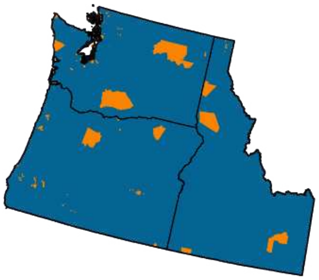
Fifth National Climate Assessment: Chapter 27

Northwest



Chapter 27. Northwest

Authors and Contributors

Federal Coordinating Lead Author

Li Erikson, US Geological Survey, Pacific Coastal and Marine Science Center

Chapter Lead Author

Michael Chang, Cascadia Consulting Group

Chapter Authors

Kathleen Araújo, Boise State University, CAES Energy Policy Institute
Erica N. Asinas, University of Washington, Climate Impacts Group
Samantha Chisholm Hatfield, Oregon State University
Lisa G. Crozier, NOAA Fisheries, Northwest Fisheries Science Center
Erica Fleishman, Oregon State University
Ciarra S. Greene, Sapóoq'is Wíit'as Consulting
Eric E. Grossman, US Geological Survey, Pacific Coastal and Marine Science Center
Charles Luce, USDA Forest Service
Jayash Paudel, University of Oklahoma
Kirti Rajagopalan, Washington State University, Department of Biological Systems Engineering
Elise Rasmussen, Washington State Department of Health
Crystal Raymond, University of Washington, Climate Impacts Group
Julian J. Reyes, US Department of Agriculture
Vivek Shandas, Portland State University

Technical Contributors

Blane L. Bellerud, NOAA Fisheries, West Coast Region
Su J. Kim, NOAA Fisheries, Northwest Fisheries Science Center
Angela Pietschmann, Cascadia Consulting Group

Review Editor

Kathryn McConnell, Brown University

Cover Art

Claire Seaman

Recommended Citation

Chang, M., L. Erikson, K. Araújo, E.N. Asinas, S. Chisholm Hatfield, L.G. Crozier, E. Fleishman, C.S. Greene, E.E. Grossman, C. Luce, J. Paudel, K. Rajagopalan, E. Rasmussen, C. Raymond, J.J. Reyes, and V. Shandas, 2023: Ch. 27. Northwest. In: *Fifth National Climate Assessment*. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA. https://doi.org/10.7930/NCA5.2023.CH27

Table of Contents

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]

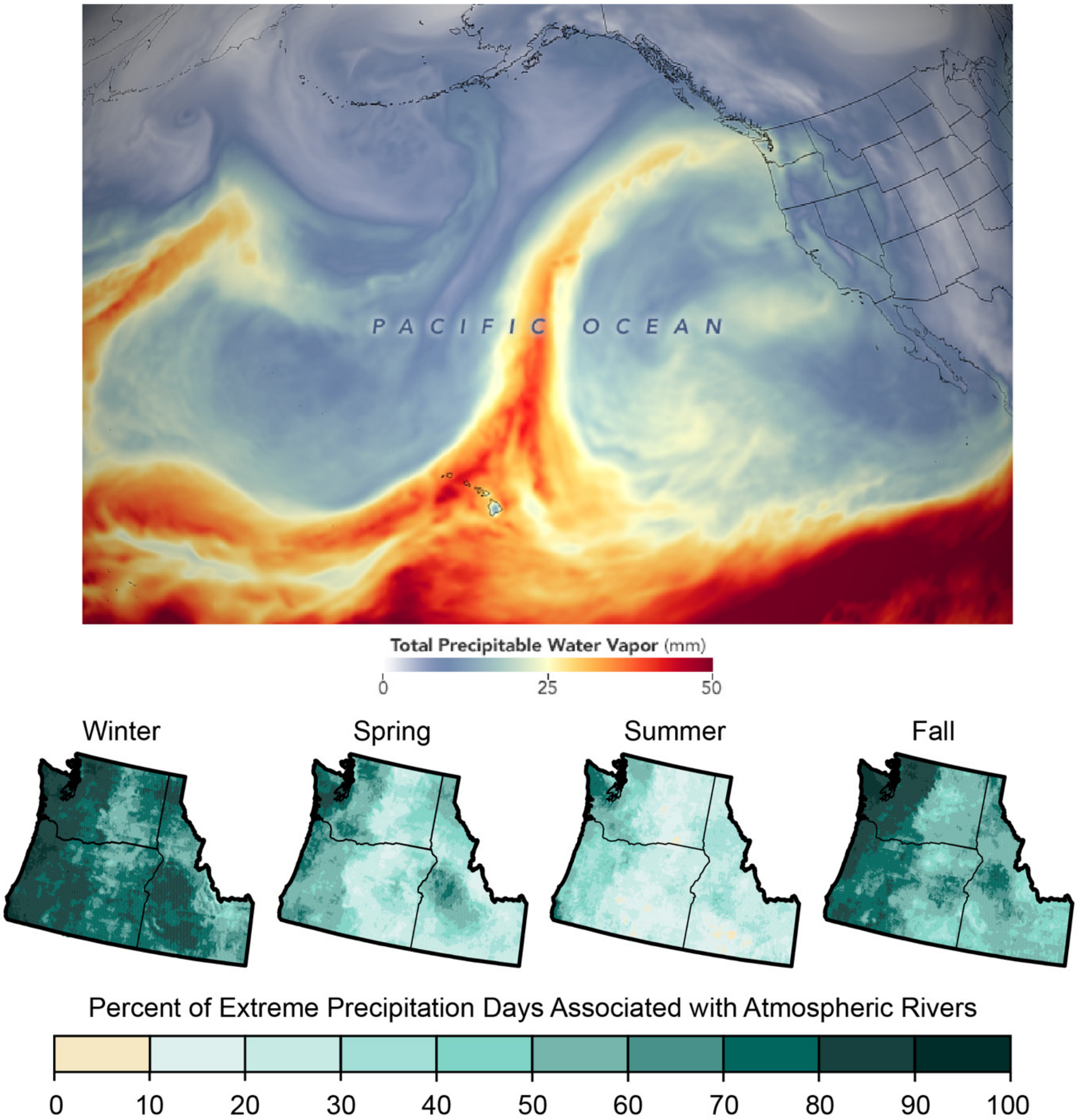
Warmer winter temperatures have led to declines in mountain snowpack, particularly in areas with warm maritime climates.[11,12,13,14] A greater proportion of winter precipitation is projected to fall as rain rather than snow.[15] Warmer winter temperatures are expected to increase snow-line elevation, 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 Slinskey 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 seabirds[48] 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 scenarios[55] 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]

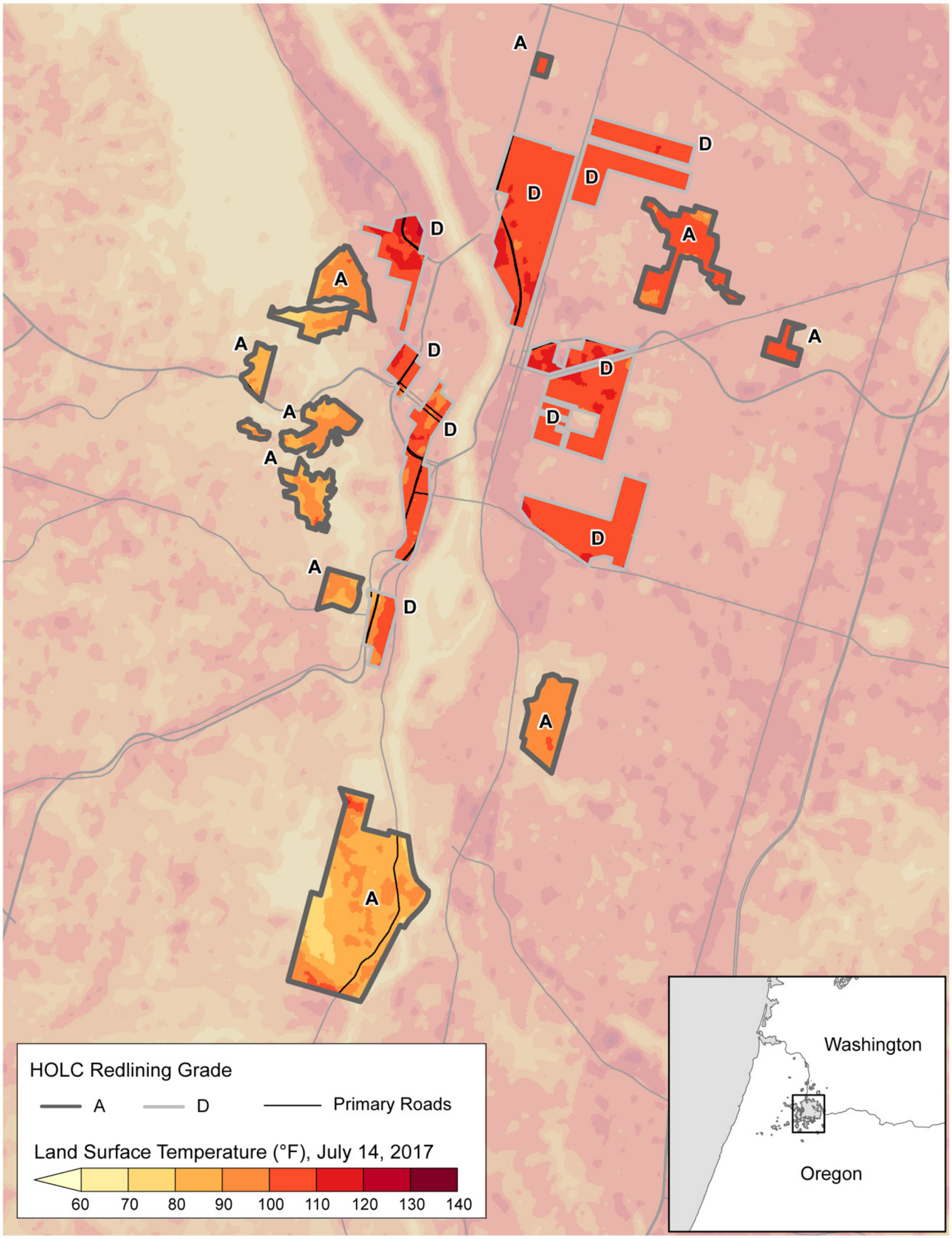
While many types of frontline communities exist—such as unhoused individuals, young children, older adults, and people with preexisting health conditions—this section highlights three communities: low-income urban communities of color, rural and natural resource–dependent communities, and Tribes and 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.[59,99,100] 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.[113,114,115] Because concurrent heat and drought are becoming more common,[116] 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.[117] Some low-elevation and dry areas are converting from forest to shrubland after wildfires, and these transitions are expected to continue in the Northwest.[118,119]

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 spring[120] 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.[117,124]

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*)[48] and common murres (*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 ecosystems[154] 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.[161,178,179] 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 habitat[182] and marine survival[174] 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.[191] 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 salmon[194] 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 wetlands[208] or the effectiveness of wetland mitigation banks[209] 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

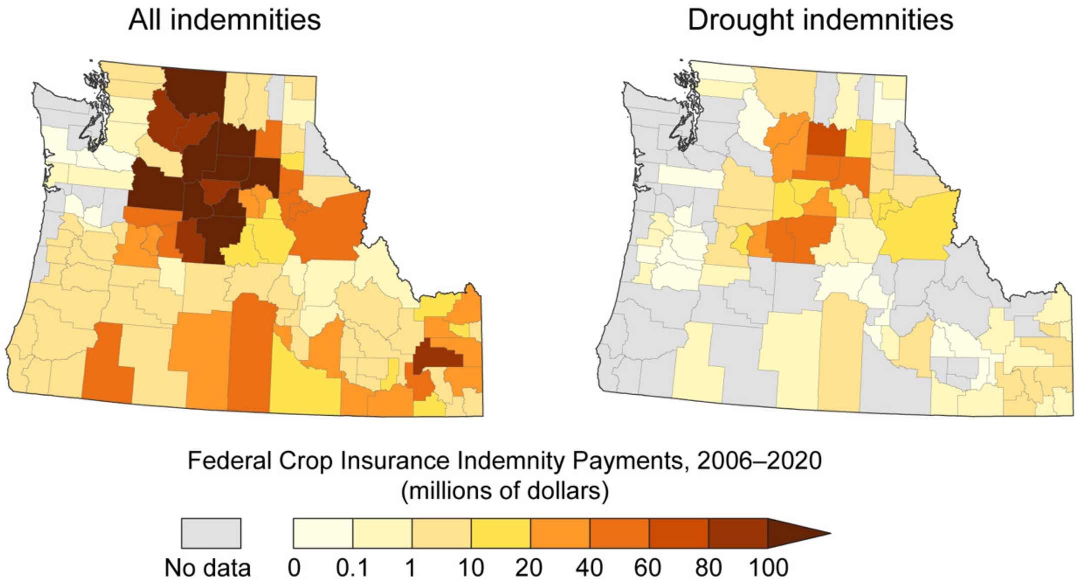
The Northwest encompasses 138.8 million acres of public and private cropland, grassland, pasture, rangeland, and forests,[214] and agricultural production totaled $6.28 billion in 2021 (in 2021 dollars).[215] The agricultural economy includes farms and ranches that have been in operation for multiple 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.[117,239,240]

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).[241] 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]

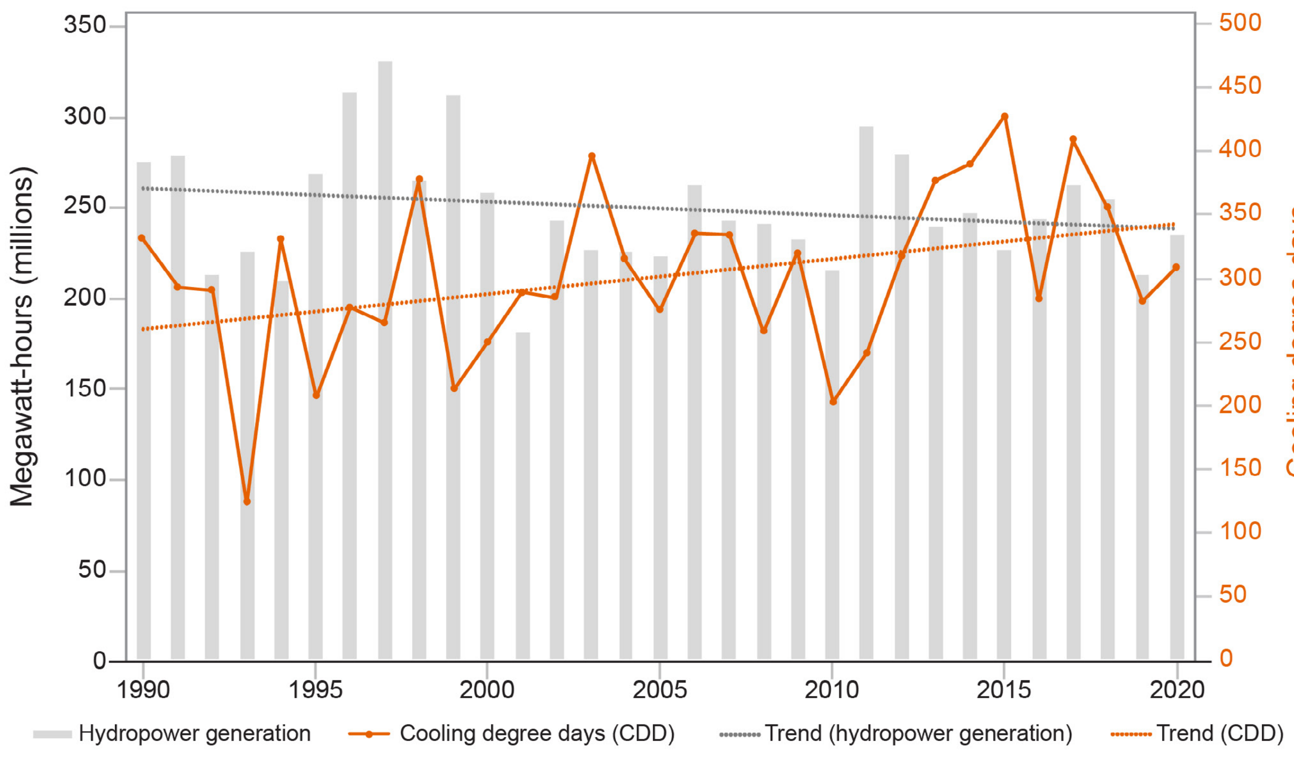
Emerging data and technologies can make drinking water and stormwater systems more resilient to climate change. For example, projections of changes in storm duration, intensity, and frequency[285] provide information needed to upgrade stormwater systems to reduce stresses from extreme precipitation.[286,287] 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.

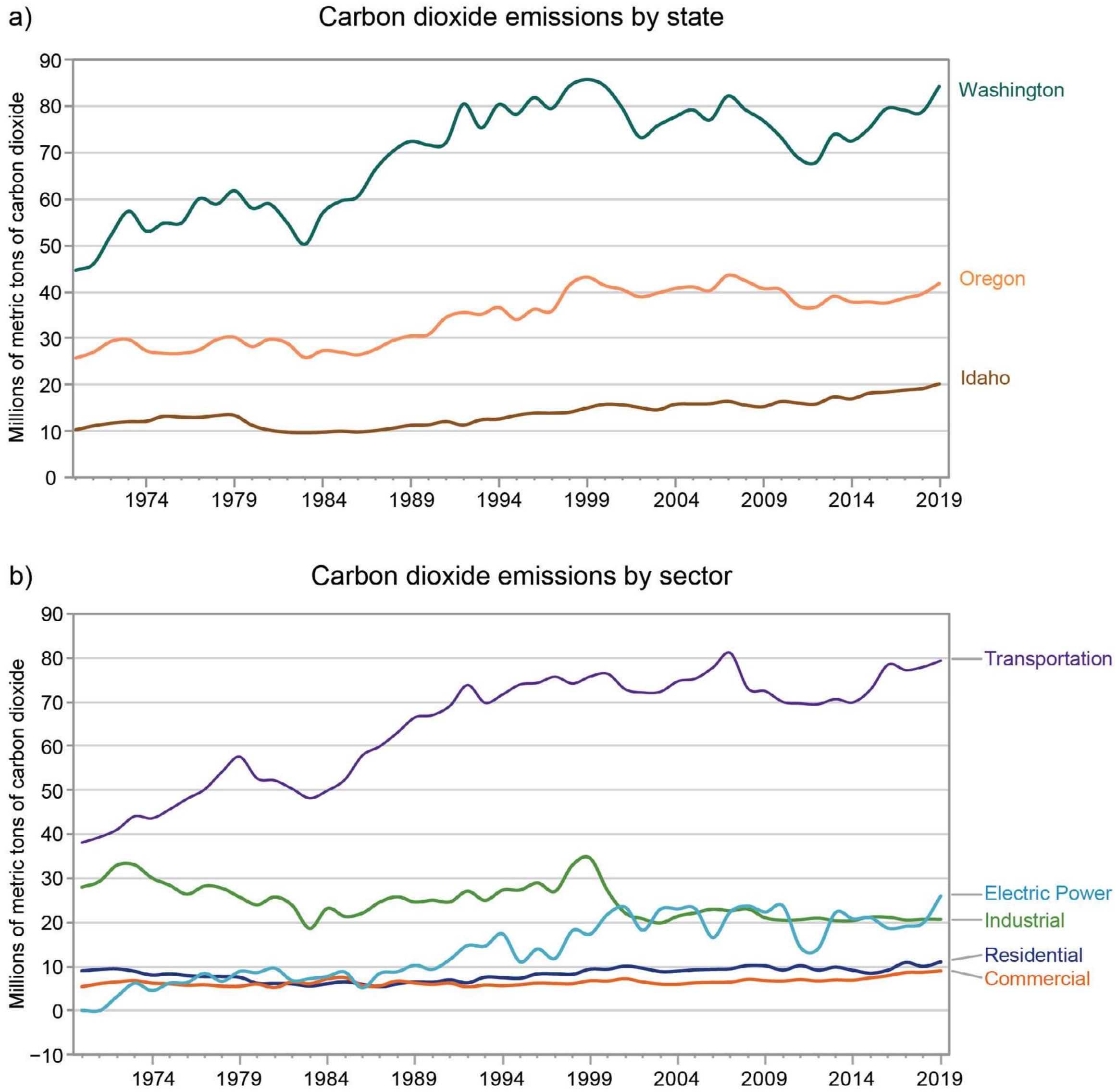
Box 27.3. Washington State's Electric Utility Wildland Fire Prevention Task Force

