

Northwest



Chapter 27. Northwest

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Introduction

The Northwest—Washington, Oregon, and Idaho—encompasses diverse communities, economies, and ecosystems, with almost 14 million residents.¹ From western coastal regions to forested mountains to arid shrub-steppe, the Northwest is home to numerous culturally and economically important native plants and animals. Northwest ecosystems provide housing, recreation, food, and income that support the collective health and well-being of the region's communities and economies. The 43 Federally Recognized Tribes in the Northwest also rely on the region's ecosystems to sustain their livelihoods. Climate change has already affected all areas in the Northwest and will continue transforming the region in consequential ways. Northwest communities are employing a variety of strategies to adapt to and prepare for climate change; however, there are limits to the long-term effectiveness of adaptation actions without comparable investments to mitigate climate change (KM 31.1).^{2,3}

Climate change observations in the Northwest are consistent with projections from previous National Climate Assessments.^{4,5,6} Annual average air temperatures in the region have risen by almost 2°F since 1900. Washington and Idaho have warmed by nearly 2°F, and Oregon has warmed by 2.5°F. Relative to 1900–2020, the annual number of extremely hot days and warm nights in the Northwest has been above the long-term average over the past decade, and the annual number of extremely cold nights over the same period has been below the long-term average.^{7,8} By the 2080s, annual average temperatures in the Northwest are projected to increase by an average of 4.7°F under a low scenario (SSP1-2.6) and by an average of 10.0°F under a very high scenario (SSP5-8.5) relative to the period 1950–1999.⁹ Future warming in the region is expected to exacerbate regional heatwave intensities (KM 27.5).^{8,10}

Warmer winter temperatures have led to declines in mountain snowpack, particularly in areas with warm maritime climates.^{11,12,13,14} A greater proportion of winter precipitation is projected to fall as rain rather than snow.¹⁵ Warmer winter temperatures are expected to increase snow-line elevation, contributing to snow-dominated watersheds transitioning to mixed rain-and-snow watersheds and mixed rain-and-snow watersheds transitioning to rain-dominated watersheds.^{16,17} Summer precipitation is projected to decline under all scenarios, although it will be variable,⁹ contributing to more frequent, longer, and more severe regional drought conditions that increase wildfire risk and decrease water availability (KMs 27.2, 27.3).

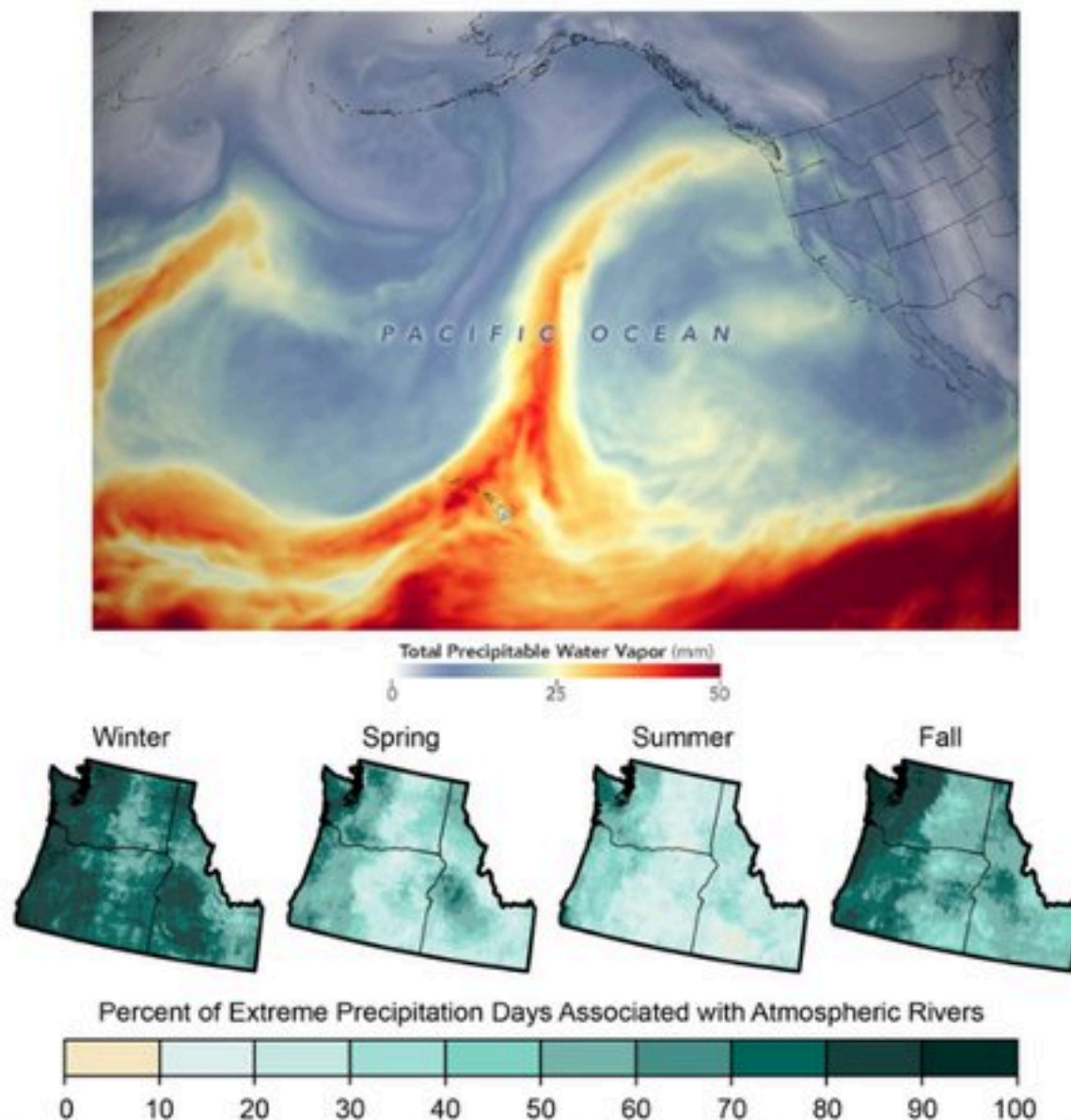
Interannual variability in precipitation is projected to persist, and observed lower streamflows in summer are expected to decrease even further due to reduced snow storage, increased evapotranspiration, and longer lags between summer precipitation events.^{18,19,20} Increasingly low precipitation in drought years has driven extremely low streamflows.²⁰ Some currently permanent streams will transition to ephemeral streams, affecting aquatic species and regional water supply (KMs 27.2, 27.4).

Decreased snow accumulation and increasing melt are raising the elevation of the snow line, or the point at which annual accumulation and melt of snow are equal, which is causing Northwest glaciers to recede,^{21,22} affecting recreation industries and regional water systems (KMs 27.3, 27.4, 27.6). Over the long term, streamflow reductions are expected in basins historically fed by glaciers.²³ Debris flows and landslides are expected to become more frequent as glacial recessions leave more bare land exposed to direct precipitation and the steep sideslopes of glaciated valleys are left unbuttressed by ice.²⁴

The frequency and intensity of extreme precipitation events are projected to increase across the region.^{7,8,25} Long, narrow bands of atmospheric water vapor transport, commonly known as atmospheric rivers (ARs), are associated with extreme precipitation in the western United States, where they contribute an average of 30%–45% of total winter precipitation (Figure 27.1).^{26,27,28} ARs can cause severe damages,²⁹ such as the widespread damage resulting from ARs witnessed in western Washington in November 2021 (KM 27.4). A greater number of strong AR events and fewer moderate and weak events are projected to occur,³⁰

although the changes in the frequency of landfalling ARs vary across climate models.^{31,32} While the average contribution of ARs to annual precipitation in coastal areas is 50% or greater,³³ ARs are projected to reach farther inland.^{34,35,36,37,38} Understanding how climate change affects ARs is critical to estimating how the region's water supply will change (KM 27.4).

Atmospheric Rivers and Extreme Precipitation in the Northwest



Extreme precipitation days are closely associated with atmospheric rivers, which are projected to be more frequent and intense and to reach farther inland.

Figure 27.1. (top) Satellite imagery shows the total precipitable water vapor on February 6, 2020. Red areas indicate more precipitable water vapor, which appears in a narrow band known as an atmospheric river (AR) directed toward the Northwest. **(bottom)** ARs are closely associated with extreme precipitation events and vary across meteorological seasons, as seen by the percentage of extreme precipitation events during 1981–2016 associated with ARs: winter (December–February), spring (March–May), summer (June–August), and fall (September–November). Fall and winter months have a higher percentage of extreme precipitation days associated with ARs, particularly in coastal regions and regions west of the Cascades. **(top)** Satellite image: Joshua Stevens, NASA Earth Observatory; **(bottom)** adapted with permission from Slinsky et al. 2020.²⁷ ©American Meteorological Society.

Seasonal coastal upwelling causes nearshore sea surface temperatures off the Washington and Oregon coasts to be cooler than offshore surface temperatures, tracking temperature trends in the slower-warming deep water.³⁹ Nonetheless, annual average coastal sea surface temperatures in the Northwest have warmed approximately 1.2°F since 1900, and the northern California Current is projected to warm by an additional 4.6°–7.3°F by the end of the century under a very high scenario (RCP8.5), affecting marine species in a variety of ways (KM 27.2).^{39,40,41,42} Human-caused carbon emissions have already driven ocean acidification of surface and subsurface waters off Oregon and Washington.⁴³ Synergies among ocean acidification, hypoxia, and human-caused nutrient inputs negatively affect many species, with cascading effects on food webs and human communities (KMs 27.2, 27.6).^{44,45,46}

Two recent periods of widespread and persistent high sea surface temperatures in 2014–2016 and in 2019, known as marine heatwaves (and informally as the “Blob” and “Blob 2.0”), temporarily increased onshore temperatures by up to 11°F above regional averages,⁴⁷ resulting in short-term shifts in species distributions and mortality of many seabirds⁴⁸ and marine mammals (KMs 10.1, 27.2).⁴⁹ These heatwaves increased the toxicity of harmful algal blooms to marine mammals and humans who consume crabs and other shellfish (KM 27.6).^{50,51,52,53,54}

Sea level is projected to increase across the Northwest under all scenarios (App. 3.3).⁵⁵ Net sea level changes vary by location in response to rising sea levels and vertical land motion, which is the long-term change in land surface elevation from processes such as tectonic forces (Table 27.1).⁵⁶ Sea levels are further affected by climate cycles, such as El Niño, which can raise sea levels up to another 7.9 inches for several months. Relative to the 1991–2009 average, relative sea levels in the Northwest are projected to rise 0.6 to 1.0 feet by 2050 for the Intermediate and High scenarios, respectively (Table 27.1),⁵⁵ placing physical structures and communities at risk (KMs 27.1, 27.4).⁵⁷ In Puget Sound, where most land is subsiding, sea levels are expected to rise 0.9 to 1.6 feet by 2050 and 3.2 to 10.2 feet by 2150 under a very high scenario (RCP8.5), relative to the reference period. On Washington’s outer coast, sea level rise is anticipated to range from 0.1 to 0.8 feet by 2050 in Neah Bay, where land is rising, and 0.5 to 1.2 feet by 2050 in Tahola, where land is subsiding, under a very high scenario (RCP8.5).⁵⁸

Table 27.1 Sea Level Rise Projections for the Northwest

Sea level rise is projected to increase across the Northwest under all sea level rise scenarios. This table illustrates the variability of sea level rise projections for 2050, 2100, and 2150 across the Northwest under the Intermediate and High sea level scenarios⁵⁵ and for specific locations under comparable scenarios (50% likelihood of exceedance and 1% likelihood of exceedance, respectively) for downscaled sea level rise projections for Washington State under a very high scenario (RCP8.5).⁵⁸ The changes are increases in feet, relative to the 1991–2009 average. See Appendix 3 for associated information on scenarios.

Location	2050	2100	2150
Northwest Region	0.60–1.03	2.64–5.98	5.40–10.86
Tacoma, WA	0.9–1.6	2.5–5.3	4.2–10.7
Neah Bay, WA	0.1–0.8	1.0–3.8	1.8–8.4
Tahola, WA	0.5–1.2	1.7–4.5	3.0–9.5

Key Message 27.1

Frontline Communities Are Overburdened, and Prioritizing Social Equity Advances Regional Resilience

Ongoing systemic oppression disproportionately exposes frontline communities in the Northwest—including low-income urban communities of color; rural and natural resource-dependent communities; and Tribes and Indigenous communities—to the consequences of extreme heat, flooding, and wildfire smoke and other climate hazards (*very high confidence*). Frontline communities often have fewer resources to cope with and adapt to climate change but have been leaders in developing climate solutions within and outside their communities (*high confidence*). Actions to limit and adapt to climate change that prioritize climate justice and redirect investments to frontline communities can advance regional resilience (*medium confidence*).

In the Northwest, a history of disenfranchisement and systemic neglect of specific populations has influenced their geographic and occupational exposure to climate-related hazards.^{59,60} Long-lasting effects of settler colonialism, racially restrictive covenants, and exclusionary laws have pushed Indigenous communities, communities of color, and low-income communities into areas that are more vulnerable to climate change.^{59,61,62}

Additionally, economic, political, and social systems play critical roles in distributing the costs and benefits of climate action (KM 20.3), limiting frontline communities' socioeconomic mobility and, thus, their capacity to adapt. As a result, these communities not only experience disproportionate climate burden but also have the fewest resources with which to respond and adapt to climate change.⁵⁹

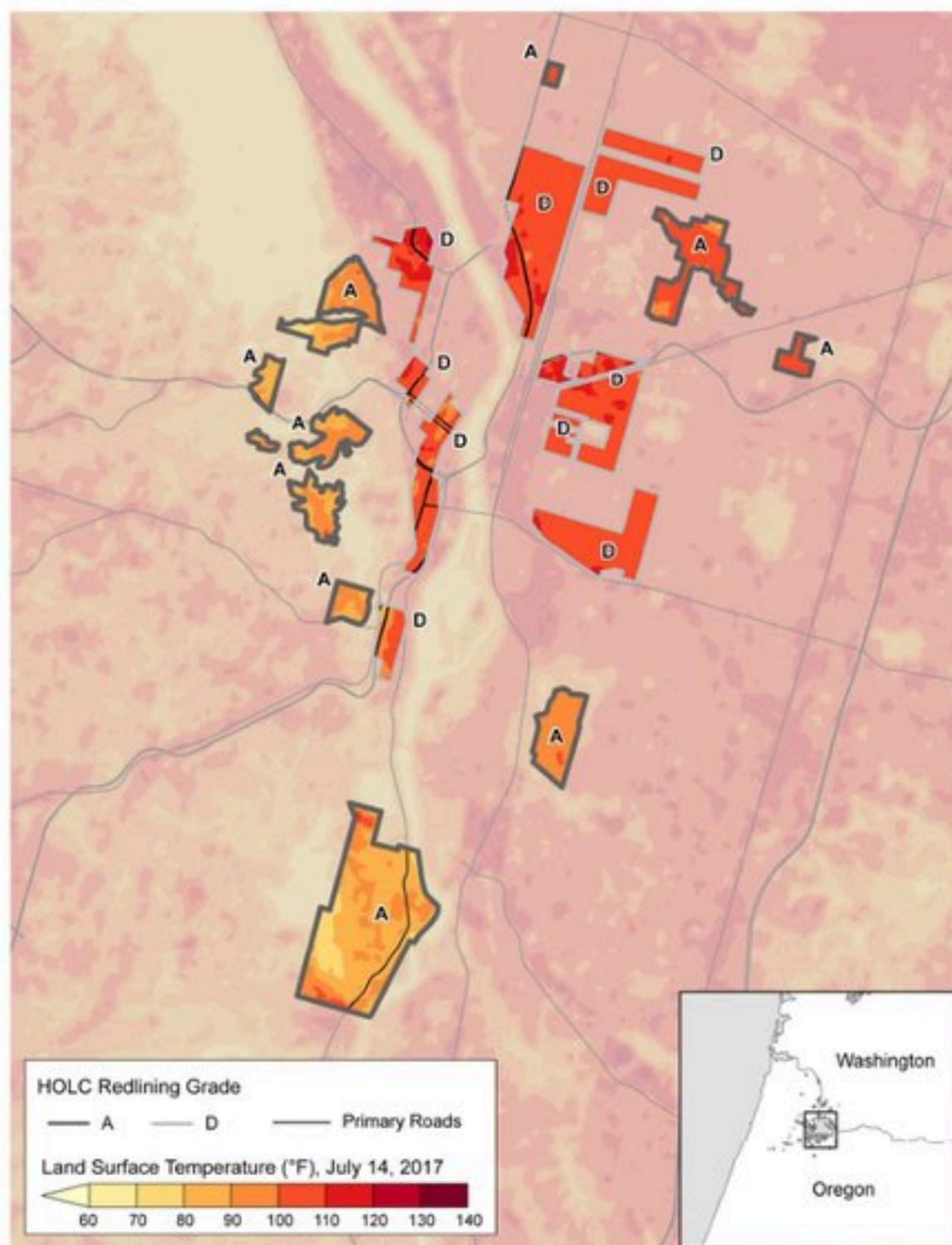
While many types of frontline communities exist—such as unhoused individuals, young children, older adults, and people with preexisting health conditions—this section highlights three communities: low-income urban communities of color, rural and natural resource-dependent communities, and Tribes and Indigenous communities.

