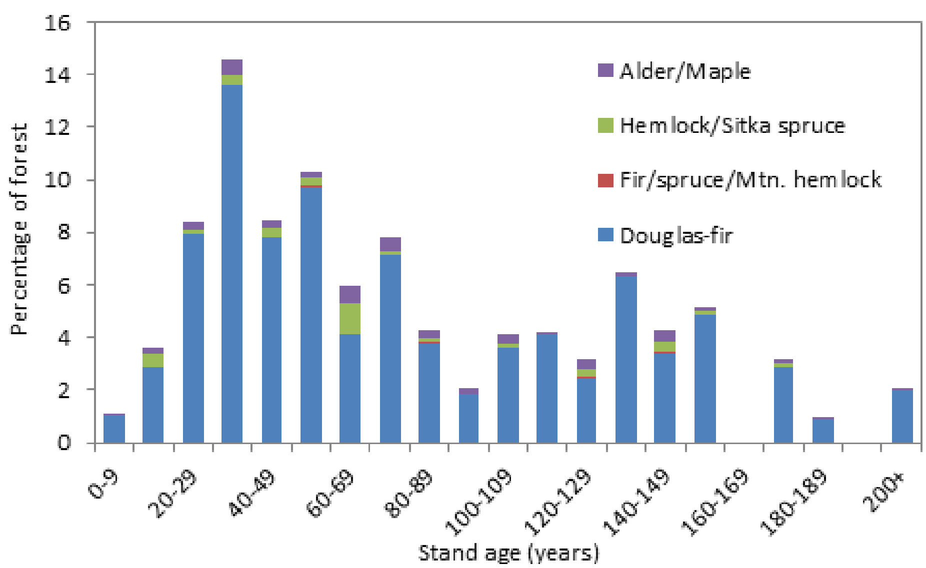


Figure 8.15—Age-class distribution in 2011, showing the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars.

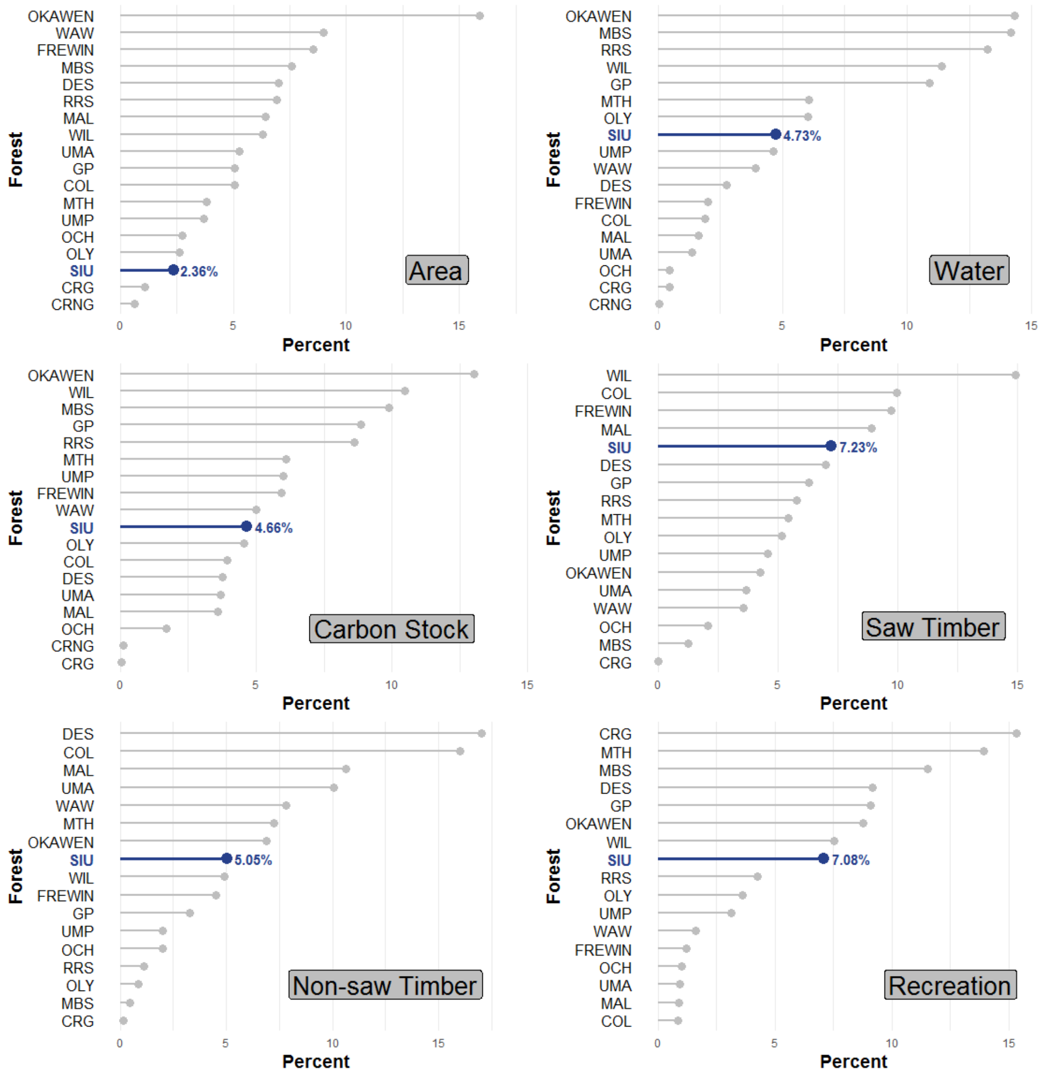


Figure 8.16—USFS Pacific Northwest Region rankings for select ecosystem services, highlighting Siuslaw National Forest. Percentages are calculated from the region-wide total for a given ecosystem service. Rank in area facilitates comparisons among forests. The services are mean annual volume of water runoff, board feet of saw timber and non-saw timber, recreation visitation, and carbon stock (as of 2013). Percentages are calculated from the region-wide total for a given ecosystem service. [Abbreviations: COL = Colville National Forest, CRG = Columbia River Gorge National Scenic Area, CRNG = Crooked River National Grassland, DES = Deschutes National Forest, FREWIN = Fremont-Winema National Forest, GP = Gifford Pinchot National Forest, MAL = Malheur National Forest, MBS = Mt. Baker-Snoqualmie National Forest, MTH = Mt. Hood National Forest, OCH = Ochoco National Forest, OKAWEN = Okanogan-Wenatchee National Forest, OLY = Olympic National Forest, RRS = Rogue River-Siskiyou National Forest, SIU = Siuslaw National Forest, UMA = Umatilla National Forest, UMP = Umpqua National Forest, WAW = Wallowa-Whitman National Forest, WIL – Willamette National Forest]

Figure Box 8.1—Oregon silverspot butterfly.

Figure Box 8.2—Solitary silver bee. Credit: National Park Service, Courtesy San Francisco Chronicle, Hevia H. Costanza.

Figure Box 8.3—Rufous hummingbird. Credit: Adobe Stock.

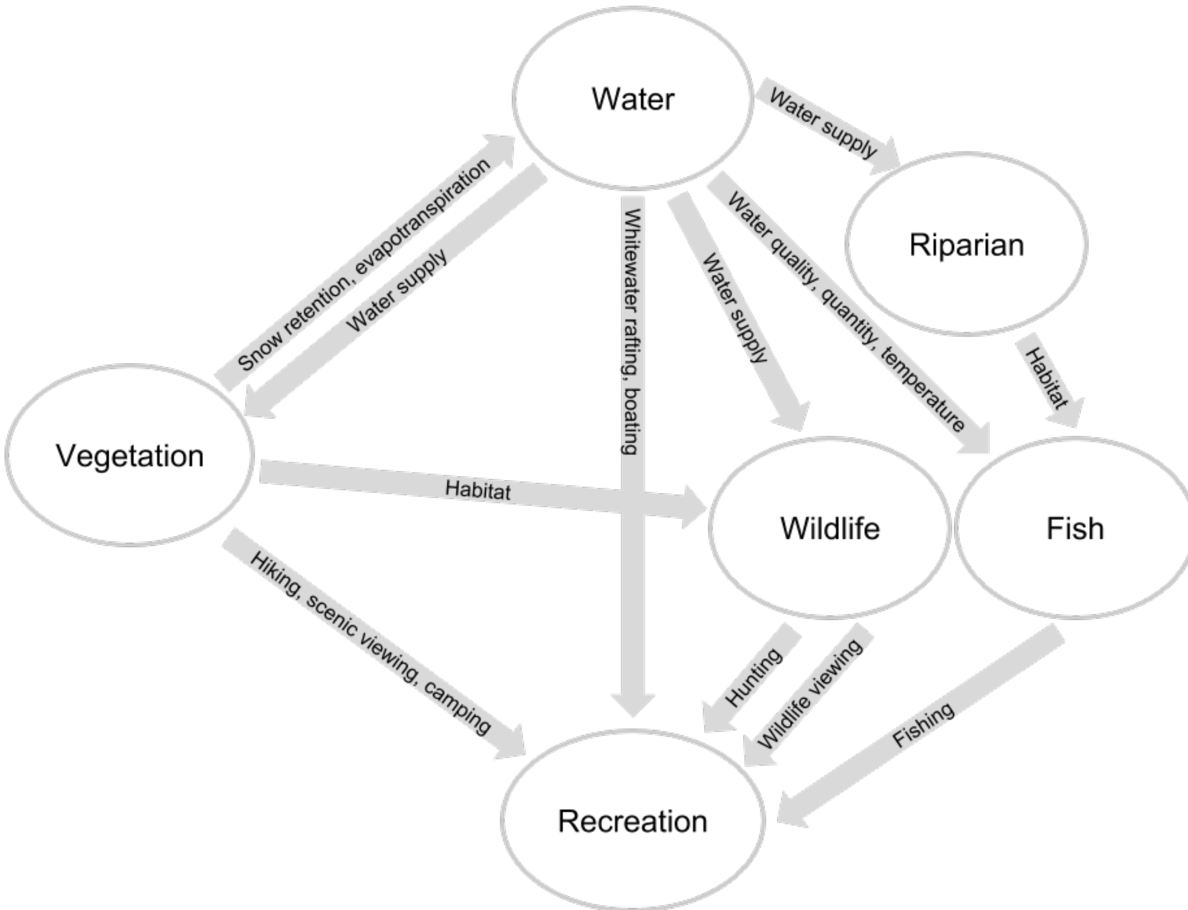


Figure 10.1—Conceptual depiction of interactions among resources.

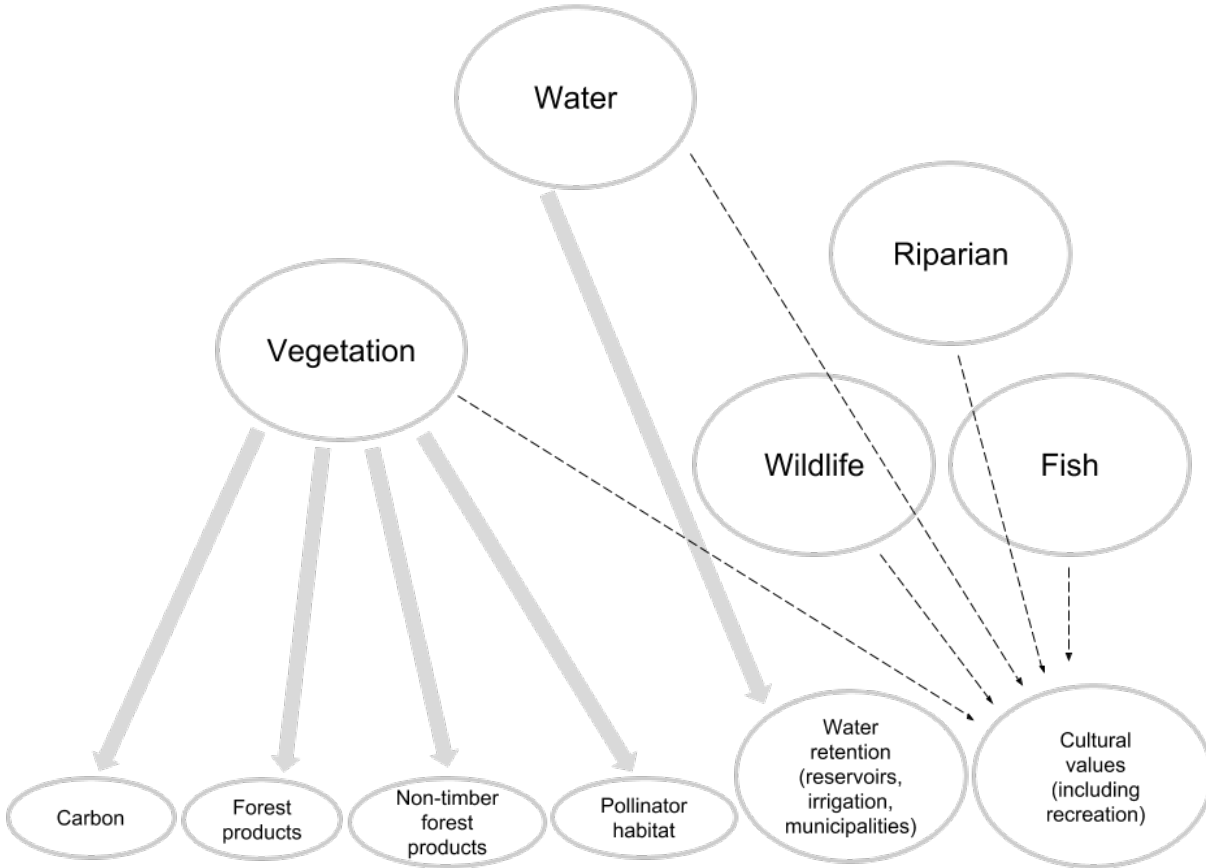


Figure 10.2—Conceptual depiction of ecosystem service benefits beyond the boundaries of a forest. Ecosystem services are listed along the bottom; recreation is considered a subset of cultural activities. Solid arrows represent quantifiable benefits, and dashed arrows represent social values that are not quantifiable.

Boxes

Box 2.1—Coastal Low Clouds in the Pacific Northwest

Low stratiform clouds are a frequent atmospheric feature of coastal Oregon and Washington summers, forming as stratus, stratocumulus, and fog, with the latter occurring when the cloud intersects with the Earth's surface. During the warm, dry marine climate typical of the West Coast in Pacific Northwest coastal summers, fog forms by advection, not radiation, when (1) warm, wet air encounters cool surface water over the Pacific Ocean, as during upwelling of cold, deep water along the coast, or (2) cool, wet air encounters warm surface water or moves inland to encounter a warm, dry continental air mass.

Although most low-cloud formation is apparent along the coast, inland surges of marine air can increase cloud cover and decrease air temperature as far east as the western Cascade Range foothills (Mass et al. 1986). Airport records of summertime cloud base height indicate that frequency of low clouds along the coast is consistently higher and tends to peak later in the summer than at inland locations (fig. box 2.1).