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 Force[299] 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 (CO_2) 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 CO_2 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).[314,316]

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.[68,100] 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).[102,318]

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

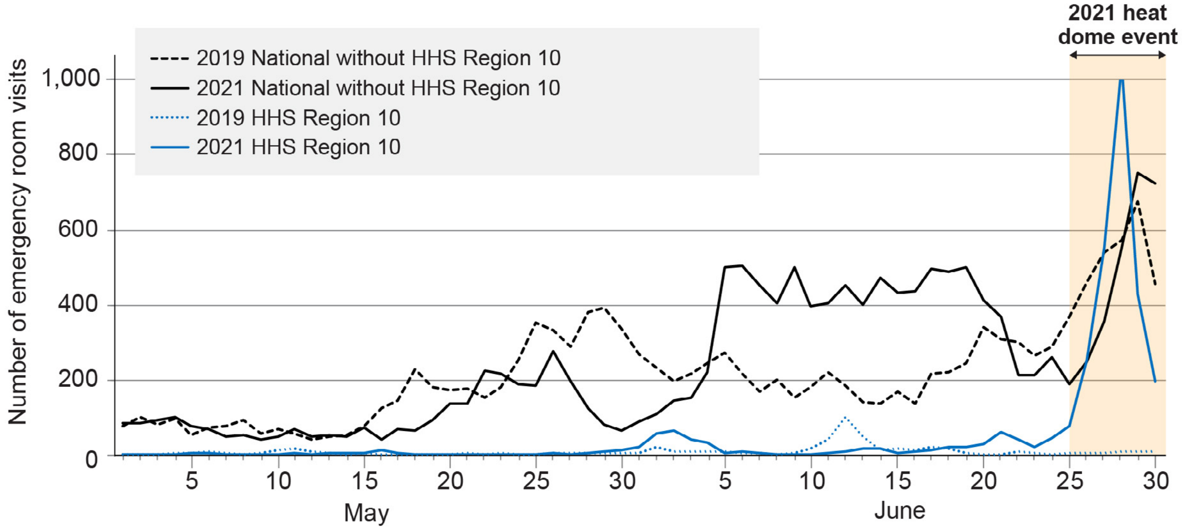
The Northwest's climate has historically been temperate and relatively mild, but shifting weather patterns associated with climate change are adversely affecting physical, mental, and community health (*very high confidence*). The incidence of illnesses and death during extreme heat events and wildfire 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

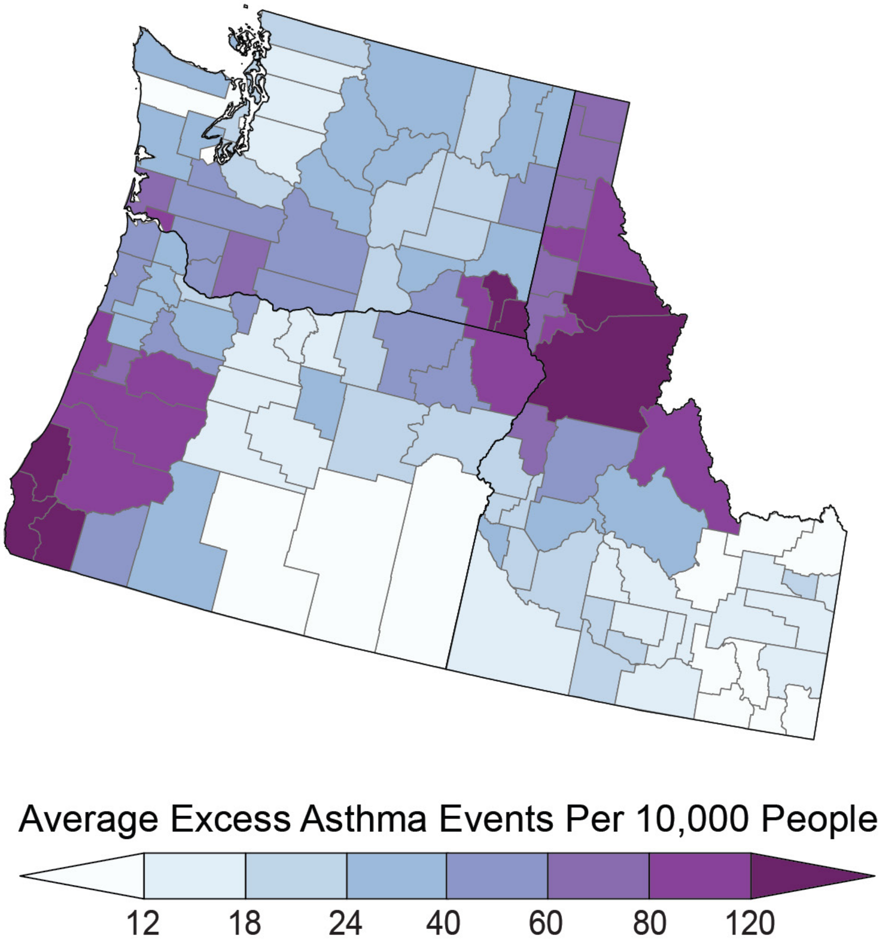


Heatwaves, such as the heat dome event in the summer of 2021, place strains on healthcare systems.

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 (μg/m^3) over the course of a summer.[322] Increased particulate matter ($PM_{2.5}$) 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 $PM_{2.5}$ 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. 2022[336] [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-ventilation 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).

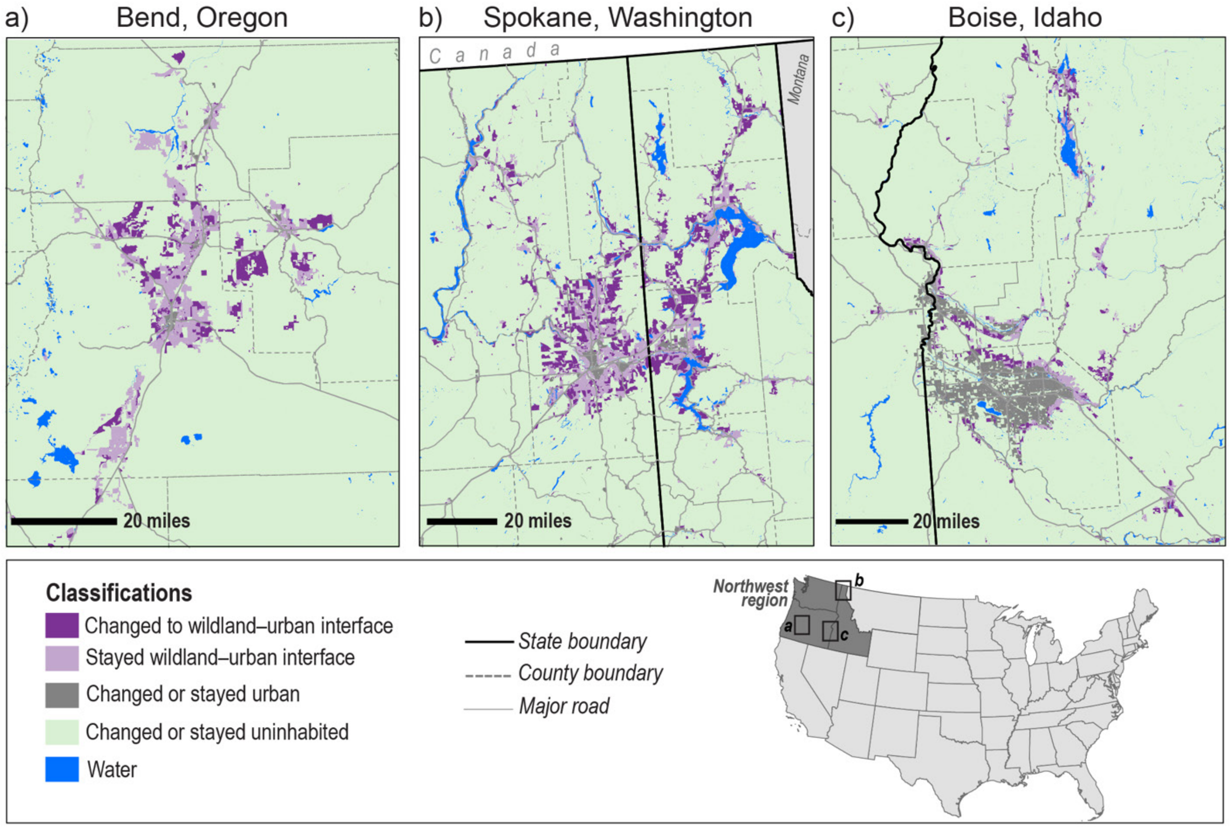
Heritage, Sense of Place, and Amenities at Risk

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),[102,103,104] 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.[79]

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.[411]

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,[412,413] 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.[59,61,62,67,68,70,71,74,75,76,77,89,92,93,95,414]

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,[79,80,81] 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,[107,109] 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 change[189] 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.[212,213] 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 opportunities 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.[100,142,273,278,279,291,307,308,311,318,323] 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.[29,281,282,283,323]

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 interrelated 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.[265,322,337,345,350,351,352,358,359,360,363,364] 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[102,103,104] and the increasing community exposure to climate-related events such as wildfires and flooding.[103,374,381] 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.[251,399,402,403,404,408,409,411] 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.

References

1. U.S. Census Bureau, 2021: 2020 Census Apportionment Results. U.S. Department of Commerce, U.S. Census Bureau. https://www.census.gov/data/tables/2020/dec/2020-apportionment-data.html

2. Kates, R.W., W.R. Travis, and T.J. Wilbanks, 2012: Transformational adaptation when incremental adaptations to climate change are insufficient. *Proceedings of the National Academy of Sciences of the United States of America*, **109** (19), 7156–7161. https://doi.org/10.1073/pnas.1115521109

3. Wilson, R.S., A. Herziger, M. Hamilton, and J.S. Brooks, 2020: From incremental to transformative adaptation in individual responses to climate-exacerbated hazards. *Nature Climate Change*, **10** (3), 200–208. https://doi.org/10.1038/s41558-020-0691-6

4. May, K., C. Luce, J. Casola, M. Chang, J. Cuhaciyan, M. Dalton, S. Lowe, G. Morishima, P. Mote, A. Petersen, G. Roesch-McNally, and E. York, 2018: Ch. 24. Northwest. In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. Reidmiller, D.R., C.W. Avery, D. Easterling, K. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart, Eds. U.S. Global Change Research Program, Washington, DC, USA, 1036–1100. https://doi.org/10.7930/nca4.2018.ch24

5. Mote, P., A.K. Snover, S. Capalbo, S.D. Eigenbrode, P. Glick, J. Littell, R. Raymondi, and S. Reeder, 2014: Ch. 21. Northwest. In: *Climate Change Impacts in the United States: The Third National Climate Assessment*. Melillo, J.M., T.C. Richmond, and G.W. Yohe, Eds. U.S. Global Change Research Program, Washington, DC, 487–513. https://doi.org/10.7930/j04q7rwx

6. Vose, R.S., D.R. Easterling, K.E. Kunkel, A.N. LeGrande, and M.F. Wehner, 2017: Ch. 6. Temperature changes in the United States. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I*. Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA, 185–206. https://doi.org/10.7930/j0n29v45

7. Frankson, R., K.E. Kunkel, S.M. Champion, D.R. Easterling, L.E. Stevens, K. Bumbaco, N. Bond, J. Casola, and W. Sweet, 2022: Washington State Climate Summary 2022. NOAA Technical Report NESDIS 150-WA. National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service, Silver Spring, MD. 5 pp. https://statesummaries.ncics.org/chapter/wa/

8. Runkle, J., K.E. Kunkel, R. Frankson, S.M. Champion, L.E. Stevens, and J. Abatzoglou, 2022: Idaho State Climate Summary 2022. NOAA Technical Report NESDIS 150-ID. National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service, Silver Spring, MD, 4 pp. https://statesummaries.ncics.org/chapter/id/

9. Rogers, M. and G.S. Mauger, 2021: Pacific Northwest Climate Projection Tool. University of Washington, Climate Impacts Group. https://cig.uw.edu/resources/analysis-tools/pacific-northwest-climate-projection-tool/

10. Salathé Jr., E.P., A. Beggs, C. McJunkin, and S. Sandhu, 2023: The relative warming rates of heat events and median days in the Pacific Northwest from observations and a regional climate model. *Journal of Climate*, **36** (8), 2471–2481. https://doi.org/10.1175/jcli-d-22-0313.1

11. Humes, K., R. Walters, J. Ryu, R. Mahler, and C. Woodruff, 2021: Water report. In: *Idaho Climate-Economy Impacts Assessment*. James A. & Louise McClure Center for Public Policy Research, University of Idaho. https://www.uidaho.edu/president/direct-reports/mcclure-center/iceia/water

12. Ikeda, K., R. Rasmussen, C. Liu, A. Newman, F. Chen, M. Barlage, E. Gutmann, J. Dudhia, A. Dai, C. Luce, and K. Musselman, 2021: Snowfall and snowpack in the western U.S. as captured by convection permitting climate simulations: Current climate and pseudo global warming future climate. *Climate Dynamics*, **57** (7), 2191–2215. https://doi.org/10.1007/s00382-021-05805-w

13. Lute, A.C. and C.H. Luce, 2017: Are model transferability and complexity antithetical? Insights from validation of a variable-complexity empirical snow model in space and time. *Water Resources Research*, **53** (11), 8825–8850. https://doi.org/10.1002/2017wr020752

14. Mote, P.W., S. Li, D.P. Lettenmaier, M. Xiao, and R. Engel, 2018: Dramatic declines in snowpack in the western US. *Npj Climate and Atmospheric Science*, **1** (1), 1–6. https://doi.org/10.1038/s41612-018-0012-1

15. Nolin, A.W. and C. Daly, 2006: Mapping “at risk” snow in the Pacific Northwest. *Journal of Hydrometeorology*, **7** (5), 1164–1171. https://doi.org/10.1175/jhm543.1

16. Clifton, C.F., K.T. Day, C.H. Luce, G.E. Grant, M. Safeeq, J.E. Halofsky, and B.P. Staab, 2018: Effects of climate change on hydrology and water resources in the Blue Mountains, Oregon, USA. *Climate Services*, **10**, 9–19. https://doi.org/10.1016/j.cliser.2018.03.001
17. Wagner, A.M., K.E. Bennett, G.E. Liston, C.A. Hiemstra, and D. Cooley, 2021: Multiple indicators of extreme changes in snow-dominated streamflow regimes, Yakima River Basin region, USA. *Water*, **13**, 2608. https://doi.org/10.3390/w13192608
18. Chang, H., I.-W. Jung, M. Steele, and M. Gannett, 2012: Spatial patterns of March and September streamflow trends in Pacific Northwest streams, 1958–2008. *Geographical Analysis*, **44** (3), 177–201. https://doi.org/10.1111/j.1538-4632.2012.00847.x
19. Dalton, M., and E. Fleishman, Ed. 2021: *Fifth Oregon Climate Assessment*. Oregon State University, Oregon Climate Change Research Institute, Corvallis, OR. https://ir.library.oregonstate.edu/concern/technical_reports/pz50h457p
20. Kormos, P.R., C.H. Luce, S.J. Wenger, and W.R. Berghuijs, 2016: Trends and sensitivities of low streamflow extremes to discharge timing and magnitude in Pacific Northwest mountain streams. *Water Resources Research*, **52** (7), 4990–5007. https://doi.org/10.1002/2015wr018125
21. Fountain, A.G., C. Gray, B. Glenn, B. Menounos, J. Pflug, and J.L. Riedel, 2022: Glaciers of the Olympic Mountains, Washington—The past and future 100 years. *Journal of Geophysical Research: Earth Surface*, **127** (4), e2022JF006670. https://doi.org/10.1029/2022jf006670
22. Frans, C., E. Istanbulluoglu, D.P. Lettenmaier, A.G. Fountain, and J. Riedel, 2018: Glacier recession and the response of summer streamflow in the Pacific Northwest United States, 1960–2099. *Water Resources Research*, **54** (9), 6202–6225. https://doi.org/10.1029/2017wr021764
23. Lee, S.-Y., A.F. Hamlet, and E.E. Grossman, 2016: Impacts of climate change on regulated streamflow, hydrologic extremes, hydropower production, and sediment discharge in the Skagit River Basin. *Northwest Science*, **90** (1), 23–43. https://doi.org/10.3955/046.090.0104
24. Lancaster, S.T., A.W. Nolin, E.A. Copeland, and G.E. Grant, 2012: Periglacial debris-flow initiation and susceptibility and glacier recession from imagery, airborne LiDAR, and ground-based mapping. *Geosphere*, **8** (2), 417–430. https://doi.org/10.1130/ges00713.1
25. Lorente-Plazas, R., T.P. Mitchell, G. Mauger, and E.P. Salathé, 2018: Local enhancement of extreme precipitation during atmospheric rivers as simulated in a regional climate model. *Journal of Hydrometeorology*, **19** (9), 1429–1446. https://doi.org/10.1175/jhm-d-17-0246.1
26. Gershunov, A., T. Shulgina, R.E.S. Clemesha, K. Guirguis, D.W. Pierce, M.D. Dettinger, D.A. Lavers, D.R. Cayan, S.D. Polade, J. Kalansky, and F.M. Ralph, 2019: Precipitation regime change in western North America: The role of atmospheric rivers. *Scientific Reports*, **9** (1), 9944. https://doi.org/10.1038/s41598-019-46169-w
27. Slinskey, E.A., P.C. Loikith, D.E. Waliser, B. Guan, and A. Martin, 2020: A climatology of atmospheric rivers and associated precipitation for the seven U.S. National Climate Assessment regions. *Journal of Hydrometeorology*, **21** (11), 2439–2456. https://doi.org/10.1175/jhm-d-20-0039.1
28. Xiong, Y. and X. Ren, 2021: Influences of atmospheric rivers on North Pacific winter precipitation: Climatology and dependence on ENSO condition. *Journal of Climate*, **34** (1), 277–292. https://doi.org/10.1175/jcli-d-20-0301.1
29. Corringham, T.W., F.M. Ralph, A. Gershunov, D.R. Cayan, and C.A. Talbot, 2019: Atmospheric rivers drive flood damages in the western United States. *Science Advances*, **5** (12). https://doi.org/10.1126/sciadv.aax4631
30. Hughes, M., D. Swales, J.D. Scott, M. Alexander, K. Mahoney, R.R. McCrary, R. Cifelli, and M. Bukovsky, 2022: Changes in extreme integrated water vapor transport on the U.S. west coast in NA-CORDEX, and relationship to mountain and inland precipitation. *Climate Dynamics*, **59** (3), 973–995. https://doi.org/10.1007/s00382-022-06168-6
31. Payne, A.E., M.-E. Demory, L.R. Leung, A.M. Ramos, C.A. Shields, J.J. Rutz, N. Siler, G. Villarini, A. Hall, and F.M. Ralph, 2020: Responses and impacts of atmospheric rivers to climate change. *Nature Reviews Earth & Environment*, **1** (3), 143–157. https://doi.org/10.1038/s43017-020-0030-5
32. Shields, C.A. and J.T. Kiehl, 2016: Atmospheric river landfall-latitude changes in future climate simulations. *Geophysical Research Letters*, **43** (16), 8775–8782. https://doi.org/10.1002/2016gl070470

33. Rutz, J.J., W.J. Steenburgh, and F.M. Ralph, 2014: Climatological characteristics of atmospheric rivers and their inland penetration over the western United States. *Monthly Weather Review*, **142** (2), 905–921. https://doi.org/10.1175/mwr-d-13-00168.1

34. Espinoza, V., D.E. Waliser, B. Guan, D.A. Lavers, and F.M. Ralph, 2018: Global analysis of climate change projection effects on atmospheric rivers. *Geophysical Research Letters*, **45** (9), 4299–4308. https://doi.org/10.1029/2017gl076968

35. Gao, Y., J. Lu, L.R. Leung, Q. Yang, S. Hagos, and Y. Qian, 2015: Dynamical and thermodynamical modulations on future changes of landfalling atmospheric rivers over western North America. *Geophysical Research Letters*, **42** (17), 7179–7186. https://doi.org/10.1002/2015gl065435