Low-Income Urban Communities of Color

Redlining, restrictive housing covenants, and other historical policies have reinforced racial and economic discrimination and exacerbated inequitable exposure to contemporary climate impacts (KM 20.3).⁶³ Formerly redlined communities in Portland, Tacoma, Seattle, and Spokane are still economically and racially segregated and continue to be deprived of equitable access to environmental amenities that protect against the consequences of climate change.^{64,65,66} Formerly redlined areas can be up to 13°F warmer than the city's average surface temperature (KM 27.4), intensifying some impacts for residents such as heat exhaustion (Figure 27.2).^{67,68} Incidences of heat-related illness and death are on the rise and are expected to increase as the climate changes.⁶⁹ Extreme heat poses the most consequential health risks for older adults, low-income households, outdoor laborers such as agricultural workers and construction workers, people who are unhoused, and others who have limited access to adaptive resources such as affordable cooling options (KM 27.5).

Previously redlined communities also have reduced diversity of plant and animal species due to land-use decisions that facilitated industrialization, reduced tree cover, and increased the severity of the urban heat island effect.^{68,70,71} Furthermore, the same factors contributing to urban heat islands—a higher proportion of water-impervious surfaces and lack of green spaces—also increase the chances of urban flooding during extreme precipitation events.^{72,73}

Redlining and Extreme Heat in Portland, Oregon



Economically and racially segregated urban communities are inequitably exposed to climate change impacts, including extreme heat.

Figure 27.2. The map shows satellite-derived land surface temperature (in °F) for July 14, 2017. Areas in Portland, Oregon, that were historically redlined—that is, areas that received Home Owners' Loan Corporation (HOLC) grades of D, or "hazardous"—experience more intense heat island effects than areas that received HOLC grades of A or B. Residents are disproportionately exposed to extreme heat in these areas, where surface temperatures are up to 13°F warmer than the city's average surface temperatures.⁶⁸ Figure credit: Portland State University and NOAA NCEI.

Rural and Natural Resource–Dependent Communities

Many rural communities depend on natural resources and therefore are particularly vulnerable to climate change (KM 27.3).⁷⁴ Workers in natural resource and outdoor-based industries will experience heightened exposure to heatwaves and wildfire smoke,^{75,76} and outdoor construction workers face higher rates of traumatic injuries when exposed to extreme heat.⁷⁷ Washington and Oregon have high numbers of agricultural workers, especially Latino migrant workers, many of whom live in areas with low community resilience to climate-related hazards.

Structural inequities limit low-income, migrant, and agricultural workers' access to clean air and drinking water, adequate living conditions, healthcare, and other social services, compromising their ability to adapt to climate-related risks.⁷⁸ As natural resource economies adapt, shifts in the seasonal availability of work and the diversification of local economies yield both positive and negative outcomes, including new economic opportunities, improved equitable occupational health and safety policies, and job security for outdoor workers and rural communities.^{79,80,81} Weather- and climate-service providers supply these communities with tools and resources—such as communication materials or user-friendly models—to help them be more resilient.^{82,83,84} Effective climate services that are inclusive of diverse perspectives and communities that also contextualize extreme weather events within long-term climate changes can reduce maladaptation and improve community resilience to climate change.^{3,74,85,86,87}

Tribes and Indigenous Communities

Tribes and Indigenous communities experience disproportionate climate impacts and systemic barriers that limit their ability to adapt to climate change (KM 16.1).^{88,89} Due to historical policies of land allotment, many landscapes have heterogeneous management across Tribal and non-Tribal jurisdictions, which can amplify wildfire or flooding risk to Tribal structures and limit the adaptation options for Tribal members. These policies complicate the ability of Tribes to access structures and spiritual locations during or after climate-related events.^{90,91} For example, some coastal Tribes, such as the Quinault Indian Nation, are adapting to coastal flooding by reacquiring fractionated land to relocate housing and key facilities.⁹² Even when Tribes manage contiguous areas of lands, limited access to funding, among other challenges, hinders planned or community-led relocation efforts (KM 9.3).^{92,93}

Climate change also affects cultural and traditional foods and other resources, leaving Tribes without traditional sustenance and medicines for religious or ceremonial purposes (KM 27.6).^{94,95} Climate change can shift resources outside usual and accustomed areas into adjacent non-Tribal jurisdictions or cause phenological shifts that affect cultural harvesting practices.⁹⁵ For example, shifts are expected in huckleberry habitat and the timing of huckleberry flowering and fruit ripening, affecting Tribes who rely on huckleberries for cultural and economic uses.⁹⁶

Climate Action and Social Equity

Climate solutions designed without input from frontline communities can result in maladaptation, increasing vulnerability and cost burden.^{97,98} For example, measures to lessen the impacts of extreme heat, like green infrastructure, have increased real estate values in cities such as Portland and Seattle, a phenomenon known as green gentrification.^{99,99,100} As utilities transfer the costs related to extreme events and the transition to renewable energy directly to consumers, utility bills are expected to become unaffordable for low-income households.¹⁰¹ Inequitable adaptation exacerbates displacement risks for low-income urban populations and can lead to cascading development pressures in rural areas (KM 27.6).^{102,103,104} The rising cost of living, alongside socioeconomic disparities, limits temporary relief and long-term recovery options for those who are affected by climate-intensified extreme weather events, such as the 2021 heat dome event.

In response to grassroots advocacy and community-led efforts, state and local climate policies in the Northwest are increasingly recognizing the importance of climate justice. These policies are prioritizing strategies such as subsidizing adaptation, redistributing benefits, and reducing harm to frontline communities.^{105,106} Despite facing disproportionate risks from climate change impacts, frontline communities have emerged as leaders in climate action, elevating policies that center social equity and confer resilience to communities across the region.⁹⁷

Key Message 27.2

Ecosystems Are Transitioning in Response to Extreme Events and Human Activity

Ecosystems are expected to change as the climate continues to change and as the magnitude and frequency of extreme events increases (*very high confidence*). Some historical and ongoing human activities reduce ecosystem resilience and the adaptive capacity of species (*very high confidence*). These human activities are expected to exacerbate many effects of climate change (*very high confidence*). Human efforts to enable ecological adaptation founded in ecological theory are expected to improve ecosystem functions and services and reduce exposure to climate-related hazards (*medium confidence*).

Ecological Effects of Climate Trends and Extreme Events

Long-term changes in climate and the frequency and magnitude of extreme events, such as droughts, floods, and heatwaves, affect species and ecological processes (Figure 27.3).^{107,108,109,110} High temperature records set in the Northwest from 2015 through 2021 were associated with many short-term or long-term ecological transformations, such as mortality or physiological damage to numerous native species of plants and animals, changes in water availability, and wildfire dynamics. Ecological effects and responses to climate change are not uniform, even among closely related species.^{111,112}

Impacts of Climate-Related Extreme Events on Northwest Ecosystems



Long-term climate changes and extreme events threaten Northwest ecosystems.

Figure 27.3. (top) Flooding on November 16, 2021, in the Nooksack River is shown. Flooding is expected to become more frequent and severe as a result of more intense rainfall and rain-on-snow events. (middle left) Non-native invasives such as the European green crab (*Carcinus maenas*) disrupt food webs as their distribution expands with warming coastal waters. (middle center) Postfire debris flows are expected to become more common with increased wildfire and precipitation intensity. (middle right) Large areas across the Northwest—such as in Idaho—are prone to increased risk of wildfires. (bottom left) Aspen is sensitive to high air temperature, leading to more dying aspen groves. (bottom center) Increases in the distribution and density of non-native invasive grasses, such as cheatgrass (*Bromus tectorum*), exacerbate wildfire risk. (bottom right) Seedlings are more sensitive than mature trees to heat stress and drought. Satellite image: (top) Lauren Dauphin and Joshua Stevens, NASA Earth Observatory. Photo credits: (middle left) ©Emily Grason; (middle center, middle right, bottom left) ©Charlie Luce; (bottom center) ©Erica Fleishman; and (bottom right) Colorado State Forest Service.

Terrestrial Ecosystems

People in the Northwest rely on forests for diverse goods, services, and cultural purposes (KMs 7.2, 27.2). Warming temperatures and decreased summer precipitation over the past four decades have contributed to increases in the size and maximum elevation of wildfires in Northwest forests, and those trends are expected to continue.^{123,124,125} Because concurrent heat and drought are becoming more common,¹²⁶ the volume of stressed or dead vegetation is increasing, which is increasing fuel load and wildfire risk. Across the western United States, many previously burned forests are reburning.¹²⁷ Some low-elevation and dry areas are converting from forest to shrubland after wildfires, and these transitions are expected to continue in the Northwest.^{128,129}

In arid woodlands and shrublands throughout the Northwest, the distribution and abundance of non-native and highly flammable cheatgrass (*Bromus tectorum*) continue to increase before and after wildfires.^{120,121} Cheatgrass establishment is associated with relatively high precipitation during autumn and spring¹²⁰ and with ground disturbance from wildfire, livestock grazing, and other types of land uses.^{121,122} Changes in human activities such as recreation, development, transportation routing, and energy transmission will also continue to affect wildfire frequency (KM 27.4).¹⁰⁴ The length of the wildfire season and the potential for human-caused ignitions in all Northwest ecosystems are expected to increase as drought frequency, duration, and intensity increase.¹²³

Climate change can affect the distribution and population dynamics of native and non-native species. When some non-native species become effective competitors with native and other non-native species, they are considered to be invasive in natural and human-dominated systems, including forests used for timber harvest or recreation. Some of these invasive species are expected to become more prevalent in response to projected increases in temperature, especially minimum winter temperature, and increases in the frequency, duration, and severity of drought across the Northwest.^{127,124}

Additionally, some insects in the Northwest that harm or kill conifers are native herbivores that are prone to outbreaks. For example, densities of native mountain pine beetles (*Dendroctonus ponderosae*) generally are low, but outbreaks can result in 60% stand-level mortality over vast forest areas.¹²⁵ The Douglas-fir beetle (*Dendroctonus pseudotsugae*), another insect native to the Northwest, can damage both stressed and healthy Douglas firs (*Pseudotsuga menziesii*). The effects of outbreaks on trees generally are greatest during hot, dry summers when trees may be water-stressed.¹²⁶ Additionally, warm winters may decrease beetle mortality, increasing the likelihood of an eruption.^{126,127}

Aquatic Ecosystems

Hydrological and thermal changes will prompt shifts in species composition of native and non-native fishes, especially where their habitats have been impaired by land use, including stream modifications and water withdrawals.^{128,129,130,131} For example, rising temperatures, disease spread, and competition threaten the native bull trout (*Salvelinus confluentus*) and cutthroat trout (*Oncorhynchus clarkii*).¹³² Non-native invasive species such as smallmouth bass (*Micropterus dolomieu*), which thrive in warmer waters, continue to expand in the Columbia River basin, competing with and consuming native salmonids.^{133,134} Increased intensity of precipitation and occurrence of rain-on-snow events will increase flood severity and frequency, endangering salmon eggs and juveniles.^{135,136,137,138,139}

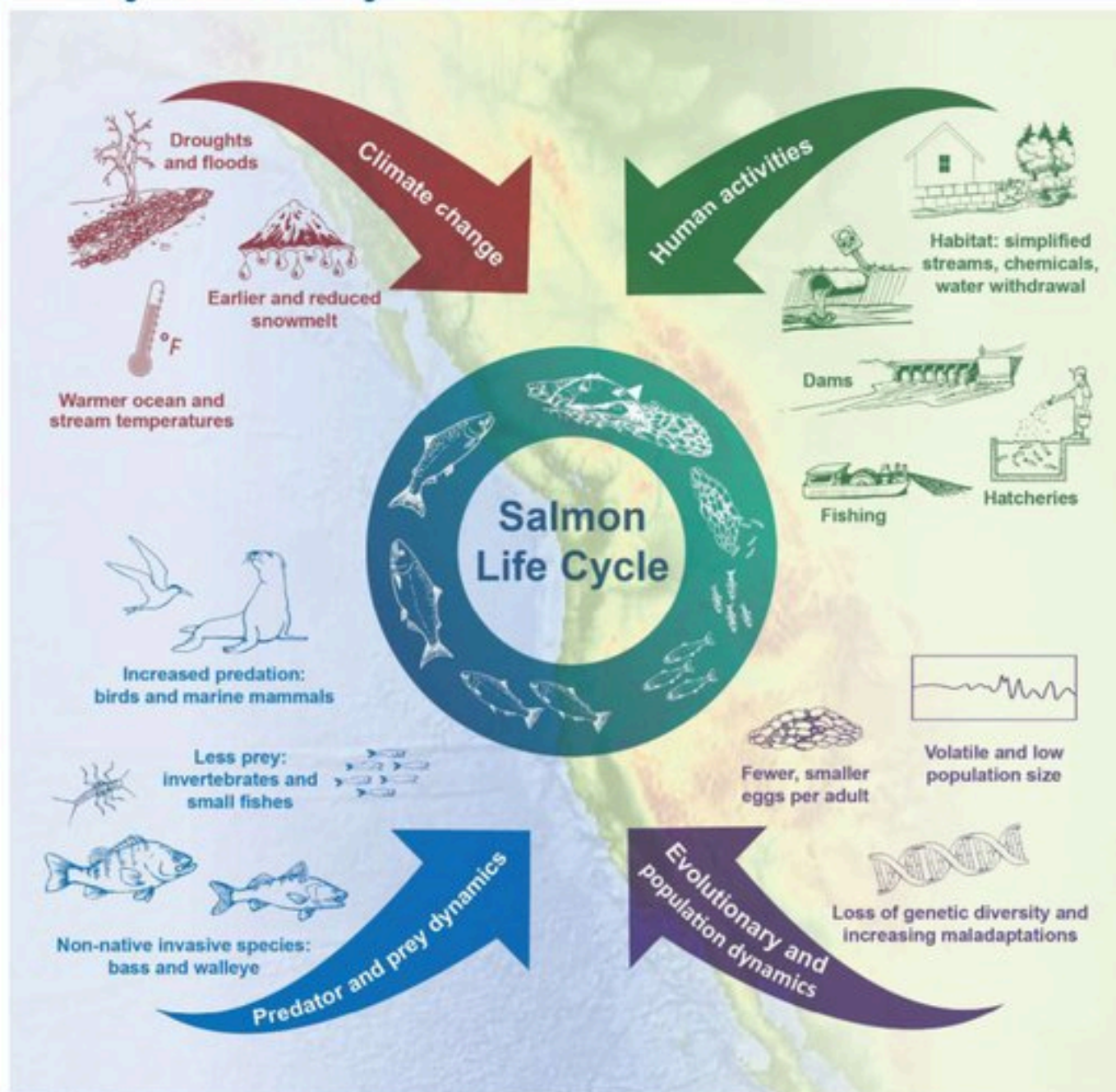
Increases in wildfire size and intensity are expected to lead to local extinctions of resident fishes,¹⁴⁰ warmer stream temperatures,¹⁴¹ and increased sediment transport, turbidity, and fine sediments in streambeds.^{142,143} Habitat connectivity can ameliorate local extinctions following wildfire and postfire debris flows, although local extinction can be permanent if habitat patches are small and are isolated by temperature or road culverts.¹⁴⁴