Summertime low clouds in the Pacific Northwest are a feature shared by other summer-dry continental west coast environments globally, including California (Clemesha et al. 2016, Filonczuk et al. 1995, Iacobellis and Cayan 2013, Schwartz et al. 2014), the Chilean coast (e.g., Garreaud et al. 2008, McIntyre et al. 2005), and the southwest African coast (e.g., Cermak 2012, Eckardt et al. 2013). Coastal clouds and fog are difficult to forecast, leading to their lack of inclusion in climate models (Cesana and Chepfer 2012, Koračin et al. 2014) and downscaled climate products (e.g., Abatzoglou and Brown 2012). This represents a significant roadblock in predicting the ways low cloudiness will interact with climate change to affect Pacific Northwest environments, where low clouds can (1) regulate land surface temperatures (Iacobellis and Cayan 2013), (2) provide shade and additional moisture for vegetation (Fischer et al. 2009, Harr 1982, Johnstone and Dawson 2010), (3) improve agricultural water-use efficiency (Baguskas et al. 2018), (4) reduce wildfire potential (Williams et al. 2018), and (5) maintain streamflows (Sawaske and Freyberg 2015) and cooler stream temperatures (Luce et al. 2014, Sawaske and Freyberg 2015).

In the future, low clouds could either mitigate higher temperature and moisture loss or serve as a positive feedback to climate change if they are reduced. The latter has been projected to occur elsewhere. For example, a regional climate simulation for California projected long-term declines in coastal fog (O'Brien et al. 2013), and historical northern California airport observations infer a possible decline of summer fog over the 20th century (Johnstone and Dawson 2010). Increasing urbanization in southern California has also been implicated in a shift in cloud height and frequency (Williams et al. 2015). However, some projections (e.g., Jacox et al. 2015) suggest upwelling of cool coastal water will intensify in the future, which could maintain or even increase coastal low cloudiness. A lack of low clouds could facilitate drier conditions that facilitate wildfire, whereas low cloud shading and moisture inputs could alleviate the drying of forest fuels (Williams et al. 2018). The role of clouds in moderating urban temperatures will also become increasingly important in the future (Williams et al. 2015).

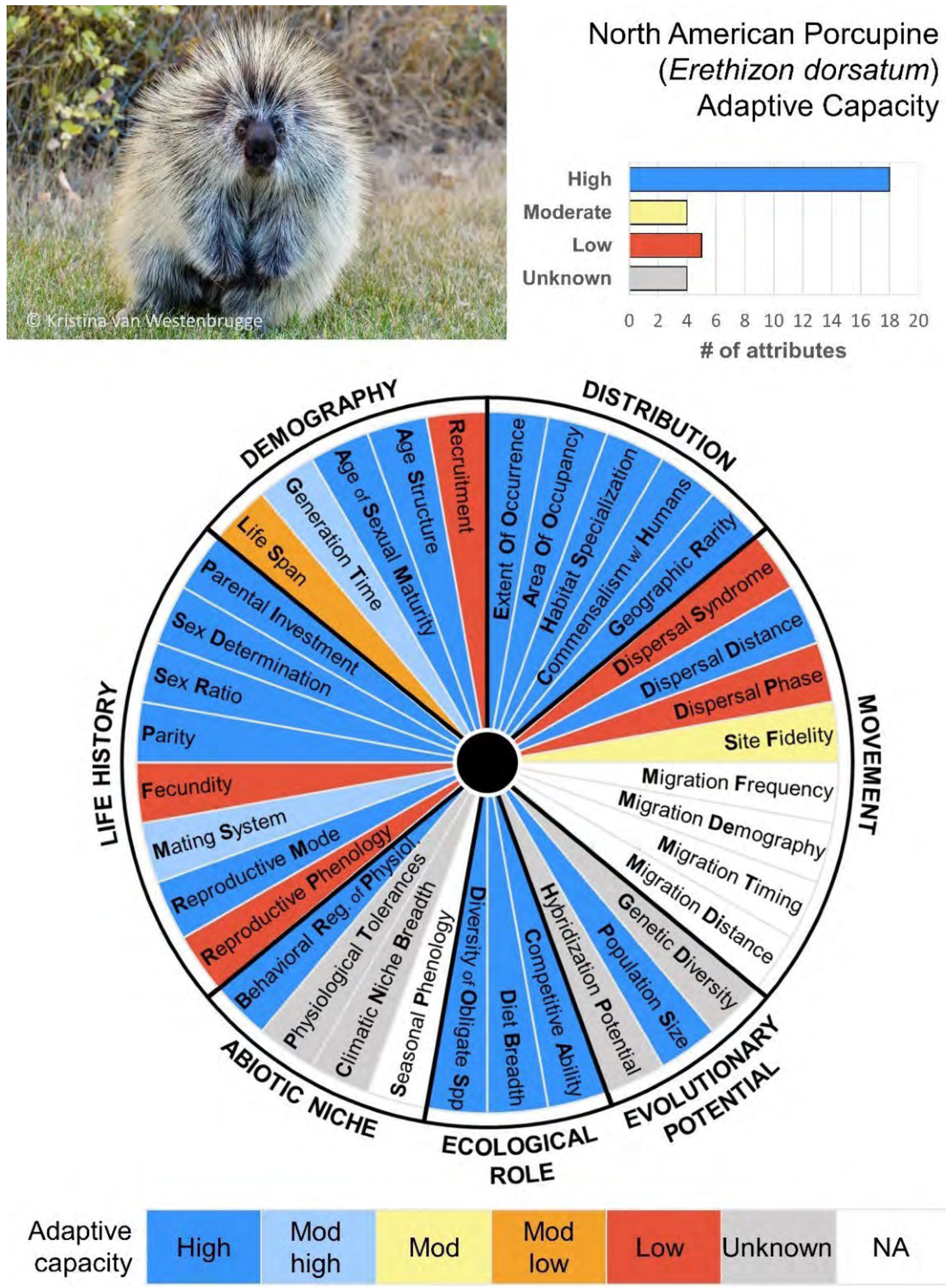
The wide-ranging effects and uncertainties discussed here demonstrate the importance of gaining a better understanding of the underlying drivers and environmental effects of low clouds throughout the western United States, including the Pacific Northwest (Torregrosa et al. 2014).

Box 6.1—Assessment of Adaptive Capacity—North American Porcupine (*Erethizon dorsatum*)

The North American (or Canadian) porcupine is a large, short-legged rodent whose dorsal side and tail are covered with up to 30,000 barb-tipped quills. It is the only extant species of the genus, and the only porcupine that occurs north of Mexico in North America. Porcupines are nocturnal, active year-round, do not hibernate, and have relatively low fecundity (only one offspring per parturition event). This common species occurs pervasively across its geographic range, which spans most of North America north of Mexico, albeit tied obligately to lacustrine (lake) and riparian (stream) habitats.

The as-yet anecdotal population declines of this species have been caused by roadkill, harvest, and lethal persecution by humans (for socioeconomic and cultural reasons). The effects of contemporary climate change on this species are largely unknown and likely context specific. Like other homeothermic organisms, their adaptive capacity is heightened by their ability to behaviorally thermoregulate, using physiological mechanisms and diel activity patterns that account for ambient air temperatures. Porcupine adaptive capacity (AC) benefits from dietary plasticity and the ability to live commensally with humans. In contrast, porcupine AC is low in terms of dispersal phase and syndrome, climatic niche breadth, low fecundity, obligate tie to riparian habitats when not in forests, reproductive phenology that is tied indirectly to weather conditions, and relatively low recruitment. Acquiring additional information pertaining to evolutionary potential, such as adaptive genetic diversity, is needed.

Although the overall AC of this species could be described as high, it is unknown whether any of the attributes ranked as “low” would be particularly influential in future non-analog climates. Strictly on the basis of linkages to aspects of climate (i.e., ignoring harvest and persecution of porcupines by humans), porcupines may merit additional attention in the OCAP assessment area, given observed patterns of porcupine rarity across the Pacific Northwest. Of the 328 mammals in the United States and Canada analyzed for sensitivity to climate change, the North American porcupine is one of the 28 or 29 most-sensitive species, using the McCain (2019) weighted model (score = 9/10) or composite model (score = 8/10), respectively.



The adaptive capacity of the North American porcupine is represented by 36 attributes grouped into 7 attribute complexes, color coded by level of adaptive capacity. The summary chart (top right) provides an overview of adaptive capacity, shown by the number of attributes within each of the criteria bins (ranging from low to high, and including unknown attributes). The two subcategories of moderate (moderately low and moderately high) are displayed in one column within “moderate,” for ease of comparison.

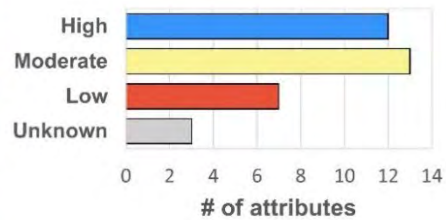
Box 6.2—Assessment of Adaptive Capacity– Humboldt's Flying Squirrel (*Glaucomys oregonensis*)

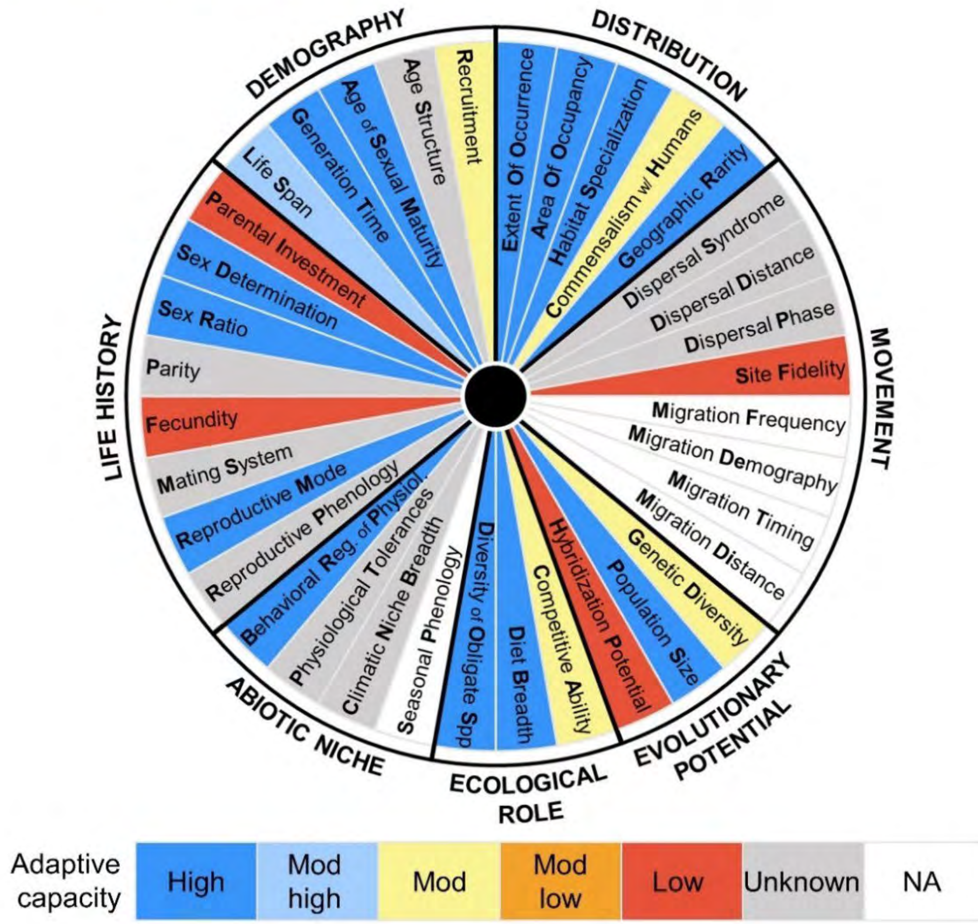
Only recently confirmed as its own species distinct from *Glaucomys sabrinus*, *G. oregonensis* (southwest British Columbia, from the coast to the Cascade Range in Washington and Oregon, and isolated pockets as far south as southern California) represents the southwestern terminus of the former *G. sabrinus* geographic range. These nocturnal squirrels forage in tree canopies and on the ground and can glide at an angle of around 27 degrees below horizontal and cover distances of greater than 45 m in a single glide (Vernes 2001) (wing loading is 2–3 times that of bats). They inhabit diverse forested communities across their range, and commonly nest in cavities in live and dead trees, or use external nests made of sticks, moss, and lichens in forks and dense clusters of branches (Carey et al. 1997).

Humboldt's flying squirrel is a keystone species, having prominent roles in the diets of spotted owls and other top-level predators (including fishers, martens, and weasels) and in dispersal of fungal spores and nutrients. Information is lacking for most dispersal-related attributes, range-wide population size, mechanism-based relationships with climatic factors, some aspects of reproduction, and two aspects of demography. Some but not all attributes are known for one to several populations of *G. sabrinus*, but climate change is likely to influence populations from different ecoregions through different aspects of climate and with different functional forms (Smith et al. 2019).

The AC of Humboldt's flying squirrel benefits from high population densities, diverse habitat associations and diet, lack of obligate relationships, ability to thermoregulate behaviorally, and certain aspects of reproduction and demography (e.g., chromosomal sex determination, balanced sex ratio). Negative factors for AC are low fecundity, altricial young, and other factors. Of the 328 mammals in the United States and Canada analyzed for sensitivity to contemporary climate change, Humboldt's flying squirrel is one of the 89 or 80 most-sensitive species, using the McCain (2019) weighted model (score = 7/10) or composite model (score = 6.5/10), respectively.

Humboldt's flying squirrel
(*Glaucomys oregonensis*)
Adaptive Capacity





The adaptive capacity of Humboldt's flying squirrel is represented by 36 attributes grouped into 7 attribute complexes, color coded by level of adaptive capacity. The summary chart (top right) provides an overview of adaptive capacity, shown by the number of attributes within each of the criteria bins (ranging from low to high, and including unknown attributes). The two subcategories of moderate (moderately low and moderately high) are displayed in one column within "moderate," for ease of comparison.

Box 6.3—Assessment of Adaptive Capacity—Acorn Woodpecker (*Melanerpes formicivorus*)

The acorn woodpecker is a cooperative breeding, non-migratory species and is common in oak habitats throughout its broad range. Limited data suggest that this species has moderately high genetic diversity and relatively high population connectivity across its range. However, populations at the northern extent of its range (primarily in Oregon) are relatively isolated from one another.

Reliance on oak woodlands for nesting and foraging limits the AC of the acorn woodpecker. The availability of acorn resources, stored in granaries, is tightly linked with reproductive success, survivorship, and abundance from year to year. Significant individual- and population- (or group) level investments in reproduction are a key component of acorn woodpecker life history. Because young birds are altricial (born helpless), significant parental investment is required, which increases the fitness of potential of breeders and cooperative non-breeders. Although cooperative breeding can increase longevity and survivorship, it results in reproductive delays for “helpers” and constrains dispersal behavior (that is, dispersal is mostly limited by opportunities for reproductive vacancies). The combination of habitat specialization, cooperative breeding, high site fidelity, and limited dispersal flexibility could restrict the ability of this species to spatially track suitable climate space.