36. Mahoney, K., D. Swales, M.J. Mueller, M. Alexander, M. Hughes, and K. Malloy, 2018: An examination of an inland-penetrating atmospheric river flood event under potential future thermodynamic conditions. *Journal of Climate*, **31** (16), 6281–6297. https://doi.org/10.1175/jcli-d-18-0118.1

37. Warner, M.D. and C.F. Mass, 2017: Changes in the climatology, structure, and seasonality of northeast Pacific atmospheric rivers in CMIP5 climate simulations. *Journal of Hydrometeorology*, **18** (8), 2131–2141. https://doi.org/10.1175/jhm-d-16-0200.1

38. Massoud, E.C., V. Espinoza, B. Guan, and D.E. Waliser, 2019: Global climate model ensemble approaches for future projections of atmospheric rivers. *Earth's Future*, **7** (10), 1136–1151. https://doi.org/10.1029/2019EF001249

39. Howard, E.M., H. Frenzel, F. Kessouri, L. Renault, D. Bianchi, J.C. McWilliams, and C. Deutsch, 2020: Attributing causes of future climate change in the California Current System with multimodel downscaling. *Global Biogeochemical Cycles*, **34** (11), e2020GB006646. https://doi.org/10.1029/2020gb006646

40. Jewett, L. and A. Romanou, 2017: Ch. 13. Ocean acidification and other ocean changes. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I*. Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA, 364–392. https://doi.org/10.7930/j0qv3jqb

41. Siedlecki, S.A., D. Pilcher, E.M. Howard, C. Deutsch, P. MacCready, E.L. Norton, H. Frenzel, J. Newton, R.A. Feely, S.R. Alin, and T. Klinger, 2021: Coastal processes modify projections of some climate-driven stressors in the California Current System. *Biogeosciences*, **18** (9), 2871–2890. https://doi.org/10.5194/bg-18-2871-2021

42. Sunday, J.M., E. Howard, S. Siedlecki, D.J. Pilcher, C. Deutsch, P. MacCready, J. Newton, and T. Klinger, 2022: Biological sensitivities to high-resolution climate change projections in the California Current Marine Ecosystem. *Global Change Biology*, **28** (19), 5726–5740. https://doi.org/10.1111/gcb.16317

43. Feely, R.A., S.R. Alin, B. Carter, N. Bednaršek, B. Hales, F. Chan, T.M. Hill, B. Gaylord, E. Sanford, R.H. Byrne, C.L. Sabine, D. Greeley, and L. Juranek, 2016: Chemical and biological impacts of ocean acidification along the west coast of North America. *Estuarine, Coastal and Shelf Science*, **183** (Part A), 260–270. https://doi.org/10.1016/j.ecss.2016.08.043

44. Doney, S.C., D.S. Busch, S.R. Cooley, and K.J. Kroeker, 2020: The impacts of ocean acidification on marine ecosystems and reliant human communities. *Annual Review of Environment and Resources*, **45**, 83–112. https://doi.org/10.1146/annurev-environ-012320-083019

45. Feely, R.A., R.R. Okazaki, W.-J. Cai, N. Bednaršek, S.R. Alin, R.H. Byrne, and A. Fassbender, 2018: The combined effects of acidification and hypoxia on pH and aragonite saturation in the coastal waters of the California Current Ecosystem and the northern Gulf of Mexico. *Continental Shelf Research*, **152**, 50–60. https://doi.org/10.1016/j.csr.2017.11.002

46. Pelletier, G., L. Bianucci, W. Long, T. Khangaonkar, T. Mohamedali, A. Ahmed, and C. Figueroa-Kaminsky, 2017: Salish Sea Model: Ocean Acidification Module and the Response to Regional Anthropogenic Nutrient Sources. Publication No. 17-03-009. State of Washington, Department of Ecology. https://apps.ecology.wa.gov/publications/documents/1703009.pdf

47. Gentemann, C.L., M.R. Fewings, and M. García-Reyes, 2017: Satellite sea surface temperatures along the West Coast of the United States during the 2014–2016 northeast Pacific marine heat wave. *Geophysical Research Letters*, **44** (1), 312–319. https://doi.org/10.1002/2016gl071039

48. Jones, T., J.K. Parrish, W.T. Peterson, E.P. Bjorkstedt, N.A. Bond, L.T. Ballance, V. Bowes, J.M. Hipfner, H.K. Burgess, J.E. Dolliver, K. Lindquist, J. Lindsey, H.M. Nevins, R.R. Robertson, J. Roletto, L. Wilson, T. Joyce, and J. Harvey, 2018: Massive mortality of a planktivorous seabird in response to a marine heatwave. *Geophysical Research Letters*, **45** (7), 3193–3202. https://doi.org/10.1002/2017gl076164

49. NMFS, 2022: 2019-2022 Gray Whale Unusual Mortality Event along the West Coast and Alaska. National Oceanic and Atmospheric Administration, National Marine Fisheries Service. https://www.fisheries.noaa.gov/national/marine-life-distress/2019-2022-gray-whale-unusual-mortality-event-along-west-coast-and

50. Amaya, D.J., A.J. Miller, S.-P. Xie, and Y. Kosaka, 2020: Physical drivers of the summer 2019 North Pacific marine heatwave. *Nature Communications*, **11** (1), 1903. https://doi.org/10.1038/s41467-020-15820-w

51. Bond, N.A., M.F. Cronin, H. Freeland, and N. Mantua, 2015: Causes and impacts of the 2014 warm anomaly in the NE Pacific. *Geophysical Research Letters*, **42** (9), 3414–3420. https://doi.org/10.1002/2015gl063306

52. Oliver, E.C.J., J.A. Benthuysen, S. Darmaraki, M.G. Donat, A.J. Hobday, N.J. Holbrook, R.W. Schlegel, and A. Sen Gupta, 2021: Marine heatwaves. *Annual Review of Marine Science*, **13** (1), 313–342. https://doi.org/10.1146/annurev-marine-032720-095144

53. Peterson, W.T., J.L. Fisher, P.T. Strub, X. Du, C. Risien, J. Peterson, and C.T. Shaw, 2017: The pelagic ecosystem in the Northern California Current off Oregon during the 2014–2016 warm anomalies within the context of the past 20 years. *Journal of Geophysical Research: Oceans*, **122** (9), 7267–7290. https://doi.org/10.1002/2017jc012952

54. Trainer, V.L., S.K. Moore, G. Hallegraeff, R.M. Kudela, A. Clement, J.I. Mardones, and W.P. Cochlan, 2020: Pelagic harmful algal blooms and climate change: Lessons from nature's experiments with extremes. *Harmful Algae*, **91**, 101591. https://doi.org/10.1016/j.hal.2019.03.009

55. Sweet, W.V., B.D. Hamlington, R.E. Kopp, C.P. Weaver, P.L. Barnard, D. Bekaert, W. Brooks, M. Craghan, G. Dusek, T. Frederikse, G. Garner, A.S. Genz, J.P. Krasting, E. Larour, D. Marcy, J.J. Marra, J. Obeysekera, M. Osler, M. Pendleton, D. Roman, L. Schmied, W. Veatch, K.D. White, and C. Zuzak, 2022: Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 111 pp. https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report-sections.html

56. Newton, T.J., R. Weldon, I.M. Miller, D. Schmidt, G. Mauger, H. Morgan, and E. Grossman, 2021: An assessment of vertical land movement to support coastal hazards planning in Washington state. *Water*, **13** (3). https://doi.org/10.3390/w13030281

57. Taherkhani, M., S. Vitousek, P.L. Barnard, N. Frazer, T.R. Anderson, and C.H. Fletcher, 2020: Sea-level rise exponentially increases coastal flood frequency. *Scientific Reports*, **10** (1), 6466. https://doi.org/10.1038/s41598-020-62188-4

58. Miller, I.M., H. Morgan, G. Mauger, T. Newton, R. Weldon, D. Schmidt, M. Welch, and E. Grossman, 2018: Projected Sea Level Rise for Washington State—A 2018 Assessment. University of Washington, 24 pp. https://cig.uw.edu/projects/projected-sea-level-rise-for-washington-state-a-2018-assessment/

59. UW Climate Impacts Group, 2018: *An Unfair Share: Exploring the Disproportionate Risks from Climate Change Facing Washington State Communities*. University of Washington, Seattle, WA. https://cig.uw.edu/projects/an-unfair-share/

60. Voelkel, J., D. Hellman, R. Sakuma, and V. Shandas, 2018: Assessing vulnerability to urban heat: A study of disproportionate heat exposure and access to refuge by socio-demographic status in Portland, Oregon. *International Journal of Environmental Research and Public Health*, **15** (4), 640. https://doi.org/10.3390/ijerph15040640

61. Farrell, J., P.B. Burow, K. McConnell, J. Bayham, K. Whyte, and G. Koss, 2021: Effects of land dispossession and forced migration on Indigenous peoples in North America. *Science*, **374** (6567), 4943. https://doi.org/10.1126/science.abe4943

62. Lane, H.M., R. Morello-Frosch, J.D. Marshall, and J.S. Apte, 2022: Historical redlining is associated with present-day air pollution disparities in U.S. cities. *Environmental Science & Technology Letters*, **9** (4), 345–350. https://doi.org/10.1021/acs.estlett.1c01012

63. Alvarez, C.H., 2023: Structural racism as an environmental justice issue: A multilevel analysis of the state racism index and environmental health risk from air toxics. *Journal of Racial and Ethnic Health Disparities*, **10** (1), 244–258. https://doi.org/10.1007/s40615-021-01215-0

64. Colon, J., 2016: The Disproportionate Impacts of Climate Change on Communities of Color in Washington State. Front and Centered, 6 pp. https://frontandcentered.org/the-disproportionate-impacts-of-climate-change-on-communities-of-color-in-washington-state/

65. Digital Scholarship Lab and the National Community Reinvestment Coalition, 2020: Not even past: Social vulnerability and the legacy of redlining. In: *American Panorama*. Nelson, R. and E. Ayers, Eds. The Digital Scholarship Lab and the National Community Reinvestment Coalition. https://dsl.richmond.edu/socialvulnerability/

66. Priske, M., 2020: Environmental Racism and Economic Health Injustice: Exploring the LatinX Community in Eugene, Oregon. ArcGIS. https://storymaps.arcgis.com/stories/d519ab45cfc646438b8e91e846d674af

67. Bencivengo, A., E. Clark, M. Davies, E. Kushkowski, A. Loukides, F. Marten, A. Miller, L.I. Parker, H. Wise, and S. Witte, 2017: Vulnerability and Climate Change Adaptation Planning: Heat and Floods in Portland, Oregon. Reed College, Environmental Studies Department Junior Seminar, 62 pp. https://www.reed.edu/es/assets/es_300_2017_vulnerability-and-climate-change-adaptation-planning.pdf

68. Hoffman, J.S., V. Shandas, and N. Pendleton, 2020: The effects of historical housing policies on resident exposure to intra-urban heat: A study of 108 US urban areas. *Climate*, **8** (1), 12. https://doi.org/10.3390/cli8010012

69. Arnold, L., M.D. Scheuerell , and T. Busch Isaksen 2022: Mortality associated with extreme heat in Washington state: The historical and projected public health burden. *Atmosphere*, **13** (9), 1392. https://doi.org/10.3390/atmos13091392

70. Earth Economics, 2020: Urban Heat Island Analysis. Earth Economics, Tacoma, WA, 2 pp. https://cms.cityoftacoma.org/enviro/urbanforestry/tacomawa_heatislandanalysis.pdf

71. Schell, C.J., K. Dyson, T.L. Fuentes, S.D. Roches, N.C. Harris, D.S. Miller, C.A. Woelfle-Erskine, and M.R. Lambert, 2020: The ecological and evolutionary consequences of systemic racism in urban environments. *Science*, **369** (6510), 4497. https://doi.org/10.1126/science.aay4497

72. He, B.-J., J. Zhu, D.-X. Zhao, Z.-H. Gou, J.-D. Qi, and J. Wang, 2019: Co-benefits approach: Opportunities for implementing sponge city and urban heat island mitigation. *Land Use Policy*, **86**, 147–157. https://doi.org/10.1016/j.landusepol.2019.05.003

73. Richards, D.R. and P.J. Edwards, 2018: Using water management infrastructure to address both flood risk and the urban heat island. *International Journal of Water Resources Development*, **34** (4), 490–498. https://doi.org/10.1080/07900627.2017.1357538

74. Fischer, A.P., 2019: Pathways of adaptation to external stressors in coastal natural-resource-dependent communities: Implications for climate change. *World Development*, **108**, 235–248. https://doi.org/10.1016/j.worlddev.2017.12.007

75. Childs, M.L., J. Li, J. Wen, S. Heft-Neal, A. Driscoll, S. Wang, C.F. Gould, M. Qiu, J. Burney, and M. Burke, 2022: Daily local-level estimates of ambient wildfire smoke/$PM_{2.5}$ for the contiguous US. *Environmental Science & Technology*, **56** (19), 13607–13621. https://doi.org/10.1021/acs.est.2c02934

76. Tigchelaar, M., D.S. Battisti, and J.T. Spector, 2020: Work adaptations insufficient to address growing heat risk for U.S. agricultural workers. *Environmental Research Letters*, **15** (9), 094035. https://doi.org/10.1088/1748-9326/ab86f4

77. Calkins, M.M., D. Bonauto, A. Hajat, M. Lieblich, N. Seixas, L. Sheppard, and J.T. Spector, 2019: A case-crossover study of heat exposure and injury risk among outdoor construction workers in Washington State. *Scandinavian Journal of Work, Environment & Health*, **45** (6), 588–599. https://doi.org/10.5271/sjweh.3814

78. Oregon Health Authority, 2020: Climate and Health in Oregon 2020 Report. Oregon Health Authority, Public Health Division. https://www.oregon.gov/oha/ph/healthyenvironments/climatechange/documents/2020/climate%20and%20health%20in%20oregon%202020%20-%20full%20report.pdf

79. Miller, A.B., P.L. Winter, J.J. Sánchez, D.L. Peterson, and J.W. Smith, 2022: Climate change and recreation in the western United States: Effects and opportunities for adaptation. *Journal of Forestry*, **120** (4), 453–472. https://doi.org/10.1093/jofore/fvab072

80. Petersen-Rockney, M., P. Baur, A. Guzman, S.F. Bender, A. Calo, F. Castillo, K. De Master, A. Dumont, K. Esquivel, C. Kremen, J. LaChance, M. Mooshammer, J. Ory, M.J. Price, Y. Socolar, P. Stanley, A. Iles, and T. Bowles, 2021: Narrow and brittle or broad and nimble? Comparing adaptive capacity in simplifying and diversifying farming systems. *Frontiers in Sustainable Food Systems*, **5**, 564900. https://doi.org/10.3389/fsufs.2021.564900

81. Weiler, A.M., 2022: Farmworkers, climate change, and "converging crises". *Gastronomica*, **22** (1), 44–49. https://doi.org/10.1525/gfc.2022.22.1.44

82. Lavoie, A.L., K. Dentzman, and C.B. Wardropper, 2021: Using diffusion of innovations theory to understand agricultural producer perspectives on cover cropping in the inland Pacific Northwest, USA. *Renewable Agriculture and Food Systems*, **36** (4), 384–395. https://doi.org/10.1017/s1742170520000423

83. Roesch-McNally, G., A. Garrett, and M. Fery, 2020: Assessing perceptions of climate risk and adaptation among small farmers in Oregon's Willamette Valley. *Renewable Agriculture and Food Systems*, **35** (6), 626–630. https://doi.org/10.1017/s1742170519000267

84. Wardropper, C.B., J.P. Angerer, M. Burnham, M.E. Fernández-Giménez, V.S. Jansen, J.W. Karl, K. Lee, and K. Wollstein, 2021: Improving rangeland climate services for ranchers and pastoralists with social science. *Current Opinion in Environmental Sustainability*, **52**, 82–91. https://doi.org/10.1016/j.cosust.2021.07.001

85. Boag, A.E., J. Hartter, L.C. Hamilton, N.D. Christoffersen, F.R. Stevens, M.W. Palace, and M.J. Ducey, 2018: Climate change beliefs and forest management in eastern Oregon: Implications for individual adaptive capacity. *Ecology and Society*, **23** (4). https://doi.org/10.5751/es-10355-230401

86. Haltinner, K. and D. Sarathchandra, 2021: Considering attitudinal uncertainty in the climate change skepticism continuum. *Global Environmental Change*, **68**, 102243. https://doi.org/10.1016/j.gloenvcha.2021.102243

87. Maas, A., C. Wardropper, G. Roesch-McNally, and J. Abatzoglou, 2020: A (mis)alignment of farmer experience and perceptions of climate change in the U.S. inland pacific northwest. *Climatic Change*, **162** (3), 1011–1029. https://doi.org/10.1007/s10584-020-02713-6

88. Hand, J.P., 2008: Global climate change: A serious threat to Native American lands and culture. *Environmental Law Reporter-News & Analysis*, **38**, 10329. https://heinonline.org/HOL/LandingPage?handle=hein.journals/elrna38&div=28&id=&page=

89. Vinyeta, K. and K. Lynn, 2013: Exploring the Role of Traditional Ecological Knowledge in Climate Change Initiatives. Gen. Tech. Rep. PNW-GTR-879. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, 37 pp. https://doi.org/10.2737/pnw-gtr-879

90. Burkett, M., R.R.M. Verchick, and D. Flores, 2017: Reaching Higher Ground: Avenues to Secure and Manage New Land for Communities Displaced by Climate Change. Research Paper No. 2017-07. Loyola University New Orleans College of Law, Center for Progressive Reform. https://ssrn.com/abstract=3034040

91. Ford, J.K. and E. Giles, 2015: Climate change adaptation in Indian country: Tribal regulation of reservation lands and natural resources. *William Mitchell Law Review*, **41** (2), 519–551. http://open.mitchellhamline.edu/wmlr/vol41/iss2/3/

92. Watkinson-Schutten, M., 2022: Decolonizing climate adaptation by reacquiring fractionated tribal lands. In: *The Oxford Handbook of Indigenous Sociology*. Walter, M., T. Kukutai, A.A. Gonzales, and R. Henry, Eds. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780197528778.013.42

93. Maldonado, J., D. Antrobus, C. Comardelle, S.R. Cox, L. Laukea, C. Jones, P. Keys, H. Mullen, M. Neale, and D. Sambo Dorough, 2021: Ch. 10. Protection-in-place & community-led relocation. In: *Status of Tribes and Climate Change Report*. Marks-Marino, D., Ed. Institute for Tribal Environmental Professionals, 241–259. http://nau.edu/stacc2021

94. Jantarasami, L.C., R. Novak, R. Delgado, E. Marino, S. McNeeley, C. Narducci, J. Raymond-Yakoubian, L. Singletary, and K.P. Whyte, 2018: Ch. 15. Tribes and Indigenous Peoples. In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart, Eds. U.S. Global Change Research Program,, Washington, DC, USA, 572–603. https://doi.org/10.7930/nca4.2018.ch15

95. Lynn, K., J. Daigle, J. Hoffman, F. Lake, N. Michelle, D. Ranco, C. Viles, G. Voggesser, and P. Williams, 2014: Ch. 4. The impacts of climate change on tribal traditional foods. In: *Climate Change and Indigenous Peoples in the United States: Impacts, Experiences and Actions*. Maldonado, J.K., B. Colombi, and R. Pandya, Eds. Springer, Cham, Switzerland, 37–48. https://doi.org/10.1007/978-3-319-05266-3_4

96. Prevéy, J.S., L.E. Parker, C.A. Harrington, C.T. Lamb, and M.F. Proctor, 2020: Climate change shifts in habitat suitability and phenology of huckleberry (*Vaccinium membranaceum*). *Agricultural and Forest Meteorology*, **280**, 107803. https://doi.org/10.1016/j.agrformet.2019.107803

97. Front and Centered, 2020: Accelerating a Just Transition in Washington State: Climate Justice Strategies from the Frontlines. Front and Centered, 6 pp. https://frontandcentered.org/accelerating-a-just-transition-in-wa-state/

98. Shi, L. and S. Moser, 2021: Transformative climate adaptation in the United States: Trends and prospects. *Science*, **372** (6549), 8054. https://doi.org/10.1126/science.abc8054

99. Hellman, D. and V. Shandas, 2020: Community Resilience to Climate Change: Theory, Research and Practice. Portland State University. https://doi.org/10.15760/pdxopen-24