Coastal and Marine Ecosystems

The 2014–2016 marine heatwave had numerous effects in the highly productive California Current marine ecosystem,^{145,146,147} including the first documented domoic acid poisoning of sea lions, with detectable levels of domoic acid in dolphins, whales, and seals off the Washington coast.¹⁴⁸ These toxins are now detectable year-round in sea lions, not just during algal blooms.¹⁴⁹ Changes in the ecosystem during the heatwave also caused mass mortality of seabirds, such as Cassin's auklets (*Ptychoramphus aleuticus*)¹⁸ and common murrelets (*Uria aalge*)¹⁵⁰ and led to extensive closures of crab and shellfish fisheries.⁵⁴ Many salmon populations also contracted sharply after the heatwave.¹⁵¹ Preliminary evidence indicates that, following extreme heat in June 2021, numerous shellfish species became thermally stressed or died.¹⁵² The frequency and intensity of marine heatwaves are expected to increase.¹⁵³ These marine heatwaves are expected to have broad-ranging impacts on marine ecosystems¹⁵⁴ and increase the incidence of human–wildlife conflict, such as entanglement of whales in fishing gear.¹⁵⁵ While the impacts of future marine heatwaves on species will vary—some species will decline, others will increase, and others will shift their distributions—current regulations and practices may not adequately respond to these impacts, potentially leading to disruptions in fisheries (KM 27.3).¹⁴⁵

Salmon abundance, age at maturation, and size at maturity are widely correlated with climate trends (Figure 27.4).^{156,157,158,159} Idaho's Snake River spring and summer Chinook and sockeye salmon are at particularly high risk across multiple future temperature scenarios (Box 27.1).^{160,161,162,163,164,165} Increasing temperatures are expected to increase the duration and spatial extent of enabling conditions for harmful algal blooms,^{166,167} increasing threats to marine mammals, fish, and shellfish. Population instability increases volatility in fisheries and the extinction risk for species that are already at low abundance.^{168,169}

Interacting Stressors Affecting Salmon Resilience



Stressors stemming from interactions between human activities and natural systems affect freshwater and marine ecosystems and reduce salmon resilience to climate change.

Figure 27.4. Human activities and climate change alter the physical environment in concert, often amplifying their impacts through cumulative effects over the salmon life cycle. They also directly and indirectly alter freshwater and marine systems. Natural systems respond to changes in their environment through both evolutionary and ecological processes. The sum of these many different processes has led to declines in many populations of salmon over decades and reduced their ability to cope with future climate change. Figure credit: NOAA Fisheries.

Box 27.1. Snake River Sockeye Salmon

Snake River sockeye salmon, an important species for the region, is highly vulnerable to climate change.^{161,170,171,172} Application of conservation genetics and interagency and Tribal cooperation^{173,174} have sustained this culturally and ecologically unique population.

Over 150 years, a variety of human activities have affected Idaho sockeye. For example, overfishing, construction of dams that blocked migration for periods of time, and stocking of non-native fish populations altered aquatic ecological processes in complex ways.¹⁷⁵ Numerous factors contributed to sockeye declines until almost no fish returned from the ocean in the 1990s. All 16 adults known to have returned during that decade were captured and taken into a breeding program.^{176,177} Subsequently, a collaboration among federal, state, and Tribal biologists increased reproduction of the captive fish, allowing the release of smolts and some adults to the wild to spawn. In 2014, a peak of 1,579 sockeye salmon returned to Idaho's Sawtooth Mountains.¹⁵¹

In July 2015, a record-breaking heatwave combined with low snowpack from the previous winter led to high water temperatures that killed nearly all naturally migrating adults, highlighting the vulnerability of this life stage in sockeye salmon.^{161,170,179} To protect genetic diversity in hot years and maximize reproductive capacity, adults have been collected at dams and transported upriver nearly 500 miles. By the 2040s, temperatures in the free-flowing Salmon River, which travels 425 miles in central and eastern Idaho, could rise several degrees more than larger rivers downstream under SRES A1B and B1 scenarios (similar to intermediate and high scenarios). The Salmon River could lose nearly half its streamflow during the adult migration window, threatening this endangered species.¹⁶¹ Extensive water withdrawals and habitat modifications in the Salmon River basin^{171,180,181} exacerbate these conditions. Nevertheless, the quality of juvenile rearing habitat¹⁸² and marine survival¹⁷⁴ are relatively high in this population, and reintroduction programs are widely supported.¹⁸³ Additional actions to restore cool, clean water throughout the basin would support the population's natural adaptation to climate change.^{181,184,185}

Ability of Ecosystems and Species to Adapt to Climate Change

Historic and contemporary land use interacts with climate change to affect species' adaptive capacity—their genetic, physical, and behavioral ability to respond to environmental change.^{186,187} Many different strategies to adapt and build resilience within Northwest ecosystems include ecological protection and management, assisted migration, market-based mechanisms, and conservation of genetic diversity.^{188,189,190}

Protection and restoration of natural water bodies and processes that maintain water availability and quality can offset some effects of land use, including the growing demand for irrigation that reduces streamflow and freshwater habitat quality.¹⁶ Similarly, modification of natural or built flood-control structures can reduce adverse downstream effects of changes in hydrology, sedimentation, and shoreline erosion and improve water quality and capacity for groundwater drainage in agricultural systems.¹⁹⁰ These efforts can lead to cascading benefits for habitats, supporting salmonids, other fishes, shellfish, and shorebirds.^{192,193}

Restoration of floodplains that provide habitat for salmon¹⁹⁴ also benefits humans by reducing the current and future exposure of agriculture and infrastructure to flooding from the combined effects of higher sea levels, storm surge, and stream runoff.^{195,196} As several dams and other barriers to historical spawning areas have been removed in recent decades, fishes have rapidly recolonized newly accessible habitat in some cases.^{197,198,199,200}

Reintroduction of fire and thinning of non-fire-resistant vegetation reduce wildfire severity and risk in some Northwest forests and woodlands, especially dry forest types where vegetation has accumulated due to past fire exclusion policies.^{201,202} These forest management practices also have the potential to reduce drought-related mortality.²⁰³ Burning and forest thinning may not decrease wildfire severity and risks in wet or cold forest types^{204,205} but can increase plant and animal diversity.

Wetlands offer some protection against extreme weather events.²⁰⁶ Wetland mitigation banks create or enhance wetlands in a given location as compensation for loss or degradation of other wetlands. The number of these banks has increased across the region,²⁰⁷ but long-term evaluations of created wetlands²⁰⁸ or the effectiveness of wetland mitigation banks²⁰⁹ are uncommon. Market-based approaches, such as temporary water-right leases or permanent transfers, have the potential to support ecosystem functions, such as instream flow augmentation for fish health, with payments to users of competing resources.²¹⁰ However, market and political bottlenecks affect the efficacy of these approaches.²¹¹

The ability of species to adapt to climate change is varied, and the likelihood of adaptation depends in part on the amount of genetic variation in a population or species, which is often related to the number of individuals and their relatedness.¹⁸⁸ Evolutionary responses to recent climate change have generally been less than what might be expected, and these constraints are not fully understood.^{212,213} The feasibility of quantifying abundance, relatedness, and genetic variation varies among populations and species, and these measures have not been estimated for many populations and species.

Key Message 27.3

Impacts to Regional Economies Have Cascading Effects on Livelihoods and Well-Being

Climate change impacts to the Northwest's natural resource- and outdoor-dependent economies will be variable, given the diversity of industries, land cover, and climatic zones (*very high confidence*). Impacts to these industries will have cascading effects on community livelihoods and well-being (*high confidence*). While some industries and resource-dependent communities are resilient to climate-related stresses, economic responses to climate change can benefit affected industries, workers, and livelihoods (*medium confidence*).

Agricultural Industries and Livelihoods

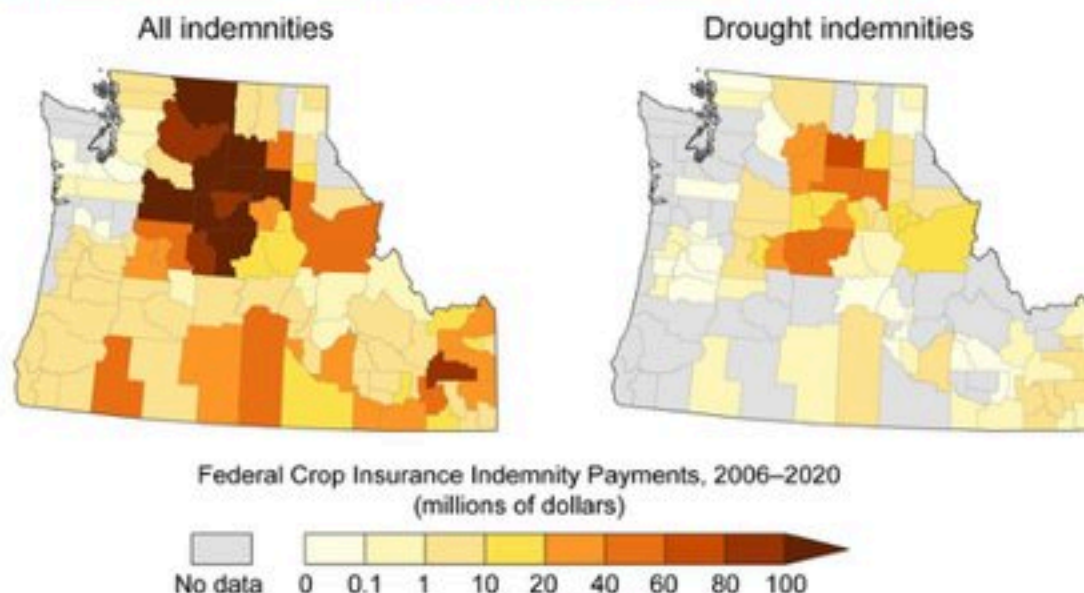
The Northwest encompasses 138.8 million acres of public and private cropland, grassland, pasture, rangeland, and forests,²¹⁴ and agricultural production totaled \$6.28 billion in 2021 (in 2021 dollars).²¹⁵ The agricultural economy includes farms and ranches that have been in operation for multiple generations and is dependent on a seasonal migrant workforce, mostly from Mexico and Central America (KM 27.1).

Climate change affects crop production quantity and quality, and multiple competing effects depend on crop and region, causing increases and decreases in projected yields (Box 27.2; KM 11.1).²¹⁶ Chill accumulation—exposure to cold temperatures during dormancy—is key for fruit set and fruit quality in perennial crops and is expected to decrease in the southern parts of the Northwest and increase in the northern parts.²¹⁷ Increased exposure to extreme temperatures can induce cosmetic effects (e.g., sunburn in apples) that make crops increasingly unmarketable.²¹⁸ Pest pressures are expected to increase due to climate change; however, preliminary research indicates that the efficacy of non-chemical control of pests can also increase, providing opportunities for reduced pesticide use and environmental benefits.²¹⁷ Warmer autumns have been linked to potential increased risk of honeybee (*Apis mellifera*) colony failure in the following spring even in the absence of other stressors,^{219,220} thereby affecting the specialty crop industry that relies on managed honeybees. While increasing temperatures in some regions may present new economic opportunities, such as winegrape growing in Puget Sound,²²¹ other climate-related impacts such as wildfire smoke may impede these emerging industries.²²²

Drought conditions have also affected the region's agricultural lands and rangelands. Across the region, the 2021 drought resulted in reduced access to irrigation water and yield loss for several crops.²²³ Significant yield declines between 2020 and 2021 in winter wheat, spring wheat, and barley were also attributed to drought.²²⁴ Droughts have also decreased forage availability and productivity, affecting livestock operations and management of habitat for other species.²²⁵ Market approaches such as temporary leasing of water can alleviate drought impacts on agricultural productivity and the regional economy to a certain extent.²²⁶ Similarly, grass banks, which allow landowners to lease forage space for ranchers in exchange for implementation of conservation projects by ranchers, can allow ranchers to better manage forage shortages caused by drought and are gaining popularity in the western United States.^{227,228}

Increasing trends in crop insurance loss payments—an indicator associated with economic disruption of agricultural production due to extreme events and impacts—reflect the region's warming temperatures and declining snowpack (Figure 27.5).^{229,230} Agricultural producer perceptions of climate risk affect the efficacy of place-based adaptation and resilience efforts, and operations that adapt to extreme weather and changing climate conditions may see improved productivity and resilience (KMs 6.1, 27.1).^{3,82,83,87,231}

Agricultural Losses Through Crop Insurance Indemnity Payments



Increasing trends in crop insurance loss payments reflect the economic disruption of agricultural production due to extreme events including droughts.

Figure 27.5. These county-level maps compare all crop insurance indemnity payments from the US Department of Agriculture Risk Management Agency (**left**) with those specifically due to drought, from 2006 through 2020 (**right**). All indemnity payments reflect both biophysical and socioeconomic impacts from weather- and climate-driven events, including major droughts, on important commodities such as wheat and potatoes. Figure credit: USDA. See figure metadata for additional contributors.