There is no clear evidence of the climate change vulnerability of the acorn woodpecker independent of its reliance on oak woodlands. Some studies suggest that the abundance and range extent of this species will increase, although other studies indicate that this positive effect may be constrained by stressors in oak communities (e.g., climate change, sudden oak death, and human development). Minimal information on the physiological tolerance and behavioral flexibility of the woodpecker is available. Conservation of this species will depend on maintenance of mature oak forests with oaks capable of producing large mast crops and places for the woodpeckers to nest, roost, and store mast. Management practices that preserve the historical age structure of forests, with an emphasis on snags and dead limbs used for granaries and nesting, are particularly important.

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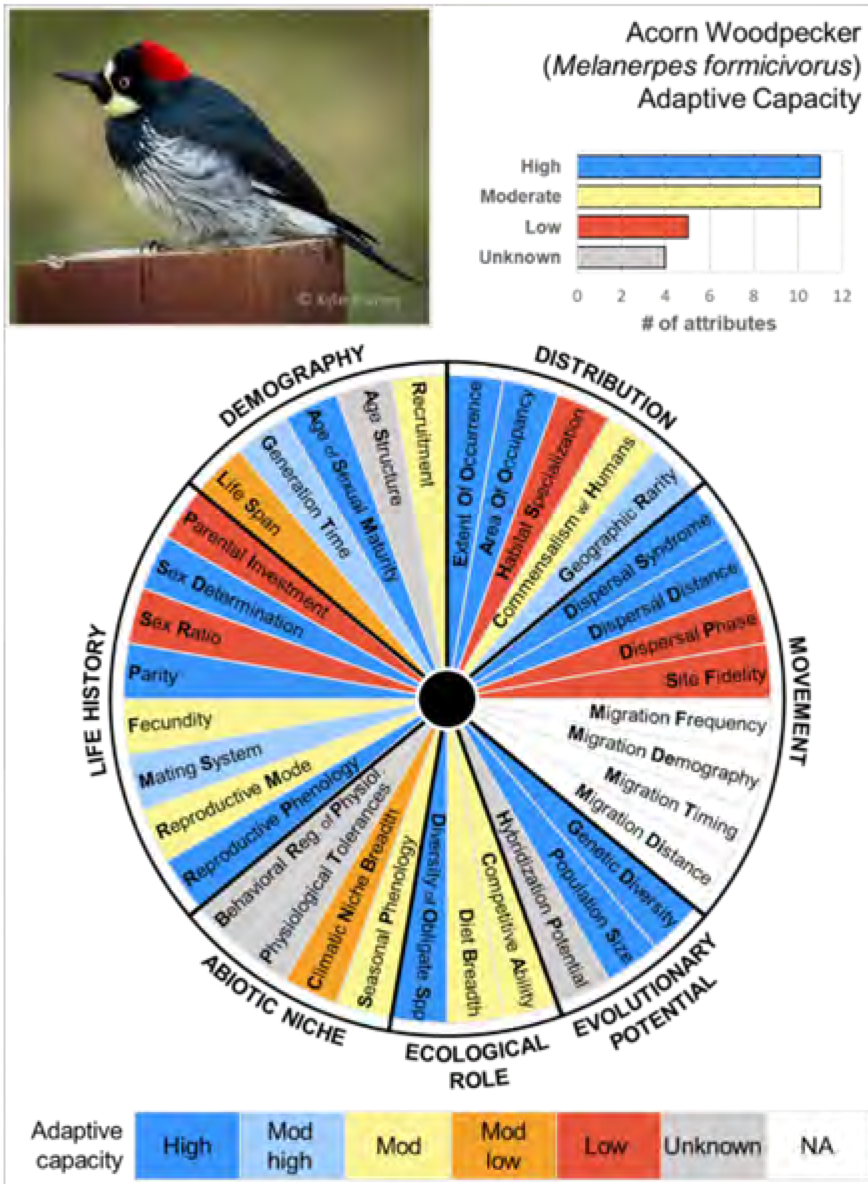


The adaptive capacity of the acorn woodpecker is represented by 36 attributes grouped into 7 attribute complexes, color coded by level of adaptive capacity. The summary chart (top right) provides an overview of adaptive capacity, shown by the number of attributes within each of the criteria bins (ranging from low to high, and including unknown attributes). The two subcategories of moderate (moderately low and moderately high) are displayed in one column within “moderate,” for ease of comparison.

Box 6.4—Assessment of Adaptive Capacity—Marbled Murrelet (*Brachyramphus marmoratus*)

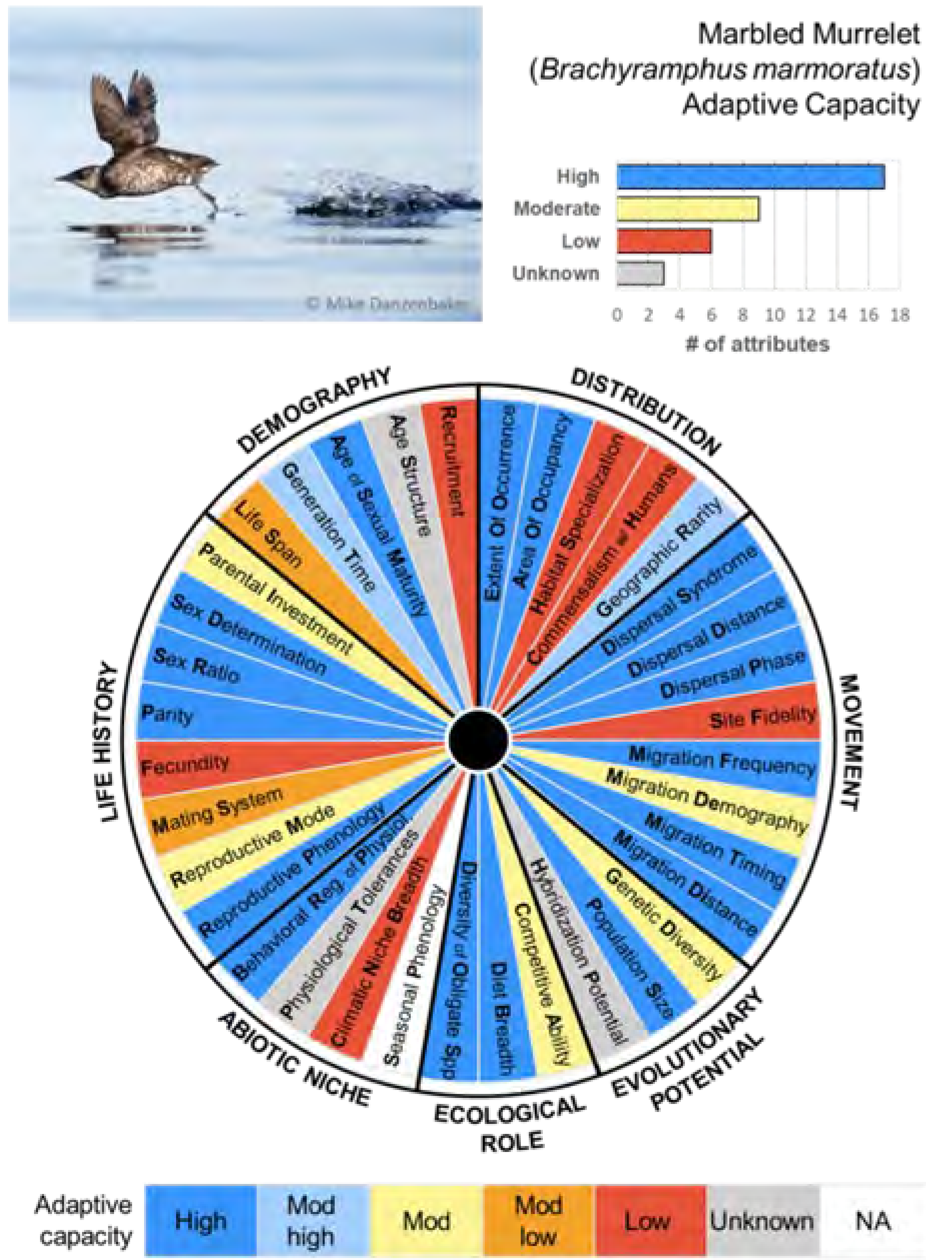
Marbled murrelets are a highly mobile species, using both marine and terrestrial habitats across different life stages and seasons. However, there is much uncertainty about their seasonal migratory and dispersal behavior, including the timing and environmental controls (physiology), demographics, routes, and distances. Information on migration is restricted to a few well-studied populations and observations of banded birds, because of the challenges associated with at-sea sampling and the difficulty of capturing and observing birds.

In terrestrial habitats, murrelets are associated with old-growth, coniferous forests and sea-facing talus slopes or cliffs along the coastline and nearshore islands of northwestern North America. Loss and fragmentation of old-growth forests have contributed to the isolation and declines of murrelet populations throughout their range, but particularly in the southern portion. Breeding site fidelity has been shown to increase when nesting habitat is lost or increasingly fragmented, which may further restrict murrelet distribution and their capacity for tracking climate. Habitat fragmentation also affects genetic diversity and may be driving genetic divergence in this species. Numerous genetic studies point to the importance of maintaining the three distinct genetic "populations" across the marbled murrelet range in order to preserve genetic diversity and evolutionary adaptive capacity.

Murrelets lack the "geographic plasticity" to track suitable climate in space (Grémillet and Boulinier 2009). Therefore, it is likely that they will need to rely on their moderately flexible foraging ecology, which directly affects reproductive success, to accommodate climate change *in situ*. However, this foraging strategy may not compensate for periods when ocean productivity is poor. In fact, climate change is expected to have dual effects on marbled murrelet populations by: (1) increasing the potential for terrestrial habitat loss from wildfires, insect infestations, disease outbreaks, and severe storms, and (2) exacerbating conditions unfavorable to murrelets in the marine environment that may disrupt food web dynamics.

Within the marine environment, climate change is likely to have profound bottom-up effects on marine productivity in conjunction with top-down effects of human fisheries. Given their low fecundity and recruitment, narrow habitat requirements in terrestrial and marine systems, and breeding site fidelity (and central-place foraging strategy), murrelets may have limited resilience to changing conditions. Although their overall AC could be considered high, these characteristics are potentially major barriers for this species.

A recent study of long-term murrelet occupancy data in Oregon showed that murrelet colonization rates were greatly reduced during warm ocean conditions with low prey availability (Betts et al. 2019). The authors suggest that murrelet terrestrial habitat might best be evaluated only in years following marine conditions that are favorable to murrelet reproduction (e.g., years with abundant food resources) to avoid misclassification of unoccupied nesting habitat due to poor ocean conditions that limit murrelet reproduction. Further, the results suggests that murrelets favor nesting near conspecific and closer to the ocean. Therefore, larger stands of contiguous forest habitat may be especially valuable if murrelets are indeed relying on conspecific attraction and access to ocean resources when selecting nest sites.



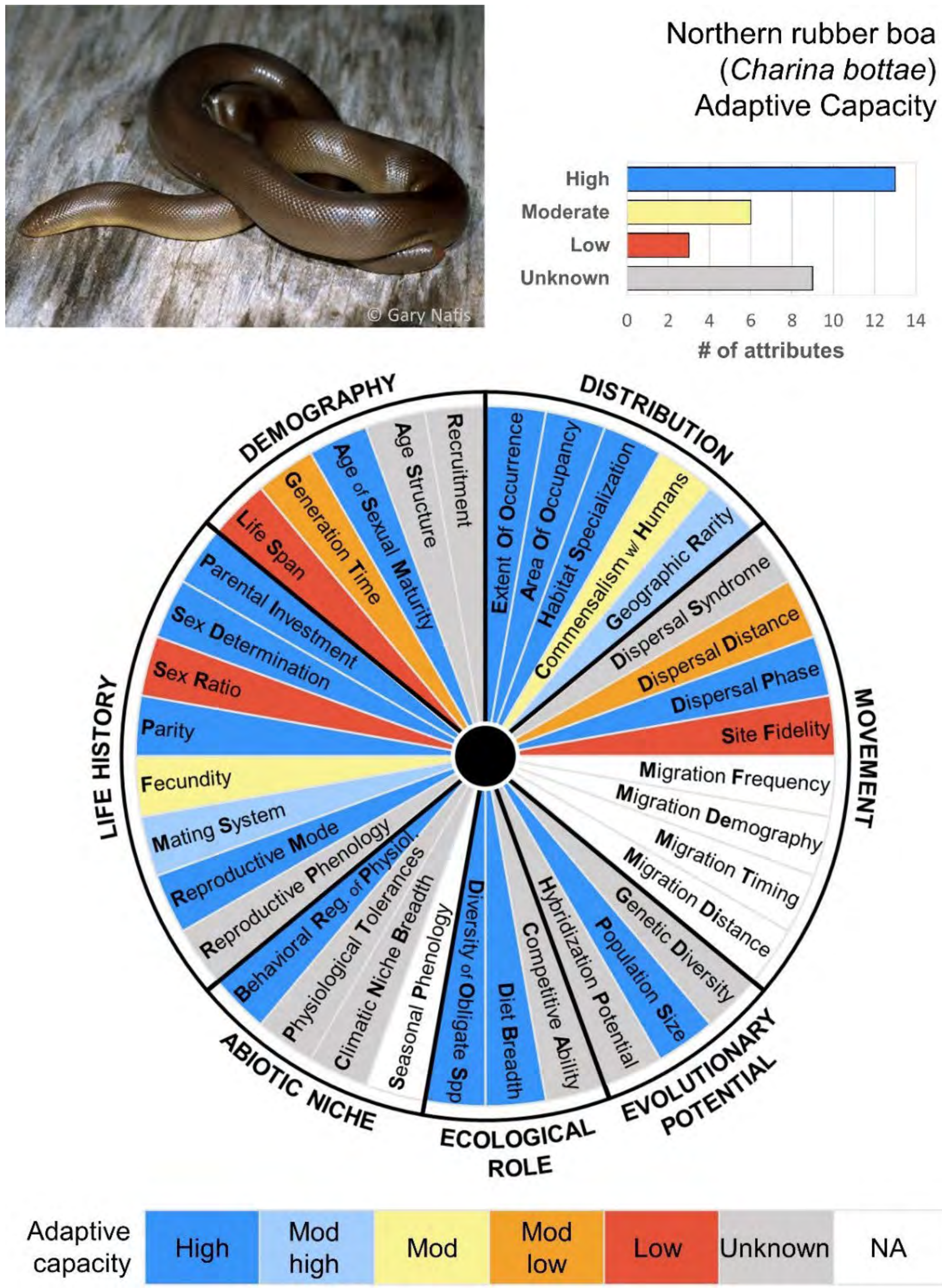
The adaptive capacity of the marbled murrelet is represented by 36 attributes grouped into 7 attribute complexes, color coded by level of adaptive capacity. The summary chart (top right) provides an overview of adaptive capacity, shown by the number of attributes within each of the criteria bins (ranging from low to high, and including unknown attributes). The two subcategories of moderate (moderately low and moderately high) are displayed in one column within "moderate," for ease of comparison.