100. Makido, Y., D. Hellman, and V. Shandas, 2019: Nature-based designs to mitigate urban heat: The efficacy of green infrastructure treatments in Portland, Oregon. *Atmosphere*, **10** (5), 282. https://doi.org/10.3390/atmos10050282

101. Puget Sound Sage, 2020: Powering the Transition: Community Priorities for a Renewable and Equitable Future. Puget Sound Sage. https://pugetsoundsage.org/research/clean-healthy-environment/community-energy/

102. Blazina, A. and K. Davis, 2022: The Wildland-Urban Interface: Mapping Washington State's Fastest-Growing Environment. Washington State Department of Natural Resources. https://storymaps.arcgis.com/stories/7016c437623a445997c072a05e26afbb

103. Mockrin, M.H., D. Helmers, S. Martinuzzi, T.J. Hawbaker, and V.C. Radeloff, 2022: Growth of the wildland-urban interface within and around U.S. National Forests and Grasslands, 1990–2010. *Landscape and Urban Planning*, **218**, 104283. https://doi.org/10.1016/j.landurbplan.2021.104283

104. Radeloff, V.C., D.P. Helmers, H.A. Kramer, M.H. Mockrin, P.M. Alexandre, A. Bar-Massada, V. Butsic, T.J. Hawbaker, S. Martinuzzi, A.D. Syphard, and S.I. Stewart, 2018: Rapid growth of the US wildland-urban interface raises wildfire risk. *Proceedings of the National Academy of Sciences of the United States of America*, **115** (13), 3314–3319. https://doi.org/10.1073/pnas.1718850115

105. City of Boise, 2021: Boise's Climate Action Roadmap: Our Community's Plan for Climate Action. City of Boise. https://www.cityofboise.org/media/15045/boise-climate-roadmap.pdf

106. King County Climate Equity Community Task Force, 2020: Section II: Sustainable & resilient frontline communities. In: *King County 2020 Strategic Climate Action Plan*. Stroble, J. and S. Rahman, Eds., King County, WA. https://your.kingcounty.gov/dnrp/climate/documents/scap-2020-approved/2020-scap-sustainable-and-resilient-frontline-communities-section.pdf

107. Germain, S.J. and J.A. Lutz, 2020: Climate extremes may be more important than climate means when predicting species range shifts. *Climatic Change*, **163** (1), 579–598. https://doi.org/10.1007/s10584-020-02868-2

108. Noy-Meir, I., 1973: Desert ecosystems: Environment and producers. *Annual Review of Ecology and Systematics*, **4** (1), 25–51. https://doi.org/10.1146/annurev.es.04.110173.000325

109. Rangwala, I., W. Moss, J. Wolken, R. Rondeau, K. Newlon, J. Guinotte, and W.R. Travis, 2021: Uncertainty, complexity and constraints: How do we robustly assess biological responses under a rapidly changing climate? *Climate*, **9** (12), 177. https://doi.org/10.3390/cli9120177

110. Singer, M.C., 2017: Shifts in time and space interact as climate warms. *Proceedings of the National Academy of Sciences of the United States of America*, **114** (49), 12848–12850. https://doi.org/10.1073/pnas.1718334114

111. Fogarty, F.A., D.R. Cayan, L.L. DeHaan, and E. Fleishman, 2020: Associations of breeding-bird abundance with climate vary among species and trait-based groups in southern California. *PLoS ONE*, **15** (3), e0230614. https://doi.org/10.1371/journal.pone.0230614

112. Harsch, M.A. and J. HilleRisLambers, 2016: Climate warming and seasonal precipitation change interact to limit species distribution shifts across western North America. *PLoS ONE*, **11** (7), e0159184. https://doi.org/10.1371/journal.pone.0159184

113. Abatzoglou, J.T. and A.P. Williams, 2016: Impact of anthropogenic climate change on wildfire across western US forests. *Proceedings of the National Academy of Sciences of the United States of America*, **113** (42), 11770–11775. https://doi.org/10.1073/pnas.1607171113

114. Alizadeh, M.R., J.T. Abatzoglou, C.H. Luce, J.F. Adamowski, A. Farid, and M. Sadegh, 2021: Warming enabled upslope advance in western US forest fires. *Proceedings of the National Academy of Sciences of the United States of America*, **118** (22), e2009717118. https://doi.org/10.1073/pnas.2009717118

115. Holden, Z.A., A. Swanson, C.H. Luce, W.M. Jolly, M. Maneta, J.W. Oyler, D.A. Warren, R. Parsons, and D. Affleck, 2018: Decreasing fire season precipitation increased recent western US forest wildfire activity. *Proceedings of the National Academy of Sciences of the United States of America*, **115** (36), E8349–E8357. https://doi.org/10.1073/pnas.1802316115

116. Alizadeh, M.R., J. Adamowski, M.R. Nikoo, A. AghaKouchak, P. Dennison, and M. Sadegh, 2020: A century of observations reveals increasing likelihood of continental-scale compound dry-hot extremes. *Science Advances*, **6** (39), 4571. https://doi.org/10.1126/sciadv.aaz4571

117. Halofsky, J.E., D.L. Peterson, and B.J. Harvey, 2020: Changing wildfire, changing forests: The effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA. *Fire Ecology*, **16** (1), 4. https://doi.org/10.1186/s42408-019-0062-8

118. Coop, J.D., S.A. Parks, C.S. Stevens-Rumann, S.D. Crausbay, P.E. Higuera, M.D. Hurteau, A. Tepley, E. Whitman, T. Assal, B.M. Collins, K.T. Davis, S. Dobrowski, D.A. Falk, P.J. Fornwalt, P.Z. Fulé, B.J. Harvey, V.R. Kane, C.E. Littlefield, E.Q. Margolis, M. North, M.-A. Parisien, S. Prichard, and K.C. Rodman, 2020: Wildfire-driven forest conversion in western North American landscapes. *BioScience*, **70** (8), 659–673. https://doi.org/10.1093/biosci/biaa061

119. Parks, S.A., S.Z. Dobrowski, J.D. Shaw, and C. Miller, 2019: Living on the edge: Trailing edge forests at risk of fire-facilitated conversion to non-forest. *Ecosphere*, **10** (3), e02651. https://doi.org/10.1002/ecs2.2651

120. Bradley, B.A., C.A. Curtis, and J.C. Chambers, 2016: Ch. 9. *Bromus* response to climate and projected changes with climate change. In: *Exotic Brome-Grasses in Arid and Semiarid Ecosystems of the Western US: Causes, Consequences, and Management Implications*. Germino, M.J., J.C. Chambers, and C.S. Brown, Eds. Springer, Cham, Switzerland, 257–274. https://doi.org/10.1007/978-3-319-24930-8_9

121. Williamson, M.A., E. Fleishman, R.C. Mac Nally, J.C. Chambers, B.A. Bradley, D.S. Dobkin, D.I. Board, F.A. Fogarty, N. Horning, M. Leu, and M. Wohlfeil Zillig, 2020: Fire, livestock grazing, topography, and precipitation affect occurrence and prevalence of cheatgrass (*Bromus tectorum*) in the Central Great Basin, USA. *Biological Invasions*, **22** (2), 663–680. https://doi.org/10.1007/s10530-019-02120-8

122. Mack, R.N. and J.N. Thompson, 1982: Evolution in steppe with few large, hooved mammals. *The American Naturalist*, **119** (6), 757–773. http://www.jstor.org/stable/2460961

123. Balch, J.K., B.A. Bradley, J.T. Abatzoglou, R.C. Nagy, E.J. Fusco, and A.L. Mahood, 2017: Human-started wildfires expand the fire niche across the United States. *Proceedings of the National Academy of Sciences of the United States of America*, **114** (11), 2946–2951. https://doi.org/10.1073/pnas.1617394114

124. Gervais, J.A., R. Kovach, A. Sepulveda, R. Al-Chokhachy, J. Joseph Giersch, and C.C. Muhlfeld, 2020: Climate-induced expansions of invasive species in the Pacific Northwest, North America: A synthesis of observations and projections. *Biological Invasions*, **22** (7), 2163–2183. https://doi.org/10.1007/s10530-020-02244-2

125. Abrams, J., H. Huber-Stearns, M. Steen-Adams, E.J. Davis, C. Bone, M.F. Nelson, and C. Moseley, 2021: Adaptive governance in a complex social-ecological context: Emergent responses to a native forest insect outbreak. *Sustainability Science*, **16** (1), 53–68. https://doi.org/10.1007/s11625-020-00843-5

126. Agne, M.C., P.A. Beedlow, D.C. Shaw, D.R. Woodruff, E.H. Lee, S.P. Cline, and R.L. Comeleo, 2018: Interactions of predominant insects and diseases with climate change in Douglas-fir forests of western Oregon and Washington, U.S.A. *Forest Ecology and Management*, **409**, 317–332. https://doi.org/10.1016/j.foreco.2017.11.004

127. Bentz, B.J., J. Régnière, C.J. Fettig, E.M. Hansen, J.L. Hayes, J.A. Hicke, R.G. Kelsey, J.F. Negrón, and S.J. Seybold, 2010: Climate change and bark beetles of the western United States and Canada: Direct and indirect effects. *BioScience*, **60** (8), 602–613. https://doi.org/10.1525/bio.2010.60.8.6

128. Elliott, J., S.I. Passy, K.L. Pound, G. Merritt, S. Polkowske, and C.A. Larson, 2022: Strong but heterogeneous distributional responses to climate change are projected for temperate and semi-arid stream vertebrates. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **32** (8), 1291–1305. https://doi.org/10.1002/aqc.3805

129. Jacobs, G.R., R.F. Thurow, J.M. Buffington, D.J. Isaak, and S.J. Wenger, 2021: Climate, fire regime, geomorphology, and conspecifics influence the spatial distribution of Chinook salmon Redds. *Transactions of the American Fisheries Society*, **150** (1), 8–23. https://doi.org/10.1002/tafs.10270

130. Reid, A.J., A.K. Carlson, I.F. Creed, E.J. Eliason, P.A. Gell, P.T.J. Johnson, K.A. Kidd, T.J. MacCormack, J.D. Olden, S.J. Ormerod, J.P. Smol, W.W. Taylor, K. Tockner, J.C. Vermaire, D. Dudgeon, and S.J. Cooke, 2019: Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews*, **94** (3), 849–873. https://doi.org/10.1111/brv.12480

131. Wenger, S.J., D.J. Isaak, C.H. Luce, H.M. Neville, K.D. Fausch, J.B. Dunham, D.C. Dauwalter, M.K. Young, M.M. Elsner, B.E. Rieman, A.F. Hamlet, and J.E. Williams, 2011: Flow regime, temperature, and biotic interactions drive differential declines of trout species under climate change. *Proceedings of the National Academy of Sciences of the United States of America*, **108** (34), 14175–14180. https://doi.org/10.1073/pnas.1103097108

132. Al-Chokhachy, R., M. Lien, B.B. Shepard, and B. High, 2021: The interactive effects of stream temperature, stream size, and non-native species on Yellowstone cutthroat trout. *Canadian Journal of Fisheries and Aquatic Sciences*, **78** (8), 1073–1083. https://doi.org/10.1139/cjfas-2020-0408

133. Rubenson, E.S., D.J. Lawrence, and J.D. Olden, 2020: Threats to rearing juvenile Chinook salmon from nonnative smallmouth bass inferred from stable isotope and fatty acid biomarkers. *Transactions of the American Fisheries Society*, **149** (3), 350–363. https://doi.org/10.1002/tafs.10237

134. Rubenson, E.S. and J.D. Olden, 2020: An invader in salmonid rearing habitat: Current and future distributions of smallmouth bass (*Micropterus dolomieu*) in the Columbia River Basin. *Canadian Journal of Fisheries and Aquatic Sciences*, **77** (2), 314–325. https://doi.org/10.1139/cjfas-2018-0357

135. Freeman, M.C., K.R. Bestgen, D. Carlisle, E.A. Frimpong, N.R. Franssen, K.B. Gido, E. Irwin, Y. Kanno, C. Luce, S. Kyle McKay, M.C. Mims, J.D. Olden, N. LeRoy Poff, D.L. Propst, L. Rack, A.H. Roy, E.S. Stowe, A. Walters, and S.J. Wenger, 2022: Toward improved understanding of streamflow effects on freshwater fishes. *Fisheries*, **47** (7), 290–298. https://doi.org/10.1002/fsh.10731

136. Goode, J.R., J.M. Buffington, D. Tonina, D.J. Isaak, R.F. Thurow, S. Wenger, D. Nagel, C. Luce, D. Tetzlaff, and C. Soulsby, 2013: Potential effects of climate change on streambed scour and risks to salmonid survival in snow-dominated mountain basins. *Hydrological Processes*, **27** (5), 750–765. https://doi.org/10.1002/hyp.9728

137. Gould, G.K., M. Liu, M.E. Barber, K.A. Cherkauer, P.R. Robichaud, and J.C. Adam, 2016: The effects of climate change and extreme wildfire events on runoff erosion over a mountain watershed. *Journal of Hydrology*, **536**, 74–91. https://doi.org/10.1016/j.jhydrol.2016.02.025

138. Nicol, C.L., J.C. Jorgensen, C.B. Fogel, B. Timpane-Padgham, and T.J. Beechie, 2022: Spatially overlapping salmon species have varied population response to early life history mortality from increased peak flows. *Canadian Journal of Fisheries and Aquatic Sciences*, **79** (2), 342–351. https://doi.org/10.1139/cjfas-2021-0038

139. Srivastava, A., E.S. Brooks, M. Dobre, W.J. Elliot, J.Q. Wu, D.C. Flanagan, J.A. Gravelle, and T.E. Link, 2020: Modeling forest management effects on water and sediment yield from nested, paired watersheds in the interior Pacific Northwest, USA using WEPP. *Science of The Total Environment*, **701**, 134877. https://doi.org/10.1016/j.scitotenv.2019.134877

140. Dunham, J.B., M.K. Young, R.E. Gresswell, and B.E. Rieman, 2003: Effects of fire on fish populations: Landscape perspectives on persistence of native fishes and nonnative fish invasions. *Forest Ecology and Management*, **178** (1), 183–196. https://doi.org/10.1016/s0378-1127(03)00061-6

141. Isaak, D.J., C.H. Luce, B.E. Rieman, D.E. Nagel, E.E. Peterson, D.L. Horan, S. Parkes, and G.L. Chandler, 2010: Effects of climate change and wildfire on stream temperatures and salmonid thermal habitat in a mountain river network. *Ecological Applications*, **20** (5), 1350–1371. https://doi.org/10.1890/09-0822.1

142. Goode, J.R., C.H. Luce, and J.M. Buffington, 2012: Enhanced sediment delivery in a changing climate in semi-arid mountain basins: Implications for water resource management and aquatic habitat in the northern Rocky Mountains. *Geomorphology*, **139**, 1–15. https://doi.org/10.1016/j.geomorph.2011.06.021

143. Maturana, O., D. Tonina, J.A. McKean, J.M. Buffington, C.H. Luce, and D. Caamaño, 2014: Modeling the effects of pulsed versus chronic sand inputs on salmonid spawning habitat in a low-gradient gravel-bed river. *Earth Surface Processes and Landforms*, **39** (7), 877–889. https://doi.org/10.1002/esp.3491

144. Rieman, B., D. Lee, D. Burns, R. Gresswell, M. Young, R. Stowell, J. Rinne, and P. Howell, 2003: Status of native fishes in the western United States and issues for fire and fuels management. *Forest Ecology and Management*, **178** (1), 197–211. https://doi.org/10.1016/s0378-1127(03)00062-8

145. Free, C.M., S.C. Anderson, E.A. Hellmers, B.A. Muhling, M.O. Navarro, K. Richerson, L.A. Rogers, W.H. Satterthwaite, A.R. Thompson, J.M. Burt, S.D. Gaines, K.N. Marshall, J.W. White, and L.F. Bellquist, 2023: Impact of the 2014–2016 marine heatwave on US and Canada West Coast fisheries: Surprises and lessons from key case studies. *Fish and Fisheries*, **24** (4), 652–674. https://doi.org/10.1111/faf.12753

146. Morgan, C.A., B.R. Beckman, L.A. Weitkamp, and K.L. Fresh, 2019: Recent ecosystem disturbance in the Northern California Current. *Fisheries*, **44** (10), 465–474. https://doi.org/10.1002/fsh.10273

147. Shanks, A.L., L.K. Rasmuson, J.R. Valley, M.A. Jarvis, C. Salant, D.A. Sutherland, E.I. Lamont, M.A.H. Hainey, and R.B. Emlet, 2020: Marine heat waves, climate change, and failed spawning by coastal invertebrates. *Limnology and Oceanography*, **65** (3), 627–636. https://doi.org/10.1002/lno.11331

148. McCabe, R.M., B.M. Hickey, R.M. Kudela, K.A. Lefebvre, N.G. Adams, B.D. Bill, F.M.D. Gulland, R.E. Thomson, W.P. Cochlan, and V.L. Trainer, 2016: An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions. *Geophysical Research Letters*, **43** (19), 10366–10376. https://doi.org/10.1002/2016gl070023

149. Akmajian, A.M., J.J. Scordino, and A. Acevedo-Gutiérrez, 2017: Year-round algal toxin exposure in free-ranging sea lions. *Marine Ecology Progress Series*, **583**, 243–258. https://doi.org/10.3354/meps12345

150. Piatt, J.F., J.K. Parrish, H.M. Renner, S.K. Schoen, T.T. Jones, M.L. Arimitsu, K.J. Kuletz, B. Bodenstein, M. García-Reyes, R.S. Duerr, R.M. Corcoran, R.S.A. Kaler, G.J. McChesney, R.T. Golightly, H.A. Coletti, R.M. Suryan, H.K. Burgess, J. Lindsey, K. Lindquist, P.M. Warzybok, J. Jahncke, J. Roletto, and W.J. Sydeman, 2020: Extreme mortality and reproductive failure of common murres resulting from the northeast Pacific marine heatwave of 2014–2016. *PLoS ONE*, **15** (1), e0226087. https://doi.org/10.1371/journal.pone.0226087

151. Ford, M.J., 2022: Biological Viability Assessment Update for Pacific Salmon and Steelhead Listed Under the Endangered Species Act: Pacific Northwest. NOAA Technical Memorandum NMFS-NWFSC-171. National Oceanic and Atmospheric Administration, National Marine Fisheries Service. https://doi.org/10.25923/kq2n-ke70

152. Raymond, W.W., J.S. Barber, M.N. Dethier, H.A. Hayford, C.D.G. Harley, T.L. King, B. Paul, C.A. Speck, E.D. Tobin, A.E.T. Raymond, and P.S. McDonald, 2022: Assessment of the impacts of an unprecedented heatwave on intertidal shellfish of the Salish Sea. *Ecology*, **103** (10), e3798. https://doi.org/10.1002/ecy.3798

153. Frölicher, T.L., E.M. Fischer, and N. Gruber, 2018: Marine heatwaves under global warming. *Nature*, **560** (7718), 360–364. https://doi.org/10.1038/s41586-018-0383-9

154. Smith, K.E., M.T. Burrows, A.J. Hobday, N.G. King, P.J. Moore, A. Sen Gupta, M.S. Thomsen, T. Wernberg, and D.A. Smale, 2023: Biological impacts of marine heatwaves. *Annual Review of Marine Science*, **15** (1), 119–145. https://doi.org/10.1146/annurev-marine-032122-121437

155. Samhouri, J.F., B.E. Feist, M.C. Fisher, O. Liu, S.M. Woodman, B. Abrahms, K.A. Forney, E.L. Hazen, D. Lawson, J. Redfern, and L.E. Saez, 2021: Marine heatwave challenges solutions to human-wildlife conflict. *Proceedings of the Royal Society B: Biological Sciences*, **288** (1964), 20211607. https://doi.org/10.1098/rspb.2021.1607

156. Cline, T.J., J. Ohlberger, and D.E. Schindler, 2019: Effects of warming climate and competition in the ocean for life-histories of Pacific salmon. *Nature Ecology & Evolution*, **3** (6), 935–942. https://doi.org/10.1038/s41559-019-0901-7

157. Litzow, M.A., F.J. Mueter, and A.J. Hobday, 2014: Reassessing regime shifts in the North Pacific: Incremental climate change and commercial fishing are necessary for explaining decadal-scale biological variability. *Global Change Biology*, **20** (1), 38–50. https://doi.org/10.1111/gcb.12373