Forest Industries and Livelihoods

Northwest forests provide multiple ecosystem and economic services. Rising temperatures and increased frequency of ecological disturbances may affect forest structure and growth (KM 27.2),²³² leading to reductions in the quantity and quality of forest products and commercially important timber species.^{233,234,235,236} For example, these impacts could lead to the increase in density and distribution of ponderosa pine at higher elevations in the Blue Mountains ecoregion and the expansion of western Cascade

Range Douglas fir into higher elevations, affecting timber supply and carbon sequestration potential.^{234,237,238} Dry coniferous forests and woodlands in lower to middle elevations—such as those on the east side of the Cascade Range, the Palouse Prairie–forest ecotone in Idaho, and drier areas of the Rocky Mountains—will experience large increases in wildfire frequency, extent, and severity, threatening forest and timber management initiatives.^{157,239,240}

Climate impacts to forest industries will affect the livelihoods of communities dependent on timber and non-timber forest products.^{234,237} While rural timber-based economies face additional economic risks from wildfires and drought, they also have local knowledge and insight to effectively reduce some of these risks (KM 27.1).²⁴¹ Despite this, climate impacts to forest product industries can lead to economic depression within some communities, resulting in migration away from these communities (KM 27.6).²⁴² However, localized species shifts could induce industries and private landowners to make new financially beneficial adaptation choices.^{235,242} Other emerging opportunities, such as cross-laminated timber, can support local timber economies while providing sustainable and less carbon-intensive alternatives for construction.²⁴³

Reforestation and afforestation are expected to benefit ecosystem functions, such as increasing water quality, long-term carbon storage capacity, and viability of some native species (KM 7.2).²⁴⁴ Tribal forest enterprises use harvest and conservation techniques reliant on Indigenous value systems to support improved forest management.²⁴⁵ For example, the Confederated Tribes of the Colville Reservation are employing innovative drone technologies to conduct forest inventories, enabling them to improve their forest and timber management efforts, air and water quality, wildlife habitat, preservation of cultural areas and practices, and carbon sequestration potential.²⁴⁶

Commercial Fisheries and Livelihoods

Climate change has affected fisheries in the Northwest (KMs 27.2, 10.2). Marine heatwaves and harmful algal blooms have led to climate-induced fishery losses on the West Coast, accounting for a \$641.1 million (in 2022 dollars) reduction in commercial fishing revenue.²⁴⁷ Climate change can also intensify stressors such as decreasing catch and landing rates and accelerating the graying of the fleet phenomenon—the increasing average age of commercial fishers.^{248,249} Fishery losses and closures can affect fishing-adjacent industries, such as hospitality, and the cultural identity of residents who directly or indirectly rely on fishing.²⁵⁰

Tribes account for over half of federal fishery loss requests.²⁴⁷ Further population declines, especially of Pacific salmon, will have additional consequences for Tribal communities reliant on fish for subsistence, ceremonies, and health.^{95,251} Ocean acidification, hypoxia events, and algal blooms are also hurting Tribal Dungeness crab fisheries.²⁵² It is not always feasible for Tribes to secure loans and equipment and to thrive in competitive market systems. However, many Tribes are utilizing Indigenous approaches and Tribal–federal partnerships to increase the resilience of their commercial and subsistence fisheries.²⁵³

Tourism, Recreation, and Customer Service Industries

The outdoor tourism and recreation industry in the Northwest supports \$51.9 billion (in 2022 dollars) in annual expenditures and employs more than 588,000 individuals.²⁵⁴ The economic impacts of climate change on the recreation industry will vary.⁷⁹ The snow season is projected to decrease by nearly half by the end of the century in parts of the Cascade Range.²⁵⁵ Snow-based recreational industries such as skiing have already lost revenue due to the decrease in snow days, and future impacts to snowpack are expected to further harm snow-based recreational industries.^{256,257} In contrast, earlier spring snowmelt and increasing temperatures can increase access to hiking trails and campgrounds, thereby extending these seasons. However, a regional shift from a snow- to a rain-dominated system (KM 27.6)^{16,258} may present new operational and maintenance challenges from increased flooding and erosion.²⁵⁹ Recently burned areas

typically are closed as a safety precaution, and poor air quality from wildfire smoke can deter outdoor activities and recreation.^{79,260}

Higher temperatures may increase the demand for water-based and warm-weather activities such as boating, cycling, and fishing (KM 27.6).^{79,261} For example, economic gains for cycling activities in Washington are expected to increase due to the declining numbers of cold days.²⁶² However, climate change can reduce the quality and aesthetics of recreational sites, affecting user preference and leading to reduced visitation rates.⁷⁹

Changes in recreation management may produce inequitable outcomes. Rising costs to access recreation sites and limited ability to travel to alternative destinations will disproportionately affect low-income visitors. Increased cost of living in high-amenity areas such as ski resort towns will also stress workers and adjacent communities (KM 27.6).²⁶³ Outdoor activities such as skiing and hiking can improve overall health and thereby reduce healthcare costs; however, decreased access to such activities can lead to increased risk of chronic diseases, mental health impacts, and loss of cultural heritage and connection to place (KM 27.6).²⁶⁴

Box 27.2. Tribal Agricultural Economies Are Adapting to Climate Change

Northwest Tribal economies are diverse, and many are affected by climate change. Tribes are utilizing innovative approaches that braid Indigenous and Western sciences together to respond to these challenges.

Climate change is affecting Tribal agriculture.²⁶⁵ The Nez Perce Tribe is currently working with non-Tribal managers to pilot regenerative agricultural practices that integrate Traditional Ecological Knowledge to improve economic, ecological, and cultural resilience.²⁶⁶ The Yakama Nation is reacquiring agricultural lands to promote food sovereignty and to train the next generation's Tribal members in sustainable and regenerative farming.^{267,268}

Just Transition and Community Livelihoods

As local economies in the Northwest shift to low-carbon industries and climate-adaptive practices, historically overburdened workers will face higher exposure to climate-related hazards as well as risks of being excluded from economic shifts to a green economy (KM 27.1).^{76,97,269} Local governments, Tribes, labor unions, and community groups across the region are evaluating and adopting policies and programs that support a just transition (KM 20.3).⁹⁷ Efforts toward a just transition in the Northwest region include investments in low-carbon sectors, local economic diversification plans, training and skills development for workers in resource-dependent and fossil fuel-dependent industries, financial assistance for impacted communities, and worker protections.^{270,271} Despite progress in specific sectors, efforts that account for historically overburdened workers can reduce potential livelihood disruptions caused by economic shifts associated with decarbonization.^{97,272}

Key Message 27.4

Infrastructure Systems Are Stressed by Climate Change but Can Enable Mitigation and Adaptation

Recent extreme events have stressed water systems and housing, transportation, and energy infrastructure across the Northwest (*very high confidence*). Extreme precipitation, droughts, and heatwaves will intensify due to climate change and continue to threaten these interrelated systems (*very high confidence*). Given the complexity of and interdependencies among infrastructure systems, an impact or a response within one sector can cascade to other sectors (*very high confidence*). Cross-sectoral planning, which can include redesigning aging infrastructure and incorporating climate considerations into land-use decisions, can increase resilience to future climate variability and extremes (*high confidence*).

Infrastructure systems are threatened by extreme events such as drought, wildfire, heatwaves, floods, and landslides (KM 12.2).²⁷³ Climate change has revealed vulnerabilities in infrastructure planning and design, which are typically based on historical conditions and do not account for recent increases in the frequency or severity of extreme events. Isolated communities and those without alternatives if infrastructure fails are among the most vulnerable. Designing resilient infrastructure requires accounting for interdependencies among the built environment's physical and social elements.^{274,275,276}

Water Infrastructure

Droughts in the last decade in the Northwest demonstrated water supply vulnerabilities, such as depletion of reservoirs across central and eastern Oregon and southern Idaho.^{277,278} Some water sources, infrastructure, and operations that treat and convey water were resilient during these droughts. However, some water providers were forced to access alternative sources, institute mandatory or voluntary conservation measures, or otherwise modify their operations. Small rural water providers are vulnerable because they usually depend on a single water source or sources with limited capacity and because operators generally have limited resources for planning, upgrades, and emergency response (KM 27.1). Wildfires in 2020 and 2021 damaged physical elements of the water delivery and treatment systems, disrupted electricity systems, and increased the amount of sediment in waterways and reservoirs.^{142,279} These vulnerabilities will increase as droughts and wildfires become more frequent and severe.

About 30% of Northwest households use septic systems to treat their wastewater.²⁸⁰ Sea level rise, high temperatures, extreme precipitation, and high streamflows reduce the function of septic systems.^{281,282} For example, saturated soils impede wastewater treatment in drainfields.²⁸³ Failures of wastewater storage and treatment will negatively affect human health and increase nitrogen loads in waterways.²⁸⁴

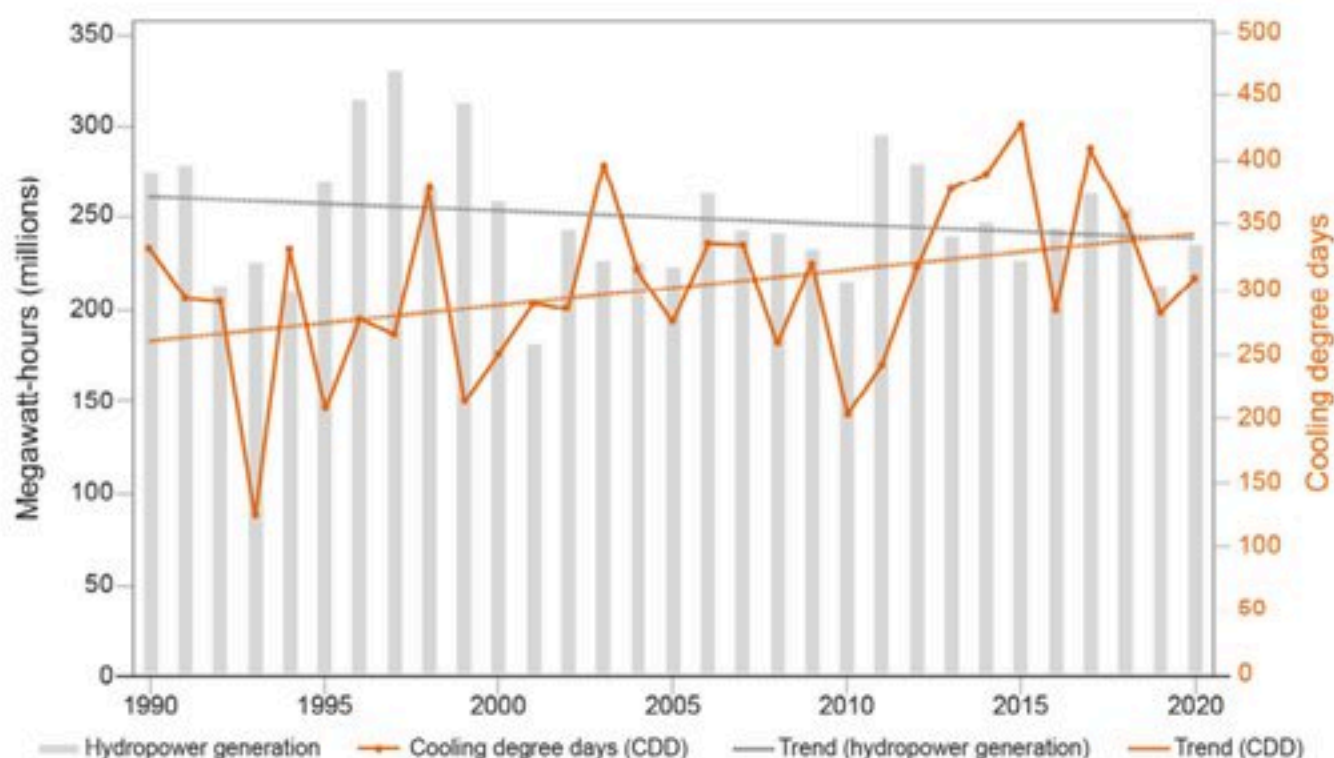
Emerging data and technologies can make drinking water and stormwater systems more resilient to climate change. For example, projections of changes in storm duration, intensity, and frequency²⁸⁵ provide information needed to upgrade stormwater systems to reduce stresses from extreme precipitation.^{286,287} Water utilities can reduce water losses during delivery and alleviate stress to the system during hotter summers and more severe droughts by upgrading distribution lines and minimizing water losses during treatment.²⁸⁸ Water-efficient appliances, sprinklers with soil moisture sensors, drought resilient plants, and conservation education and incentives can also reduce water demand.²⁸⁸

Energy Infrastructure

Climate change impacts nearly every aspect of the energy system, with interdependencies and cascading effects in other critical sectors (KMs 5.1, 12.2, 31.1; Focus on Compound Events). For instance, less snow, earlier snowmelt, and more frequent and intense droughts will alter the seasonal capacity of hydropower, a primary source of regional energy, to meet electricity demand.^{278,289,290,291} Earlier snowmelt is also increasing the need for water storage in Idaho reservoirs.¹¹ Removal of dams may support salmon recovery but can reduce resilience in the regional power system (Box 27.1).²⁹²

Increasing temperatures and heatwaves are shifting the seasonal timing and spatial footprint of electricity demand.^{291,293} Cooling degree days, a metric associated with energy demand for cooling, are increasing across the Northwest, and the region's population increases will also affect the electricity demand, potentially leading to energy shortfalls (Figure 27.6).²⁹⁴ Population growth and droughts are expected to amplify competing claims to the water supply by irrigators, Tribes, power plants, and other water rights holders,^{295,296} highlighting the interdependencies of energy, water, and agricultural systems. Strategies such as demand-side management (voluntarily shifts in power loads) and ongoing additions of solar power, such as that being pursued by the Nez Perce Tribe,²⁹⁷ can increase the resilience of energy infrastructure.

Annual Cooling Degree Days Relative to Annual Hydropower Generation



Hydropower generation is currently meeting the number of cooling degree days but might not continue to do so as temperatures and heatwaves increase in the future.

Figure 27.6. Cooling degree days—the annual cumulative number of days on which the average temperature is greater than 65°F—are typically used to measure cooling energy demand. During 1990–2020, the annual number of cooling degree days (orange lines) increased, whereas annual hydropower generation (in millions of megawatt-hours, gray bars) decreased slightly. Hydropower generation may not meet projected future cooling demand, especially during summer. Figure credit: Boise State University and Cascadia Consulting Group.

Electricity transmission and distribution grids are both a source of wildfire risk and are also at risk from wildfire, particularly in hot, dry, and windy conditions. Electric utilities and land management agencies are evaluating potential actions that they can take to reduce future wildfire risk and impacts on electricity systems (Box 27.3). Some Northwest electric utilities are exercising public safety power shutoffs or “fast trip” programs that trigger outages when faults are detected.²⁹⁸ Such shutoffs can reduce the likelihood of ignitions from the electric grid when complemented by other risk-mitigation measures but can also negatively affect local economies and human health (Focus on Western Wildfires). Risks to electric grid infrastructure from wildfires may also be higher in remote areas, as monitoring capacity is less robust.

