Fourth Oregon Climate Assessment Report

State of climate science: 2019

Oregon Climate Change Research Institute
occri.net/ocar4

Recommended citation:

Mote, P.W., J. Abatzoglou, K.D. Dello, K. Hegewisch, and D.E. Rupp, 2019: Fourth Oregon Climate Assessment Report. Oregon Climate Change Research Institute. occri.net/ocar4.

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Fourth Oregon Climate Assessment Report

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Summary

Oregon is already experiencing statewide impacts of a changing climate. In August 2018, Portland and the Willamette Valley experienced some of the worst air quality on the planet owing to smoke from wildfires near and far. Ranchers in southern and eastern Oregon reported significant economic losses caused by lack of water from a low winter snowpack and a hot and dry summer. Climate change touches all corners of Oregon, but our frontline communities are most vulnerable. These include the economically disadvantaged and those who depend on natural resources for their livelihood: rural residents including Native Americans.

The state continues to warm as a result of the heat-trapping gases emitted into the atmosphere from global activity. This report represents a convergence of evidence of the risks that Oregon is facing, and will face in a changing climate, drawing from the past three Oregon Climate Assessment Reports, the 4th US National Climate Assessment, and other peer-reviewed literature, and other analyses performed by the Oregon Climate Change Research Institute (OCCRI) and research partners.

Observed Climate

Oregon continues to warm in all seasons, in part due to human activity. The entire Pacific Northwest has warmed about 2˚F since 1900. The last three years (2016-2018) were all warmer than the 1970-1999 average, and 2015 still stands as Oregon's warmest year on record. Annual precipitation varies between wet and dry years, with no discernible trend. The year 2018 was much drier than normal, and 11 counties received an emergency drought declaration, even coastal Lincoln County, because of historically low flows in the Siletz River.

Future Climate

Warming is projected to continue in all seasons, dependent on global activity. Oregon is projected to warm by about 4-9˚F by 2100, depending in part on whether global emissions follow a lower (RCP 4.5) or higher (RCP 8.5) path. The Paris Agreement, signed in 2016, is a non-binding international agreement meant to limit global temperature increase to 2˚C, which would require global emissions to be even lower than RCP4.5. Temperature projections using both RCP 4.5 and 8.5 are similar until about 2040. Warming is likely to be enhanced in mountainous areas in winter and spring, and muted on the coast in summer.

Changes in rainfall will accentuate extremes. Annual precipitation is not projected to change, but models generally suggest modest increases in winter precipitation and decreases in summer precipitation. Extreme precipitation may change more (~20%) in eastern Oregon than western Oregon (~10%) by mid-century. Heavy rainfall can lead to slope instability and landslides, and close important transportation corridors

Sea level rise projections have not changed substantially through mid-century, though estimates of the maximum plausible sea level by the end of the century (2100) have increased to 8.2 feet. However, even after global temperature stabilizes, ice sheets will continue melting irreversibly until they reach a new equilibrium which could take millennia. Warming beyond the global 2˚C target could lead to irreversible melting of Greenland, highlighting the importance of global policy meant to limit warming. Stabilizing global climate soon could limit sea level rise to less than 3.3 feet even in 2300.

Hot days will become more frequent in Oregon in a changing climate. Most locations, except the cooler mountains and the coast, will see an increase of about 30 days over 86˚F by mid-century compared with the recent past. Hot days and warm nights pose a human health risk. Farmworkers and other outdoor laborers are more vulnerable to heat related illness or death. In urban areas, economically disadvantaged communities are the most vulnerable.