158. Ohlberger, J., E.J. Ward, D.E. Schindler, and B. Lewis, 2018: Demographic changes in Chinook salmon across the northeast Pacific Ocean. *Fish and Fisheries*, **19** (3), 533–546. https://doi.org/10.1111/faf.12272

159. Welch, D.W., A.D. Porter, and E.L. Rechisky, 2021: A synthesis of the coast-wide decline in survival of West Coast Chinook salmon (*Oncorhynchus tshawytscha*, Salmonidae). *Fish and Fisheries*, **22** (1), 194–211. https://doi.org/10.1111/faf.12514

160. Crozier, L.G., B.J. Burke, B.E. Chasco, D.L. Widener, and R.W. Zabel, 2021: Climate change threatens Chinook salmon throughout their life cycle. *Communications Biology*, **4** (1), 222. https://doi.org/10.1038/s42003-021-01734-w

161. Crozier, L.G., J.E. Siegel, L.E. Wiesebron, E.M. Trujillo, B.J. Burke, B.P. Sandford, and D.L. Widener, 2020: Snake River sockeye and Chinook salmon in a changing climate: Implications for upstream migration survival during recent extreme and future climates. *PLoS ONE*, **15** (9), e0238886. https://doi.org/10.1371/journal.pone.0238886

162. Isaak, D.J., C.H. Luce, D.L. Horan, G.L. Chandler, S.P. Wollrab, and D.E. Nagel, 2018: Global warming of salmon and trout rivers in the northwestern U.S.: Road to ruin or path through purgatory? *Transactions of the American Fisheries Society*, **147** (3), 566–587. https://doi.org/10.1002/tafs.10059

163. Isaak, D.J., S.J. Wenger, E.E. Peterson, J.M. Ver Hoef, D.E. Nagel, C.H. Luce, S.W. Hostetler, J.B. Dunham, B.B. Roper, S.P. Wollrab, G.L. Chandler, D.L. Horan, and S. Parkes-Payne, 2017: The NorWeST summer stream temperature model and scenarios for the Western U.S.: A crowd-sourced database and new geospatial tools foster a user community and predict broad climate warming of rivers and streams. *Water Resources Research*, **53** (11), 9181–9205. https://doi.org/10.1002/2017wr020969

164. Keefer, M.L., T.S. Clabough, M.A. Jepson, E.L. Johnson, C.A. Peery, and C.C. Caudill, 2018: Thermal exposure of adult Chinook salmon and steelhead: Diverse behavioral strategies in a large and warming river system. *PLoS ONE*, **13** (9), e0204274. https://doi.org/10.1371/journal.pone.0204274

165. Zhang, X., H.-Y. Li, Z.D. Deng, L.R. Leung, J.R. Skalski, and S.J. Cooke, 2019: On the variable effects of climate change on Pacific salmon. *Ecological Modelling*, **397**, 95–106. https://doi.org/10.1016/j.ecolmodel.2019.02.002

166. Moore, S.K., J.A. Johnstone, N.S. Banas, and E.P. Salathé, 2015: Present-day and future climate pathways affecting *Alexandrium* blooms in Puget Sound, WA, USA. *Harmful Algae*, **48**, 1–11. https://doi.org/10.1016/j.hal.2015.06.008

167. Ralston, D.K. and S.K. Moore, 2020: Modeling harmful algal blooms in a changing climate. *Harmful Algae*, **91**, 101729. https://doi.org/10.1016/j.hal.2019.101729

168. Munsch, S.H., C.M. Greene, N.J. Mantua, and W.H. Satterthwaite, 2022: One hundred-seventy years of stressors erode salmon fishery climate resilience in California's warming landscape. *Global Change Biology*, **28** (7), 2183–2201. https://doi.org/10.1111/gcb.16029

169. Sullaway, G.H., A.O. Shelton, and J.F. Samhouri, 2021: Synchrony erodes spatial portfolios of an anadromous fish and alters availability for resource users. *Journal of Animal Ecology*, **90** (11), 2692–2703. https://doi.org/10.1111/1365-2656.13575

170. Crozier, L.G., M.M. McClure, T. Beechie, S.J. Bograd, D.A. Boughton, M. Carr, T.D. Cooney, J.B. Dunham, C.M. Greene, M.A. Haltuch, E.L. Hazen, D.M. Holzer, D.D. Huff, R.C. Johnson, C.E. Jordan, I.C. Kaplan, S.T. Lindley, N.J. Mantua, P.B. Moyle, J.M. Myers, M.W. Nelson, B.C. Spence, L.A. Weitkamp, T.H. Williams, and E. Willis-Norton, 2019: Climate vulnerability assessment for Pacific salmon and steelhead in the California Current Large Marine Ecosystem. *PLoS ONE*, **14** (7), e0217711. https://doi.org/10.1371/journal.pone.0217711

171. WCR, 2015: ESA Recovery Plan for Snake River Sockeye Salmon (*Oncorhynchus nerka*). National Oceanic and Atmospheric Administration, National Marine Fisheries Service, West Coast Region. https://repository.library.noaa.gov/view/noaa/16001

172. Waples, R.S., O.W. Johnson, and R.P. Jones Jr., 1991: Status Review for Snake River Sockeye Salmon. NOAA Technical Memorandum NMFS F/NWC-19. National Oceanic and Atmospheric Administration, National Marine Fisheries Service. https://repository.library.noaa.gov/view/noaa/21168

173. Johnson, E.L., C.C. Kozfkay, J.H. Powell, M.P. Peterson, D.J. Baker, J.A. Heindel, K.E. Plaster, J.L. McCormick, and P.A. Kline, 2020: Evaluating artificial propagation release strategies for recovering endangered Snake River sockeye salmon. *North American Journal of Aquaculture*, **82** (3), 331–344. https://doi.org/10.1002/naaq.10148

174. Kozfkay, C.C., M. Peterson, B.P. Sandford, E.L. Johnson, and P. Kline, 2019: The productivity and viability of Snake River sockeye salmon hatchery adults released into Redfish Lake, Idaho. *Transactions of the American Fisheries Society*, **148** (2), 308–323. https://doi.org/10.1002/tafs.10136

175. Selbie, D.T., B.A. Lewis, J.P. Smol, and B.P. Finney, 2007: Long-term population dynamics of the endangered Snake River sockeye salmon: Evidence of past influences on stock decline and impediments to recovery. *Transactions of the American Fisheries Society*, **136** (3), 800–821. https://doi.org/10.1577/t06-100.1

176. Good, T.P., R.S. Waples, and P. Adams, 2005: Updated Status of Federally Listed ESUs of West Coast Salmon and Steelhead. NOAA Technical Memorandum NMFS-NWFSC-66. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center, 598 pp. https://repository.library.noaa.gov/view/noaa/3413

177. Kalinowski, S.T., D.M. Van Doornik, C.C. Kozfkay, and R.S. Waples, 2012: Genetic diversity in the Snake River sockeye salmon captive broodstock program as estimated from broodstock records. *Conservation Genetics*, **13** (5), 1183–1193. https://doi.org/10.1007/s10592-012-0363-9

178. Crozier, L.G., L.E. Weisebron, J.E. Siegel, B.J. Burke, T.M. Marsh, B.P. Sandford, and D.L. Widener, 2018: Passage and Survival of Adult Snake River Sockeye Salmon Within and Upstream from the Federal Columbia River Power System: 2008–2017 National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center, Fish Ecology Division, Seattle, WA. https://www.webapps.nwfsc.noaa.gov/assets/26/9567_03132020_144513_Crozier.et.al.2018-Adult-Sockeye-2008-2017-USACE.pdf

179. NMFS, 2016: 2015 Adult Sockeye Salmon Passage Report. National Oceanic and Atmospheric Administration, National Marine Fisheries Service. https://www.columbiariverkeeper.org/sites/default/files/2017/08/8.pdf

180. WCR, 2021: Endangered Species Act Section 7 Formal Consultation and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation for Authorizing Operation and Maintenance of Water Diversions Located on the Salmon-Challis National Forest in the Lemhi River Watershed, HUC 17060204, Lemhi County, Idaho. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, West Coast Region. https://doi.org/10.25923/r94p-xe17

181. Walters, A.W., K.K. Bartz, and M.M. Mcclure, 2013: Interactive effects of water diversion and climate change for juvenile Chinook salmon in the Lemhi River Basin (U.S.A.). *Conservation Biology*, **27** (6), 1179–1189. https://doi.org/10.1111/cobi.12170

182. Evans, M.L., A.E. Kohler, R.G. Griswold, K.A. Tardy, K.R. Eaton, and J.D. Ebel, 2020: Salmon-mediated nutrient flux in Snake River sockeye salmon nursery lakes: The influence of depressed population size and hatchery supplementation. *Lake and Reservoir Management*, **36** (1), 75–86. https://doi.org/10.1080/10402381.2019.1654571

183. Krueger, C.C., W.W. Taylor, and S.-J. Youn, 2019: Ch. 1. Fishery management success: Action, collaboration, communication, and commitment. In: *From Catastrophe to Recovery: Stories of Fishery Management Success*. Krueger, C.C., W.W. Taylor, and S.-J. Youn, Eds. American Fisheries Society. https://doi.org/10.47886/9781934874554.ch1

184. Crozier, L.G., M.D. Scheuerell, and R.W. Zabel, 2011: Using time series analysis to characterize evolutionary and plastic responses to environmental change: A case study of a shift toward earlier migration date in sockeye salmon. *The American Naturalist*, **178** (6), 755–773. https://doi.org/10.1086/662669

185. Quinn, T.P. and D.J. Adams, 1996: Environmental changes affecting the migratory timing of American shad and sockeye salmon. *Ecology*, **77** (4), 1151–1162. https://doi.org/10.2307/2265584

186. Bennett, J.M., R.H. Clarke, G.F.B. Horrocks, J.R. Thomson, and R. Mac Nally, 2015: Climate drying amplifies the effects of land-use change and interspecific interactions on birds. *Landscape Ecology*, **30** (10), 2031–2043. https://doi.org/10.1007/s10980-015-0229-x

187. Habel, J.C. and F.E. Zachos, 2012: Habitat fragmentation versus fragmented habitats. *Biodiversity and Conservation*, **21** (11), 2987–2990. https://doi.org/10.1007/s10531-012-0349-4

188. Carja, O. and J.B. Plotkin, 2019: Evolutionary rescue through partly heritable phenotypic variability. *Genetics*, **211** (3), 977–988. https://doi.org/10.1534/genetics.118.301758

189. Nimmo, D.G., A. Haslem, J.Q. Radford, M. Hall, and A.F. Bennett, 2016: Riparian tree cover enhances the resistance and stability of woodland bird communities during an extreme climatic event. *Journal of Applied Ecology*, **53** (2), 449–458. https://doi.org/10.1111/1365-2664.12535

190. Thompson, L.M., L.L. Thurman, C.N. Cook, E.A. Beever, C.M. Sgrò, A. Battles, C.A. Botero, J.E. Gross, K.R. Hall, A.P. Hendry, A.A. Hoffmann, C. Hoving, O.E. LeDee, C. Mengelt, A.B. Nicotra, R.A. Niver, F. Pérez-Jvostov, R.M. Quiñones, G.W. Schuurman, M.K. Schwartz, J. Szymanski, and A. Whiteley, 2023: Connecting research and practice to enhance the evolutionary potential of species under climate change. *Conservation Science and Practice*, **5** (2), e12855. https://doi.org/10.1111/csp2.12855

191. UNEP, 2019: Sand and Sustainability: Finding New Solutions for Environmental Governance of Global Sand Resources. United Nations Environment Programme. https://wedocs.unep.org/handle/20.500.11822/28163;jsessionid=333820b5a8c38cdd7f7f44fc1984d9ae

192. Grossman, E.E., A.W. Stevens, D. P, D. George, and D. Finlayson, 2020: Sediment export and impacts associated with river delta channelization compound estuary vulnerability to sea-level rise. *Marine Geology*, **430**, 106336. https://doi.org/10.1016/j.margeo.2020.106336

193. Knox, R.L., E.E. Wohl, and R.R. Morrison, 2022: Levees don't protect, they disconnect: A critical review of how artificial levees impact floodplain functions. *Science of The Total Environment*, **837**, 155773. https://doi.org/10.1016/j.scitotenv.2022.155773

194. Bond, M.H., T.G. Nodine, T.J. Beechie, and R.W. Zabel, 2019: Estimating the benefits of widespread floodplain reconnection for Columbia River Chinook salmon. *Canadian Journal of Fisheries and Aquatic Sciences*, **76** (7), 1212–1226. https://doi.org/10.1139/cjfas-2018-0108

195. Grossman, E.E., S.C. Crosby, A.W. Stevens, D.J. Nowacki, N.R. vanAredonk, and C.A. Curran, 2022: Assessment of Vulnerabilities and Opportunities to Restore Marsh Sediment Supply at Nisqually River Delta, West-Central Washington. USGS Open-File Report 2022–1088. U.S. Geological Survey, 50 pp. https://doi.org/10.3133/ofr20221088

196. Moritsch, M.M., K.B. Byrd, M. Davis, A. Good, J.Z. Drexler, J.T. Morris, I. Woo, L. Windham-Myers, E. Grossman, G. Nakai, K.L. Poppe, and J.M. Rybczyk, 2022: Can coastal habitats rise to the challenge? Resilience of estuarine habitats, carbon accumulation, and economic value to sea-level rise in a Puget Sound estuary. *Estuaries and Coasts*, **45** (8), 2293–2309. https://doi.org/10.1007/s12237-022-01087-5

197. Copeland, T., B.J. Bowersox, M.W. Ackerman, and C. Camacho, 2019: Patterns of iteroparity in wild Snake River steelhead. *Transactions of the American Fisheries Society*, **148** (5), 926–937. https://doi.org/10.1002/tafs.10187

198. Morley, S.A., M.M. Foley, J.J. Duda, M.M. Beirne, R.L. Paradis, R.C. Johnson, M.L. McHenry, M. Elofson, E.M. Sampson, R.E. McCoy, J. Stapleton, and G.R. Pess, 2020: Shifting food web structure during dam removal—Disturbance and recovery during a major restoration action. *PLoS ONE*, **15** (9), e0239198. https://doi.org/10.1371/journal.pone.0239198

199. Penaluna, B.E., G.H. Reeves, Z.C. Barnett, P.A. Bisson, J.M. Buffington, C.A. Dolloff, R.L. Flitcroft, C.H. Luce, K.H. Nislow, J.D. Rothlisberger, and M.L. Warren Jr, 2018: Using natural disturbance and portfolio concepts to guide aquatic–riparian ecosystem management. *Fisheries*, **43** (9), 406–422. https://doi.org/10.1002/fsh.10097

200. Quinn, T.P., M.H. Bond, S.J. Brenkman, R. Paradis, and R.J. Peters, 2017: Re-awakening dormant life history variation: Stable isotopes indicate anadromy in bull trout following dam removal on the Elwha River, Washington. *Environmental Biology of Fishes*, **100** (12), 1659–1671. https://doi.org/10.1007/s10641-017-0676-0

201. Hessburg, P.F., S.J. Prichard, R.K. Hagmann, N.A. Povak, and F.K. Lake, 2021: Wildfire and climate change adaptation of western North American forests: A case for intentional management. *Ecological Applications*, **31** (8), e02432. https://doi.org/10.1002/eap.2432

202. Prichard, S.J., P.F. Hessburg, R.K. Hagmann, N.A. Povak, S.Z. Dobrowski, M.D. Hurteau, V.R. Kane, R.E. Keane, L.N. Kobziar, C.A. Kolden, M. North, S.A. Parks, H.D. Safford, J.T. Stevens, L.L. Yocom, D.J. Churchill, R.W. Gray, D.W. Huffman, F.K. Lake, and P. Khatri-Chhetri, 2021: Adapting western North American forests to climate change and wildfires: 10 common questions. *Ecological Applications*, **31** (8), e02433. https://doi.org/10.1002/eap.2433

203. Vose, J.M., D.L. Peterson, C.H. Luce, and T. Patel-Weynand, 2019: Effects of Drought on Forests and Rangelands in the United States: Translating Science into Management Responses. Gen. Tech. Rep. WO-98. U.S. Department of Agriculture, Forest Service, Washington Office, Washington, DC, 227 pp. https://doi.org/10.2737/wo-gtr-98

204. Halofsky, J.E., D.L. Peterson, and H.R. Prendeville, 2018: Assessing vulnerabilities and adapting to climate change in northwestern U.S. forests. *Climatic Change*, **146** (1-2), 89–102. https://doi.org/10.1007/s10584-017-1972-6

205. Reilly, M.J., A. Zuspan, J.S. Halofsky, C. Raymond, A. McEvoy, A.W. Dye, D.C. Donato, J.B. Kim, B.E. Potter, N. Walker, R.J. Davis, C.J. Dunn, D.M. Bell, M.J. Gregory, J.D. Johnston, B.J. Harvey, J.E. Halofsky, and B.K. Kerns, 2022: Cascadia burning: The historic, but not historically unprecedented, 2020 wildfires in the Pacific Northwest, USA. *Ecosphere*, **13** (6), e4070. https://doi.org/10.1002/ecs2.4070

206. Endter-Wada, J., K.M. Kettenring, and A.E. Sutton-Grier, 2018: Sustaining wetlands to mitigate disasters and protect people. *Frontiers in Ecology and the Environment*, **16** (8), 431–431. https://doi.org/10.1002/fee.1959

207. WA State Department of Ecology, 2022: Mitigation Bank Projects. State of Washington, Department of Ecology. https://ecology.wa.gov/water-shorelines/wetlands/mitigation/wetland-mitigation-banking/mitigation-bank-projects

208. Van den Bosch, K. and J.W. Matthews, 2017: An assessment of long-term compliance with performance standards in compensatory mitigation wetlands. *Environmental Management*, **59** (4), 546–556. https://doi.org/10.1007/s00267-016-0804-1

209. Oja, E.B., L.K. Swartz, E. Muths, and B.R. Hossack, 2021: Amphibian population responses to mitigation: Relative importance of wetland age and design. *Ecological Indicators*, **131**, 108123. https://doi.org/10.1016/j.ecolind.2021.108123

210. Khanal, R., M.P. Brady, C.O. Stöckle, K. Rajagopalan, J. Yoder, and M.E. Barber, 2021: The economic and environmental benefits of partial leasing of agricultural water rights. *Water Resources Research*, **57** (11), e2021WR029712. https://doi.org/10.1029/2021wr029712

211. Leonard, B., C. Costello, and G.D. Libecap, 2019: Expanding water markets in the western United States: barriers and lessons from other natural resource markets. *Review of Environmental Economics and Policy*, **13** (1), 43–61. https://doi.org/10.1093/reep/rey014

212. Gienapp, P., C. Teplitsky, J.S. Alho, J.A. Mills, and J. Merilä, 2008: Climate change and evolution: Disentangling environmental and genetic responses. *Molecular Ecology*, **17** (1), 167–178. https://doi.org/10.1111/j.1365-294x.2007.03413.x

213. Merilä, J. and A.P. Hendry, 2014: Climate change, adaptation, and phenotypic plasticity: The problem and the evidence. *Evolutionary Applications*, **7** (1), 1–14. https://doi.org/10.1111/eva.12137

214. Bigelow, D.P. and A. Borchers, 2017: Major Uses of Land in the United States, 2012. EIB-178. U.S. Department of Agriculture, Economic Research Service. https://www.ers.usda.gov/publications/pub-details/?pubid=84879

215. ERS, 2023: Data Files: U.S. and State-Level Farm Income and Wealth Statistics. U.S. Department of Agriculture, Economic Research Service, accessed March 20, 2023. https://www.ers.usda.gov/data-products/farm-income-and-wealth-statistics/data-files-u-s-and-state-level-farm-income-and-wealth-statistics/

216. Rajagopalan, K., K.J. Chinnayakanahalli, C.O. Stockle, R.L. Nelson, C.E. Kruger, M.P. Brady, K. Malek, S.T. Dinesh, M.E. Barber, A.F. Hamlet, G.G. Yorgey, and J.C. Adam, 2018: Impacts of near-term climate change on irrigation demands and crop yields in the Columbia River Basin. *Water Resources Research*, **54** (3), 2152–2182. https://doi.org/10.1002/2017wr020954