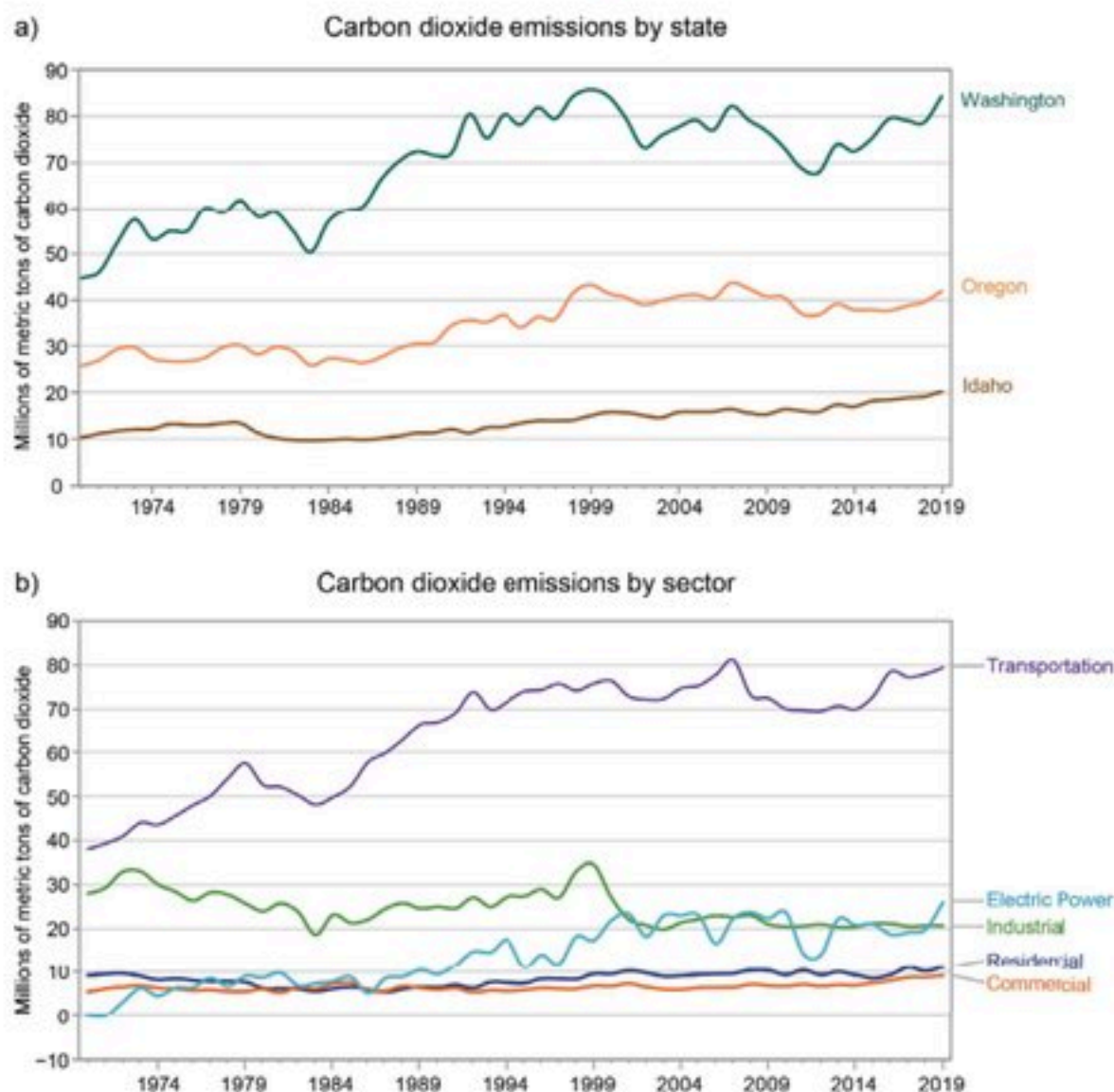
Box 27.3. Washington State’s Electric Utility Wildland Fire Prevention Task Force

Many states, including those in the Northwest, are taking new action on climate-related challenges for critical energy infrastructure. For example, in response to western wildfires in 2019 ignited by electricity transmission lines or that temporarily reduced electric services, the Washington State Legislature convened the Electric Utilities Wildland Fire Prevention Task Force²⁹⁹ with the intent of increasing electricity infrastructure resilience through improved coordination across agencies and information sources. The task force advised the Washington State Department of Natural Resources on vegetation management, communication protocols, and investigation protocols related to wildfire risk and electricity reliability. The three outcomes of the task force’s work were a model agreement for managing vegetation outside rights-of-way, protocols for coordinated investigation of wildfires that interact with utilities, and coordination of annual information exchanges among land managers, utility operators, and wildfire experts.

Carbon emissions have been increasing on an absolute basis in the Northwest (Figure 27.7). The shift to low-carbon energy systems can be complex, and there are varied trade-offs and co-benefits between technological innovations that can enhance the viability of clean energy sources and increase the resilience of both infrastructure systems and the communities and industries dependent on them (KM 5.3).^{300,301}

Transitions to low-carbon energy may be perceived as requiring substantial time to accomplish, yet research has shown that considerable low-carbon transitions can occur in less than 15 years.³⁰² Considering these conditions, states, local governments, and utilities have begun to develop low-carbon and decarbonization plans and pathways. Oregon passed legislation to eliminate carbon emissions from the power grid by 2040, and Washington passed legislation to reduce carbon emissions by 95% from 1990 levels by 2050. In Idaho, cities such as Boise and utilities such as Idaho Power have carbon reduction plans.^{105,303} Agencies and utilities are utilizing diverse strategies including energy conservation and efficiency investments; design approaches such as buildings with southern-facing windows to reduce cooling needs; harnessing renewable gas from farms and municipal landfills; and exploring and utilizing alternative energy sources while investing in decarbonization technologies.^{300,304,305,306}

Carbon Dioxide Emissions from Fossil Fuels by State and Sector



Carbon dioxide emissions from fossil fuel consumption vary widely by sector and state.

Figure 27.7. These graphs show carbon dioxide (CO₂) emissions (in millions of metric tons) from fossil fuel consumption by state (**top**) and sector (**bottom**). Carbon dioxide emissions from fossil fuel consumption are greatest in Washington, followed by Oregon and Idaho. Transportation emits more CO₂ than other sectors across Idaho, Oregon, and Washington. Figure credit: Boise State University and Cascadia Consulting Group.

Transportation Infrastructure

Atmospheric rivers in 2021 illustrated existing understanding of how landslides and flooding can disrupt transportation routes.^{307,308} The disruption of transportation routes can lead to injury or death due to a lack of evacuation routes and cutoff from critical emergency services, healthcare, and other goods and services.^{29,309} In extreme cases, the loss of transportation routes and social services may displace households and reduce regional labor supply.³¹⁰ Much of the Northwest's transportation infrastructure, such as railroads, bridges, and highways, is aging and thereby increasing vulnerability to climate-related hazards. For example, the average age of all surveyed bridges in Oregon is 46 years old, and the typical design life is

75 years.³¹¹ Some state transportation agencies, such as Washington State Department of Transportation and Oregon Department of Transportation, have assessed climate risks to their routes and highways and various adaptation options (KM 13.1).^{312,313}

Transportation is the largest source of greenhouse gas emissions in the Northwest (Figure 27.7), and utilities and transportation agencies across the region are exploring electrification options to reduce emissions. However, efforts to electrify the transportation sector will increase electricity demand and place additional stress on the regional energy system (KM 13.1).^{314,315,316} Electric vehicles' energy efficiency and electricity sources will affect the potential magnitude of reduction in transportation-related emissions (KM 13.4).^{314,315}

Housing and Land Use

The majority of the land in urban areas is devoted to residential housing, which provides shelter to people during extreme events but can also exacerbate exposure to harmful impacts. The specific location of urban housing structures can directly affect the severity of local climate impacts. Urban areas are warmer than their surrounding landscapes, a phenomenon known as the urban heat island effect, and some urban neighborhoods can experience temperatures upwards of 13°F warmer than other areas of the same city (KMs 27.1, 12.2). Residential density in urban areas is increasing more in historically lower-income neighborhoods, reducing the availability of green space and increasing the extent of impervious surfaces, thereby worsening heat island effects.^{68,300} Urban trees and other vegetation could provide shade, but there are trade-offs between mitigating heat islands and conserving water.³¹⁷ Creating incentives or requirements for water-efficient landscaping (xeriscaping) while also providing shade and stormwater absorption could help reduce adverse impacts from extreme heat and storms.

Similarly, the location of housing beyond urban centers also interacts with the impacts from climate change. For example, housing in the wildland-urban interface (WUI)—or locations where wildland vegetation and houses meet—has increased over the past several decades and increases the risk of wildfire impacts on housing structures (KM 27.6).^{302,318}

Furthermore, the quality of materials and types of amenities in both urban and rural housing design and construction affect exposure to some impacts, such as wildfire smoke. Households with access to HVAC and air filtration systems can improve indoor air quality and reduce wildfire smoke exposure;^{319,320} however, they may be insufficient to mitigate anticipated increases in the number of wildfire smoke days and associated high concentrations of fine particulate matter and other pollutants.^{321,322}

Climate change will also affect digital infrastructure, such as internet infrastructure systems. For example, fiber conduits and nodes in the greater Seattle area are at risk of inundation from sea level rise by the 2030s,³²³ jeopardizing telecommuting strategies that some jurisdictions are using to reduce vehicle-miles traveled by employees and associated transportation-related emissions.

Because land-use laws determine how human activity is distributed in space and how infrastructure is built, they affect mitigation of and adaptation to climate change.³²⁴ While each state has a different set of land-use policies, state-level land-use planning guidelines can limit or expand opportunities for local land-use plans to respond to climate change (KMs 6.2, 12.3). Nevertheless, land-use laws and policies can facilitate adaptation in multiple ways, including protection (protecting existing structures from climate-related hazards via engineered structures), accommodation (continued use in hazardous locations, like flood zones, by improving design or development standards such as raising foundations or creating natural floodplains), or retreat (restricting new development in hazardous locations).^{324,325,326,327}

Key Message 27.5

Climate Change Amplifies Health Inequities

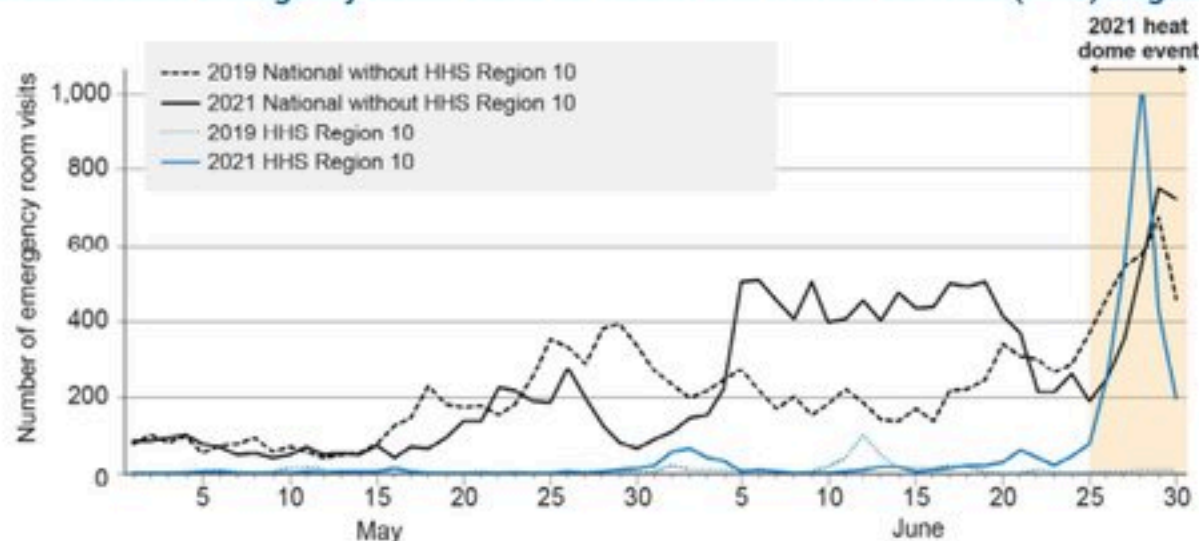
The Northwest's climate has historically been temperate and relatively mild, but shifting weather patterns associated with climate change are adversely affecting physical, mental, and community health (*very high confidence*). The incidence of illnesses and death during extreme heat events and wildfire smoke days is increasing, and climate change is stressing health systems (*high confidence*). Climate-related health risks disproportionately affect certain individuals and groups (*very high confidence*). Climate resilience efforts can be leveraged to improve health, especially among the most vulnerable populations (*high confidence*).

Multiple public health challenges have been associated with climate change. Those whose livelihoods are dependent on the weather—like outdoor day laborers and wildland firefighters—and people with preexisting health conditions and limited coping capacities face some of the gravest challenges (KM 15.1). COVID-19 has overextended the public health sector since 2020 and strained traditional approaches to reducing public health impacts from climate-induced disasters (such as cooling or warming shelters), because convening groups in large areas has been prohibited or limited (Focus on COVID-19 and Climate Change).

Physical Health Impacts of Climate Change

Climate change amplifies health risks, especially for those with underlying health conditions, and leads to physical health impacts such as premature mortality from heatwaves, compromised respiratory health due to wildfire smoke, infectious and vector-borne diseases, exposure to mold and environmental health hazards, diseases in some foods and natural resources such as shellfish toxins (KMs 27.2, 27.6), and exposure to toxicants (KM 15.1). Heatwaves and extreme heat, which are increasing in frequency and intensity, kill more people annually than any other natural hazard.^{328,329} Increasing frequency of wildfires will increase the number of poor air quality days.⁷⁵ Together, heat and wildfire smoke have caused thousands of deaths in the Northwest since 2018. The greatest number of deaths occurred in summer 2021 (Figure 27.8)³³⁰ when almost a thousand people perished during an extraordinary heatwave that was partially attributed to climate change.^{331,332} Although it is unknown whether events such as the 2021 heat dome are an anomaly or will become increasingly frequent in the Northwest,³³³ future heat-related morbidity and mortality across the Northwest are expected to increase across all scenarios.^{69,334} Many of these deaths were preventable and happened because communities were maladapted to the level of heat, which disproportionately affected women, people of color, and people with chronic illnesses and placed additional strain on the Northwest's healthcare system.^{69,330}

Heat-Related Emergency Room Visits for Health and Human Services (HHS) Region 10

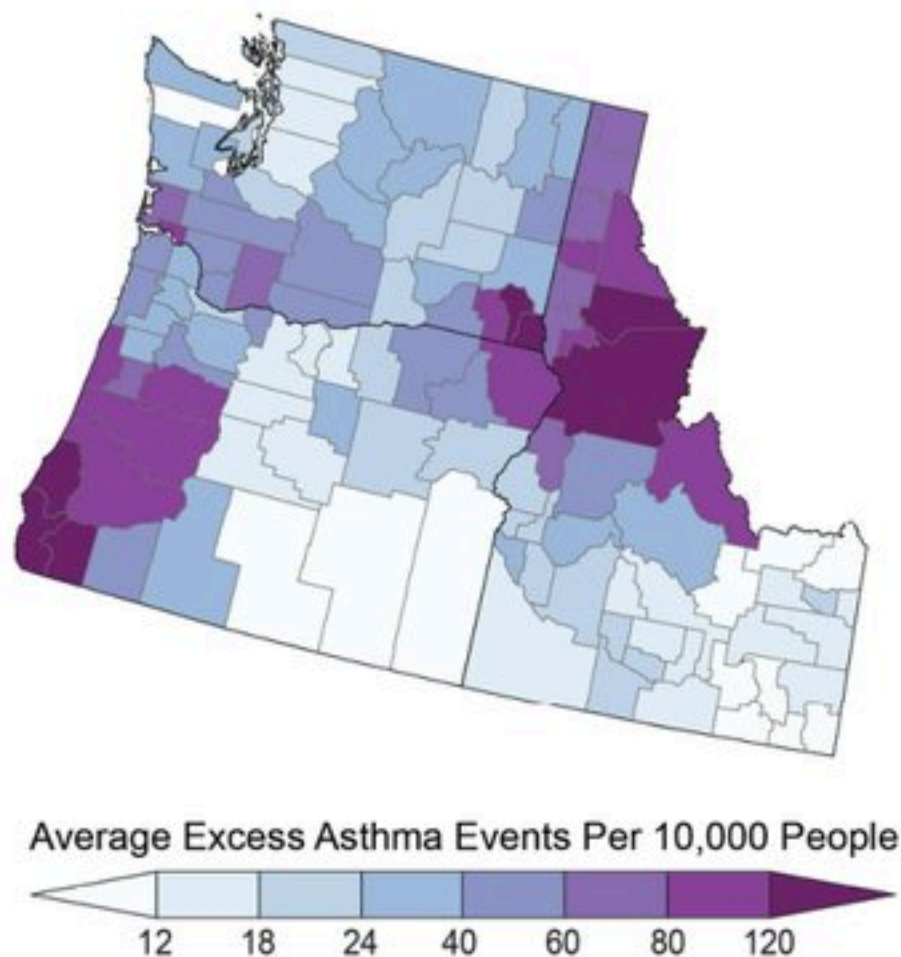


Heatwaves, such as the heat dome event in the summer of 2021, place strains on healthcare systems.