Box 6.5—Assessment of Adaptive Capacity—Northern Rubber Boa (*Charina bottae*)

The northern rubber boa has a "slow" life history with a relatively low reproductive rate and long lifespan. Information on the ecology of this species, beyond a few well-studied populations in Oregon and Idaho, is generally lacking. This species is presumed to be patchily distributed across its broad range, and although they occur in diverse habitats, boas appear to require specific hibernacula conditions for overwintering and thermoregulation.

There are inferred population declines based largely on habitat trends (e.g., land conversion to agriculture and road development), although the effects of climate change on this species are unknown. This includes information on climatic niche breadth and climate-related threats that could inform their sensitivity or reliance on climatic cues for triggering key processes like reproduction and seasonal movement. As is true for other ectothermic animals, temperature tolerances and behavioral regulation of physiology are likely to be critical components of their AC.

Preliminary information for this species suggests some flexibility in temperature tolerance, with a preference for cooler temperatures. Behavioral and energetic constraints with respect to temperature would, therefore, be valuable information for discerning the climatic vulnerability if the boa. Acquiring additional information pertaining to its evolutionary potential, such as local abundances and adaptive genetic diversity are a priority. Although the overall AC of this species could be described as high, there are numerous AC-related attributes unknown for this species, and much of the evidence in support of this designation is limited.



The adaptive capacity of the northern rubber boa is represented by 36 attributes grouped into 7 attribute complexes, color coded by level of adaptive capacity. The summary chart (top right) provides an overview of adaptive capacity, shown by the number of attributes within each of the criteria bins (ranging from low to high, and including unknown attributes). The two subcategories of moderate (moderately low and moderately high) are displayed in one column within "moderate," for ease of comparison.

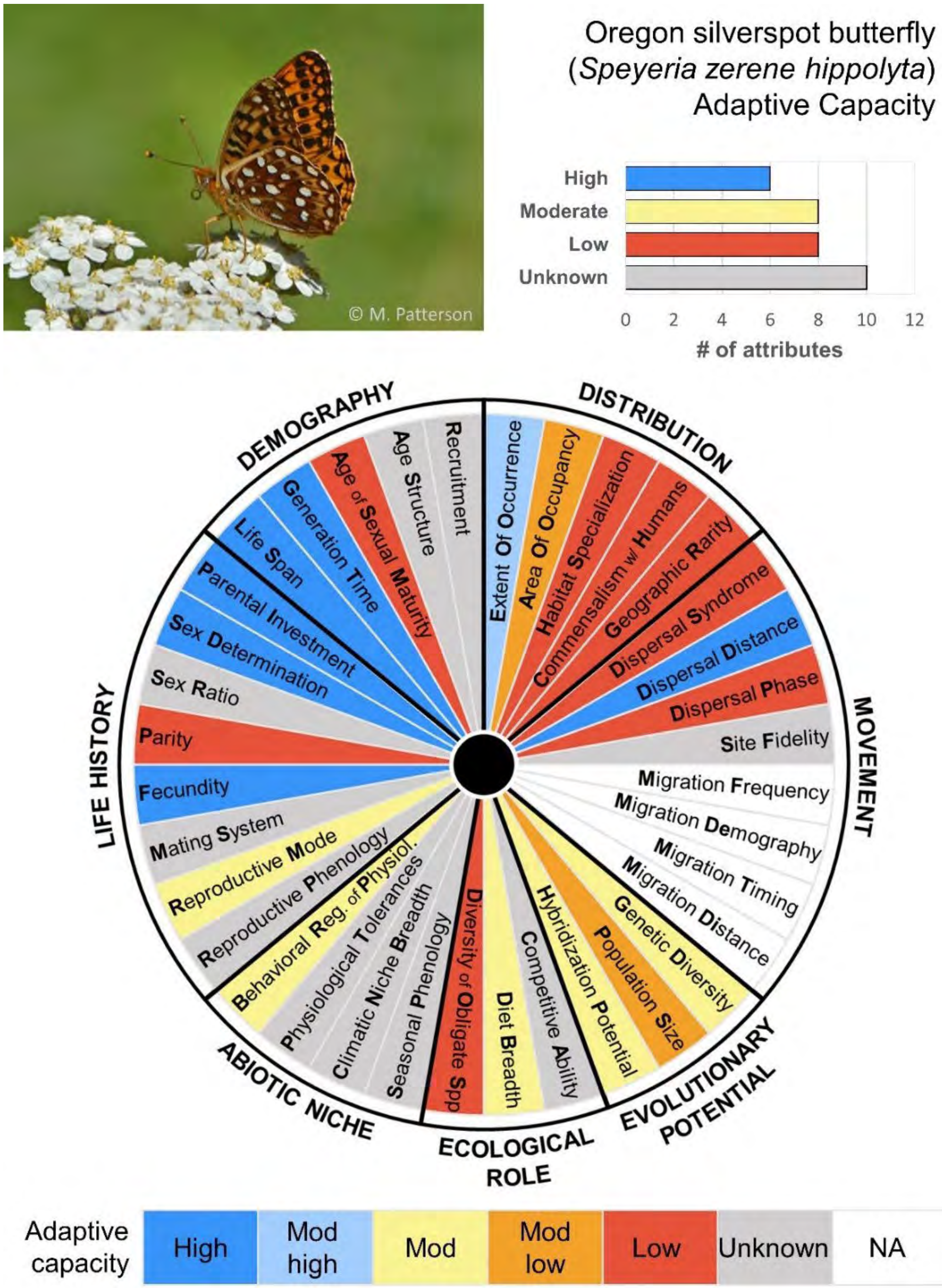
Box 6.6—Assessment of Adaptive Capacity—Oregon Silverspot Butterfly (*Speyeria zerene hippolyta*)

The Oregon silverspot butterfly (*Speyeria zerene hippolyta*) is found along the coast of the Pacific Northwest and has been listed as Threatened under the U.S. Endangered Species Act since 1980. Oregon silverspots have been extirpated from most of their range and are currently restricted to only 5 localities (1 in California and 4 in Oregon). This species occurs in early-successional coastal grasslands, coastal salt-spray meadows, stabilized dunes, and montane meadows, with a specific reliance on the early blue violet as a larval host plant. Habitat loss and degradation, particularly the encroachment of nonnative vegetation, have been the key threats to Oregon silverspot persistence and remain the focus of conservation efforts.

The effects of climate change are unknown, but climate-linked mechanisms for future decline have been hypothesized. For example, a critical issue potentially facing Oregon silverspot butterflies under climate change is a shift in seasonal timing (phenology) of key life-cycle events, such as egg deposition, growth rates of immature stages, and timing of maturation of adults. The timing of these events is linked to the seasonal cycles of plants that provide food and shelter.

Because the Oregon silverspot is monophagous (eats only one food) with respect to the early blue violet, a mismatch in the timing of emergence of larvae and host plants could be catastrophic. Likewise, a mismatch between adults and nectar sources could result in nectar limitation that reduces fecundity. The climatic niche breadth and physiological tolerances of the Oregon silverspot are not well understood; more data on this topic are needed to support adaptation planning efforts. Information is also needed on specific cue requirements and flexibility pertaining to phenology and potential mismatches, especially the timing of reproduction and dispersal.

The rarity of the Oregon silverspot makes it particularly vulnerable to stochastic events because population redundancy on the landscape is extremely limited, and the distance (or isolation) between populations restricts its ability to recolonize and track shifting climate. To minimize continued population losses, much effort has been directed at reintroducing Oregon silverspots to extirpated and near-extirpated sites, which has stimulated analyses of the genetic implications of previous population bottlenecks and the introgression of DNA from captively-reared individuals. Genetic structuring and diversity are estimated to be moderate, which may offer a valuable platform for facilitating evolutionary adaptation through continued reintroductions that optimize genetic diversity and through habitat restoration efforts that increase connectivity.



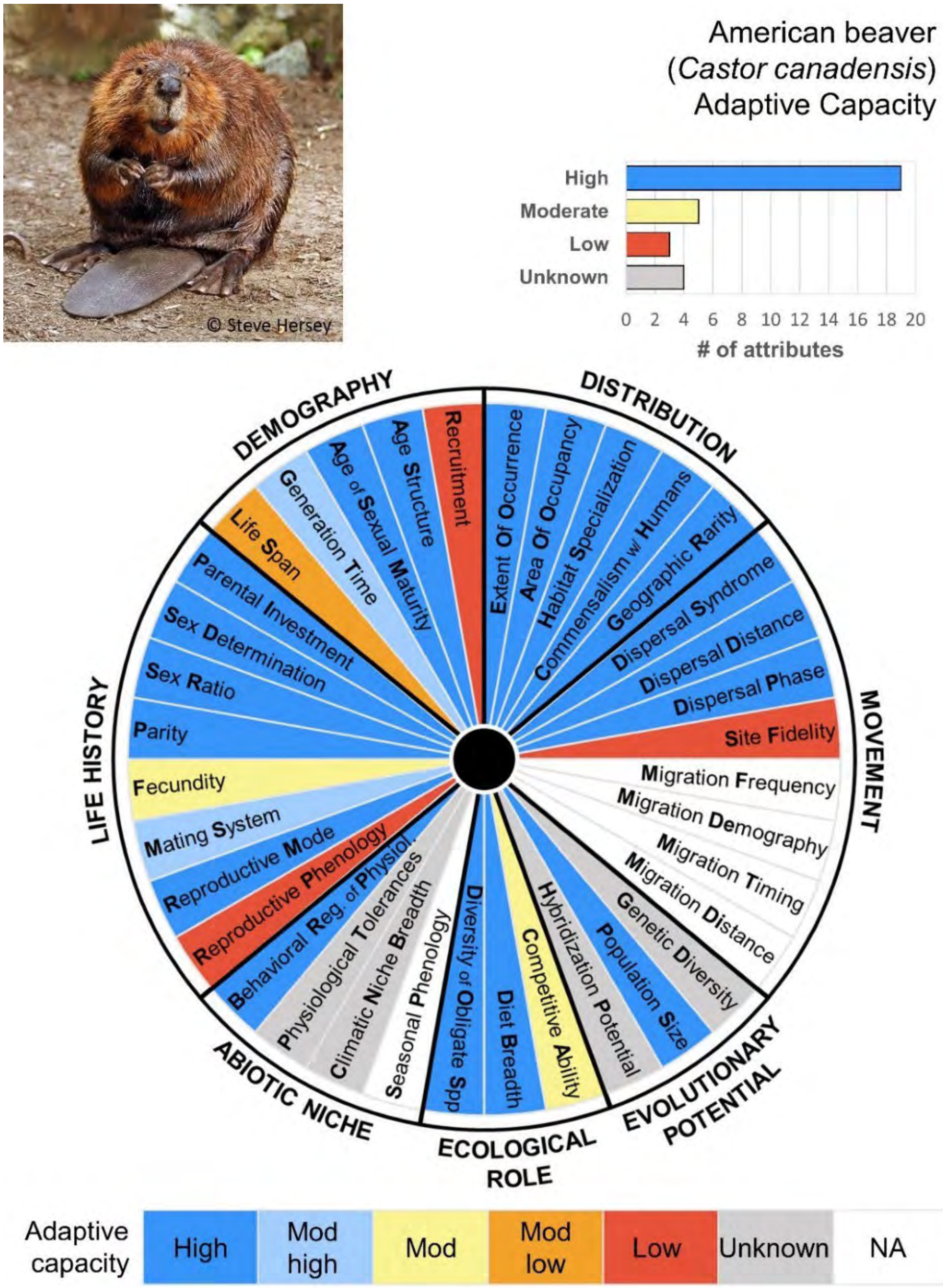
The adaptive capacity of the Oregon silverspot butterfly is represented by 36 attributes grouped into 7 attribute complexes, color coded by level of adaptive capacity. The summary chart (top right) provides an overview of adaptive capacity, shown by the number of attributes within each of the criteria bins (ranging from low to high, and including unknown attributes). The two subcategories of moderate (moderately low and moderately high) are displayed in one column within "moderate," for ease of comparison.

Box 6.7—Assessment of Adaptive Capacity—American Beaver (*Castor canadensis*)

The American beaver (*Castor canadensis*) has a “slow” life history with a relatively low reproductive rate and long lifespan. The ecology of this species is generally well known for all but a few attributes. Beavers occur pervasively across their geographic range, which spans most of North America north of Mexico, albeit tied obligately to lacustrine and stream habitats. Population declines and subsequent recovery of this species reflect harvest and persecution by humans for socioeconomic and cultural reasons. However, the effects of contemporary climate change on this species are largely unknown and likely context specific.

The AC of beavers is heightened by their ability to behaviorally thermoregulate using diel activity patterns that account for water and ambient air temperatures. The AC of beavers also benefits from their dietary plasticity, ability to live commensally with humans (if beavers are not removed), and low natal-site fidelity. In contrast, AC is lowest in terms of their obligate tie to aquatic habitats, reproductive phenology that is tied indirectly to weather conditions, and relatively low recruitment.

Acquiring additional information pertaining to the evolutionary potential of beavers, such as adaptive genetic diversity, is a priority. Although the overall AC of this species could be described as high, it is unknown whether any of the attributes ranked as “low” AC would be important in future non-analog climates. Based on linkages to aspects of climate (and ignoring harvest and persecution of beavers by humans), beaver populationss seem unlikely to be greatly diminished by contemporary climate change in the short term, particularly in the OCAP assessment area.