217. Noorazar, H., L. Kalcsits, V.P. Jones, M.S. Jones, and K. Rajagopalan, 2022: Climate change and chill accumulation: Implications for tree fruit production in cold-winter regions. *Climatic Change*, **171** (3), 34. https://doi.org/10.1007/s10584-022-03339-6

218. Willsea, N., V. Blanco, K. Rajagopalan, T. Campbell, O. Howe, and L. Kalcsits, 2023: Reviewing the tradeoffs between sunburn mitigation and red color development in apple under a changing climate. *Horticulturae*, **9** (4), 492. https://doi.org/10.3390/horticulturae9040492

219. Gallinat, A.S., R.B. Primack, and D.L. Wagner, 2015: Autumn, the neglected season in climate change research. *Trends in Ecology & Evolution*, **30** (3), 169–176. https://doi.org/10.1016/j.tree.2015.01.004

220. Rajagopalan, K., G. DeGrandi-Hoffman, M. Pruett, V.P. Jones, V. Corby-Harris, J. Pireaud, R. Curry, B. Hopkins, and T. Northfield, 2022: Changing Honey Bee Overwintering Dynamics Under Warmer Autumns and Winters Create New Risks for Pollination Services. Research Square. https://doi.org/10.21203/rs.3.rs-1394621/v1

221. Jones, G. and H. Schultz, 2016: Climate change and emerging cool climate wine regions. *Wine and Viticulture Journal*, **31** (6), 51–53. https://search.informit.org/doi/10.3316/informit.523901697092406

222. Mirabelli-Montan, Y.A., M. Marangon, A. Graça, C.M. Mayr Marangon, and K.L. Wilkinson, 2021: Techniques for mitigating the effects of smoke taint while maintaining quality in wine production: A review. *Molecules*, **26** (6), 1672. https://doi.org/10.3390/molecules26061672

223. Ansah, E.O. and O.S. Walsh, 2021: Impact of 2021 drought in the Pacific Northwest. *Crops & Soils*, **54** (6), 46–49. https://doi.org/10.1002/crso.20145

224. NASS, 2021: Small Grains 2021 Summary. U.S. Department of Agriculture, National Agricultural Statistics Service. https://www.nass.usda.gov/publications/todays_reports/reports/smgr0921.pdf

225. Winford, E. and K. Lee, 2021: Rangelands report. In: *Idaho Climate-Economy Impacts Assessment*. James A. and Louise McClure Center for Public Policy Research, University of Idaho, Boise, ID. https://www.uidaho.edu/president/direct-reports/mcclure-center/iceia/land

226. Chengot, R., J.W. Knox, and I.P. Holman, 2021: Evaluating the feasibility of water sharing as a drought risk management tool for irrigated agriculture. *Sustainability*, **13** (3). https://doi.org/10.3390/su13031456

227. Coppock, D.L., 2020: Improving drought preparedness among Utah cattle ranchers. *Rangeland Ecology & Management*, **73** (6), 879–890. https://doi.org/10.1016/j.rama.2020.08.003

228. Peck, D., J. Derner, W. Parton, M. Hartman, and B. Fuchs, 2019: Flexible stocking with Grass-Cast: A new grassland productivity forecast to translate climate outlooks for ranchers. *Western Economics Forum*, **17** (1), 24–39. https://doi.org/10.22004/ag.econ.287342

229. Diffenbaugh, N.S., F.V. Davenport, and M. Burke, 2021: Historical warming has increased U.S. crop insurance losses. *Environmental Research Letters*, **16** (8), 084025. https://doi.org/10.1088/1748-9326/ac1223

230. Reyes, J.J. and E. Elias, 2019: Spatio-temporal variation of crop loss in the United States from 2001 to 2016. *Environmental Research Letters*, **14** (7), 074017. https://doi.org/10.1088/1748-9326/ab1ac9

231. Malek, K., P. Reed, J. Adam, T. Karimi, and M. Brady, 2020: Water rights shape crop yield and revenue volatility tradeoffs for adaptation in snow dependent systems. *Nature Communications*, **11** (1), 3473. https://doi.org/10.1038/s41467-020-17219-z

232. Gaines, W.L., P.F. Hessburg, G.H. Aplet, P. Henson, S.J. Prichard, D.J. Churchill, G.M. Jones, D.J. Isaak, and C. Vynne, 2022: Climate change and forest management on federal lands in the Pacific Northwest, USA: Managing for dynamic landscapes. *Forest Ecology and Management*, **504**, 119794. https://doi.org/10.1016/j.foreco.2021.119794

233. Davis, K.T., P.E. Higuera, S.Z. Dobrowski, S.A. Parks, J.T. Abatzoglou, M.T. Rother, and T.T. Veblen, 2020: Fire-catalyzed vegetation shifts in ponderosa pine and Douglas-fir forests of the western United States. *Environmental Research Letters*, **15** (10), 1040b8. https://doi.org/10.1088/1748-9326/abb9df

234. Halofsky, J.E., D.L. Peterson, and R.A. Gravenmier, 2022: Climate Change Vulnerability and Adaptation in Southwest Oregon. Gen. Tech. Rep. PNW-GTR-995. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, 445 pp. https://doi.org/10.2737/pnw-gtr-995

235. Hashida, Y. and D.J. Lewis, 2022: Estimating welfare impacts of climate change using a discrete-choice model of land management: An application to western U.S. forestry. *Resource and Energy Economics*, **68**, 101295. https://doi.org/10.1016/j.reseneeco.2022.101295

236. Restaino, C.M., D.L. Peterson, and J. Littell, 2016: Increased water deficit decreases Douglas fir growth throughout western US forests. *Proceedings of the National Academy of Sciences of the United States of America*, **113** (34), 9557–9562. https://doi.org/10.1073/pnas.1602384113

237. Hudec, J.L., J.E. Halofsky, D.L. Peterson, and J.J. Ho, 2019: Climate Change Vulnerability and Adaptation in Southwest Washington. Gen. Tech. Rep. PNW-GTR-977. U.S. Department of Agriculture, Forest Service. Pacific Northwest Research Station, Portland, OR, 249 pp. https://doi.org/10.2737/pnw-gtr-977

238. Kerns, B.K., D.C. Powell, S. Mellmann-Brown, G. Carnwath, and J.B. Kim, 2018: Effects of projected climate change on vegetation in the Blue Mountains ecoregion, USA. *Climate Services*, **10**, 33–43. https://doi.org/10.1016/j.cliser.2017.07.002

239. Hicke, J.A., A.J.H. Meddens, and C.A. Kolden, 2016: Recent tree mortality in the western United States from bark beetles and forest fires. *Forest Science*, **62** (2), 141–153. https://doi.org/10.5849/forsci.15-086

240. Morgan, P., E.K. Heyerdahl, E.K. Strand, S.C. Bunting, J.P. Riser Ii, J.T. Abatzoglou, M. Nielsen-Pincus, and M. Johnson, 2020: Fire and land cover change in the Palouse Prairie–forest ecotone, Washington and Idaho, USA. *Fire Ecology*, **16** (1), 2. https://doi.org/10.1186/s42408-019-0061-9

241. Paveglio, T.B., C. Moseley, M.S. Carroll, D.R. Williams, E.J. Davis, and A.P. Fischer, 2015: Categorizing the social context of the wildland urban interface: Adaptive capacity for wildfire and community "archetypes". *Forest Science*, **61** (2), 298–310. https://doi.org/10.5849/forsci.14-036

242. Hashida, Y. and D.J. Lewis, 2019: The intersection between climate adaptation, mitigation, and natural resources: An empirical analysis of forest management. *Journal of the Association of Environmental and Resource Economists*, **6** (5), 893–926. https://doi.org/10.1086/704517

243. Scouse, A., S.S. Kelley, S. Liang, and R. Bergman, 2020: Regional and net economic impacts of high-rise mass timber construction in Oregon. *Sustainabile Cities and Society*, **61**, 102154. https://doi.org/10.1016/j.scs.2020.102154.

244. Law, B.E., T.W. Hudiburg, L.T. Berner, J.J. Kent, P.C. Buotte, and M.E. Harmon, 2018: Land use strategies to mitigate climate change in carbon dense temperate forests. *Proceedings of the National Academy of Sciences of the United States of America*, **115** (14), 3663–3668. https://doi.org/10.1073/pnas.1720064115

245. Mucioki, M., J. Sowerwine, D. Sarna-Wojcicki, F.K. Lake, and S. Bourque, 2021: Conceptualizing Indigenous Cultural Ecosystem Services (ICES) and benefits under changing climate conditions in the Klamath River Basin and their implications for land management and governance. *Journal of Ethnobiology*, **41** (3), 313–330. https://doi.org/10.2993/0278-0771-41.3.313

246. WA DNR, 2020: Summary of Natural and Working Lands Carbon Inventories and Incentive Programs in Washington. Washington Department of Natural Resources. https://app.leg.wa.gov/reportstothelegislature/home/getpdf?filename=dnr%20carbon%20sequestration%20report_8f19b00b-5acf-4c97-83b4-16cecb559803.pdf

247. Bellquist, L., V. Saccomanno, B.X. Semmens, M. Gleason, and J. Wilson, 2021: The rise in climate change-induced federal fishery disasters in the United States. *PeerJ*, **9**, e11186. https://doi.org/10.7717/peerj.11186

248. Cramer, L.A., C. Flathers, D. Caracciolo, S.M. Russell, and F. Conway, 2018: Graying of the fleet: Perceived impacts on coastal resilience and local policy. *Marine Policy*, **96**, 27–35. https://doi.org/10.1016/j.marpol.2018.07.012

249. Haugen, B.I., L.A. Cramer, G.G. Waldbusser, and F.D.L. Conway, 2021: Resilience and adaptive capacity of Oregon's fishing community: Cumulative impacts of climate change and the graying of the fleet. *Marine Policy*, **126**, 104424. https://doi.org/10.1016/j.marpol.2021.104424

250. Ritzman, J., A. Brodbeck, S. Brostrom, S. McGrew, S. Dreyer, T. Klinger, and S.K. Moore, 2018: Economic and sociocultural impacts of fisheries closures in two fishing-dependent communities following the massive 2015 U.S. West Coast harmful algal bloom. *Harmful Algae*, **80**, 35–45. https://doi.org/10.1016/j.hal.2018.09.002

251. Chang, M., H. Kennard, L. Nelson, K. Wrubel, S. Gagnon, R. Monette, and J. Ledford, 2020: Makah traditional knowledge and cultural resource assessment: A preliminary framework to utilize traditional knowledge in climate change planning. *Parks Stewardship Forum*, **36** (1). https://doi.org/10.5070/p536146381

252. Schlinger, C., O. Conroy-Ben, C. Cooley, N. Cooley, M. Cruz, D. Dotson, J. Doyle, M.J. Eggers, P. Hardison, M. Hatch, C. Hogue, K. Jacobson Hedin, C. Jones, K. Lanphier, D. Marks-Marino, D. Mosley, F. Olsen Jr., and M. Peacock, 2021: Ch. 4.2. Water. In: *Status of Tribes and Climate Change Report*. Marks-Marino, D., Ed. Institute for Tribal Environmental Professionals, Flagstaff, AZ, 98–141. http://nau.edu/stacc2021

253. NWIFC, 2016: Climate Change and Our Natural Resources: A Report from the Treaty Tribes in Western Washington. Northwest Indian Fisheries Commission. https://nwifc.org/w/wp-content/uploads/downloads/2017/01/CC_and_Our_NR_Report_2016-1.pdf

254. Mojica, J., K. Cousins, and T. Madsen, 2021: Economic Analysis of Outdoor Recreation in Oregon. Earth Economics, Tacoma, WA. https://static1.squarespace.com/static/561dcdc6e4b039470e9afc00/t/5ffe3084ce56a6552b7a3c71/1610494115376/EconomicAnalysisofOutdoorRecreationinOregon_OTC-EarthEconomics_SmallRes.pdf

255. Snover, A.K., N.J. Mantua, J.S. Littell, M.A. Alexander, M.M. McClure, and J. Nye, 2013: Choosing and using climate change scenarios for ecological-impact assessments and conservation decisions. *Conservation Biology*, **27** (6), 1147–1157. https://doi.org/10.1111/cobi.12163

256. Maas, A. and K.E. Himes, 2021: Recreation and tourism report. In: *Idaho Climate-Economy Impacts Assessment*. James A. & Louise McClure Center for Public Policy Research, University of Idaho, Boise, ID. https://www.uidaho.edu/president/direct-reports/mcclure-center/iceia/recreation-and-tourism

257. Wlostowski, A.N., K.S. Jennings, R.E. Bash, J. Burkhardt, C.W. Wobus, and G. Aggett, 2021: Dry landscapes and parched economies: A review of how drought impacts nonagricultural socioeconomic sectors in the US Intermountain West. *WIREs Water*, **9** (1). https://doi.org/10.1002/wat2.1571

258. Tohver, I.M., A.F. Hamlet, and S.-Y. Lee, 2014: Impacts of 21st-century climate change on hydrologic extremes in the Pacific Northwest region of North America. *Journal of the American Water Resources Association*, **50** (6), 1461–1476. https://doi.org/10.1111/jawr.12199

259. Musselman, K.N., F. Lehner, K. Ikeda, M.P. Clark, A.F. Prein, C. Liu, M. Barlage, and R. Rasmussen, 2018: Projected increases and shifts in rain-on-snow flood risk over western North America. *Nature Climate Change*, **8** (9), 808–812. https://doi.org/10.1038/s41558-018-0236-4

260. Kim, M.-K. and P.M. Jakus, 2019: Wildfire, national park visitation, and changes in regional economic activity. *Journal of Outdoor Recreation and Tourism*, **26**, 34–42. https://doi.org/10.1016/j.jort.2019.03.007

261. Peterson, D.L., M.S. Hand, J.J. Ho, and S.K. Dante-Wood, 2022: Ch. 7. Climate change effects on outdoor recreation in Southwest Oregon. In: *Climate Change Vulnerability and Adaptation in Southwest Oregon*. Halofsky, J.E., Peterson D.L., and R.A. Gravenmier, Eds. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, OR, 361–398. https://www.fs.usda.gov/pnw/pubs/pnw-gtr995.pdf

262. Chan, N.W. and C.J. Wichman, 2020: Climate change and recreation: Evidence from North American cycling. *Environmental and Resource Economics*, **76** (1), 119–151. https://doi.org/10.1007/s10640-020-00420-5

263. Hjerpe, E., A. Hussain, and T. Holmes, 2020: Amenity migration and public lands: Rise of the protected areas. *Environmental Management*, **66** (1), 56–71. https://doi.org/10.1007/s00267-020-01293-6

264. NRDC, 2019: Climate Change and Health in Washington. IB: 19-09-B. National Research Defense Council, 11 pp. https://www.nrdc.org/sites/default/files/climate-change-health-impacts-washington-ib.pdf

265. Whyte, K., C. Avery, E. Azzuz, J. Breckinridge, C. Cooley, K. Cozzetto, R. Croll, M. Cruz, P. Ezcurra, P. Hardison, C. Jones, F. Lake, C. Magee, D.M. Marks-Marino, D., H. Mullen, C. Nelson, A. Pairis, H. Panci, B. Rodriguez, H. Sorensen, C. Spriggs, and A. Warneke, 2021: Ch. 4. Ecosystems & biodiversity. In: *Status of Tribes and Climate Change Report*. Marks-Marino, D., Ed. Institute for Tribal Environmental Professionals, 56–80. http://nau.edu/stacc2021

266. NIFA, 2021: Improving the Ecological Services of Nez Perce Lands Through Agriculture Management and Decision Support Tools. U.S. Department of Agriculture, National Institue of Food and Agriculture. https://portal.nifa.usda.gov/web/crisprojectpages/1024991-improving-the-ecological-services-of-nez-perce-lands-through-agriculture-management-and-decision-support-tools.html

267. King, A., 2021: Yakama Nation seeks food sovereignty in new farming venture with weighty history. *Oregon Public Broadcasting*, December 13, 2021. https://www.opb.org/article/2021/12/12/yakama-nation-food-sovereignty-farming-venture/

268. Yakama Nation, 2019: Climate Action Plan for the Territories of the Yakama Nation. Yakama Nation. https://mrsc.org/getmedia/7e788879-99dd-4711-9cc8-c6cacefe6cd4/m58totyncap.pdf.aspx

269. Matsumoto, S., 2022: Environmental justice for food system workers: Heat-illness prevention standards as one step toward just transition. *Pace Environmental Law Review*, **40** (1). https://ssrn.com/abstract=4338860

270. Henry, M.S., M.D. Bazilian, and C. Markuson, 2020: Just transitions: Histories and futures in a post-COVID world. *Energy Research & Social Science*, **68**, 101668. https://doi.org/10.1016/j.erss.2020.101668

271. Roemer, K.F. and J.H. Haggerty, 2021: Coal communities and the U.S. energy transition: A policy corridors assessment. *Energy Policy*, **151**, 112112. https://doi.org/10.1016/j.enpol.2020.112112

272. Proctor, K.W., G.S. Murthy, and C.W. Higgins, 2021: Agrivoltaics align with Green New Deal goals while supporting investment in the US' rural economy. *Sustainability*, **13** (1), 137. https://doi.org/10.3390/su13010137

273. Shortridge, J. and J.S. Camp, 2019: Addressing climate change as an emerging risk to infrastructure systems. *Risk Analysis*, **39** (5), 959–967. https://doi.org/10.1111/risa.13234

274. Araújo, K., 2022: Ch. 1. The evolving field of energy transitions. In: *Routledge Handbook of Energy Transitions*. Araújo, K., Ed. Taylor & Francis, London, UK, 17. https://doi.org/10.4324/9781003183020

275. Araújo, K. and D. Shropshire, 2021: A meta-level framework for evaluating resilience in net-zero carbon power systems with extreme weather events in the United States. *Energies*, **14** (14), 4243. https://doi.org/10.3390/en14144243.