Figure 27.8. The graph shows the number of heat-related emergency department visits for US Department of Health and Human Services (HHS) Region 10 (which includes Alaska, Oregon, Idaho, and Washington), relative to the rest of the country, from May 1–June 30 in 2019 and 2021. There was a sharp increase in emergency department visits for heat-related illness during the 2021 heat dome event in HHS Region 10, relative to the heat-related emergency department visits for the region in 2019. HHS Region 10 also experienced relatively more heat-related emergency department visits during the 2021 heat dome event compared to the rest of the country over the same time period. Adapted from Schramm et al. 2021.³³⁵

Wildfire smoke can be severe in the region, particularly in highly populated areas, Idaho, and eastern Washington and Oregon.^{321,336} In the western US, smoke events from 2004 through 2009 were associated with a 7.2% increase in respiratory hospital admissions among adults over 65, compared to the previous decade. In Washington, smoke-related mortality increased during the 2020 wildfire season, when the ambient total particulate matter concentration changed from near zero to 100 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) over the course of a summer.³²² Increased particulate matter ($\text{PM}_{2.5}$) due to wildfire smoke in the West has been associated with a predisposition to COVID-19 and higher COVID-19 case rates and mortality.³³⁷ Future wildfire seasons—and increases in $\text{PM}_{2.5}$ associated with those wildfire seasons—is projected to increase excess asthma incidences by the 2050s under a very high scenario (RCP8.5; Figure 27.9); Washington, Oregon, and Idaho are expected to see an increase of 25.7, 41.9, and 29.4 wildfire smoke-related emergency department visits per 10,000 persons, respectively.³³⁶ The anticipated financial burden of healthcare costs associated with wildfire smoke exposure is expected to significantly increase across the Northwest.^{336,338,339}

Projected Asthma Burden per Wildfire Season in 2050



Excess asthma burden associated with wildfire smoke is expected to disproportionately affect the Northwest.

Figure 27.9. Northern Idaho, coastal Oregon, and southwest Washington are expected to face some of the highest wildfire smoke-related asthma burden in the Northwest. Excess asthma incidences related to wildfire smoke are expected to increase across the Northwest. The figure shows the average expected total number of excess asthma events per 10,000 people per wildfire season by the 2050s under a very high scenario (RCP8.5). Adapted from Stowell et al. 2022³³⁶ [CC BY 4.0].

Additional health-related impacts are associated with heatwaves and wildfire smoke.³⁴⁰ Lower birth weight and premature birth are attributed to these events,^{341,342} although empirical evidence from the Northwest is still emerging. Similarly, evidence of an association between repeated long-term exposure to wildfire smoke and cancer incidence is emerging.³⁴³

People with access to air-conditioners or air purifiers, along with the financial capacity to operate these systems, will fare better than those whose homes are poorly insulated and allow for a greater concentration of ambient pollutants to enter indoor spaces. Young children and older adults are particularly vulnerable, as are those who live in trailer parks, recreational vehicles, or historically disinvested urban areas. Discriminatory policies such as redlining also contribute to greater exposure to heat and other climate-induced events, such as urban flooding (KM 27.1).

Mental Health Impacts and Climate Change

Each extreme event has its own set of observed mental health consequences, including some overlapping disorders such as post-traumatic stress, anxiety, depression, and suicide.^{344,345} Negative mental health outcomes have been observed before and after a climate-related extreme event.³⁴⁶ For example, wildfire smoke can limit outdoor activities, reducing individuals' ability to exercise, recreate, and relieve stress, leading to additional mental health consequences (KM 27.6). Mental health consequences of climate change may resolve quickly; however, long-term impacts can be delayed and, in the case of post-traumatic stress, can even affect future generations.^{347,348}

Idaho, Oregon, and Washington have a higher prevalence of mental illness relative to the rest of the country.³⁴⁹ The mental health impacts of climate change will continue to be uneven. Youth concerned about climate change, Tribal communities losing cultural resources at a rapid pace, and houseless individuals who experience increased exposures to climate change have a higher prevalence of climate-related mental illnesses compared to other populations.^{345,350,351,352}

Community Health and Well-Being Impacts

Climate change impacts community health and well-being in many ways. Increased temperatures are associated with an increase in violence and self-harm, including suicide.^{344,353} The magnitude and duration of droughts in the Northwest are projected to increase and potentially disrupt agricultural production and exacerbate food insecurity,³⁵⁴ which can cause psychological distress.³⁵⁵ Extreme events will continue to disrupt medical care and services, and injury and illness from such events are expected to exceed the capacity of the healthcare system. Strengthening community and social cohesion can improve community health outcomes and increase preparedness for disasters and extreme events.^{356,357}

Tribal Well-Being Impacts

Climate change is disrupting Tribal communities' access to traditional foods, compounding legacy effects of settler colonialism that have led to increased consumption of processed foods, which is associated with higher rates of diabetes, heart disease, and obesity for Tribal communities.^{358,359,360} Algal blooms have contaminated shellfish to the point that they cannot be consumed during traditional seasons (KM 27.2). Increasing temperatures have created more favorable conditions for transmission of parasitic and invasive species among food sources such as deer and fish.^{361,362} The continued effects of climate change on the phenology of important species and access to cultural resources are expected to disrupt multiple cultural and ceremonial activities, compounding mental, cultural, and physical well-being issues for Tribes.^{265,352,363} Impacts to these cultural resources and sites disrupt intergenerational teachings, an important component of Indigenous health and a method to address intergenerational trauma (KM 27.6).³⁶⁴

Climate Action Can Benefit Human Health and Address Inequities

Historically, the intersection of climate change and health has been unclear, leading to insufficient capacity and resources for health agencies to properly respond and prioritize climate change actions.³⁶⁵ However, because of the health consequences of recent extreme events, public health responses to climate change have become an essential part of climate adaptation, and health resilience frameworks, such as the CDC's Building Resilience Against Climate Effects (BRACE) or Oregon's Climate Equity Blueprint, are becoming more common.³⁶⁶ Many strategies—such as setting universal climate and health goals and providing adequate resources to communities and populations to reach these goals—offer promise for avoiding negative public health outcomes due to climate change and can advance regional resilience (KM 27.1).³⁶⁷ For example, investments to increase electric vehicle adoption and active transportation (e.g., walking, biking) are expected to lead to greenhouse gas emissions reductions, improvements in air quality, and reductions in fatal traffic accidents.³⁶⁸ Investments in cooling options—such as shade coverage from trees, cross-ven-

tilation in apartment units, and air-conditioning capacity—can support communities, particularly formerly redlined communities, in adapting to extreme heat events (KM 27.1).³⁶⁹

Key Message 27.6

Climate Change Affects Heritage and Sense of Place

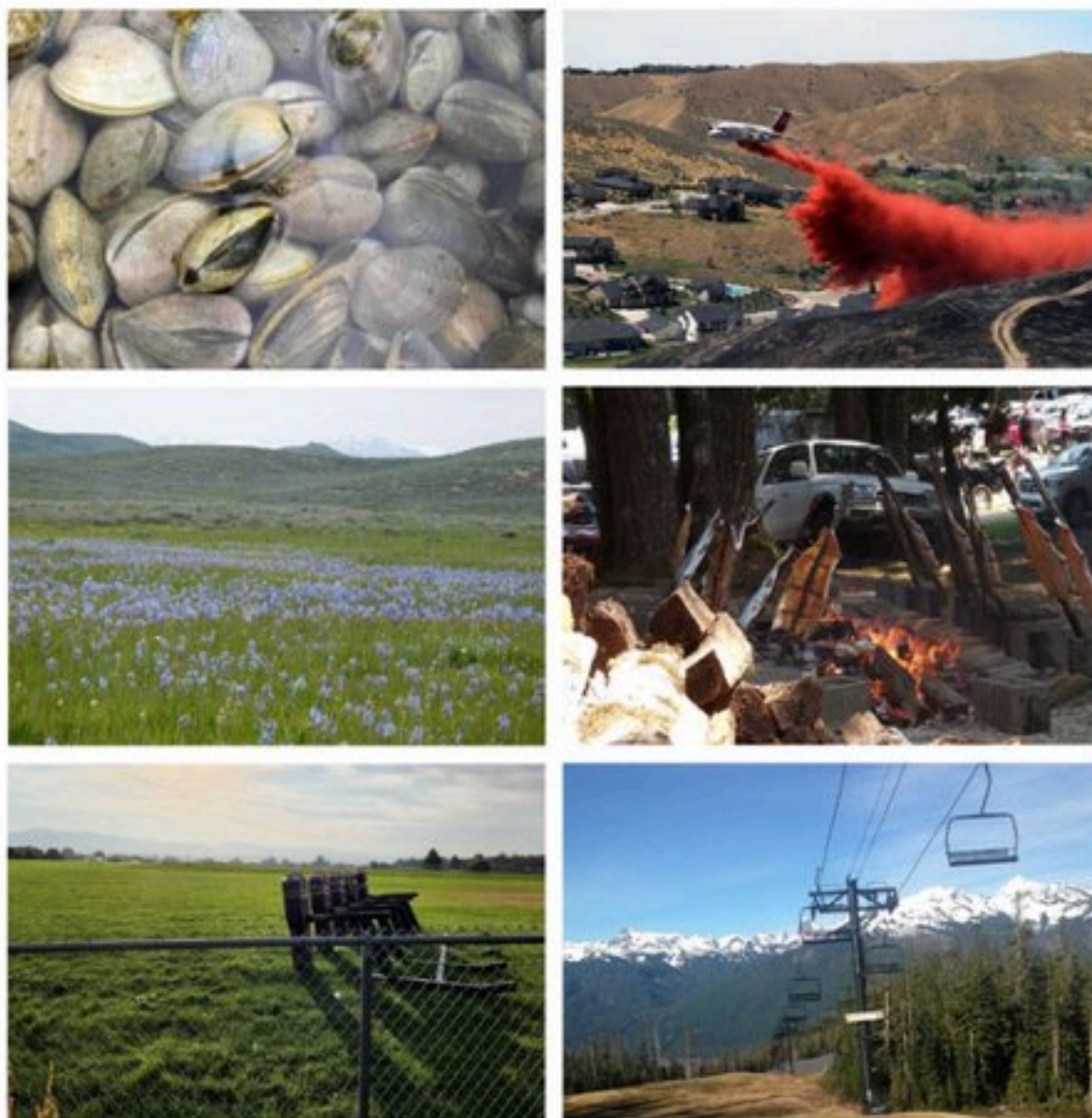
Climate change has disrupted sense of place in the Northwest, affecting noneconomic values such as proximity and access to nature and residents' feelings of security and stability (*high confidence*). Place-based communities, including Tribes, face additional challenges from climate change because of cultural and economic relationships with their locale (*very high confidence*). Leveraging local or Indigenous Knowledge and value systems can spur climate action to ensure that local heritage and sense of place persist for future generations (*medium confidence*).

The heritage of the Northwest is intertwined with the diversity of landscapes, economies, and quality of life (Figure 27.10). Climate change affects all these core characteristics of the Northwest, with impacts on the quality of life and sense of place—the attachment or relationship that people feel to their locations and environment—for all communities and the ability to share the familiar parts of where one lives with others and across generations.³⁷⁰ While there are differences among cultures' relationships, there are deep commonalities. Supporting the continued emotional and cultural well-being of residents across the region will require a mutual appreciation from multiple perspectives across diverse communities.

Sense of Stability and Security

Climate change can negatively affect peoples' sense of security and stability due to disruptions to supply chains and food systems, which underpin economies and communities (KM 18.2; Focus on Risks to Supply Chains).^{371,372} For example, a forest products industry requires regular inputs of timber and cannot thrive on supplies that increasingly come in pulses or waves due to drought, wildfires, and insect infestations.³⁷³ Climate change impacts to natural resource economies will affect residents' financial security and livelihoods (KM 27.3) and will have cascading impacts across regional to international economic systems (KM 19.2).

Heritage, Sense of Place, and Amenities at Risk



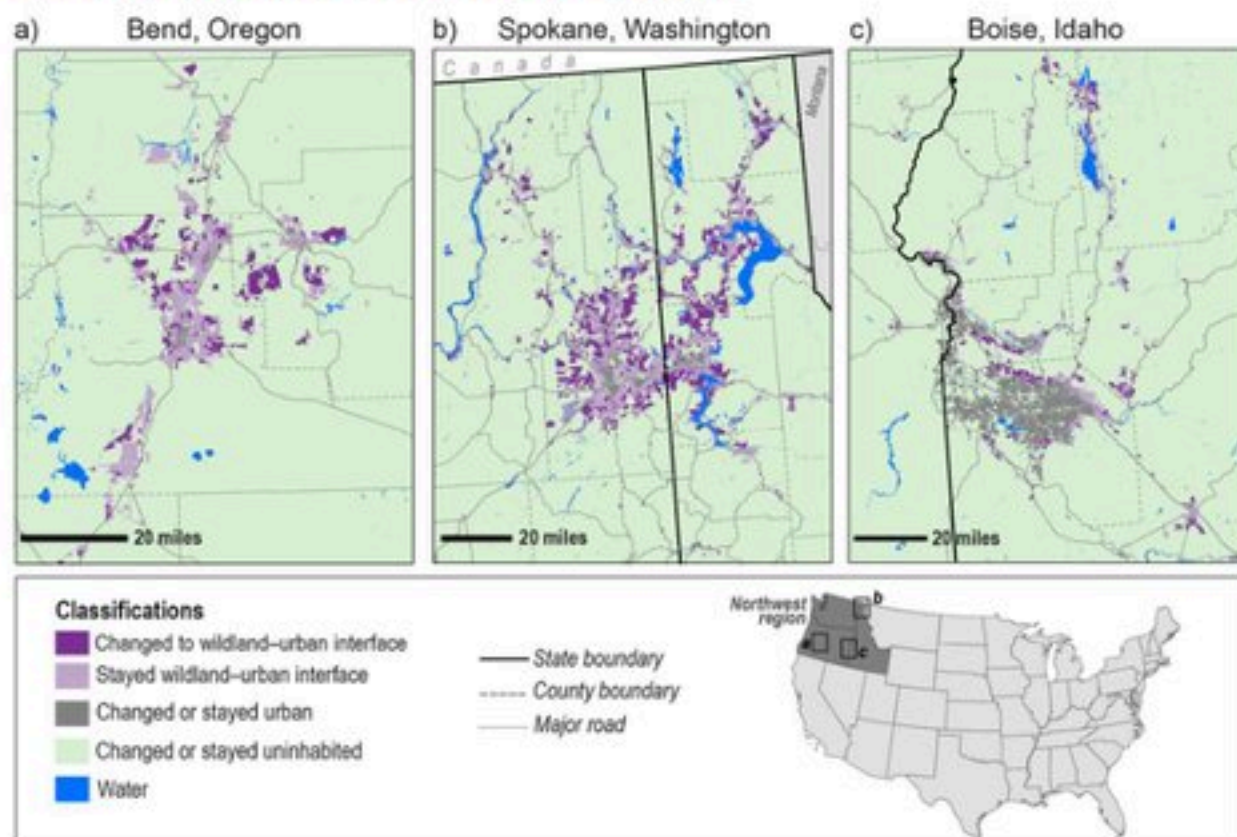
The heritage of the Northwest is intertwined with the diversity of landscapes, economies, and quality of life.