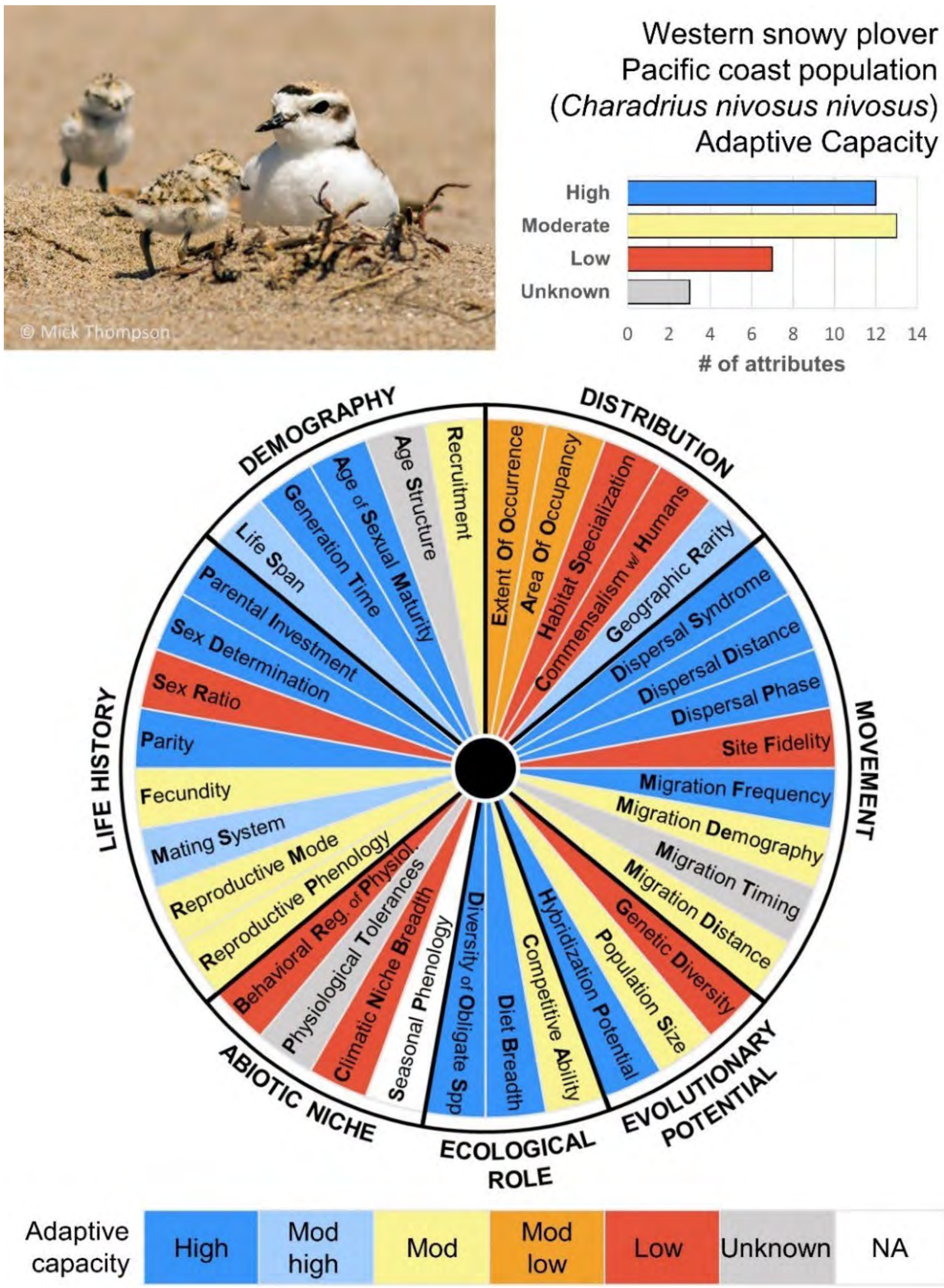
The adaptive capacity of the American beaver is represented by 36 attributes grouped into 7 attribute complexes, color coded by level of adaptive capacity. The summary chart (top right) provides an overview of adaptive capacity, shown by the number of attributes within each of the criteria bins (ranging from low to high, and including unknown attributes). The two subcategories of moderate (moderately low and moderately high) are displayed in one column within "moderate," for ease of comparison.

Box 6.8—Assessment of Adaptive Capacity—Western Snowy Plover (*Charadrius nivosus nivosus*)

The Pacific coast population of the western snowy plover is a federally threatened subspecies. These plovers are patchily distributed along the coasts of Washington, Oregon, and California, with the most of the population occurring in California. Population declines have been widespread and attributed to habitat loss and conversion, largely due to human disturbances associated with beach recreation and development. Concerted effort has been directed towards habitat restoration, including removing nonnative beachgrasses and mitigating human disturbance.

Although this species has high movement capacity, plovers exhibit a high degree of site fidelity to both breeding and wintering locations, making habitat restoration and protection efforts even more crucial. Numerous studies of their genetic population structure confirm that plovers have no evidence of genetic differentiation between coastal and interior populations. Regardless of breeding isolation, the occasional long-distance migrant into interior populations appears to maintain genetic homogenization. Latent genetic signatures of recent population bottlenecks are also evident (estimated as low effective population sizes). Combined with their relatively low population size, fecundity, and recruitment, this reduction in genetic diversity across populations of plovers indicates a constrained evolutionary potential.

There is no information on the physiological tolerances of plovers as with respect to climate change, but behavioral flexibility and climatic niche breadth are presumably low. More information that links these climatic tolerances to other aspects of species life history, such as migration and breeding phenology, would significantly improve our understanding of the AC of plovers. As outlined in the State of Oregon Conservation Program, restoration and protection of existing breeding and wintering sites will continue to be critical for ensuring the persistence of western snowy plover because this species has shown low flexibility in site selection and life history.



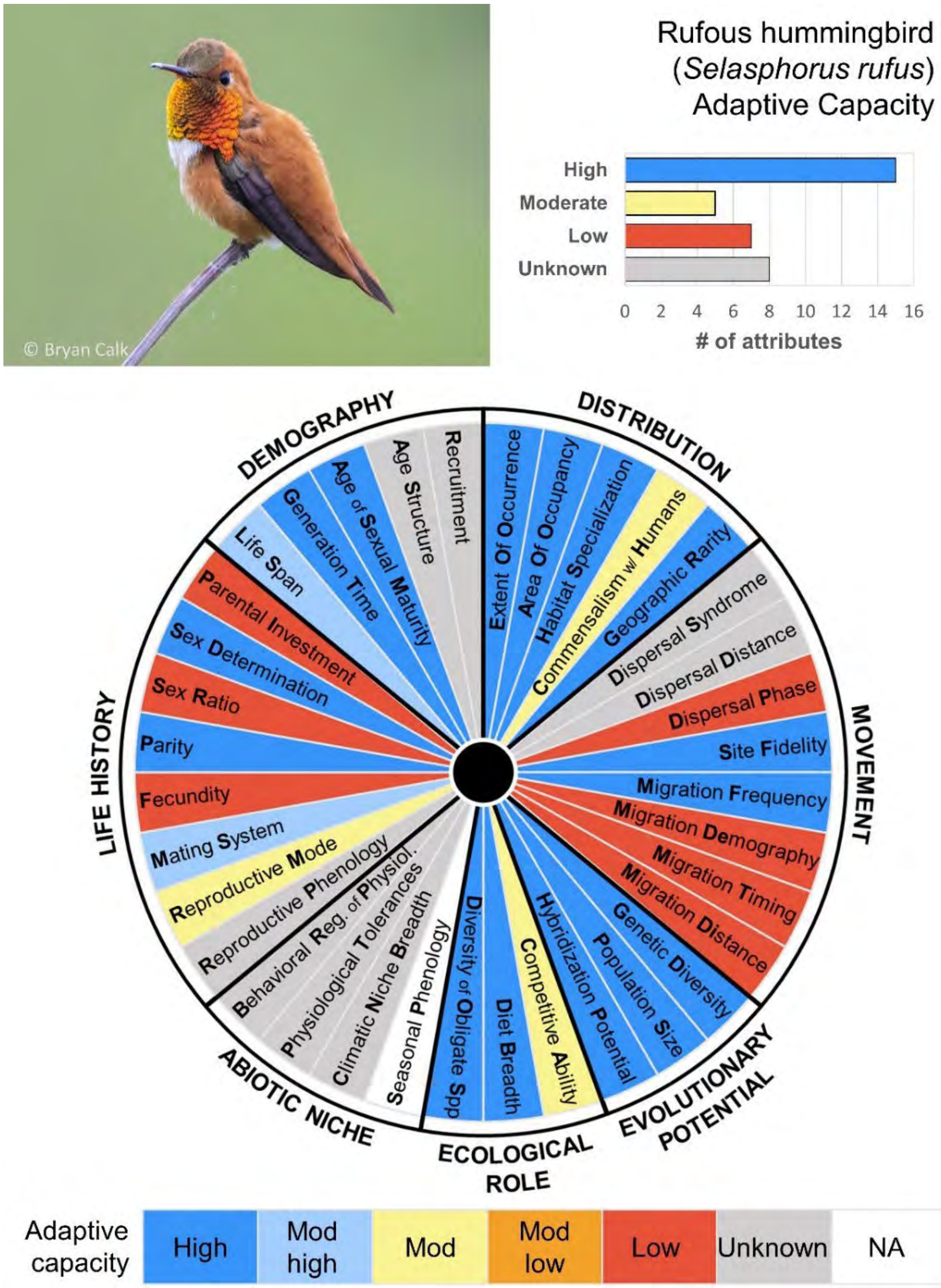
The adaptive capacity of the western snowy plover is represented by 36 attributes grouped into 7 attribute complexes, color coded by level of adaptive capacity. The summary chart (top right) provides an overview of adaptive capacity, shown by the number of attributes within each of the criteria bins (ranging from low to high, and including unknown attributes). The two subcategories of moderate (moderately low and moderately high) are displayed in one column within "moderate," for ease of comparison.

Box 6.9—Assessment of Adaptive Capacity—Rufous Hummingbird (*Selasphorus rufus*)

The rufous hummingbird is a long-distance migrant, occurring seasonally across western North America from southeastern Alaska to Mexico. This species is well studied with respect to patterns of migration, but demographic (i.e., population and breeding) data and information on non-migratory movement (e.g., natal dispersal) and climatic niche are lacking. In general, evidence for assessing the AC of many attributes is low and comes from only a few studies.

Information on population size and genetic structure, in addition to evidence of hybridization with Allen's hummingbird, suggests that the rufous hummingbird has a relatively high evolutionary AC. However, fine-scaled information on local abundance, breeding demographics, and adaptive genetic diversity would provide evidence to support this conclusion. Numerous studies have investigated the physiology of rufous hummingbirds, mostly pertaining to metabolic demands for migration, but there is no information on physiological tolerances or behavioral flexibility to reduce exposure under climate change. Two studies have examined coarse correlations between the phenology and occurrence of rufous hummingbirds in order to forecast climate-induced shifts, but do not provide details with respect to climatic niche breadth and the range of conditions to which this species is adapted.

The broad geographic range of the rufous hummingbird encompasses a long and spatially variable migratory route, so its climatic niche breadth is relatively wide, although seasonal climatic cues appear significant for triggering migration. One study suggests a degree of flexibility in migration phenology, although a dependence on floral phenology (i.e., spring blooming) and the potential for resource mismatch appear to be limiting factors. More information is needed on sensitivity of the rufous hummingbird to climate change in the context of other aspects of its life history and migratory behavior that may constrain AC.



The adaptive capacity of the rufous hummingbird is represented by 36 attributes grouped into 7 attribute complexes, color coded by level of adaptive capacity. The summary chart (top right) provides an overview of adaptive capacity, shown by the number of attributes within each of the criteria bins (ranging from low to high, and including unknown attributes). The two subcategories of moderate (moderately low and moderately high) are displayed in one column within "moderate," for ease of comparison.

Box 7.1—Regional recreation may shift towards the Oregon Coast

The Oregon Coast receives recreational visits during all seasons of the year. It is important to consider recreation at the regional scale (e.g., the state of Oregon), as people may choose their destination and activity based on weather conditions in different parts of the region. As weather patterns shift because of climate change, understanding these choices becomes even more important. For example, intense wildfires during the summer and fall of 2017 closed popular hiking trails in the Cascade Range, including sections of the Pacific Crest Trail (PCT). Anecdotal data such as online trip reports suggest that a portion of PCT hikers opted to shift to the Oregon Coast Trail to continue their hike while sections of the PCT were closed.

The Coast can serve as a temperature refuge for people to escape inland heat waves. Research indicates that recreational activity generally increases as temperature increases, but in extreme heat, people tend to shift towards recreational areas near bodies of water (Fisichelli et al. 2015). This pattern has already been observed anecdotally by public land managers. In the future, the Oregon Coast may experience increased visitation because of both climate-related and non-climate related weather patterns that create more desirable conditions on the Coast compared with inland areas. Increased visitation without increased managerial capacity or infrastructure can affect visitor experiences and lead to resource degradation (Manning 2010). Therefore, it is important to consider whether existing facilities, staffing, and programming provisions can adequately meet projected increases in peak-season demand, and to prepare to accommodate this demand.

Box 7.2—Recreation during the shoulder season is likely to increase with climate change

Although summer is the peak season for recreation visitation on the Oregon Coast, the area offers year-round recreation opportunities due to its mild climate and low elevation. Warm and sunny days during the “shoulder seasons” (spring and fall) attract substantial use from local residents, who are drawn by favorable weather conditions and by ease of access and relative lack of crowding (in comparison to summer) at high-use sites. Warm and sunny weekends in the fall and spring are draws for residents from the Portland Metro Area and the Willamette Valley. With warmer temperatures projected to arrive earlier in the spring and cooler temperatures projected to arrive later in the fall, the number of days that are conducive to warm-weather recreation in the shoulder seasons may increase, leading to an increase in aggregate visitation levels at recreation sites on the Oregon Coast.

Most recreation sites on the Oregon Coast are open year-round, so such an expansion of the shoulder season will not necessarily cause these locations to open earlier in the spring or close later in the fall. However, some land managers in the OCAP assessment area have anecdotally observed that “busy seasons” at certain year-round sites are beginning earlier in the spring. As larger crowds begin arriving earlier in the year, land managers are required to transition from off-season construction and improvement projects to a full focus on daily operations and maintenance tasks; this transition necessitates a rethinking of workforce demands and program of work schedules. For example, if the switch to a busy season occurs earlier in the calendar year, land managers may be required to bring on seasonal employees sooner than they have in the past. There may also be public pressure to expand operating seasons of seasonal sites as aggregate visitation increases.

Box 7.3—Evacuation and alternative access routes are needed in areas vulnerable to flooding

Many access roads to recreation areas within the Oregon Dunes NRA are at low elevations and/or in close proximity to the shoreline. Both factors make these access roads vulnerable to flooding caused by rainfall, storm surges, or rising sea level. For example, the access road to the Umpqua Dunes OHV staging area (operated by Siuslaw National Forest) is located a few meters from the beach and routinely floods during the rainy season, blocking recreational access for days or weeks at a time during the winter months. Flooding also periodically occurs on Horsfall Road, located on the south end of the NRA, and these flood events block access to and from the multiple campgrounds, day-use sites, and OHV staging areas along the road corridor. Repeated flooding in such areas, combined with increased incidence of strong storm surges, highlights the importance of designating routes for both evacuation and alternative ways to access recreation sites.

Box 7.4—Campgrounds near aquifers are vulnerable to flooding

Some recreation sites in the coastal dune zone are vulnerable to flooding because of shallow aquifers and proximity to inland lakes or the shoreline. For example, in 2017 a large portion of Carter Lake Campground (operated by Siuslaw National Forest in Oregon Dunes NRA) was flooded for several months following high winter rainfall. Pictured in the images below, the campground is located immediately north of Carter Lake, a small, naturally occurring inland lake within the coastal dunes zone. The lake rises and falls with the aquifer and precipitation inputs and does not have a distinct outlet. Therefore, heavy rains caused the lake to overtop its typical banks and flood much of the campground. This flood event did not occur during the busy season, so visitors were not displaced to other areas, but the flood demonstrates the vulnerability of this recreation site to flooding caused by heavy rainfall. Although not an issue for the Carter Lake Campground flood, there is a potential for floods to overflow toilet vaults and contaminate water sources with harmful pathogens and chemicals, which might require water or wastewater tanks to be pumped sooner than originally scheduled (USEPA 2017).

The images below depict Carter Lake Campground in March 2017 during the flood (left) and in July 2017, after flooding and the normal state of the area. In the photo, it can be seen that water levels reached several feet up the wall of the restroom; not visible in this photo are campsites flooded on either side of the road.