Changes in snow & future water supply

Nearly every location in Oregon has seen a decline in spring snowpack, and it will continue to significantly decline through mid-century, especially at lower elevations. Oregon's mountain snowpack serves myriad economic, ecological, and social functions, and the snowcapped volcanic peaks are part of the state's cultural identity. Mountain snowpack acts as a natural reservoir which enhances summertime surface and groundwater supply. Meager mountain snowpack creates water scarcity in the state, as evidenced by droughts in 2015 and 2018. Snowpack is crucial for Oregon's vibrant recreation industry. In 2015, low snowpack resulted in a multi-million dollar loss in ski resort revenues in the Northwest. Recent research shows that the observed declines in snowpack since 1985 were smaller than they would have been without natural climate variability, which is expected to reverse and produce much larger declines.

These changes in snowpack present a dual risk to the state. In winter, increases in average streamflow will be the result of precipitation falling as rain instead of snow and rapid runoff, increasing flood risk in some basins. Summer flows may be reduced by as much as 50% in some basins, presenting challenges to junior water rights holders, hydroelectric power generation, and those not served by reservoir or groundwater storage. Lower flows also impact important commercial and tribal fisheries.

Fire risk

Fire activity is strongly linked to summer climate, with the largest fires occurring exclusively in warm and dry summers. The most obvious impact of climate change in the west in recent years has been fire. Recent catastrophic fires in California and major wildfires in Oregon highlight the vulnerability of the state to increasing wildfire in a warming climate. The Eagle Creek Fire September 2017 closed I-84, a crucial transportation corridor between western and eastern Oregon. Fire risk is projected to increase across the entire state by mid-century, with the largest increases in the Willamette Valley and eastern Oregon. The associated wildfire smoke creates a health hazard for vulnerable communities, especially outdoor laborers and children, who may be exposed to poor air quality.

Agriculture and the natural resources economy

Climate change may also present a potential opportunity for agriculture with a longer growing season, though producers may be limited by water availability and limited adaptive capacity. Oregon's $48.5B agriculture industry (2015) is a cornerstone of the state's economy. By mid-century in the higher emissions scenario, parts of western Oregon will see a lengthening of the growing season by about two months, and the rest of the state would see an increase of about a month. Warmth will arrive earlier in the spring and last longer in fall. Though some crops may thrive in a longer growing season, concerns about the incidence of pests and weeds, reduced crop quality, and increased irrigation demand may hamper production. Forests may experience drought stress due to lower soil moisture in the summer, and timber production can be affected.

The challenges are great, but there are opportunities to adapt to a rapidly changing Oregon. Adaptive capacity is not equal across and within communities and sectors. However, careful management of natural resources can help reduce the climate risks that the natural resources economy faces. Such management includes creating resilient agro-ecosystems, building more robust water markets, and managing forests while considering natural resources and wildfire prevention. Reducing barriers for socioeconomic groups most affected by climate change can take the form of rules and policy meant to limit the exposure of these groups to fire and heat. There is a need to build community capacity and leadership in frontline communities to participate in the processes of climate-related decisions Additionally, modernizing crucial infrastructure (bridges, roads, buildings, and culverts) may mitigate climate risk and build resilience into systems.

About this report. The Oregon Climate Change Research Institute (OCCRI) periodically assesses the state of knowledge of climate science as it pertains to Oregon, fulfilling the legislative mandate that created OCCRI. This summary was written by Kathie Dello and Philip Mote, January 2019.

Oregon Climate Assessment Report 4

State of climate science: 2019

Introduction

This report, required by state law under HB3543, provides a comprehensive assessment of the state of science of climate change as it pertains to Oregon, covering the physical, biological, and social dimensions. The first chapter summarizes the current state of knowledge of physical changes in climate and hydrology, focusing on the period since the previous Oregon Climate Assessment Report (OCAR3, Dalton et al. 2017); and the second chapter covers the impacts. The second chapter is, verbatim, the Northwest chapter of the Fourth National Climate Assessment (NCA4) which was released by the federal government November 23, 2018. It is available for download separately:

https://nca2018.globalchange.gov/downloads/NCA4_Ch24_Northwest_Full.pdf

The Oregon Climate Change Research Institute (OCCRI), created by the state legislature (HB3543, 2007), includes a small staff housed at Oregon State University and a larger network of over 150 researchers in Oregon and beyond. OCCRI's vision is to achieve a climate-prepared Northwest by building a climate knowledge network, cultivating climate-informed communities, and advancing the understanding of regional climate, impacts, and adaptation.