Figure 27.10. These photos illustrate different heritages, cultural traditions, and amenities at risk from climate change. **(top left)** Coastal change is threatening beaches and shellfish habitat for the Swinomish Tribe, threatening cultural activities like the Swinomish Clam Bake. **(top right)** Fire retardant drops protect vulnerable homes in the wildland–urban interface. **(center left)** Culturally important foods, such as camas, will be affected by climate change. **(center right)** Climate change is affecting salmon, potentially affecting the ability of some Tribes to roast and smoke salmon. **(bottom left)** Wildfire smoke days are increasing, affecting school recreation opportunities. **(bottom right)** Warmer winters, such as the winter of 2015, will lead to less winter snow, affecting ski resorts such as Mount Baker Ski Resort, Washington, which had no snow on February 15, 2015, during the height of ski season. Photo credits: (top left) ©Richard A. Walker; (top right) National Interagency Fire Center; (center left and bottom left) ©Charles Luce; (center right) ©Samantha Chisholm Hatfield; (bottom right) ©Duncan Howat.

Many in the Northwest have moved from city centers to an expanding wildland–urban interface (WUI) (Figure 27.11),^{302,303,304} increasing community exposure to wildfires and floods.³⁷⁴ Homes dependent on shallow wells are at risk from more frequent and intense drought conditions (KM 27.4).³⁷⁵ Increases in the frequency

of algal blooms or outbreaks of forest diseases and pests reduce the value of homes with water frontage or surrounded by forest (KM 19.3).^{376,377,378} The decline of home values, aggregated across communities, can lead to local economic and community instability by reducing the desire or ability to rebuild after fires and floods.^{379,380} Although insured households may be able to rebuild, climate risks can increase insurance costs and decrease insurance availability, affecting which residents and businesses thrive in the future.³⁸¹

Growth in Wildland–Urban Interface (1990–2020)



The growth of homes in the wildland–urban interface puts an increasing number of people at risk of wildfire and flooding.

Figure 27.11. The maps show growth in the wildland–urban interface (WUI; dark purple) areas, which are associated with increased wildfire and flooding risks, between 1990 and 2020 near Bend, Oregon (a); Spokane, Washington (b); and Boise, Idaho (c). Bend and Spokane have experienced fast rates of development and population growth that have led to new areas being developed as WUI. Figure credit: USDA Forest Service, NOAA NCEI, and CISESS NC.

Environmental Amenities and Sense of Place

Northwest residents value the region for its environmental amenities like good air and water quality and proximity to recreational opportunities.^{263,382} Climate change has already started and will continue to disrupt many kinds of outdoor recreational activities.^{79,383} Multiple recreational seasons have simultaneously shortened and shifted. Skiing and snowmobiling seasons have started later and become shorter over much of the region, especially in the Cascades,^{13,384} affecting winter recreation businesses (KM 27.3). Loss of spring snowmelt will shift opportunities for rafting, kayaking, and canoeing into rainy winter months, when rapidly fluctuating flow conditions are less safe. Water-based recreation demand is expected to increase in spring

and summer months; however, reduced water quality and harmful algal blooms are expected to restrict these recreation opportunities.³⁸⁹

Many previously forested trails and camping areas have already lost forest cover due to wildfires and drought.³⁸⁵ As the frequency of disturbances increases, so will the number of dead and downed trees,³⁸⁶ closing roads, trails, and campgrounds and potentially causing injuries or death for recreationists.³⁸⁷ Greater flooding risk in winter months will pose risks to recreational facilities and users.³⁸⁸ More frequent smoke and extreme heat events will increase risks to outdoor summer recreationists, especially for high-exertion activities.³⁸⁹ State health agencies, such as the Idaho Department of Health and Welfare, have developed recreation guidelines for K-12 and adult fitness activities and sports in response to increasing wildfire smoke days and decreased air quality.³⁹⁰

Climate change will also affect recreational and subsistence hunting, gathering, and fishing activities. Although some game species may benefit from increased shrub cover and reduced winter mortality, increasing populations can lead to other challenges, affecting managed resources and increasing pathogen spread.^{391,392} Algal blooms and increased toxin levels will lead to shellfish harvest closures, sometimes lasting entire seasons. While these impacts will affect recreational hunters and fishers, impacts will be greater for households and communities that are nutritionally dependent on these resources, such as Tribal communities and households reliant on subsistence diets.³⁹³

Amenity migration, or movement of people to areas with higher environmental quality or increased access to amenities, will be affected by climate change in various ways.^{394,395} For example, people moving to the WUI to be closer to environmental amenities will experience increased risks of wildfires and, in some cases, landslides (Figure 27.11). Additionally, there are compounding challenges for communities that are receiving an influx of amenity migrants, especially rural and low-income communities where established residents provide the labor force but may become priced out by increasing costs of housing and other necessities.^{396,397} Interacting stresses between socioeconomic and development impacts associated with migration and climate change will affect communities in high-amenity areas in the Northwest, such as ski communities in the Cascade Range or island communities in the San Juan Islands.³⁹⁸

Tribal Cultures and Connection to the Land

Climate change has affected Tribal harvesting, hunting, and ceremonial practices.³⁹⁹ Climate change will impact Pacific salmon (KM 27.2) and other cultural resources such as Pacific lamprey, deer, elk, bear, berries, eel, flounder, sturgeon, shellfish, and seaweeds.⁴⁰⁰ Plant die-offs and range shifts can disrupt and impede Tribal access to traditional foods, thereby affecting Tribes' and Indigenous Peoples' sense of place and connections (KM 27.5).³⁶³ Extreme weather events and extreme heat and cold can prevent Tribal members, especially elders, from participating in Tribal ceremonies. Access to ceremonial sites can also be disrupted or damaged by flooding, landslides, and wildfires, exacerbating degradation associated with other land-use decisions (KM 27.1).

Indigenous Knowledges can be utilized to increase resilience to climate change for Tribes.²⁵¹ Tribal landscape management is one method for maintaining connections to landscapes and preserving ceremonial sites, medicinal plants, and gravesite locations for future generations.^{401,402,403} However, federal, state, and local jurisdictions have prevented some Tribes from utilizing Indigenous management techniques such as prescribed burning, which can remove underbrush to reduce fire risk and establish wildlife corridors (KM 27.2), thereby limiting Tribes' ability to exercise their sovereignty and to maintain a sense of place for future generations.^{404,405,406,407,408} Western adaptation options of replacement, fortification, or relocation (KM 27.4) may not be possible or appropriate, as some sites (e.g., gravesites and ceremonial sites) do not have one-to-one exchange equivalents. Despite these limitations, federal-Tribal partnerships can increase landscape resilience to future climate change risks.^{409,410}

Maintaining a Sense of Place and Heritage for the Northwest

Climate change poses an existential threat to the ability of Northwest communities to maintain their sense of place and heritage for future generations. Many cultures rely on nature-based experiences to transfer knowledge and form cultural identity. For example, the Swinomish Tribe holds cultural clam bakes, where community elders transfer Traditional Knowledges about the natural world that are vital to maintain their cultural well-being and heritage.³⁹⁹ However, recent shoreline changes and projected beach loss threaten access to these culturally important shellfish harvest areas, reducing opportunities to hold cultural clam bakes.⁴⁰⁰

Communities across the Northwest pride themselves on their environmental values and actions, such as promoting conservation or voluntarily employing sustainable practices. Leveraging these community values can lead to innovative climate adaptation and mitigation policies at the local level,^{402,403} furthering regional climate mitigation and adaptation goals (KM 27.4) to ensure that the heritage and the communities of the Northwest persist for future generations.

Traceable Accounts

Process Description

The Northwest chapter focuses on advances in regional climate science and understanding of the social and economic impacts of climate change. Therefore, the author team reflects the breadth and depth of scholarship and experiences about climate science, impacts, and responses. The author team was recruited from a list of nominated authors, regional experts from past assessments and conferences, and recommendations from authors or author candidates. The author team includes: 1) a diversity of expertise in the areas of physical climate science, social sciences, economics, public health, ecosystem services, adaptation, and mitigation; 2) a diversity of geographies and institutions that represent each state in the Northwest; 3) a range of experiences and career stages that includes university researchers, practitioners, and state government employees; and 4) a diversity across multiple demographic characteristics, including gender, race, and ethnicity.

Initial Key Message themes were developed via consensus, and these Key Messages were confirmed at the Northwest's regional engagement workshop on February 1, 2022. Specific content within the Key Messages was further refined based on comments from the regional engagement workshop and public comments on the Zero Order Draft. Authors were assigned to Key Message-specific teams based on their expertise and were charged with developing the text, citations, Traceable Accounts, and Key Messages. Key Message narratives were developed to ensure that content built off prior National Climate Assessments (NCAs) and was not repetitive of previous NCAs (Table 27.2). Author meetings were generally held biweekly throughout development of the Fifth National Climate Assessment (NCA5) for discussions and deliberations and to ensure that deadlines were met. Additionally, the smaller Key Message teams met frequently to refine their Key Messages, text, figures, and Traceable Accounts.

Table 27.2. How NCA5 Northwest Chapter Built on Prior NCAs

NCA5 Key Message	How NCA5 Built on NCA3 ⁵ and NCA4 ⁴
27.1 Frontline Communities	Since NCA4, much more research has been published on the distributional burden of climate change on various communities across the Northwest. NCA5 expands on the literature base to focus on the different dimensions of how climate change inequitably impacts various groups. Additionally, NCA5 focuses on some of the emerging information on how different frontline groups are advancing climate action within their communities and states.
27.2 Ecosystem Changes	More research has been published since both NCA3 and NCA4 on the ecological impacts of climate change. NCA5 builds on this work by focusing on ecological responses across the Northwest to extreme events and the interaction between climate change and human activity (e.g., land use). Additionally, NCA5 builds on how different types of adaptation responses, such as restoration, can build ecological resilience.
27.3 Economics and Well-Being	Since NCA3 and NCA4, there has been more scholarship on the economic impacts of climate change. NCA5 dives deeper into some economic impacts previously discussed, including impacts to the natural resource economy. NCA5 also provides a synthesis of new research on the recreational impacts of climate change and economic opportunities in a low-carbon future.
27.4 Infrastructure and Resilience	NCA5 builds on NCA3 and NCA4 by focusing on different types of infrastructure systems and their responses to climate change. NCA5 also highlights the trade-offs of climate action across systems, such as the trade-off between transportation electrification and energy resilience. Additionally, NCA5 focuses on how infrastructure systems and the built environment are the largest contributors of greenhouse gas emissions and provides a narrative on climate mitigation and decarbonization in the region.
27.5 Health Inequities	Since NCA4, more extreme events, such as large wildfires, more wildfire smoke days, and extreme heatwaves, have led to health consequences. NCA5 builds on NCA4, which delved into a variety of impacts, by focusing primarily on heat and smoke impacts to public health. Additionally, NCA5 adds emerging research on the mental and community health impacts of climate change.
27.6 Heritage and Sense of Place	Since NCA4, there has been more research that establishes how regional sense of place is changing due to climate change. NCA5 provides more in-depth coverage on many of the topics covered in NCA4, such as sense of security from extreme events, how different amenities are changing, and how different iconic parts of the Northwest are being affected. Additionally, NCA5 provides additional discussion of climate-related migration and how that affects a community's identity and sense of place.

Key Message 27.1

Frontline Communities Are Overburdened, and Prioritizing Social Equity Advances Regional Resilience

Description of Evidence Base

Recent studies and reports have built on decades of research that have provided strong evidence that the prevalence of people of color in a community continues to be the most significant predictor for where environmental hazards are sited throughout the Northwest, due to racialized and racist policies.^{59,60,62,63,64,65,66,97} A wealth of evidence, including peer-reviewed research, gray literature, and government reports and resources, links racial and socioeconomic demographics across the Northwest with disproportionate exposure and vulnerability of frontline communities to a variety of climate

hazards and extreme events, including wildfire, wildfire smoke and impaired air quality, extreme heat, and flooding.^{59,61,62,67,68,70,71,74,75,76,77,89,92,93,95,494}

Additionally, NCA5 listening sessions and community-led research provided evidence on the lived experiences of frontline communities with climate impacts and how these communities are implementing community-informed climate resilience priorities. The literature supports the diversity of approaches that frontline communities are utilizing to increase their resilience to climate change, including for urban communities of color,^{59,97} rural and natural resource-dependent communities,^{79,90,93} and Tribal and Indigenous communities.^{93,265} Peer-reviewed literature and gray literature document that while frontline communities are inherently resilient to both climate change and other forms of oppression, policies and other structural barriers continue to prevent frontline communities from enacting community-led adaptation strategies.^{78,90,91,92,93}

Major Uncertainties and Research Gaps

While the priorities and needs of frontline communities are increasingly being considered in state and local government policies, plans, and budgets in the Northwest, such efforts are in early stages of implementation. While these efforts are resulting in some benefits to frontline communities in the near term, long-term outcomes are yet to be seen. Advancing climate justice and social equity in the region is dependent on institutions' ability to transform and meet the needs of frontline communities.

While community-led research and plans provide documentation of frontline communities' priorities, it is critical to note that these sources probably do not represent the full range of perspectives, values, and experiences of the diverse communities in the Northwest. Assessment authors understand that communities are not monoliths and that many adaptation and resilience strategies are culturally, temporally, and geographically specific; therefore, the information in this assessment cannot be used to make blanket statements about all communities experiencing environmental and climate injustices in the region.

Description of Confidence and Likelihood

Based on the breadth of available research and literature, authors concluded that there is *very high confidence* that frontline communities are experiencing disproportionately high exposure to climate-related hazards, although there is variation across the types of frontline communities.

Additionally, because of the wealth of community-led documentation, government reports, and preliminary peer-reviewed research, authors concluded that there is *high confidence* that frontline communities generally have fewer resources to adapt and respond to climate change but are leading efforts to increase resilience to climate change and extreme events.

While there is a growing body of evidence suggesting that the priorities, values, and needs of frontline communities are increasingly being considered in state and local policies and plans, these efforts are still in early stages of implementation and long-term outcomes remain to be seen. In addition, existing efforts are not yet sufficient to meet the scale and speed of justice-centered climate action required to secure a safe and livable future for frontline communities. Therefore, authors of this Key Message have *medium confidence* that the extent of these efforts will deliver long-term resilience benefits and climate justice to the region.

Key Message 27.2

Ecosystems Are Transitioning in Response to Extreme Events and Human Activity

Description of Evidence Base

Strong evidence supports the projection that ecosystems will change as climate changes. Numerous assessments project extensive changes in species distributions as climate changes. Additionally, extreme events (e.g., droughts, floods, and heatwaves), which are becoming more frequent and intense, may be equally relevant to the physical condition and population dynamics of species,^{307,309} especially those with short generation times.¹¹⁰ Multiple peer-reviewed publications and government reports document the extensive impacts of extreme events on Northwest ecosystems, especially in the past two decades. Given projections of future climate, it is expected that wildfire will continue to affect forest systems,^{113,114,115,116,117,118,119,120,121,123} changes in hydrology and temperature will affect aquatic ecosystems,^{128,129,130,131,132,133,134,138,139} and ocean acidification and marine heatwaves will affect coastal and marine systems.^{42,48,54,145,146,147,148,149,150,151,152,154,155,159,415}

In addition, robust peer-reviewed evidence documents how these ecosystem-level changes will have myriad effects on native species, including game species,^{391,392} trees,^{232,234,237,238,244} marine taxa,^{148,149,150} and the region's iconic salmonids.^{48,159,160,161,162,163,164,165,415}

Extensive evidence within the peer-reviewed literature also demonstrates the widespread impact of human land uses on the extent to which species can adapt to environmental change, including climate change.^{104,118,119,120,121,122,144} For example, fine-grained variation in land cover, including land cover types associated with human activities, affects the resilience of species or ecological processes to climate variability and change¹⁸⁹ and the extent to which land uses function as stressors. Historical and recent fragmentation of a species' habitat and barriers to movement affect its capacity to adapt to both human-caused and natural forms of environmental change.^{129,130,144,186,187}

There is extensive evidence that conservation of genetic diversity and ecological protection and restoration can benefit ecosystem processes and increase species' adaptive capacity.^{120,121,122,192,193,194,195,196} For example, restoration via removal of impassable dams and structures across the Northwest has restored some natural ecological and hydrological processes that allow anadromous fishes to access historical habitat.^{194,197,198,199,200} However, evidence of the effectiveness of other types of ecological management, such as vegetation removal to mitigate wildfire risk and market-based ecosystem management tools, is limited, especially in the long term.^{204,205,206,208,209}

Major Uncertainties and Research Gaps

Relations between climate and population dynamics of most species are complex, so there is uncertainty in projections even for well-studied species. Moreover, distributions, abundances, or other species-level metrics more closely reflect interactions among climate variables, and interactions among species, rather than single climate variables.^{111,112}

Evolutionary responses to climate are also complex.^{232,233} The likelihood of adaptation depends in part on the amount of genetic variation in a population or species, which is often related to the number of individuals and their relatedness.¹⁸⁸ The feasibility of quantifying abundance, relatedness, and genetic variation differs among populations and species, and these measures have not been estimated for a majority of populations and species. Furthermore, empirical estimates of opposing selection pressures in different environments are difficult to obtain. Similarly, phenotypic plasticity, its heritability, and potential response to selection have not been estimated in most taxa. Accordingly, the adaptive capacity of most taxa is highly uncertain.