276. Guidotti, R., H. Chmielewski, V.U. Unnikrishnan, P. Gardoni, T. McAllister, and J.W. Lindt, 2016: Modeling the resilience of critical infrastructure: The role of network dependencies. *Sustainable and Resilient Infrastructure*, **1** (3–4), 153–168. https://doi.org/10.1080/23789689.2016.1254999

277. Bumbaco, K.A., M.H. Rogers, L.W. O'Neill, D.J. Hoekema, and C.L. Raymond, 2022: 2021 Pacific Northwest Water Year Impacts Assessment. Office of the Washington State Climatologist, Climate Impacts Group, Oregon State Climatologist, Idaho Department of Water Resources, and the National Oceanic and Atmospheric Administration's National Integrated Drought Information System. https://www.drought.gov/documents/2021-pacific-northwest-water-year-impacts-assessment

278. Bumbaco, K.A., C.L. Raymond, L.W. O'Neill, A. Mehta, and D.J. Hoekema, 2023: 2022 Pacific Northwest Water Year Impacts Assessment. Office of the Washington State Climatologist, Climate Impacts Group, Oregon State Climatologist, Idaho Department of Water Resources, and the National Oceanic and Atmospheric Administration's National Integrated Drought Information System. https://www.drought.gov/documents/2022-pacific-northwest-water-year-impacts-assessment

279. Bumbaco, K.A., C.L. Raymond, L.W. O'Neill, and D.J. Hoekema, 2021: 2020 Pacific Northwest Water Year Impacts Assessment. Office of the Washington State Climatologist, Climate Impacts Group, Oregon State Climatologist, Idaho Department of Water Resources, and the National Oceanic and Atmospheric Administration's National Integrated Drought Information System. https://cig.uw.edu/publications/2020-pacific-northwest-water-year-impacts-assessment/

280. U.S. Census Bureau, 1990: Historical Census of Housing Tables: Sewage Disposal. U.S. Department of Commerce, U.S. Census Bureau. https://www.census.gov/data/tables/time-series/dec/coh-sewage.html

281. Cox, A.H., D. Surabian, G.W. Loomis, J.D. Turenne, and J.A. Amador, 2020: Temporal variability in the vertical separation distance of septic system drainfields along the southern Rhode Island coast. *Water, Air, & Soil Pollution*, **231** (3), 107. https://doi.org/10.1007/s11270-020-04488-z

282. Kohler, L.E., J. Silverstein, and B. Rajagopalan, 2016: Modeling on-site wastewater treatment system performance fragility to hydroclimate stressors. *Water Science and Technology*, **74** (12), 2917–2926. https://doi.org/10.2166/wst.2016.467

283. Hoghooghi, N., J.S. Pippin, B.K. Meyer, J.B. Hodges, and B.P. Bledsoe, 2021: Frontiers in assessing septic systems vulnerability in coastal Georgia, USA: Modeling approach and management implications. *PLoS ONE*, **16** (8), e0256606. https://doi.org/10.1371/journal.pone.0256606

284. Devereux, R., Y. Wan, J.L. Rackley, V. Fasselt, and D.N. Vivian, 2021: Comparative analysis of nitrogen concentrations and sources within a coastal urban bayou watershed: A multi-tracer approach. *Science of The Total Environment*, **776**, 145862. https://doi.org/10.1016/j.scitotenv.2021.145862

285. Mauger, G.S. and J.S. Won, 2019: Expanding the Ensemble of Precipitation Projections for King County. University of Washington, Climate Impacts Group, Seattle, WA. https://cig.uw.edu/publications/expanding-the-ensemble-of-precipitation-projections-for-king-county/

286. Morgan, H., G. Mauger, J. Won, and D. Gould, 2021: Projected Changes in Extreme Precipitation Web Tool. University of Washington Climate Impacts Group. https://doi.org/10.6069/79cv-4233

287. Salathé Jr., E.P., A.F. Hamlet, C.F. Mass, S.-Y. Lee, M. Stumbaugh, and R. Steed, 2014: Estimates of twenty-first-century flood risk in the Pacific Northwest based on regional climate model simulations. *Journal of Hydrometeorology*, **15** (5), 1881–1899. https://doi.org/10.1175/jhm-d-13-0137.1

288. Van Abs, D.J., 2016: Climate Change Adaptation in the Water Supply Sector. Rutgers, The State University of New Jersey. https://njadapt.rutgers.edu/docman-lister/conference-materials/166-climate-change-adaptation-in-water-supply-sector-final-1/file

289. EIA, n.d.: U.S. State Profiles and Energy Estimates. U.S. Energy Information Administration. https://www.eia.gov/state/

290. Turner, S.W., N. Voisin, K.D. Nelson, and V.C. Tidwell, 2022: Drought Impacts on Hydroelectric Power Generation in the Western United States: A Multiregional Analysis of 21st Century Hydropower Generation. PNNL-33212. U.S. Department of Energy, Pacific Northwest National Laboratory, Richland, WA. https://doi.org/10.2172/1887470

291. Voisin, N., A. Dyreson, T. Fu, M. O'Connell, S.W.D. Turner, T. Zhou, and J. Macknick, 2020: Impact of climate change on water availability and its propagation through the western U.S. power grid. *Applied Energy*, **276**, 115467. https://doi.org/10.1016/j.apenergy.2020.115467

292. Pitcock, B., T. Lazarte, and C. Christen, 2020: Lower Snake River Hydropower Dams: A Resilience Assessment of Regional Impacts with Proposed Dam Removal. Boise State University, 19 pp. https://wpwww-prod.s3.us-west-2.amazonaws.com/uploads/sites/151/2020/05/Resilience-with-Dams.pdf

293. Hall, S.M., 2021: Energy report. In: *Idaho Climate-Economy Impacts Assessment*. James A. & Louise McClure Center for Public Policy Research, University of Idaho, Boise, ID. https://www.uidaho.edu/president/direct-reports/mcclure-center/iceia

294. Turner, S.W.D., N. Voisin, J. Fazio, D. Hua, and M. Jourabchi, 2019: Compound climate events transform electrical power shortfall risk in the Pacific Northwest. *Nature Communications*, **10** (1), 8. https://doi.org/10.1038/s41467-018-07894-4

295. Cederholm, C.J., D.H. Johnson, R.E. Bilby, L.G. Dominguez, A.M. Garrett, W.H. Graeber, E.L. Greda, M.D. Kunze, B.G. Marcot, J.F. Palmisano, R.W. Plotnikoff, W.G. Pearcy, C.A. Simenstad, and P.C. Trotter, 2000: Pacific Salmon and Wildlife—Ecological Contexts, Relationships, and Implications for Management. Special Edition Technical Report. Washington Department of Fish and Wildlife, Olympia, WA. https://wdfw.wa.gov/publications/00063

296. Yoder, J., C. Raymond, R. Basu, S. Deol, A. Fremier, K. Garcia, G. Mauger, J. Padowski, M. Rogers, and A. Stahl, 2022: Climate Change and Stream Flow: Barriers and Opportunities. Preliminary project report to the Washington State Department of Ecology. Washington State, Department of Ecology, Water Resources Program, Olympia, WA. https://apps.ecology.wa.gov/publications/documents/2211029.pdf

297. Nez Perce Tribe, 2022: *Nimiipuu Energy May* 2022. Nez Perce Tribe. https://vimeo.com/710582042

298. EPI, 2023: Wildfire-Grid Risk, Power Talk. Boise State University, Energy Policy Institute. https://www.boisestate.edu/epi/upcomingevents/

299. Utility Wildland Fire Prevention Advisory Committee—Duties—Report—Membership—Immunity. RCW 76.04.780, Washington State Legislature, 2022. https://app.leg.wa.gov/rcw/default.aspx?cite=76.04.780

300. Araújo, K.M., T.J. Foxon, J. Markard, R. Raven, and R. Schaeffer, 2022: Ch. 29. Reconceptualizing the next frontier in energy transitions. In: *Routledge Handbook of Energy Transitions*. Araújo, K.M., Ed. Taylor & Francis, London, UK, 6. https://doi.org/10.4324/9781003183020-34

301. Black, G., D. Shropshire, and K. Araújo, 2021: Ch. 22. Small modular reactor (SMR) adoption: Opportunities and challenges for emerging markets. In: *Handbook of Small Modular Nuclear Reactors*, 2nd ed. Ingersoll, D.T. and M.D. Carelli, Eds. Woodhead Publishing, 557–593. https://doi.org/10.1016/b978-0-12-823916-2.00022-9

302. Araújo, K.M., 2018: *Low Carbon Energy Transitions: Turning Points in National Policy and Innovation*. Oxford University Press. https://doi.org/10.1093/oso/9780199362554.001.0001

303. Idaho Power, 2021: Integrated Resource Plan. Idaho Power. https://docs.idahopower.com/pdfs/aboutus/planningforfuture/irp/2021/2021%20irp_web.pdf

304. Araújo, K., D. Mahajan, R. Kerr, and M. da Silva, 2017: Global biofuels at the crossroads: An overview of technical, policy, and investment complexities in the sustainability of biofuel development. *Agriculture*, **7** (4). https://doi.org/10.3390/agriculture7040032

305. Aumeier, S.E., D.E. Shropshire, T. Allen, K. Araújo, C. Bell, M. Craig, J. Parsons, and T. Righetti, 2021: Emerging Energy Market Analysis Initiative, Methodological Framework. INL/EXT-21-65347. U.S. Department of Energy, Idaho National Laboratory, Idaho Falls, ID. https://doi.org/10.2172/1838119

306. Shropshire, D.E., K. Araujo, C. Koerner, C. Bell, R. Johnson, J. Parsons, S. Gerace, E. Holubynak, T. Righetti, and S.E. Aumeier, 2023: Microreactor Applications in U.S. Markets, Evaluation of State-Level Legal, Regulatory, Economic and Technology Implications. INL/RPT-23-71733. U.S. Department of Energy, Idaho National Laboratory, Idaho Falls, ID. https://doi.org/10.2172/1964093

307. Ellingwood, B.R., H. Cutler, P. Gardoni, W.G. Peacock, J.W. van de Lindt, and N. Wang, 2016: The Centerville virtual community: A fully integrated decision model of interacting physical and social infrastructure systems. *Sustainable and Resilient Infrastructure*, **1** (3-4), 95–107. https://doi.org/10.1080/23789689.2016.1255000

308. Markolf, S.A., C. Hoehne, A. Fraser, M.V. Chester, and B.S. Underwood, 2019: Transportation resilience to climate change and extreme weather events—Beyond risk and robustness. *Transport Policy*, **74**, 174–186. https://doi.org/10.1016/j.tranpol.2018.11.003

309. Dye, A.W., J.B. Kim, A. McEvoy, F. Fang, and K.L. Riley, 2021: Evaluating rural Pacific Northwest towns for wildfire evacuation vulnerability. *Natural Hazards*, **107** (1), 911–935. https://doi.org/10.1007/s11069-021-04615-x

310. Rodrigue, J.-P., 2020: *The Geography of Transport Systems*, 5th ed. Routledge, London, UK, 480 pp. https://doi.org/10.4324/9780429346323

311. Rempel, A. and M. Babbar-Sebens, 2021: Built environment. In: *Fifth Oregon Climate Assessment*. Oregon Climate Change Research Institute, Oregon State University, Corvallis, OR, 113–136. https://ir.library.oregonstate.edu/concern/technical_reports/pz50h457p

312. Oregon DOT, 2014: Climate Change Vulnerability Assessment and Adaptation Options Study. Oregon Department of Transportation. https://www.fhwa.dot.gov/environment/sustainability/resilience/pilots/2013-2015_pilots/oregon/final_report/odotreport.pdf

313. WSDOT, 2011: Climate Impacts Vulnerability Assessment. Washington State, Department of Transportation. https://wsdot.wa.gov/sites/default/files/2021-10/Climate-Impact-AssessmentforFHWA-12-2011.pdf

314. Faria, R., P. Marques, P. Moura, F. Freire, J. Delgado, and A.T. de Almeida, 2013: Impact of the electricity mix and use profile in the life-cycle assessment of electric vehicles. *Renewable and Sustainable Energy Reviews*, **24**, 271–287. https://doi.org/10.1016/j.rser.2013.03.063

315. Hawkins, T.R., B. Singh, G. Majeau-Bettez, and A.H. Strømman, 2013: Comparative environmental life cycle assessment of conventional and electric vehicles. *Journal of Industrial Ecology*, **17** (1), 53–64. https://doi.org/10.1111/j.1530-9290.2012.00532.x

316. Peng, T., X. Ou, and X. Yan, 2018: Development and application of an electric vehicles life-cycle energy consumption and greenhouse gas emissions analysis model. *Chemical Engineering Research and Design*, **131**, 699–708. https://doi.org/10.1016/j.cherd.2017.12.018

317. Gober, P., A. Middel, A. Brazel, S. Myint, H. Chang, J.D. Duh, and L. House-Peters, 2012: Tradeoffs between water conservation and temperature amelioration in Phoenix and Portland: Implications for urban sustainability. *Urban Geography*, **33** (7), 1030–1054. https://doi.org/10.2747/0272-3638.33.7.1030

318. Kramer, H.A., M.H. Mockrin, P.M. Alexandre, and V.C. Radeloff, 2019: High wildfire damage in interface communities in California. *International Journal of Wildland Fire*, **28** (9), 641–650. https://doi.org/10.1071/wf18108

319. May, N.W., C. Dixon, and D.A. Jaffe, 2021: Impact of wildfire smoke events on indoor air quality and evaluation of a low-cost filtration method. *Aerosol and Air Quality Research*, **21** (7), 210046. https://doi.org/10.4209/aaqr.210046

320. Stauffer, D.A., D.A. Autenrieth, J.F. Hart, and S. Capoccia, 2020: Control of wildfire-sourced $PM_{2.5}$ in an office setting using a commercially available portable air cleaner. *Journal of Occupational and Environmental Hygiene*, **17** (4), 109–120. https://doi.org/10.1080/15459624.2020.1722314

321. Liu, J.C., L.J. Mickley, M.P. Sulprizio, F. Dominici, X. Yue, K. Ebisu, G.B. Anderson, R.F.A. Khan, M.A. Bravo, and M.L. Bell, 2016: Particulate air pollution from wildfires in the Western US under climate change. *Climatic Change*, **138** (3), 655–666. https://doi.org/10.1007/s10584-016-1762-6

322. Liu, Y., E. Austin, J. Xiang, T. Gould, T. Larson, and E. Seto, 2021: Health impact assessment of the 2020 Washington state wildfire smoke episode: Excess health burden attributable to increased $PM_{2.5}$ exposures and potential exposure reductions. *GeoHealth*, **5** (5), e2020GH000359. https://doi.org/10.1029/2020gh000359

323. Durairajan, R., C. Barford, and P. Barford, 2018: Lights out: Climate change risk to Internet infrastructure. *Proceedings of the Applied Networking Research Workshop*, Montreal, QC, Canada. Association for Computing Machinery, 9–15. https://doi.org/10.1145/3232755.3232775

324. Adams-Schoen, S.J. and M. Smith, 2023: Land-use law and climate change. In: *Sixth Oregon Climate Assessment*. Fleishman, E., Ed. Oregon State University, Oregon Climate Change Research Institute, Corvallis, OR. https://doi.org/10.5399/osu/1161

325. Adams-Schoen, S.J., 2018: Beyond localism: Harnessing state adaptation lawmaking to facilitate local climate resilience. *Michigan Journal of Environmental & Administrative Law*, **8** (1). https://repository.law.umich.edu/mjeal/vol8/iss1/5

326. Grannis, J., J. Wyman, M. Singer, and J. Shoaf, 2012: Coastal management in the face of rising seas: Legal strategies for Connecticut. *Sea Grant Law and Policy Journal*, **5** (1), 59–88. https://www.georgetownclimate.org/reports/coastal-management-in-the-face-of-rising-seas-legal-strategies-for-connecticut.html

327. Siders, A., 2013: Managed Coastal Retreat: A Legal Handbook on Shifting Development away from Vulnerable Areas. Columbia Public Law Research Paper No. 14-365. Columbia University. https://doi.org/10.2139/ssrn.2349461

328. Bumbaco, K.A., K.D. Dello, and N.A. Bond, 2013: History of Pacific Northwest heat waves: Synoptic pattern and trends. *Journal of Applied Meteorology and Climatology*, **52** (7), 1618–1631. https://doi.org/10.1175/jamc-d-12-094.1

329. NWS, 2021: Weather Related Fatality and Injury Statistics. National Oceanic and Atmospheric Administration, National Weather Service. https://www.weather.gov/hazstat/

330. Silberner, J., 2021: Heat wave causes hundreds of deaths and hospitalisations in Pacific Northwest. *British Medical Journal*, **374**. https://doi.org/10.1136/bmj.n1696

331. Philip, S.Y., S.F. Kew, G.J. van Oldenborgh, F.S. Anslow, S.I. Seneviratne, R. Vautard, D. Coumou, K.L. Ebi, J. Arrighi, R. Singh, M. van Aalst, C. Pereira Marghidan, M. Wehner, W. Yang, S. Li, D.L. Schumacher, M. Hauser, R. Bonnet, L.N. Luu, F. Lehner, N. Gillett, J. Tradowsky, G.A. Vecchi, C. Rodell, R.B. Stull, R. Howard, and F.E.L. Otto, 2021: Rapid attribution analysis of the extraordinary heat wave on the Pacific coast of the US and Canada in June 2021. *Earth System Dynamics*, **13** (4), 1689–1713. https://doi.org/10.5194/esd-13-1689-2022

332. Zhang, X., T. Zhou, W. Zhang, L. Ren, J. Jiang, S. Hu, M. Zuo, L. Zhang, and W. Man, 2023: Increased impact of heat domes on 2021-like heat extremes in North America under global warming. *Nature Communications*, **14** (1), 1690. https://doi.org/10.1038/s41467-023-37309-y

333. Thompson, V., A.T. Kennedy-Asser, E. Vosper, Y.T.E. Lo, C. Huntingford, O. Andrews, M. Collins, G.C. Hegerl, and D. Mitchell, 2022: The 2021 western North America heat wave among the most extreme events ever recorded globally. *Science Advances*, **8** (18), 6860. https://doi.org/10.1126/sciadv.abm6860

334. Isaksen, T.B., M. Yost, E. Hom, and R. Fenske, 2014: Projected health impacts of heat events in Washington State associated with climate change. *Reviews on Environmental Health*, **29** (1-2), 119–123. https://doi.org/10.1515/reveh-2014-0029

335. Schramm, P.J., A. Vaidyanathan, L. Radhakrishnan, A. Gates, K. Hartnett, and P. Breysse, 2021: Heat-related emergency department visits during the Northwestern heat wave—United States. *Morbidity and Mortality Weekly Report*, **70**, 1020–1021. https://doi.org/10.15585/mmwr.mm7029e1

336. Stowell, J.D., C.-E. Yang, J.S. Fu, N.C. Scovronick, M.J. Strickland, and Y. Liu, 2022: Asthma exacerbation due to climate change-induced wildfire smoke in the western US. *Environmental Research Letters*, **17** (1), 014023. https://doi.org/10.1088/1748-9326/ac4138

337. Zhou, X., K. Josey, L. Kamareddine, M.C. Caine, T. Liu, L.J. Mickley, M. Cooper, and F. Dominici, 2021: Excess of COVID-19 cases and deaths due to fine particulate matter exposure during the 2020 wildfires in the United States. *Science Advances*, **7** (33), 8789. https://doi.org/10.1126/sciadv.abi8789

338. Kochi, I., G.H. Donovan, P.A. Champ, and J.B. Loomis, 2010: The economic cost of adverse health effects from wildfire-smoke exposure: A review. *International Journal of Wildland Fire*, **19** (7), 803–817. https://doi.org/10.1071/wf09077

339. McDermot, D. and M. Kadlec, 2022: Increased Medical and Emergency Department Claims for Asthma Following Wildfire Smoke Exposure in Washington State, 2014–2018. Washington State Health Services Research Project Research Brief No. 104. Washington State Office of Financial Management. https://ofm.wa.gov/sites/default/files/public/dataresearch/researchbriefs/brief104.pdf

340. Gasparrini, A., Y. Guo, M. Hashizume, E. Lavigne, A. Zanobetti, J. Schwartz, and A. Tobias, 2015: Mortality risk attributable to high and low ambient temperature: A multicountry observational study. *The Lancet*, **386** (9991), 369–375. https://doi.org/10.1016/s0140-6736(14)62114-0

341. Clayton, S., C. Manning, K. Krygsman, and M. Speiser, 2017: Mental Health and Our Changing Climate: Impacts, Implications, and Guidance. American Psychological Association and ecoAmerica, Washington, DC. https://www.apa.org/news/press/releases/2017/03/mental-health-climate.pdf

342. Pacheco, S.E., 2020: Catastrophic effects of climate change on children's health start before birth. *The Journal of Clinical Investigation*, **130** (2), 562–564. https://doi.org/10.1172/jci135005

343. Korsiak, J., L. Pinault, T. Christidis, R.T. Burnett, M. Abrahamowicz, and S. Weichenthal, 2022: Long-term exposure to wildfires and cancer incidence in Canada: A population-based observational cohort study. *The Lancet Planetary Health*, **6** (5), e400–e409. https://doi.org/10.1016/s2542-5196(22)00067-5

344. Belova, A., C.A. Gould, K. Munson, M. Howell, C. Trevisan, N. Obradovich, and J. Martinich, 2022: Projecting the suicide burden of climate change in the United States. *GeoHealth*, **6** (5), e2021GH000580. https://doi.org/10.1029/2021gh000580

345. Cianconi, P., S. Betrò, and L. Janiri, 2020: The impact of climate change on mental health: A systematic descriptive review. *Frontiers in Psychiatry*, **11**, 74. https://doi.org/10.3389/fpsyt.2020.00074

346. Jones, R.T., D.P. Ribbe, P. Cunningham, and J.D. Weddle, 2003: Psychosocial correlates of wildfire disaster: Post disaster adult reactions. *Fire Technology*, **39** (2), 103–117. https://doi.org/10.1023/a:1024229812303

347. Ursano, R.J., J.C. Morganstein, and R. Cooper, 2017: APA Resource Document: Resource Document on Mental Health and Climate Change. American Psychological Association. https://www.psychiatry.org/file%20library/psychiatrists/directories/library-and-archive/resource_documents/2017-resource-document-mental-health-climate-change.pdf

348. WHO, 2013: *Mental Health Action Plan 2013-2020*. World Health Organization, Geneva, Switzerland. https://www.who.int/publications/i/item/9789241506021

349. Mental Health America, 2020: Ranking the States. Mental Health America. https://mhanational.org/sites/default/files/State%20of%20Mental%20Health%20in%20America%20-%202020_0.pdf