Globally, concentrations of greenhouse gases continue to rise. Last year, carbon dioxide concentrations measured at the long-term monitoring site on Mauna Loa in Hawaii exceeded 410 parts per million by volume (ppmv) for much of 2018, having topped 400 ppmv for the first time only in 2014[1]. Current carbon dioxide concentrations are 46% higher than they were prior to the Industrial Revolution.

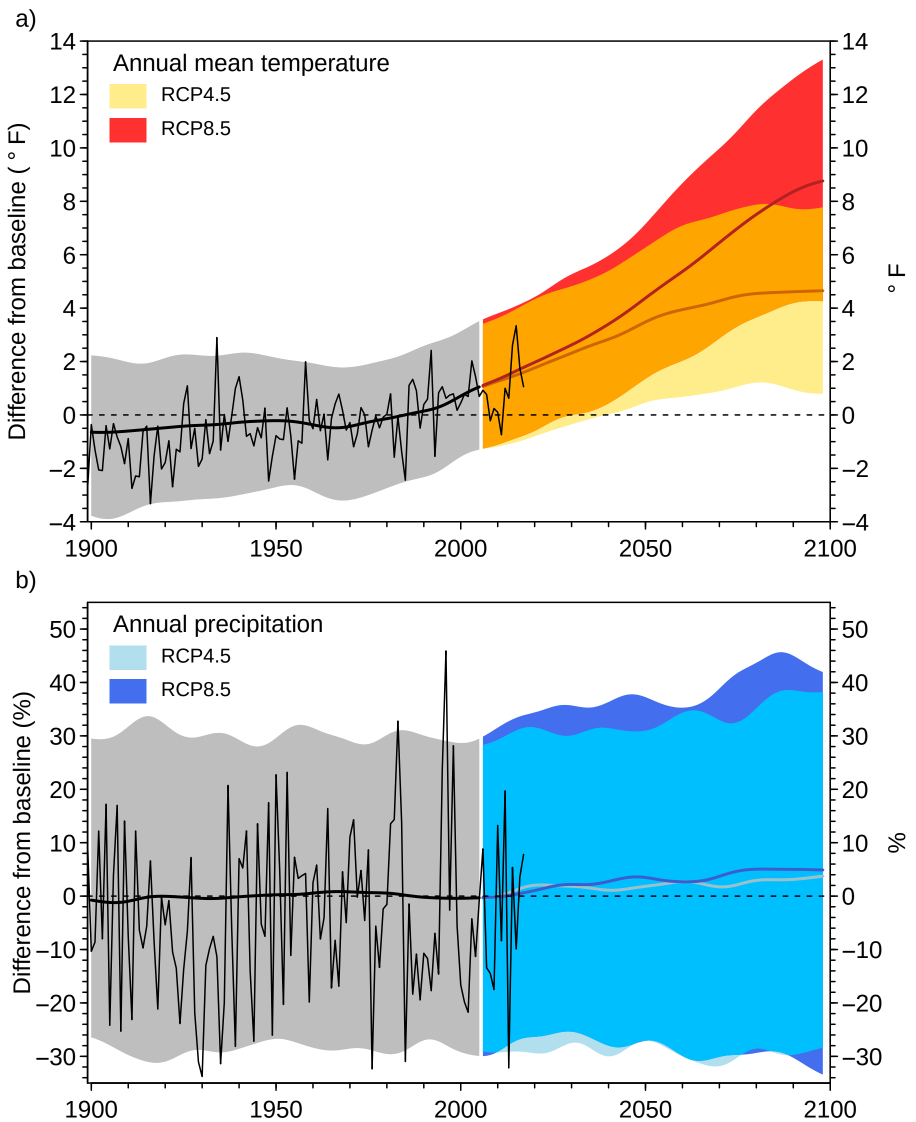

Figure 1. Observed, simulated, and projected changes in Oregon's mean annual (a) temperature and (b) precipitation from the baseline (1970–1999) under a low (RCP 4.5) and a high (RCP 8.5) future emissions scenario. Thin black lines are observed values (1900-2017) from the National Centers for Environmental Information. The thicker solid lines depict the mean values of simulations from 35 climate models for the 1900-2005 period based on observed climate forcings (black line) and the 2006-2099 period for the two future scenarios (orange and red lines in the top panel, blue and grey in the bottom panel). The shading depicts the range in annual temperatures from all models. The mean and range have been smoothed to emphasize long-term (greater than year-to-year) variability.

Regionally Averaged Trends

Oregon's warming trend continues. As shown in the observations in Figure 1a, after the record-warm 2015 (the recent peak of the observed temperature graph), calendar years 2016 and 2017 were also warmer than the 1970-1999 average though not as warm as 2015. The temperature of calendar