Also, data on which biological and physical attributes affect viability most strongly are not available for most species.

The extent to which restoration efforts can increase genetic variation and ecosystem function and productivity is uncertain, especially given the extensive anthropogenic modification of ecosystem structure, composition, and function. Because ecosystems rarely can be restored to a historical state, restoration actions tend to focus on increasing ecosystems' capacity to support diverse and valued functions and services and enhanced genetic and species variation. Information needs include improved understanding of habitat quality, stress tolerance, and adaptation capacity of diverse species. There are substantial gaps in understanding of the complex interactions within and among species, communities, and biogeochemical processes, all of which are being modified by climate change and land use.

Description of Confidence and Likelihood

The enormous body of evidence on ecological sensitivity to climate yields *very high confidence* in projections of change, despite uncertainty in how individual and interacting ecological components will respond. Similarly, although adaptive capacity is difficult to quantify, there is *very high confidence* that such capacity has been reduced by decreases in abundance and genetic diversity of many native species. There is *very high confidence* that human activities and land uses interact with ecological responses to climate change, and in many cases exacerbate these effects.

Climate change impacts could be ameliorated by changes in human actions. However, restoration to previous ecological states often is unlikely. For example, certain non-native invasive species are unlikely to be eradicated, and land modifications rarely can be completely reversed. Furthermore, climate change will modify some species and ecosystem characteristics regardless of human actions. Although the scientific community has medium to low confidence that ecosystem restoration efforts can increase genetic variation in many native species, there is high to medium confidence that reconnecting and improving the quality of species' habitats can increase the feasibility of species persistence. The likelihood of ecological recovery is location- and context-specific and depends on factors including the severity of ecological stressors; the location, timing, design, and scope of restoration actions; and the potential to restore abiotic and biotic processes, land cover, and flows of energy and genes. Thus, the authors have *medium confidence* that human-led adaptation efforts can reduce exposure to climate-related hazards.

Key Message 27.3

Impacts to Regional Economies Have Cascading Effects on Livelihoods and Well-Being

Description of Evidence Base

Over the past several decades, multiple peer-reviewed studies have established how climate change affects diverse annual and perennial cropping systems,^{216,217,218,219,220,221,222,223} fishery systems,^{225,247,248,249,250,253} forestry systems,^{233,234,236,237,242,244} and the tourism industry.^{16,79,256,257,258,261}

Despite these varying climate impacts, there is emerging science, including peer-reviewed sciences, that indicates that the Northwest continues to maintain economic resilience to climate change due to the region's inherent diversification. For example, federal crop insurance for the Northwest shows multiple weather- and climate-related causes of crop loss (e.g., drought, heat, freeze, frost, excess moisture), demonstrating the diversity of risks agricultural producers experience.²³⁰ However, new and emerging opportuni-

ties in these important economic sectors are also beginning to be noted.^{82,83,87,231,243,244,245} The effectiveness and extent of these new adaptation and mitigation opportunities is still unclear.

Emerging case studies, gray literature, and frameworks, such as the just transition framework, are being implemented across the Northwest to transition to a low-carbon economy.^{97,246,303,416,417} There are frameworks and evidence that associate economic resilience with prioritizing worker protections and marginalized labor populations.^{270,272} However, such publications in the Northwest region are still relatively new and limited in extent.

Major Uncertainties and Research Gaps

Recent events such as the 2021 heat dome have highlighted the significant impacts of extreme weather. Regional industries are investing in research that can increase understanding of risk factors associated with extreme weather and assess whether the risks are high enough to warrant additional infrastructure investments and management alternatives to limit damage. Much of the existing literature on climate change impacts on the region is based on limited climate ensembles rather than large ensembles, which are key to understanding extreme weather probabilities and impacts. New efforts addressing this gap are starting to be initiated, especially those addressing the regional agricultural industry.

The potential for new adaptation and mitigation opportunities is still unclear. Additional region-specific information is necessary to obtain a better picture of the potential. The region is still in its early phases of implementing low-carbon economy transition plans and strategies. There are still many gaps associated with the efficacy of implementing these plans. Evaluation of the recently launched efforts should provide valuable information for future streamlining of these efforts.

Description of Confidence and Likelihood

Because of the wealth of peer-reviewed research published across multiple decades, we have very *high confidence* that climate change is affecting—oftentimes in negative ways—natural resource- and outdoor-dependent economies, although the ways they are affected will be variable depending on the location and industry or commodity. Based on robust peer-reviewed literature and a growing number of publications specific to the Northwest, there is *high confidence* that climate change effects on these industries will have cascading impacts on the livelihoods of resource-dependent communities. Because of an emerging evidence base in the peer-reviewed literature—and a nascent evidence base specific to the Northwest region—the authors have *medium confidence* that the region's natural resource industries are effectively responding to climate change and that a transition to a low-carbon economy can impart economic resilience, especially for those disproportionately impacted, such as workers in fossil fuel-dependent industries and outdoor laborers.

Key Message 27.4

Infrastructure Systems Are Stressed by Climate Change but Can Enable Mitigation and Adaptation

Description of Evidence Base

There is considerable evidence that climate change and extreme events have negatively affected built infrastructure, especially older infrastructure, in the Northwest.^{100,142,273,278,279,296,307,308,311,318,323} Evidence varies among sectors, and multiple studies document effects of drought on water infrastructure and supply,²⁷⁷ effects of wildfires on virtually all types of infrastructure,^{142,277,418} and effects of extreme precipitation and flooding on water and transportation infrastructure.^{29,280,282,283,323}

Multiple studies highlight the interdependencies of systems.^{274,275,276,291,294,310,314,315,316} Within the Northwest, infrastructure system dependencies can spark conflicts about trade-offs among uses and between adaptation to and mitigation of climate change. These trade-offs have been documented in peer-reviewed publications and government reports and plans.^{293,295,296,314,315,316,419} Furthermore, some studies suggest that climate adaptation and mitigation actions across infrastructure systems can lead to cascading consequences in other sectors, such as public health, water conservation, and land use (Focus on Western Wildfires).^{277,278}

Despite these conflicts and trade-offs, emerging case studies document approaches to manage trade-offs in use of water, transportation, and electricity infrastructure. There are examples of new technology and data products to support adaptation^{285,286,300,304,305,306} and case studies of collaborative efforts to address these complex systems and their responses to climate change.^{105,303,418}

Major Uncertainties and Research Gaps

Trade-offs among uses of infrastructure and efforts to increase infrastructure resilience create substantial uncertainties in the social and environmental effects of those actions. For example, electrification of mass transit and vehicles can reduce emissions of greenhouse gases but strain energy supplies, affecting adoption of electric vehicles across communities. Similarly, provision of air-conditioning and air filtration, especially in regions where they are currently rare, can alleviate the public health consequences of extreme heat but strain energy supplies. Potential consequences of decreasing wildfire exposure may come at the expense of those medically dependent on electricity.

Description of Confidence and Likelihood

The available research, peer-reviewed literature, and case studies indicate that there is *very high confidence* that climate change, climate hazards, and climate-related extreme events have stressed the Northwest's built infrastructure, and that there is *very high confidence* that climate change will continue to stress these systems. Additionally, there is broad agreement that these infrastructure systems are complex and inter-related and, therefore, that climate-related impacts or responses to extreme events will present trade-offs and lead to conflicts over use. Within the Northwest, documentation of these conflicts and trade-offs varies among sectors and locations. Nevertheless, the literature continues to highlight trade-offs among systems. Therefore, there is *very high confidence* that climate-related disruptions and efforts to adapt to and mitigate the effects of climate change on a given infrastructure system may stress other infrastructure systems. Multiple case studies highlighted how practitioners are managing these conflicts and trade-offs via collaborative planning, engineering, and design. Given the breadth of case studies across sectors, there is *high confidence* that cross-sectoral and multisystem planning will increase the resilience of built infrastructure systems to future climate change.

Key Message 27.5

Climate Change Amplifies Health Inequities

Description of Evidence Base

An extensive peer-reviewed literature base documents the physical and mental health impacts of extreme events and climate change,^{69,75,321,322,330,334,335,336,337,340,341,345} and a smaller but growing evidence base documents the community health impacts of climate change.^{344,353,355} The Northwest has experienced more extreme heat events, wildfires, and wildfire smoke days in the past decade, and research has documented mortality and morbidity directly associated with these hazards and impacts.^{69,328,329,330,334} The evidence connecting extreme heat, for example, to poor mental health outcomes such as anxiety, psychological fatigue, and suicide is still emerging, although researchers and clinicians are developing promising methodologies and approaches to address climate-related mental health needs.³⁴⁵

Multiple lines of evidence document the inequitable distribution of climate-related health risks among Northwest communities.^{265,322,337,345,350,352,352,358,359,360,363,364} There are some gaps specific to the Northwest region on climate change impacts to community health (e.g., domestic violence). However, both national and international peer-reviewed articles document these associations. Multiple case studies and gray literature and an emerging peer-reviewed literature base document how health professionals and communities are responding to increasing public and community health challenges induced or exacerbated by climate change.^{356,357,364,367}

Major Uncertainties and Research Gaps

Reports and published studies have focused on community impacts following extreme events, or other traumatic events felt at the community level, that may reduce social cohesion. More research is needed to better understand the regional extent of mental health challenges from climate change and to inform protocols to better prepare health professionals for climate-related community health impacts. There are also opportunities to decolonize public health methods and improve the integration of local and Indigenous knowledge systems and methodologies to better inform public health research.

There is still uncertainty about the extent that climate change will place additional stress on healthcare services in the Northwest. Preliminary research based on previous extreme weather events highlighted medication and medical equipment supply chain challenges, yet the demand for healthcare is expected to increase due to extreme events. However, compounding stresses that lead to shortage of healthcare workers, other public health challenges (e.g., COVID-19), and acute climate-related extreme events are beginning to illuminate potential gaps in the healthcare system.

There is still uncertainty in associating community health impacts, such as domestic violence, with climate change and its subsequent impacts on the healthcare system.

Description of Confidence and Likelihood

Given the breadth of literature documenting climate change impacts on physical, mental, and community health, the authors have *very high confidence* that climate change is adversely affecting public and community health outcomes in the Northwest. The authors have *high confidence* that mortality and illnesses related to extreme heat events and poor air quality is increasing and further stressing the public health sector. This confidence assignment is based on research that illuminates the association between morbidity and mortality during and after extreme heat events, such as the 2021 heat dome, and the increasing number of wildfire smoke days across the region. The authors also have *very high confidence* that climate change and extreme events worsen existing health disparities, unequally distributing the health burden on groups such as older adults, communities of color, Tribal communities, and low-income communities. On the basis of emerging research and case studies, the authors have *high confidence* that climate adaptation and mitigation efforts can lead to health co-benefits.

Key Message 27.6

Climate Change Affects Heritage and Sense of Place

Description of Evidence Base

In the Northwest, a growing evidence base of scientific literature, gray literature, and community knowledges continues to elucidate the interactions between climate change and the regional amenities and lifestyles that make the Northwest an attractive place to live, work, and visit. For example, multiple peer-reviewed publications document the ways in which climate impacts have disrupted key industries

that are critical to supply chains and economic and community stability^{249,371,372,373} and local infrastructure (KM 27.4).³⁷⁵ Additionally, multiple peer-reviewed publications document the interactions between climate change and land use, such as growth of the wildland-urban interface^{302,303,304} and the increasing community exposure to climate-related events such as wildfires and flooding.^{303,374,381} Multiple publications document these cumulative risks to safety, amenity access, and sense of place across the Northwest.^{376,377,378,379,380,388}

The literature has documented how places with more or higher-quality environmental amenities (e.g., recreation, proximity to outdoors, good air and water quality, less traffic congestion) drives migration to more rural and exurban areas.^{263,382} A wealth of gray literature and some peer-reviewed research document how climate change affects amenities, including recreation across all seasons^{79,384} and environmental quality.³⁹⁰ There are multiple peer-reviewed publications that document how impacts to these amenities can lead to regional emigration, migration, and displacement, especially as a result of climate-related extremes.^{394,395,396,397,398}

There are multiple lines of research that detail climate-related impacts to place-based communities. For example, climate change will affect Tribes' cultural and subsistence resources,^{92,251,265,363,364,399,400} which can have adverse impacts on Tribal sense of place and Tribal health and well-being (KM 27.5).^{93,95,363,393,401} Other communities that have generational ties to specific rural or exurban areas—such as industry-specific workers and communities of color—will experience indirect and cascading amenity impacts from climate change that can drive migration either from or into specific regions.^{394,396,398}

There are multiple examples of how leveraging community knowledges can result in successful adaptation outcomes; however, the bulk of this research is specific to Tribal communities.^{258,399,402,403,404,408,409,411} There is emerging research that documents how other types of local knowledge and community values can drive climate action.^{412,413}

Major Uncertainties and Research Gaps

Generally, the social science research within the Northwest is still developing and strengthening understanding of the connections between climate change and regional sense of place and heritage. Therefore, there are still many uncertainties and research gaps. This includes understanding social and economic responses to extreme events or repeated exposures to climate hazards, how these responses drive intra-regional migration, and how amenity migration can lead to cascading effects of displacement of other place-based communities (e.g., communities that strongly identify with specific industries, such as timber or fishing). There is also uncertainty in motivators for climate action by institutions. While some research is available on the social and political dimensions of climate action, including many case studies, the evidence base is nascent.

Description of Confidence and Likelihood

Research on climate change impacts to regional amenities, heritage, and sense of place varies by place, amenity, culture, and place. However, a common theme across the evidence base is that climate change is disrupting these regional values and cultures. Accordingly, the authors have *high confidence* that climate change is affecting regional amenities, heritage, and sense of place. Additionally, the authors have *very high confidence* that climate change is affecting place-based communities, such as Tribes and natural resource-based communities, given the breadth of regional and national research on these disproportionate impacts. Extensive scholarship highlights how integrating local and Indigenous Knowledges can support community resilience to climate change. However, there is limited research on how local heritage and values, such as environmental or sustainability values, can lead to climate adaptation and mitigation actions. Therefore, the authors have *medium confidence* that regional heritage and values can spur climate action to ensure the persistence of heritages, cultures, and amenities across the Northwest.

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