March, 2017 July, 2017

Box 7.5—The Oregon Coast Trail

The Oregon Coast Trail (OCT) follows the entire length of the Oregon coastline, from the Columbia River to the California border. The official OCT route follows the beach wherever possible, following trails or roads to navigate around obstructions such as headlands and inlets. The Oregon Parks and Recreation Department administers the OCT, although the trail crosses lands managed by multiple entities.

The first plan for the OCT was conceived in 1971, and the first segment was officially opened in 1975. The OCT was declared "hikeable" in 1988, although large sections required users to walk along highway 101. In 2014, the state designated 505 km of the OCT as an Oregon Scenic Trail. As of 2020, the State of Oregon is leading an ongoing, collaborative effort to reroute OCT sections that still follow Highway 101 or other major roadways, citing safety concerns for trail users and motorists.

The OCT is primarily a hiking route and attracts a variety of user types: (1) *through hikers* who follow the full length of the trail on an extended overnight trip, (2) *section hikers* who follow a portion of the trail on shorter overnight trips, and (3) *day users* who hike the OCT as part of a day trip to the beach. Extended trips on the OCT lead visitors through a scenic and dynamic coastal landscape interspersed with vibrant coastal communities for which the trail provides economic activity for businesses along the route.

Because much of the OCT follows the beach, the route can be blocked by high tides or storm surges, which are projected to increase in frequency and intensity with climate change. Sections of the OCT that cross headlands and upland areas may be washed out by landslides. For section hikers, access to trail sections may become more frequently blocked as roads, parking areas, and trails become flooded by more frequent, continuous periods rain. Anecdotal evidence suggests that the OCT provides an alternative to the Pacific Crest Trail when wildfires trigger area closures in the Oregon Cascade Range (D. Hendricks, personal communication[2]). Therefore, increased wildfire activity in the interior could lead to additional use of the OCT as a long-distance hiking destination.

Box 7.6—Harmful algal blooms will affect freshwater recreation

Harmful algal blooms (HABs) can be a concern for lakes and rivers in the OCAP assessment area, especially in the upland and coastal dunes recreation zones. Factors that contribute to HAB occurrences include high water temperatures and nutrient inputs (Paerl and Huisman 2008). Most HABs in freshwater are triggered by rapid multiplication of cyanobacteria. Although not all algal blooms are harmful, some species of cyanobacteria produce toxins that can harm human and animal health. These toxins create health hazards for recreational users, pets, and other animals. HABs can be visually identified as foamy, scummy, or slimy layers floating on top of the water. Freshwater blooms are most commonly blue-green, but can also be brownish red, black, dark green, or white (Oregon Health Authority 2020). Climate change may cause increased frequency of HABs in the OCAP assessment area through warmer water temperatures, higher levels of carbon dioxide in the air and water, and rainfall patterns that trigger periods of increased freshwater salinity or increased nutrient runoff (Paerl and Huisman 2008).

According to the Oregon Health Authority, four freshwater bodies in the assessment area had at least one HAB advisory between 2007 and 2018: Siltcoos Lake, Tenmile Lake, Devils Lake, and Big Creek Reservoir, with the former three lakes having multiple advisories (Oregon Health Authority 2020). Although HABs are not widespread within the assessment area, they do constitute local issues of concern. State and county agencies maintain responsibility for water quality and public health for recreational waters in Oregon, and the USFS partners with these agencies on surveillance, monitoring, and public notice of HABs on national forest lands. For example, the USFS Pacific Northwest Region recommends that units perform visual monitoring for HABs throughout the recreation season, display informational posters at recreation sites with a history of HABs or with conditions that indicate an HAB is present, and conduct water quality sampling when resources are available (Casamassa 2019).

Box 7.7—Harmful algal blooms are likely to affect recreational marine fisheries

Harmful algal blooms (HABs), such as red tides, are increasingly common along the Oregon Coast with detrimental impacts to marine ecosystems, public health, and recreational and industrial fisheries (McKibben et al. 2015). The frequency of HABs in marine areas is expected to increase with climate change, as ocean nutrients increasingly move northward, and ocean temperatures rise (Cai et al 2014). Although outbreaks are known to coincide with warm-water events (McKibben et al. 2015), uncertainty exists about how future episodes might be associated with changing climate and ocean conditions on the Oregon Coast (Moore et al. 2008, Wells et al. 2015).

HABs cause toxins to accumulate in shellfish, such as paralytic shellfish poison (PSP) and domoic acid (Lewitus et al 2012). Between 2007 and 2017, there were 62 recreational shellfish closures within the OCAP assessment area that affected crabs, mussels, clams, and scallops. Nearly three-quarters of closures were due to PSP, a toxin found in mussels, clams, and oysters that causes paralytic neurological distress and sometimes death in humans and animals that consume contaminated shellfish (McCabe et al. 2016). During this period, closures ranged from 1 to 8 per year (average of 4), with the majority affecting mussels (60 percent) and razor clams (23 percent). Although data on the duration of closures is incomplete, existing data indicate that closures occurred throughout the year and lasted between 1 week and 7 months[5]. Statewide closures from PSP increased between 1979 and 1996, with twice as many closures occurring between 1990 to 1996 than in all previous years. In some areas, the total number of closures has tripled since the 1980s (Lewitus et al. 2012).

Restrictions for commercial and recreational harvest of shellfish are costly to coastal economies within the study area. The large-scale 1991 closure of razor clams (*Siliqua patula* Dixon) cost Oregon and Washington $23–28 million in combined revenue (Nosho 1999). The more recent large-scale 2015–2016 bloom event is estimated at $150 million dollars in losses for the Oregon and California crab industries (Loew 2018). Recreational shellfish licenses alone are important in generating revenue in Oregon, with 2017 statewide revenues exceeding $1.7 (ODFW 2018).

The recreational and economic impacts of HABs are understudied for Oregon and do not include additional costs associated with odor, fish kill, health impact costs, and costs associated with consumer risk perception (Whitehead et al. 2003). Improved spatial and temporal monitoring and consolidation of existing data sources could greatly improve industry and management responses, along with other adaptation strategies to address HAB impacts on fishing, shellfish, and beach-based recreation.

Box 8.1—Oregon Silverspot Butterfly

The Oregon silverspot butterfly (*Speyeria zerene Hippolyta* W.H. Edwards) occupies meadow and early-seral grass-forb habitat within 15 km of the coastline from southern Washington to northern California, with the largest population on Mount Hebo, Siuslaw National Forest. The larvae feed exclusively on early blue violets (*Viola adunca* Sm.). Habitat loss from encroachment of non-native pasture grasses and shrubs is the primary reason for the continued decrease in viability of this species (USFWS 2001). Climate change may increase the vigor of encroaching shrubs and decrease soil moisture, both contributing to the reduction of food availability for the butterfly. In 2015, an unusually dry spring in the Oregon Coast Range caused drought conditions in coastal meadows. In many violet patches, the aboveground plant parts wilted early, which may have caused a large decline in the population of Oregon silverspot that year (Hammond 2016, Patterson 2016).

Box 8.2—Dune Bees

Many bees are adapted to coastal dune systems. For example, the solitary silver bee (or Pacific sand dune bee) (*Habropoda miserabilis* Cresson) is restricted to dunes along the Pacific Coast of California, Oregon, and Washington (Gordon 1984). Solitary silver bees nest in bare sand and are the primary pollinator of the coastal beach pea (*Lathyrus littoralis* [Nutt.] Endl. ex Walp.). Female dune bees dig nests 1m deep into compacted dune sand. Males detect and wait for emerging females with whom to mate. Once a common species around sand dunes, beaches, and coastal prairies, the bee has become rare, the result of habitat loss caused by human development and competition with non-native plants. Climate change may create additional stress by altering the phenology of coastal beach pea such that it may become asynchronous with silver bee nectar foraging and pollination (Ollif-Yang and Mesler 2018).

Box 8.3—Rufous Hummingbird

Many species of hummingbirds are found in coastal Oregon. All hummingbirds depend on floral resources for nectar and small insects for protein. The rufous hummingbird (*Selasphorus rufus* J.F. Gmelin), a neotropical migrant, has the longest migration of any hummingbird in the world. Along its 4,000-km (one-way) annual migration from western Mexico along the Pacific coast to southeastern Alaska, this hummingbird can be seen in open areas of Siuslaw National Forest and along mountainsides and forest edges (Healy and Calder 2020). These small (7.6 cm length) birds are found in these coastal habitats during their spring migration, taking advantage of early spring flowers. In western Oregon, the hummingbirds nest in mature second-growth forests of over 120 years old (Healy and Calder 2020, Meslow and Wight 1975). However, rufous hummingbird populations have decreased 60 percent throughout their range owing to habitat loss and invasive species (Alexander et al. 2020, Rosenberg et al. 2016). Migration appears to be timed to local floral abundance, so the presence of early spring flowers is critical. Climate change may increase stress on rufous hummingbirds by altering the seasonal availability of floral resources.

Box 8.4—Employment and Labor Income Supported by National Forests

From USFS "At-a-Glance" reports, job and income contributions for 2016 (USDA FS 2019).

Public lands contribute to economic activity in areas adjacent to them by providing recreational opportunities, forest products, water supplies, and investments in restoration and other projects. The USFS estimates its contributions to employment in terms of jobs (full-time, part-time, temporary, seasonal) and income (wages, salaries and benefits for wage earners, income to sole proprietors of businesses). Although these estimates do not capture all economic contributions provided by ecosystem services, they are a conservative estimate of how the agency brings work to local communities.

In 2016, Siuslaw National Forest supported 1,580 jobs and $73,555,000 in labor income in local communities. Recreation and forest products contribute the highest percentage of wages and benefits. Total spending by visitors to Siuslaw National Forest is $59.9 million annually. The effects of climate change on recreation and timber production may have cascading effects on socioeconomic benefits.

Footnotes

Chapter 1

[1] **Alexia Prosperi** is an air resource specialist, U.S. Department of Agriculture, Forest Service, Eastern Region, 626 East Wisconsin Ave, Milwaukee, WI 53202.

Chapter 2

[1] **James A. Miller** is an air quality specialist (currently with the Bureau of Land Management in Salt Lake City, Utah), Pacific Northwest Region, 1220 SW 3rd Avenue, Suite 1600, Portland, OR 97204; **John B. Kim** is a biological scientist, Western Wildland Environmental Threat Assessment Center, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331; **Alexia Prosperi** is an air resource specialist, U.S. Department of Agriculture, Forest Service, Eastern Region, 626 East Wisconsin Ave, Milwaukee, WI 53202; **Alex Dye** is a faculty research associate, Oregon State University College of Forestry, 3180 SW Jefferson Way, Corvallis, OR 97331.

[2] David Rupp is an assistant professor, College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, CEOAS Administration Building, Corvallis, OR 97331.

Chapter 3

[1] **Kami Ellingson** is a watershed program manager, Siuslaw National Forest, 3200 SW Jefferson Way, Corvallis, OR 97331; **Rebecca L. Flitcroft** is a research fish biologist, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331; **Paris B. Edwards** was an ORISE science communication fellow, U.S. Department of Agriculture, Northwest Climate Hub, Corvallis Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97330; **Charles H. Luce** is a research hydrologist, Rocky Mountain Research Station, 322 East Front Street, Suite 401, Boise, ID 83702; **Benjamin S. Soderquist** is a natural resource specialist, U.S. Department of Agriculture, Forest Service, Intermountain Region, 324 25th Street, Ogden, UT 84401.

[2] Exempt groundwater uses are defined by statute at ORS 537.545 and include stock watering, irrigating a lawn or noncommercial garden of 0.2 ha or less, domestic use not exceeding 56,700 liters per day, or industrial or commercial purposes not exceeding 18,900 liters per day.

[3] Includes all surface-water community systems where information is available, including Lane, Coos, Curry, Yamhill, Lincoln, Tillamook, and Polk counties.

Chapter 4

[1] **Brooke E. Penaluna** is a research fisheries biologist, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331; **Rebecca L. Flitcroft** is a research fish biologist, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331; **Dona Horan** is a fish biologist and **Daniel J. Isaak** is a research fish biologist, Rocky Mountain Research Station, 322 East Front Street, Suite 401, Boise, ID 83702; **John C. Chatel** is the threatened and endangered species program manager, Pacific Northwest Region, 1220 SW 3rd Avenue, Portland, OR 97204; **Julian D. Olden** is a professor, School of Aquatic and Fishery Sciences, University of Washington, 1122 NE Boat St, Box 355020 Seattle, WA 98195-5020; **Kelly Christiansen** is a data service specialist, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331; **Gordon H. Reeves** is a research fish ecologist (emeritus), Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331.

Chapter 5

[1] **Matthew J. Reilly** is a research forester, Western Wildland Environmental Threat Assessment Center, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331; **Douglas A. Glavich** is an ecologist, USDA Forest Service, Region 6 Ecology Program, 3200 SW Jefferson Way, Corvallis, OR 97331; **Steven A. Acker** is an ecologist (retired), Pacific Northwest Region, Area Ecology Program, 16400 Champion Way, Sandy, OR 97055; **Holly S.J. Kearns** is a plant pathologist and **Elizabeth A. Willhite** is an entomologist, Pacific Northwest Region, State and Private Forestry, Forest Health Protection, 16400 Champion Way, Sandy, OR 97055; **Becky K. Kerns** is a research ecologist, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331; **John B. Kim** is a biological scientist, Western Wildland Environmental Threat Assessment Center, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331; **Chelsea S. Monks** is a botanist, Siuslaw National Forest, 3200 SW Jefferson Way, Corvallis, OR 97331; **Chris Donaldson** is a the deputy fire staff

officer, Willamette National Forest, 3106 Pierce Parkway Suite D, Springfield, OR 97477; **Jessica E. Halofsky** is the director, Western Wildland Environmental Threat Assessment Center and Northwest Climate Hub, Pacific Northwest Research Station, 3625 93rd Avenue SW, Olympia, WA 98512.

[2] Willhite, E.A. Entomologist. Westside Forest Insect and Disease Center. U.S. Department of Agriculture Forest Service. 16400 Champion Way, Sandy, Oregon 97055.

Chapter 6

[1] **Todd M. Wilson** is a supervisory wildlife biologist Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, OR 97331; **Lindsey Thurman** is a partnerships ecologist, US Geological Survey, Northwest Climate Adaptation Science Center, 777 NW 9th St., Suite 410, Corvallis, OR 97331; **Erik A. Beever** is a research ecologist, US Geological Survey, Northern Rocky Mountain Science Center, 2327 University Ave., Ste. 2, Bozeman, MT 59715; **Peter Singleton** (retired) was a research wildlife biologist, Pacific Northwest Research Station, 1133 N Western Avenue, Wenatchee, WA 98801; **Deanna H. Olsen** is a research ecologist, Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, OR 97331; **DeAnna Williams** is a forest wildlife biologist, Siuslaw National Forest, 3200 SW Jefferson Way, Corvallis, OR 97331; **Douglas A. Glavich** is an ecologist, USDA Forest Service, Region 6 Ecology Program, 3200 SW Jefferson Way, Corvallis, OR 97331.