year 2018 is not officially available as of this writing because the continuing lapse in federal appropriations has shuttered the official climate data analysis capabilities of NOAA. However, other sources of data[2] indicate that 2018, too, was warmer than average.

Future warming rates will increasingly depend on global greenhouse gas

[1] https://www.esrl.noaa.gov/gmd/ccgg/trends/data.html

[2] http://prism.oregonstate.edu/

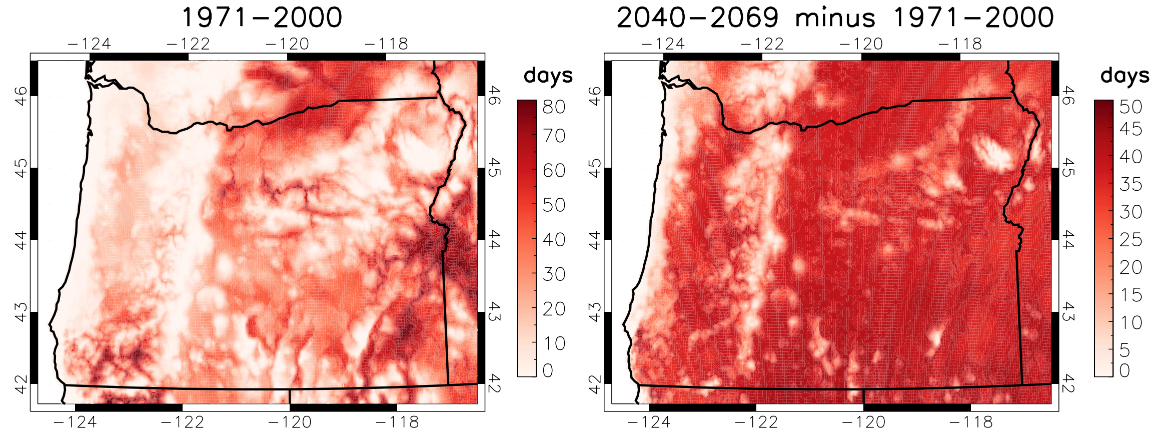

Figure 2. Projected changes in the average **n**umber of hot days (where daily high temperature >86°F, 30°C) per year. Shown are the average number of hot days per year for 1971-2000 (left panel) and projected changes by 2040-2069 assuming the high-emissions scenario RCP8.5 (right panel). Results were averaged over 20 climate models (right). Figure prepared using data on the NW Climate Toolbox, climatetoolbox.org, data source: MACA.

emissions, as can be seen by comparing the red (high emission RCP8.5) and yellow (low emission RCP4.5) thick curves and shaded regions). The Paris agreement seeks to achieve warming no greater than 2°C, which would require that emissions track below RCP4.5; consequently, even the yellow curve and shaded region are higher than the scenarios consistent with the Paris Agreement. Annual precipitation, unlike temperature, has no long-term trend toward wetter or drier. Most recent years have been fairly close to average, with the exception of 2018, which was much drier than average based on NOAA data available in December.