350. Cerveny, L.K. and J.W. Baur, 2020: Homelessness and nonrecreational camping on national forests and grasslands in the United States: Law enforcement perspectives and regional trends. *Journal of Forestry*, **118** (2), 139–153. https://doi.org/10.1093/jofore/fvz065

351. Goldman, L., 2022: *Climate Change and Youth: Turning Grief and Anxiety into Activism*, 1st ed. Taylor & Francis, New York, 352 pp. https://doi.org/10.4324/9781003051770

352. Vickery, J. and L.M. Hunter, 2016: Native Americans: Where in environmental justice research? *Society & Natural Resources*, **29** (1), 36–52. https://doi.org/10.1080/08941920.2015.1045644

353. Anderson, C.A., 2001: Heat and violence. *Current Directions in Psychological Science*, **10** (1), 33–38. https://doi.org/10.1111/1467-8721.00109

354. Enenkel, M., L. See, R. Bonifacio, V. Boken, N. Chaney, P. Vinck, L. You, E. Dutra, and M. Anderson, 2015: Drought and food security—Improving decision-support via new technologies and innovative collaboration. *Global Food Security*, **4**, 51–55. https://doi.org/10.1016/j.gfs.2014.08.005

355. Friel, S., H. Berry, H. Dinh, L. O'Brien, and H.L. Walls, 2014: The impact of drought on the association between food security and mental health in a nationally representative Australian sample. *BMC Public Health*, **14** (1), 1102. https://doi.org/10.1186/1471-2458-14-1102

356. Hetherington, E., S. McDonald, M. Wu, and S. Tough, 2018: Risk and protective factors for mental health and community cohesion after the 2013 Calgary flood. *Disaster Medicine and Public Health Preparedness*, **12** (4), 470–477. https://doi.org/10.1017/dmp.2017.91

357. Stanke, C., V. Murray, R. Amlôt, J. Nurse, and R. Williams, 2012: The effects of flooding on mental health: Outcomes and recommendations from a review of the literature. *PLoS Currents*, **4**. https://doi.org/10.1371/4f9f1fa9c3cae

358. Hearst, M.O., J. Yang, S. Friedrichsen, K. Lenk, C. Caspi, and M.N. Laska, 2021: The availability of culturally preferred fruits, vegetables and whole grains in corner stores and non-traditional food stores. *International Journal of Environmental Research and Public Health*, **18** (9), 5030. https://doi.org/10.3390/ijerph18095030

359. Patchell, B. and K. Edwards, 2014: The role of traditional foods in diabetes prevention and management among Native Americans. *Current Nutrition Reports*, **3** (4), 340–344. https://doi.org/10.1007/s13668-014-0102-6

360. Sarkar, D., J. Walker-Swaney, and K. Shetty, 2020: Food diversity and indigenous food systems to combat diet-linked chronic diseases. *Current Developments in Nutrition*, **4** (Supplement_1), 3–11. https://doi.org/10.1093/cdn/nzz099

361. Bildfell, R.J., J.W. Mertins, J.A. Mortenson, and D.F. Cottam, 2004: Hair-loss syndrome in black-tailed deer of the Pacific Northwest. *Journal of Wildlife Diseases*, **40** (4), 670–681. https://doi.org/10.7589/0090-3558-40.4.670

362. Byers, J.E., 2021: Marine parasites and disease in the era of global climate change. *Annual Review of Marine Science*, **13** (1), 397–420. https://doi.org/10.1146/annurev-marine-031920-100429

363. Donatuto, J., L. Campbell, C. Cooley, M. Cruz, J. Doyle, M. Eggers, T. Farrow Ferman, S. Gaughen, P. Hardison, C. Jones, D. Marks-Marino, A. Pairis, W. Red Elk, D. Sambo Dorough, and C. Sanders, 2021: Ch. 5. Health & wellbeing. In: *Status of Tribes and Climate Change Report*. Marks-Marino, D., Ed. Institute for Tribal Environmental Professionals, 159–173. http://nau.edu/stacc2021

364. Norton-Smith, K., K. Lynn, K. Chief, K. Cozzetto, J. Donatuto, M.H. Redsteer, L.E. Kruger, J. Maldonado, C. Viles, and K.P. Whyte, 2016: Climate Change and Indigenous Peoples: A Synthesis of Current Impacts and Experiences. Gen. Tech. Rep. PNW-GTR-944. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, 136 pp. https://www.fs.usda.gov/treesearch/pubs/53156

365. Doubleday, A., N.A. Errett, K.L. Ebi, and J.J. Hess, 2020: Indicators to guide and monitor climate change adaptation in the US Pacific Northwest. *American Journal of Public Health*, **110** (2), 180–188. https://doi.org/10.2105/ajph.2019.305403

366. State of Oregon, 2021: State of Oregon Climate Equity Blueprint. State of Oregon. https://www.oregon.gov/lcd/cpu/documents/2021_jan_climate-equity-blueprint.pdf

367. Powell, J., S. Menendian, and W. Ake, 2019: Targeted Universalism Policy & Practice. University of California, Berkeley, Haas Institute for a Fair and Inclusive Society. https://belonging.berkeley.edu/sites/default/files/targeted_universalism_primer.pdf?file=1&force=1

368. Filigrana, P., J.I. Levy, J. Gauthier, S. Batterman, and S.D. Adar, 2022: Health benefits from cleaner vehicles and increased active transportation in Seattle, Washington. *Journal of Exposure Science & Environmental Epidemiology*, **32** (4), 538–544. https://doi.org/10.1038/s41370-022-00423-y

369. Rempel, A.R., J. Danis, A.W. Rempel, M. Fowler, and S. Mishra, 2022: Improving the passive survivability of residential buildings during extreme heat events in the Pacific Northwest. *Applied Energy*, **321**, 119323. https://doi.org/10.1016/j.apenergy.2022.119323

370. Adger, W.N., J. Barnett, K. Brown, N. Marshall, and K. O'Brien, 2013: Cultural dimensions of climate change impacts and adaptation. *Nature Climate Change*, **3** (2), 112–117. https://doi.org/10.1038/nclimate1666

371. Guy, K., 2020: A Security Threat Assessment of Global Climate Change: How Likely Warming Scenarios Indicate a Catastrophic Security Future. Product of the National Security, Military, and Intelligence Panel on Climate Change, Femia, F. and C. Werrell, Eds. The Center for Climate and Security, an Institute of the Council on Strategic Risks, Washington, DC. https://climateandsecurity.org/a-security-threat-assessment-of-global-climate-change/

372. McKelvey, K.S., W.M. Block, T.B. Jain, C.H. Luce, D.S. Page-Dumroese, B.A. Richardson, V.A. Saab, A.W. Schoettle, C.H. Sieg, and D.R. Williams, 2021: Adapting research, management, and governance to confront socioecological uncertainties in novel ecosystems. *Frontiers in Forests and Global Change*, **4**, 644696. https://doi.org/10.3389/ffgc.2021.644696

373. Insley, M. and M. Lei, 2007: Hedges and trees: Incorporating fire risk into optimal decisions in forestry using a no-arbitrage approach. *Journal of Agricultural and Resource Economics*, **32** (3), 492–514. https://doi.org/10.22004/ag.econ.7084

374. Palaiologou, P., A.A. Ager, M. Nielsen-Pincus, C.R. Evers, and M.A. Day, 2019: Social vulnereability to large wildfires in the western USA. *Landscape and Urban Planning*, **189**, 99–116. https://doi.org/10.1016/j.landurbplan.2019.04.006

375. Jasechko, S. and D. Perrone, 2021: Global groundwater wells at risk of running dry. *Science*, **372** (6540), 418–421. https://doi.org/10.1126/science.abc2755

376. Holmes, T.P., E.A. Murphy, and K.P. Bell, 2006: Exotic forest insects and residential property values. *Agricultural and Resource Economics Review*, **35** (1), 155–166. https://doi.org/10.1017/s1068280500010121

377. Warziniack, T., R.G. Haight, D. Yemshanov, J.L. Apriesnig, T.P. Holmes, A.M. Countryman, J.D. Rothlisberger, and C. Haberland, 2021: Ch. 14. Economics of invasive species. In: *Invasive Species in Forests and Rangelands of the United States: A Comprehensive Science Synthesis for the United States Forest Sector*. Poland, T.M., T. Patel-Weynand, D.M. Finch, C.F. Miniat, D.C. Hayes, and V.M. Lopez, Eds. Springer, Cham, Switzerland, 305–320. https://doi.org/10.1007/978-3-030-45367-1_14

378. Wolf, D. and H.A. Klaiber, 2017: Bloom and bust: Toxic algae's impact on nearby property values. *Ecological Economics*, **135**, 209–221. https://doi.org/10.1016/j.ecolecon.2016.12.007

379. Baldauf, M., L. Garlappi, and C. Yannelis, 2020: Does climate change affect real estate prices? Only if you believe in it. *The Review of Financial Studies*, **33** (3), 1256–1295. https://doi.org/10.1093/rfs/hhz073

380. Hino, M. and M. Burke, 2021: The effect of information about climate risk on property values. *Proceedings of the National Academy of Sciences of the United States of America*, **118** (17), e2003374118. https://doi.org/10.1073/pnas.2003374118

381. Headwaters Economics, 2016: Do Insurance Policies and Rates Influence Development on Fire-Prone Lands? Headwaters Economics, 14 pp. https://headwaterseconomics.org/wildfire/solutions/insurance-wildfire-home-development/

382. Garber-Yonts, B.E., 2004: The Economics of Amenities and Migration in the Pacific Northwest: Review of Selected Literature with Implications for National Forest Management. Gen. Tech. Rep. PNW-GTR-617. U.S. Department of Agriculture, Forest Service. Pacific Northwest Research Station, Portland, OR, 48 pp. https://doi.org/10.2737/pnw-gtr-617

383. Lambers, J.H.R., A.F. Cannistra, A. John, E. Lia, R.D. Manzanedo, M. Sethi, J. Sevigny, E.J. Theobald, and J.K. Waugh, 2021: Climate change impacts on natural icons: Do phenological shifts threaten the relationship between peak wildflowers and visitor satisfaction? *Climate Change Ecology*, **2**, 100008. https://doi.org/10.1016/j.ecochg.2021.100008

384. Wobus, C., E.E. Small, H. Hosterman, D. Mills, J. Stein, M. Rissing, R. Jones, M. Duckworth, R. Hall, M. Kolian, J. Creason, and J. Martinich, 2017: Projected climate change impacts on skiing and snowmobiling: A case study of the United States. *Global Environmental Change*, **45**, 1–14. https://doi.org/10.1016/j.gloenvcha.2017.04.006

385. Sánchez, J.J., R. Marcos-Martinez, L. Srivastava, and N. Soonsawad, 2021: Valuing the impacts of forest disturbances on ecosystem services: An examination of recreation and climate regulation services in U.S. national forests. *Trees, Forests and People*, **5**, 100123. https://doi.org/10.1016/j.tfp.2021.100123

386. Vose, J.M., J.S. Clark, C.H. Luce, and T. Patel-Weynand, 2016: Effects of Drought on Forests and Rangelands in the United States: A Comprehensive Science Synthesis. Gen. Tech. Rep. WO-93b. U.S. Department of Agriculture, Forest Service, Washington Office, Washington, DC, 289 pp. https://doi.org/10.2737/wo-gtr-93b

387. Paine, L.A., 1971: Accident Hazard Evaluation and Control Decisions on Forested Recreation Sites. Res. Paper PSW-68. U.S. Department on Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA, 10 pp. https://www.fs.usda.gov/research/treesearch/28669

388. Burns, S.F., R. Pirot, K. Williams, and S. Sobieschezk, 2015: Massive debris flow event on Pacific Northwest volcanoes, USA, November 2006: Causes, effects and relationship to climate change. In: *Engineering Geology for Society and Territory - Volume* 2, Lollino, G., D. Giordan, G.B. Crosta, J. Corominas, R. Azzam, J. Wasowski, and N. Sciarra, Eds. Cham, Switzerland. Springer, 545–550. https://doi.org/10.1007/978-3-319-09057-3_90

389. Gellman, J., M. Walls, and M. Wibbenmeyer, 2022: Wildfire, smoke, and outdoor recreation in the western United States. *Forest Policy and Economics*, **134**, 102619. https://doi.org/10.1016/j.forpol.2021.102619

390. Idaho DHW, n.d.: Activity Guidelines for Wildfire Smoke Events. Idaho Department of Health and Welfare. https://idhsaa.org/asset/sports%20medicine/wildfire-table-for-schools%20mkedits.pdf

391. Inkley, D., 2013: New report addresses climate change and freshwater fish. *Fisheries*, **38** (11), 518–518. https://doi.org/10.1080/03632415.2013.848402

392. Weiskopf, S.R., O.E. Ledee, and L.M. Thompson, 2019: Climate change effects on deer and moose in the Midwest. *The Journal of Wildlife Management*, **83** (4), 769–781. https://doi.org/10.1002/jwmg.21649

393. Kourantidou, M., D. Jin, and E.J. Schumacker, 2022: Socioeconomic disruptions of harmful algal blooms in indigenous communities: The case of Quinault Indian Nation. *Harmful Algae*, **118**, 102316. https://doi.org/10.1016/j.hal.2022.102316

394. Moss, L.A.G. and R.S. Glorioso, Eds., 2014: *Global Amenity Migration: Transforming Rural Culture, Economy and Landscape*. New Ecology Press, Kaslo, BC, 435 pp.

395. Winkler, R.L. and M.D. Rouleau, 2021: Amenities or disamenities? Estimating the impacts of extreme heat and wildfire on domestic US migration. *Population and Environment*, **42** (4), 622–648. https://doi.org/10.1007/s11111-020-00364-4

396. Abrams, J.B., H. Gosnell, N.J. Gill, and P.J. Klepeis, 2012: Re-creating the rural, reconstructing nature: An international literature review of the environmental implications of amenity migration. *Conservation and Society*, **10** (3), 270–284. https://doi.org/10.4103/0972-4923.101837

397. Rickman, D.S. and H. Wang, 2020: Whither the American west economy? Natural amenities, mineral resources and nonmetropolitan county growth. *The Annals of Regional Science*, **65** (3), 673–701. https://doi.org/10.1007/s00168-020-00999-z

398. Hjerpe, E., C.A. Armatas, and M. Haefele, 2022: Amenity-based development and protected areas in the American West. *Land Use Policy*, **116**, 106064. https://doi.org/10.1016/j.landusepol.2022.106064

399. Donatuto, J., L. Campbell, and W. Trousdale, 2020: The "value" of values-driven data in identifying Indigenous health and climate change priorities. *Climatic Change*, **158** (2), 161–180. https://doi.org/10.1007/s10584-019-02596-2

400. Wang, C.J., H.A. Schaller, K.C. Coates, M.C. Hayes, and R.K. Rose, 2020: Climate change vulnerability assessment for Pacific lamprey in rivers of the western United States. *Journal of Freshwater Ecology*, **35** (1), 29–55. https://doi.org/10.1080/02705060.2019.1706652

401. Gaughen, S., S. Bliss, J. Mauck, and T. Romero, 2021: Ch. 8. Cultural resources. In: *Status of Tribes and Climate Change Report*. Marks-Marino, D., Ed. Institute for Tribal Environmental Professionals, 210–221. http://nau.edu/stacc2021

402. Long, J.W. and F.K. Lake, 2018: Escaping social-ecological traps through tribal stewardship on national forest lands in the Pacific Northwest, United States of America. *Ecology and Society*, **23** (2). https://doi.org/10.5751/es-10041-230210

403. Long, J.W., F.K. Lake, R.W. Goode, and B.M. Burnette, 2020: How traditional tribal perspectives influence ecosystem restoration. *Ecopsychology*, **12** (2). https://doi.org/10.1089/eco.2019.0055

404. Lake, F.K., V. Wright, P. Morgan, M. McFadzen, D. McWethy, and C. Stevens-Rumann, 2017: Returning fire to the land: Celebrating traditional knowledge and fire. *Journal of Forestry*, **115** (5), 343–353. https://doi.org/10.5849/jof.2016-043r2

405. Voggesser, G., K. Lynn, J. Daigle, F.K. Lake, and D. Ranco, 2014: Ch. 9. Cultural impacts to tribes from climate change influences on forests. In: *Climate Change and Indigenous Peoples in the United States: Impacts, Experiences and Actions*. Maldonado, J.K., B. Colombi, and R. Pandya, Eds. Springer, Cham, Switzerland, 107–118. https://doi.org/10.1007/978-3-319-05266-3_9

406. Warner, E.A.K., 2015: Everything old is new again: Enforcing tribal treaty provisions to protect climate change-threatened resources. *Nebraska Law Review*, **94** (4). https://digitalcommons.unl.edu/nlr/vol94/iss4/4

407. Whyte, K., 2017: Indigenous climate change studies: Indigenizing futures, decolonizing the Anthropocene. *English Language Notes*, **55** (1), 153–162. https://doi.org/10.1215/00138282-55.1-2.153

408. Whyte, K.P., 2013: Ch. 2. Justice forward: Tribes, climate adaptation and responsibility. In: *Climate Change and Indigenous Peoples in the United States: Impacts, Experiences and Actions*. Maldonado, J.K., B. Colombi, and R. Pandya, Eds. Springer, Cham, Switzerland, 9–22. https://doi.org/10.1007/978-3-319-05266-3_2

409. Flores, D. and G. Russell, 2020: Ch. 5.5. Integrating tribes and culture Into public land management. In: *Northeastern California Plateaus Bioregion Science Synthesis*. Dumroese, R.K. and W.K. Moser, Eds. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, 177–185. https://www.fs.usda.gov/research/treesearch/60223

410. Long, J., F.K. Lake, K. Lynn, and C. Viles, 2018: Ch. 11. Tribal ecocultural resources and engagement. In: *Synthesis of Science to Inform Land Management Within the Northwest Forest Plan Area*. Spies, T.A., P.A. Stine, R. Gravenmier, J.W. Long, and M.J. Reilly, Eds. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, 851–917. https://www.fs.usda.gov/research/treesearch/56333

411. Donatuto, J., E.E. Grossman, J. Konovsky, S. Grossman, and L.W. Campbell, 2014: Indigenous community health and climate change: Integrating biophysical and social science indicators. *Coastal Management*, **42** (4), 355–373. https://doi.org/10.1080/08920753.2014.923140

412. Fink, J.H., 2019: Contrasting governance learning processes of climate-leading and -lagging cities: Portland, Oregon, and Phoenix, Arizona, USA. *Journal of Environmental Policy and Planning*, **21** (1), 16–29. https://doi.org/10.1080/1523908x.2018.1487280.

413. Levenda, A.M., J. Richter, T. Miller, and E. Fisher, 2019: Regional sociotechnical imaginaries and the governance of energy innovations. *Futures*, **109**, 181–191. https://doi.org/10.1016/j.futures.2018.03.001.

414. Davies, I.P., R.D. Haugo, J.C. Robertson, and P.S. Levin, 2018: The unequal vulnerability of communities of color to wildfire. *PLoS ONE*, **13** (11), 0205825. https://doi.org/10.1371/journal.pone.0205825

415. Ward, E.J., J.H. Anderson, T.J. Beechie, G.R. Pess, and M.J. Ford, 2015: Increasing hydrologic variability threatens depleted anadromous fish populations. *Global Change Biology*, **21** (7), 2500–2509. https://doi.org/10.1111/gcb.12847

416. Kurtz, K., B. Hins-Turner, A. Abbott, L. Eschenbach, L. Williams, and M. Nepean, 2021: Roadmap to a Green Economy: Aligning Education, Workforce and Economic Development Systems. Pacific Education Institute, 59 pp. https://wsac.wa.gov/sites/default/files/2021-03-17-Green-Economy-Report.pdf

417. Van de Graaf, T. and B.K. Sovacool, 2020: *Global Energy Politics*. Wiley, 240 pp. https://www.wiley.com/en-us/global+energy+politics-p-9781509530489

418. WA DNR, 2020: Electric Utilities Wildland Fire Prevention Task Force–Final Report. Washington Department of Natural Resources, 17 pp. https://www.dnr.wa.gov/publications/rp_fire_electric_utility_taskforce_report.pdf

419. U.S. Federal Government, 2021: U.S. Climate Resilience Toolkit: Energy [Webpage]. https://toolkit.climate.gov/topics/energy-supply-and-use