[2] Wilson, T.M. 2021. Personal communication. Supervisory Wildlife Biologist, USDA Forest Service, Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, OR 97331; todd.wilson@usda.gov

[3] Wilson, T.M. 2021. Unpublished data from Coastal Meadow Study. On file with: USDA Forest Service, Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, OR 97331; todd.wilson@usda.gov

Chapter 7

[1] **Anna B. Miller** is an assistant professor, Department of Environment and Society, Quinney College of Natural Resources, Utah State University, 5215 Old Main Hill, Logan, UT 84322-5215; **Trevor Robinson** is a recreation planner, U.S. Department of Agriculture, Forest Service, Siuslaw National Forest, 3200 SW Jefferson Way, Corvallis, OR 97331; **Paris B. Edwards** was

an ORISE science communication fellow, U.S. Department of Agriculture, Northwest Climate Hub, Corvallis Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97330.

[2] Data for Siuslaw National Forest are from the NVUM survey, indicating visitors' primary activity; data for BLM land are from the BLM Recreation Management Information System, 2016.

[3] The Good Friday Earthquake of 1964, originating in Alaska near Prince William Sound, triggered a tsunami that destroyed a parking area in Siuslaw National Forest. The parking area was near the mouth of the Siltcoos River, probably located along the Siltcoos Beach Access Road (Forest Road 1070) near the modern-day Siltcoos Beach Day Use/OHV Staging Area. This information is based on personal accounts from multiple USFS employees who worked for Siuslaw National Forest.

[4] Upwelling events—winds pushing surface water to the south while simultaneously pulling cool, high-salinity, and nutrient-rich subsurface water to the surface—generally occur during the spring and summer, creating a highly productive offshore environment. See chapter 4 for additional information.

[5] D. Hendricks. July 2018. Columbia Cascades regional representative, Pacific Crest Trail Association, 1331 Garden Highway, Sacramento, CA 95833.

Chapter 8

[1] **Robert W. Hoyer** is a research assistant, Portland State University, Geography Department 1721 SW Broadway, Portland, OR 97201; **Paris B. Edwards** was an ORISE science communication fellow, U.S. Department of Agriculture, Northwest Climate Hub, Corvallis Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97330; **Anne Poopatanapong** is an assistant Threatened and Endangered Species wildlife biologist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, 1220 SW 3rd Avenue, Portland, OR 97204; **Brye J. Lefler** is a planning and partnerships specialist, Department of Agriculture, Forest Service, Pacific Northwest and Northern Regions, 1220 SW 3rd Avenue, Portland, OR 97204; **Haley Case-Scott** is a climate and environment policy assistant, White House Office of Science and Technology Policy, 1650 Pennsylvania Avenue, Washington, DC 20504; **Duncan C. McKinley** was a program specialist, U.S. Department of Agriculture, Forest Service, Office of Sustainability and Climate, 201 14th St. SW, Washington, DC 20250; **Kevin**

L. Bruce is a forest archaeologist and tribal liaison, Siuslaw National Forest, 3200 SW Jefferson Way, Corvallis, OR 97330; **Douglas A. Glavich** is an ecologist, USDA Forest Service, Region 6 Ecology Program, 3200 SW Jefferson Way, Corvallis, OR 97331; **Aurora A. Cutler** was an information and education specialist, U.S. Department of Agriculture, Forest Service, Office of Sustainability and Climate, 201 14th St. SW, Washington, DC 20250; **Alexa J. Dugan** is greenhouse gas verification forester, SCS Global Services, 2000 Powell St., Suite 600, Emeryville, CA 94608.

[2] Dunes City, Elkton, Florence, Lincoln City, Newport, Reedsport, Siletz, Tillamook, Waldport, and Willamina.

[3] Traditional ecological knowledge is "a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationships of living beings (including humans) with one another and with their environments" (Berkes 2008).

Chapter 9

[1] **Benjamin S. Soderquist** is a Natural Resource Specialist, U.S. Forest Service, Intermountain Region, 324 25th Street, Ogden, UT 84401.

Chapter 10

[1] **David L. Peterson** is a research biological scientist (emeritus), U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 400 N 34th Street, Suite 201, Seattle, WA 98103.

Appendix A. Changes in mean August stream temperature, summer flow, and winter high flow events by 6th code HUCs within the OCAP analysis area. Geospatial shapefiles summarizing conditions within the 6th code HUCs are available on the USFS shared T drive in the OCAP project folder.

		Number of days with high winter flows					Mean summer flow (cms)					Mean August Stream Temperature (°C)				
HUC Number	Stream length (km)	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
170900030201	62.41	15.74	15.58	15.53	-0.16	-0.22	0.23	0.21	0.19	-10.92	-16.77	15.09	16.47	17.46	1.38	2.37
170900030202	56.45	15.38	15.30	15.38	-0.09	0.00	0.30	0.27	0.25	-10.83	-16.74	14.98	16.36	17.35	1.37	2.36
170900030204	76.71	16.06	15.90	15.83	-0.17	-0.23	0.18	0.16	0.15	-9.86	-15.64	14.65	16.01	16.99	1.36	2.34
170900030506	44.69	15.04	14.74	14.63	-0.30	-0.40	0.18	0.15	0.14	-14.22	-20.77	11.98	13.24	14.15	1.25	2.16
170900070103	77.24	15.49	15.18	15.14	-0.30	-0.35	0.24	0.21	0.19	-12.34	-18.25	13.56	14.88	15.83	1.32	2.27
170900080101	70.31	15.20	14.91	14.76	-0.29	-0.44	0.19	0.17	0.16	-13.17	-18.55	13.81	15.14	16.10	1.33	2.29
170900080102	37.64	16.13	15.88	15.78	-0.25	-0.35	0.17	0.15	0.14	-12.40	-17.75	14.15	15.49	16.46	1.34	2.31
170900080201	41.86	15.88	15.57	15.50	-0.31	-0.37	0.29	0.26	0.24	-12.33	-17.99	13.87	15.20	16.16	1.33	2.29
170900080202	56.28	15.77	15.47	15.34	-0.29	-0.43	0.25	0.22	0.20	-13.20	-19.04	13.66	14.98	15.93	1.32	2.28
170900080203	62.58	15.54	15.20	15.10	-0.34	-0.44	0.24	0.21	0.20	-13.47	-19.34	12.13	13.39	14.30	1.26	2.17
170900080204	76.31	15.73	15.43	15.36	-0.29	-0.37	0.43	0.38	0.36	-12.42	-18.03	14.23	15.58	16.55	1.34	2.31
170900080301	50.06	15.48	15.20	15.10	-0.28	-0.38	0.21	0.18	0.16	-13.33	-19.42	12.74	14.03	14.95	1.28	2.21
171002030101	46.91	15.98	15.67	15.59	-0.31	-0.40	0.18	0.16	0.15	-12.58	-18.29	13.47	14.79	15.73	1.31	2.26
171002030102	37.43	16.06	15.74	15.79	-0.31	-0.27	0.36	0.32	0.29	-14.07	-20.20	13.31	14.61	15.56	1.31	2.25
171002030103	41.49	16.01	15.78	15.73	-0.23	-0.28	0.79	0.69	0.64	-13.93	-20.03	14.33	15.68	16.65	1.35	2.32
171002030201	39.13	15.13	14.86	14.72	-0.28	-0.42	0.16	0.13	0.13	-13.40	-18.80	12.84	14.13	15.06	1.29	2.22
171002030202	34.45	15.26	15.11	14.93	-0.15	-0.33	0.29	0.25	0.24	-13.63	-19.17	12.62	13.90	14.83	1.28	2.21
171002030203	47.16	15.45	15.28	15.16	-0.18	-0.30	0.44	0.38	0.36	-13.29	-18.77	12.99	14.28	15.22	1.29	2.23
171002030204	43.83	15.90	15.73	15.68	-0.17	-0.22	0.41	0.36	0.34	-13.04	-18.68	13.08	14.38	15.31	1.30	2.24
171002030205	29.89	15.81	15.62	15.46	-0.19	-0.36	0.24	0.20	0.19	-14.17	-20.08	12.80	14.09	15.02	1.29	2.22
171002030206	63.84	15.58	15.26	15.18	-0.31	-0.39	0.93	0.81	0.75	-14.17	-20.25	13.03	14.32	15.26	1.30	2.23
171002030207	52.49	15.75	15.61	15.61	-0.14	-0.13	0.37	0.32	0.30	-13.33	-19.03	13.90	15.23	16.19	1.33	2.29
171002030208	51.09	15.47	15.20	15.16	-0.27	-0.31	0.48	0.41	0.38	-14.36	-20.59	12.64	13.92	14.85	1.28	2.21
171002030209	56.30	15.99	15.70	15.57	-0.29	-0.42	1.99	1.72	1.60	-13.56	-19.37	14.31	15.66	16.63	1.35	2.32
171002030210	45.21	15.81	15.62	15.54	-0.19	-0.26	4.23	3.65	3.41	-13.50	-19.31	14.75	16.11	17.10	1.36	2.35
171002030301	77.62	15.67	15.55	15.52	-0.12	-0.15	0.21	0.19	0.17	-13.12	-18.70	13.74	15.06	16.02	1.32	2.28
171002030302	52.27	15.53	15.28	15.10	-0.25	-0.43	0.91	0.79	0.75	-12.10	-17.32	16.20	17.62	18.65	1.42	2.45

171002030404	33.42	15.59	15.26	15.17	-0.33	-0.42	0.48	0.41	0.38	-14.38	-20.31	12.63	13.92	14.84	1.28	2.21
171002030406	57.61	15.33	15.09	14.96	-0.24	-0.37	2.31	1.99	1.86	-12.86	-18.25	15.96	17.37	18.39	1.41	2.43
171002030800	60.95	15.27	15.09	14.98	-0.18	-0.30	5.98	5.14	4.80	-13.49	-18.95	16.80	18.25	19.29	1.44	2.49
171002030901	28.44	15.60	15.50	15.33	-0.10	-0.27	0.13	0.11	0.10	-12.99	-18.48	14.49	15.84	16.82	1.35	2.33
171002030902	31.73	15.97	15.86	15.81	-0.11	-0.16	0.13	0.11	0.11	-13.37	-19.08	13.93	15.27	16.23	1.33	2.29
171002030903	43.22	15.78	15.58	15.52	-0.20	-0.27	0.18	0.15	0.14	-14.19	-20.45	13.22	14.52	15.46	1.30	2.24
171002040101	38.12	14.86	14.78	14.68	-0.07	-0.18	0.12	0.11	0.10	-11.56	-17.51	15.08	16.46	17.46	1.38	2.37
171002040102	51.02	14.92	14.90	14.88	-0.02	-0.04	0.38	0.33	0.31	-10.74	-16.59	16.23	17.66	18.68	1.42	2.45
171002040103	36.01	14.97	14.95	15.01	-0.01	0.04	0.13	0.12	0.11	-10.59	-16.46	15.87	17.27	18.29	1.41	2.42
171002040104	64.15	15.13	15.11	15.09	-0.02	-0.04	0.76	0.68	0.63	-11.43	-17.58	16.09	17.51	18.53	1.42	2.44
171002040201	58.87	15.04	15.00	15.10	-0.04	0.06	0.10	0.09	0.09	-10.71	-16.52	14.89	16.26	17.25	1.37	2.36
171002040202	69.66	15.36	15.22	15.21	-0.14	-0.14	0.37	0.33	0.31	-11.03	-16.94	15.18	16.56	17.56	1.38	2.38
171002040203	56.87	15.32	15.09	15.12	-0.23	-0.19	1.09	0.97	0.91	-11.22	-17.30	15.91	17.32	18.34	1.41	2.43
171002040301	59.28	15.60	15.50	15.59	-0.11	-0.01	1.67	1.49	1.39	-11.55	-17.85	16.60	18.03	19.07	1.44	2.47
171002040302	50.02	15.54	15.56	15.56	0.03	0.02	0.15	0.13	0.12	-11.93	-18.38	15.16	16.54	17.53	1.38	2.37
171002040303	72.46	15.46	15.31	15.31	-0.15	-0.15	2.44	2.17	2.02	-11.61	-17.95	16.26	17.69	18.71	1.42	2.45
171002040401	36.07	15.39	15.09	15.00	-0.31	-0.39	0.20	0.17	0.16	-14.40	-20.67	10.03	11.21	12.06	1.18	2.03
171002040402	53.92	15.05	14.83	14.76	-0.22	-0.29	0.47	0.40	0.37	-14.49	-20.88	10.92	12.13	13.01	1.21	2.09
171002040403	61.61	15.05	14.68	14.59	-0.37	-0.46	0.23	0.20	0.18	-14.48	-20.99	12.14	13.41	14.32	1.26	2.17
171002040501	78.38	15.85	15.53	15.48	-0.32	-0.38	0.71	0.61	0.57	-13.80	-20.06	11.39	12.62	13.51	1.23	2.12
171002040502	74.08	16.05	15.87	15.78	-0.19	-0.27	1.46	1.26	1.17	-13.05	-19.23	13.66	14.98	15.93	1.32	2.27
171002040601	46.78	15.31	15.15	15.10	-0.15	-0.21	0.13	0.11	0.10	-12.26	-18.37	14.12	15.46	16.42	1.34	2.31
171002040602	51.55	15.12	14.96	14.87	-0.17	-0.25	0.39	0.34	0.31	-13.58	-19.83	12.98	14.27	15.21	1.29	2.23
171002040701	37.71	15.04	15.01	15.00	-0.03	-0.04	1.05	0.91	0.85	-11.86	-17.94	14.91	16.28	17.27	1.37	2.36
171002040702	26.84	16.62	16.33	16.20	-0.29	-0.42	0.23	0.20	0.18	-12.72	-18.89	13.05	14.34	15.28	1.30	2.23
171002040703	79.04	15.86	15.66	15.61	-0.20	-0.24	3.73	3.23	3.00	-12.46	-18.74	15.29	16.68	17.68	1.38	2.38
171002040704	97.04	15.97	15.86	15.76	-0.11	-0.21	3.01	2.61	2.43	-12.41	-18.56	14.38	15.73	16.70	1.35	2.32
171002040705	28.80	15.88	15.71	15.56	-0.17	-0.32	6.95	6.05	5.62	-12.80	-18.98	14.84	16.21	17.19	1.37	2.35
171002040706	48.74	16.17	15.92	15.95	-0.25	-0.22	0.14	0.12	0.11	-13.61	-19.83	12.01	13.27	14.18	1.26	2.16
171002040707	50.73	16.09	15.88	15.86	-0.21	-0.23	0.79	0.69	0.64	-13.16	-19.32	14.05	15.39	16.35	1.34	2.30
171002040708	30.01	15.75	15.60	15.54	-0.15	-0.21	0.35	0.31	0.29	-13.48	-19.60	12.84	14.13	15.06	1.29	2.22
171002040709	15.47	15.62	15.48	15.51	-0.13	-0.11	5.52	4.80	4.46	-12.57	-18.62	15.94	17.35	18.37	1.41	2.43
171002040801	24.55	15.77	15.54	15.53	-0.22	-0.24	0.31	0.26	0.24	-14.09	-20.32	11.41	12.64	13.53	1.23	2.12
171002040802	75.52	15.73	15.53	15.47	-0.20	-0.27	0.27	0.23	0.22	-13.56	-19.57	12.57	13.85	14.78	1.28	2.20
171002040803	65.22	15.60	15.44	15.38	-0.16	-0.22	0.69	0.60	0.55	-13.79	-19.97	14.06	15.39	16.36	1.34	2.30
171002040901	26.21	15.46	15.32	15.22	-0.14	-0.24	0.11	0.09	0.09	-12.98	-18.72	13.52	14.83	15.78	1.32	2.26