Spatial patterns

Previously, we checked how well global climate models (GCMs) performed at simulating Northwest climate (Rupp et al. 2013). We then statistically downscaled 20 of the best models using the Multivariate Adaptive Constructed Analogs (MACA, Abatzoglou and Brown 2012) method. OCCRI research partner Prof. John Abatzoglou has led the construction of a "climate toolbox" in which various climate quantities are computed at fine spatial resolution for both a baseline, past dataset and for changes derived each of 20 GCMs, as well as the changes averaged over all 20 GCMs (Figures 2-3).

Figure 2 shows how 'hot days', defined as the days with daily high temperatures >86F, are expected to change by mid-century (2040-2069) for the high emissions scenario. In the baseline period (1970-1999), the hottest parts of the state — lower elevation portions of eastern Oregon, as well as the Rogue River valley — experience at least 30 hot days per year. In the future, most locations except the mountains and the coast will experience at least an additional 30 hot days per year, in many places doubling the frequency of such days.

The Willamette and Umpqua valleys, along with small coastal valleys, have the longest growing season in the baseline climate, over 280 days (Fig. 3a), and the high elevations of central and Eastern Oregon have the lowest, only a couple of months. By mid-century in the high-emissions scenario (Fig. 3b), most of western Oregon would see a lengthening of the growing season by about two months. Some of the higher elevation locations in central Oregon would also see a lengthening of about two months, and the rest of the state would see lengthening of about a month. Accompanying these changes is a shift by over a month later in the date of first fall freeze in the highlands of central Oregon (Fig. 3d) and a shift by over a month toward earlier date of last spring freeze in much of western Oregon (Fig. 3f).

To augment the information from GCMs, OCCRI also runs a fine-scaled (25 km) regional model to more accurately simulate the physical processes associated with topography like mountains which influence the responses of the atmosphere (and hence temperature and precipitation) to rising greenhouse gases. Our