171002040902	41.05	15.69	15.70	15.82	0.00	0.12	0.08	0.07	0.06	-12.22	-18.34	14.78	16.14	17.13	1.36	2.35
171002040903	53.10	15.57	15.55	15.61	-0.03	0.03	0.08	0.07	0.06	-12.02	-18.36	14.95	16.32	17.31	1.37	2.36
171002050101	40.04	15.78	15.66	15.68	-0.12	-0.10	0.14	0.13	0.12	-7.08	-11.59	14.20	15.54	16.51	1.34	2.31
171002050102	25.41	16.11	16.01	15.95	-0.10	-0.17	0.13	0.12	0.12	-8.05	-12.63	14.46	15.81	16.79	1.35	2.33
171002050103	54.34	15.35	15.27	15.22	-0.08	-0.13	0.32	0.29	0.27	-11.50	-17.29	13.63	14.95	15.91	1.32	2.27
171002050104	56.78	15.42	15.45	15.49	0.04	0.08	0.33	0.31	0.29	-8.56	-13.77	15.44	16.83	17.83	1.39	2.39
171002050105	25.62	15.71	15.67	15.70	-0.04	-0.01	0.62	0.56	0.53	-8.10	-12.78	15.97	17.38	18.40	1.41	2.43
171002050201	46.03	15.41	15.38	15.43	-0.03	0.02	0.21	0.19	0.18	-9.94	-15.80	14.30	15.65	16.62	1.35	2.32
171002050202	33.88	15.24	15.26	15.35	0.02	0.11	0.15	0.13	0.12	-11.00	-17.30	14.64	16.00	16.99	1.36	2.34
171002050203	46.94	15.03	15.00	15.06	-0.03	0.03	0.27	0.24	0.22	-11.38	-17.88	15.12	16.49	17.49	1.38	2.37
171002050204	47.30	15.15	15.11	15.19	-0.04	0.04	0.50	0.45	0.42	-9.85	-15.70	15.02	16.39	17.38	1.37	2.37
171002050205	39.72	15.17	15.12	15.28	-0.05	0.11	0.85	0.75	0.70	-11.14	-17.49	15.42	16.81	17.81	1.39	2.39
171002050301	37.18	15.73	15.57	15.67	-0.16	-0.06	0.18	0.16	0.15	-11.54	-17.56	13.94	15.28	16.24	1.33	2.30
171002050302	31.35	16.02	15.85	15.89	-0.16	-0.13	0.44	0.39	0.36	-11.98	-18.28	14.05	15.39	16.35	1.34	2.30
171002050303	64.27	15.71	15.58	15.62	-0.13	-0.09	0.94	0.83	0.77	-12.04	-18.43	14.60	15.95	16.94	1.36	2.34
171002050401	38.25	15.65	15.54	15.70	-0.11	-0.06	0.33	0.29	0.27	-11.54	-17.50	13.53	14.85	15.80	1.32	2.27
171002050402	78.52	15.09	15.13	15.12	0.04	0.04	2.43	2.20	2.07	-9.87	-15.43	16.25	17.67	18.70	1.42	2.45
171002050403	43.10	15.21	15.17	15.24	-0.04	0.03	2.40	2.15	2.02	-11.18	-17.39	14.49	15.85	16.82	1.35	2.33
171002050404	46.63	15.21	15.17	15.24	-0.04	0.04	3.34	3.00	2.80	-11.43	-17.76	14.78	16.14	17.13	1.36	2.35
171002050405	64.71	15.43	15.35	15.38	-0.08	-0.05	3.51	3.14	2.93	-11.30	-17.67	14.91	16.28	17.27	1.37	2.36
171002050501	60.08	15.84	15.76	15.79	-0.07	-0.05	0.22	0.19	0.18	-12.16	-18.76	14.62	15.98	16.96	1.36	2.34
171002050502	30.68	15.33	15.31	15.32	-0.02	-0.01	0.05	0.04	0.04	-11.67	-18.14	15.13	16.51	17.51	1.38	2.38
171002050503	29.79	15.90	15.90	15.90	0.00	0.00	0.06	0.06	0.05	-12.41	-19.19	13.63	14.95	15.90	1.32	2.27
171002050601	56.62	14.99	15.00	14.96	0.01	-0.03	0.14	0.12	0.11	-12.44	-19.27	14.16	15.50	16.46	1.34	2.31
171002050602	35.68	15.27	15.25	15.24	-0.02	-0.03	0.54	0.47	0.43	-12.65	-19.63	14.30	15.65	16.62	1.35	2.32
171002050701	37.18	15.35	15.36	15.36	0.01	0.02	0.16	0.14	0.13	-12.87	-20.16	13.67	14.99	15.95	1.32	2.27
171002050702	27.08	15.55	15.51	15.45	-0.04	-0.10	0.44	0.38	0.35	-13.43	-20.95	13.84	15.17	16.13	1.33	2.29
171002050703	74.17	15.45	15.46	15.53	0.02	0.08	0.16	0.14	0.13	-12.98	-20.56	13.17	14.47	15.41	1.30	2.24
171002050704	32.16	15.38	15.34	15.50	-0.04	0.12	0.16	0.14	0.13	-12.34	-19.83	14.77	16.14	17.12	1.37	2.35
171002060102	66.57	14.61	14.46	14.38	-0.15	-0.23	0.45	0.42	0.39	-7.58	-12.57	15.18	16.56	17.56	1.38	2.38
171002060202	62.76	15.36	15.24	15.20	-0.12	-0.15	0.27	0.24	0.23	-8.69	-14.38	15.88	17.28	18.30	1.41	2.42
171002060305	80.81	14.12	14.07	14.00	-0.05	-0.12	0.71	0.66	0.62	-7.22	-12.15	15.46	16.85	17.86	1.39	2.40
171002060306	70.58	14.23	14.13	14.14	-0.10	-0.08	1.22	1.13	1.07	-7.97	-13.43	16.26	17.69	18.71	1.42	2.45
171002060307	32.41	14.53	14.31	14.44	-0.22	-0.09	0.12	0.11	0.10	-9.95	-16.35	14.79	16.16	17.15	1.37	2.35
171002060308	66.84	14.41	14.37	14.34	-0.04	-0.07	1.98	1.83	1.72	-9.42	-15.43	16.89	18.34	19.38	1.45	2.49
171002060401	55.75	15.53	15.52	15.57	-0.02	0.04	0.20	0.18	0.17	-11.03	-17.34	15.02	16.39	17.38	1.37	2.37

171002060402	45.34	15.36	15.45	15.56	0.09	0.19	0.59	0.52	0.48	-11.24	-17.66	16.31	17.73	18.76	1.42	2.45
171002060501	72.43	15.39	15.36	15.47	-0.03	0.08	0.15	0.13	0.12	-12.11	-19.00	14.50	15.85	16.83	1.35	2.33
171002060502	28.93	15.29	15.32	15.43	0.03	0.13	0.86	0.76	0.70	-11.89	-18.75	16.89	18.34	19.38	1.45	2.49
171002060601	20.33	15.75	15.60	15.66	-0.16	-0.10	0.18	0.17	0.16	-7.80	-12.66	15.02	16.39	17.39	1.37	2.37
171002060602	60.36	15.69	15.52	15.51	-0.17	-0.18	0.29	0.27	0.25	-7.76	-12.87	16.02	17.43	18.45	1.41	2.43
171002060603	29.41	15.71	15.64	15.68	-0.06	-0.03	0.77	0.70	0.66	-9.65	-15.49	15.91	17.32	18.34	1.41	2.43
171002060604	53.05	15.55	15.44	15.46	-0.10	-0.09	1.14	1.03	0.96	-9.99	-16.09	16.43	17.85	18.89	1.43	2.46
171002060701	63.85	15.39	15.47	15.55	0.08	0.17	0.25	0.22	0.20	-12.78	-20.31	14.96	16.33	17.33	1.37	2.36
171002060702	65.03	15.33	15.33	15.44	0.00	0.12	0.71	0.62	0.56	-12.62	-20.28	15.60	17.00	18.01	1.40	2.41
171002060801	72.66	14.98	14.87	14.88	-0.11	-0.10	2.45	2.24	2.10	-10.28	-16.61	16.49	17.92	18.95	1.43	2.47
171002060802	61.44	15.22	15.18	15.24	-0.03	0.02	0.20	0.18	0.16	-13.18	-21.19	14.86	16.22	17.21	1.37	2.36
171002060803	93.57	15.10	15.04	15.09	-0.06	-0.01	3.62	3.27	3.05	-11.78	-18.87	16.49	17.92	18.96	1.43	2.47
171002060804	83.74	15.27	15.16	15.24	-0.11	-0.03	5.21	4.68	4.36	-11.65	-18.94	16.73	18.17	19.21	1.44	2.48
171002070101	48.54	15.20	15.06	15.15	-0.14	-0.05	0.16	0.14	0.12	-13.11	-21.25	14.74	16.10	17.08	1.36	2.35
171002070102	40.44	15.29	15.18	15.25	-0.11	-0.04	0.19	0.17	0.15	-13.34	-21.64	14.95	16.32	17.31	1.37	2.36
171002070103	22.55	15.01	14.91	15.01	-0.10	0.00	0.63	0.55	0.50	-11.84	-19.60	16.32	17.75	18.78	1.42	2.45
171002070104	57.64	15.00	15.02	15.13	0.02	0.13	0.23	0.20	0.19	-12.03	-19.96	15.69	17.09	18.10	1.40	2.41
171003030208	70.61	14.08	14.11	14.33	0.03	0.25	35.36	28.88	25.64	-11.05	-17.57	17.67	19.15	20.22	1.48	2.55
171003030402	59.72	14.22	14.18	14.31	-0.04	0.10	36.44	30.01	26.74	-10.68	-17.00	18.40	19.91	20.99	1.51	2.59
171003030403	76.54	14.53	14.48	14.58	-0.04	0.05	24.07	19.86	17.71	-11.57	-18.50	16.93	18.38	19.42	1.45	2.50
171003030503	22.65	14.89	14.70	14.85	-0.19	-0.04	0.10	0.09	0.08	-6.85	-11.73	14.86	16.23	17.22	1.37	2.36
171003030504	40.69	14.72	14.55	14.64	-0.16	-0.08	0.37	0.35	0.33	-6.98	-11.86	16.07	17.48	18.51	1.41	2.44
171003030505	35.32	14.95	14.80	14.83	-0.15	-0.12	1.20	1.10	1.03	-10.15	-16.73	16.37	17.80	18.83	1.43	2.46
171003030603	55.87	14.23	14.20	14.28	-0.03	0.06	0.09	0.08	0.07	-9.27	-15.47	14.60	15.96	16.94	1.36	2.34
171003030604	110.96	14.41	14.36	14.39	-0.05	-0.02	0.77	0.70	0.66	-8.41	-14.23	15.26	16.65	17.64	1.38	2.38
171003030701	61.42	14.35	14.25	14.28	-0.10	-0.07	0.22	0.19	0.17	-12.62	-20.34	14.70	16.07	17.05	1.36	2.35
171003030702	26.49	14.80	14.69	14.76	-0.11	-0.04	0.19	0.17	0.16	-10.76	-17.70	15.31	16.70	17.70	1.39	2.39
171003030703	69.04	14.95	14.86	14.93	-0.09	-0.03	0.22	0.19	0.17	-12.50	-20.37	15.29	16.67	17.67	1.38	2.38
171003030704	87.64	14.70	14.62	14.71	-0.08	0.01	1.99	1.79	1.66	-11.07	-18.22	16.14	17.55	18.58	1.42	2.44
171003030705	105.57	14.84	14.78	14.87	-0.05	0.03	0.22	0.19	0.18	-13.29	-21.31	14.43	15.78	16.75	1.35	2.33
171003030706	56.05	15.19	15.07	15.23	-0.12	0.05	0.80	0.70	0.63	-12.80	-20.85	16.34	17.76	18.79	1.43	2.45
171003030707	87.55	14.92	14.87	15.02	-0.06	0.10	2.71	2.41	2.22	-11.46	-19.06	17.03	18.48	19.53	1.45	2.50
171003030801	111.20	14.87	14.80	14.96	-0.06	0.10	19.21	15.91	14.22	-13.16	-21.20	16.59	18.02	19.06	1.44	2.47
171003030802	46.84	15.29	15.27	15.45	-0.03	0.15	0.18	0.16	0.14	-11.83	-19.79	16.45	17.88	18.91	1.43	2.46
171003030803	35.92	14.54	14.53	14.73	-0.02	0.19	58.31	48.68	43.64	-13.65	-21.75	18.53	20.05	21.14	1.51	2.60
171003040203	84.43	15.05	15.06	15.22	0.01	0.17	0.56	0.50	0.45	-11.83	-19.75	14.75	16.12	17.10	1.36	2.35

171003040204	143.35	15.23	15.14	15.20	-0.09	-0.03	0.48	0.42	0.38	-12.65	-20.83	14.98	16.35	17.34	1.37	2.36
171003040205	43.77	15.04	14.97	15.07	-0.07	0.03	1.61	1.42	1.29	-11.07	-18.75	15.85	17.26	18.27	1.41	2.42
171003040301	15.76	14.96	15.00	15.08	0.04	0.12	5.05	4.47	4.07	-10.42	-17.88	18.07	19.56	20.64	1.50	2.57
171003040303	62.58	14.91	14.86	15.03	-0.05	0.12	0.20	0.18	0.16	-9.21	-16.42	18.06	19.55	20.63	1.49	2.57
171003040304	77.43	15.27	15.18	15.34	-0.08	0.07	0.19	0.17	0.16	-10.81	-18.42	15.45	16.84	17.84	1.39	2.39
171003040305	75.80	15.09	15.02	15.28	-0.07	0.19	0.12	0.11	0.10	-9.80	-17.32	16.18	17.60	18.63	1.42	2.45
171003040306	93.04	15.11	15.02	15.23	-0.08	0.13	3.87	3.44	3.15	-10.37	-17.76	17.35	18.81	19.87	1.47	2.52
171003040401	45.58	15.14	15.10	15.20	-0.05	0.05	0.10	0.08	0.08	-11.63	-19.35	15.35	16.74	17.74	1.39	2.39
171003040402	52.20	15.23	15.16	15.19	-0.07	-0.03	0.27	0.24	0.22	-11.47	-19.19	15.57	16.96	17.97	1.40	2.40
171003040403	20.67	15.27	15.23	15.33	-0.04	0.06	0.79	0.70	0.64	-10.83	-18.51	15.40	16.79	17.79	1.39	2.39
171003040404	3.61	15.17	15.14	15.48	-0.03	0.31	0.07	0.07	0.06	-10.89	-18.65	16.65	18.10	19.14	1.44	2.48