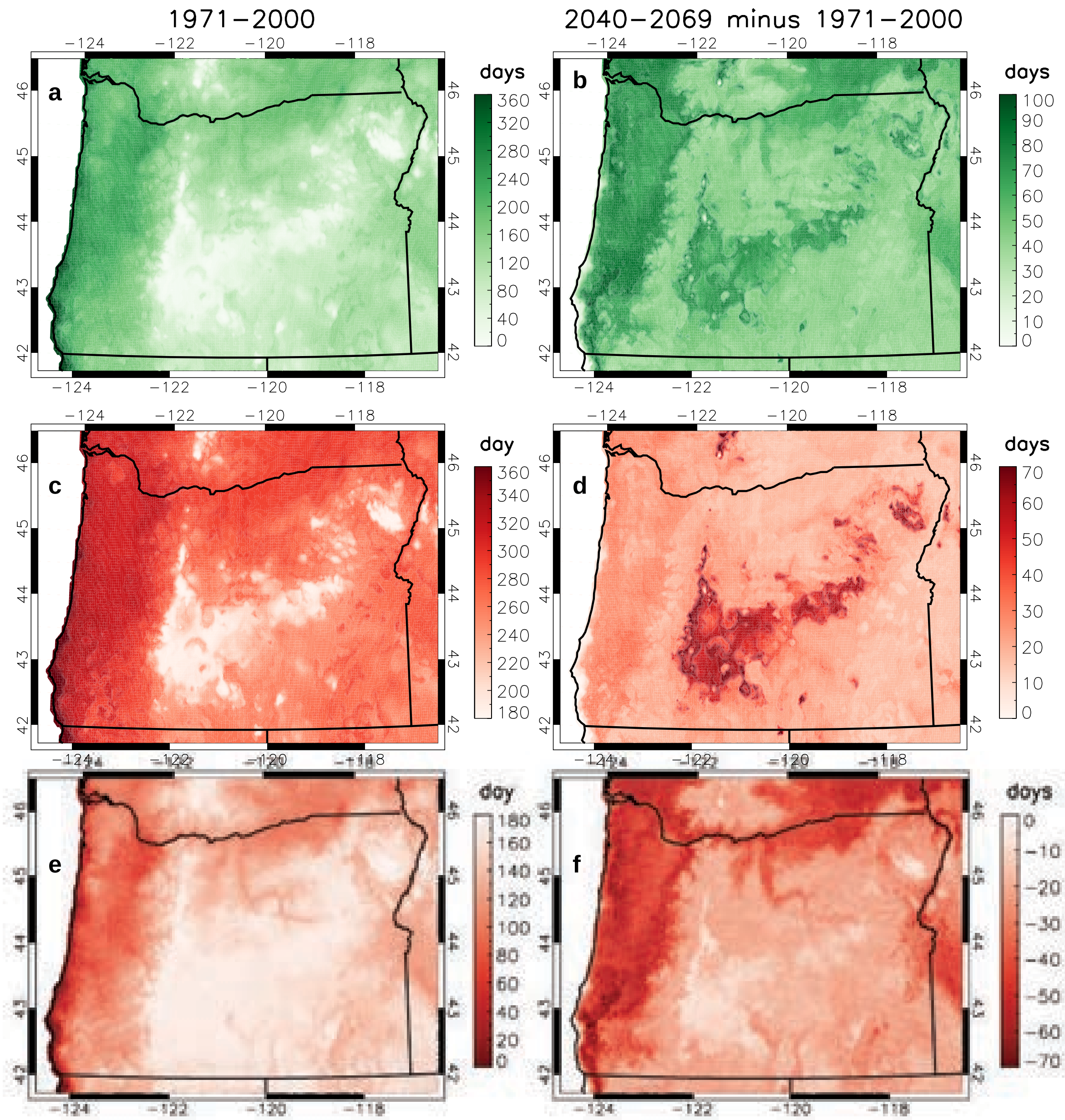

Figure 3. Baseline (left column) and projected change from baseline to mid-21st century for RCP8.5 (right column) in growing season (top), defined as the number of days with daily minimum temperature (Tmin) > 32°F (0°C); date of first fall freeze (Tmin<32°F, middle); and date of last spring freeze (Tmin<32°F, bottom). Results were averaged over 20 climate models; from data on the NW Climate Toolbox, climatetoolbox.org. Data source: MACA.

approach uses a crowd-sourced climate modeling platform to generate a 'superensemble', that is, a very large collection of simulations that allows better statistical representation especially of extremes (Mote et al 2015).

Figure 4 shows the seasonal mean changes in temperature from this regional modeling superensemble. These results are for the lower-emissions RCP4.5 scenario, which by mid-century (2030-59) is noticeably lower than RCP8.5. In winter and spring, warming is 10-20% larger in the mountains, especially the Sierras and the Cascades, than in surrounding areas. Analysis indicates that 'snow-albedo feedback', in which modest warming is accentuated where snow disappears, is primarily responsible for these changes. In the Northwest (see Table 2.2 of Dalton et al, 2017) as well as globally, the ocean warms less than land. As with many GCMs, our regional model projects larger warming in summer, which leads to sharp spatial contrasts between land and ocean warming across the coastal mountains. In other words, Oregon's coastal areas will only warm about 0.4°F (0.2°C) per decade, the rest of western Oregon around 0.7°F (0.4°C) per decade, and eastern Oregon more than 0.9°F (0.5°C) per decade. Similar patterns are visible in fall, though with smaller magnitudes.

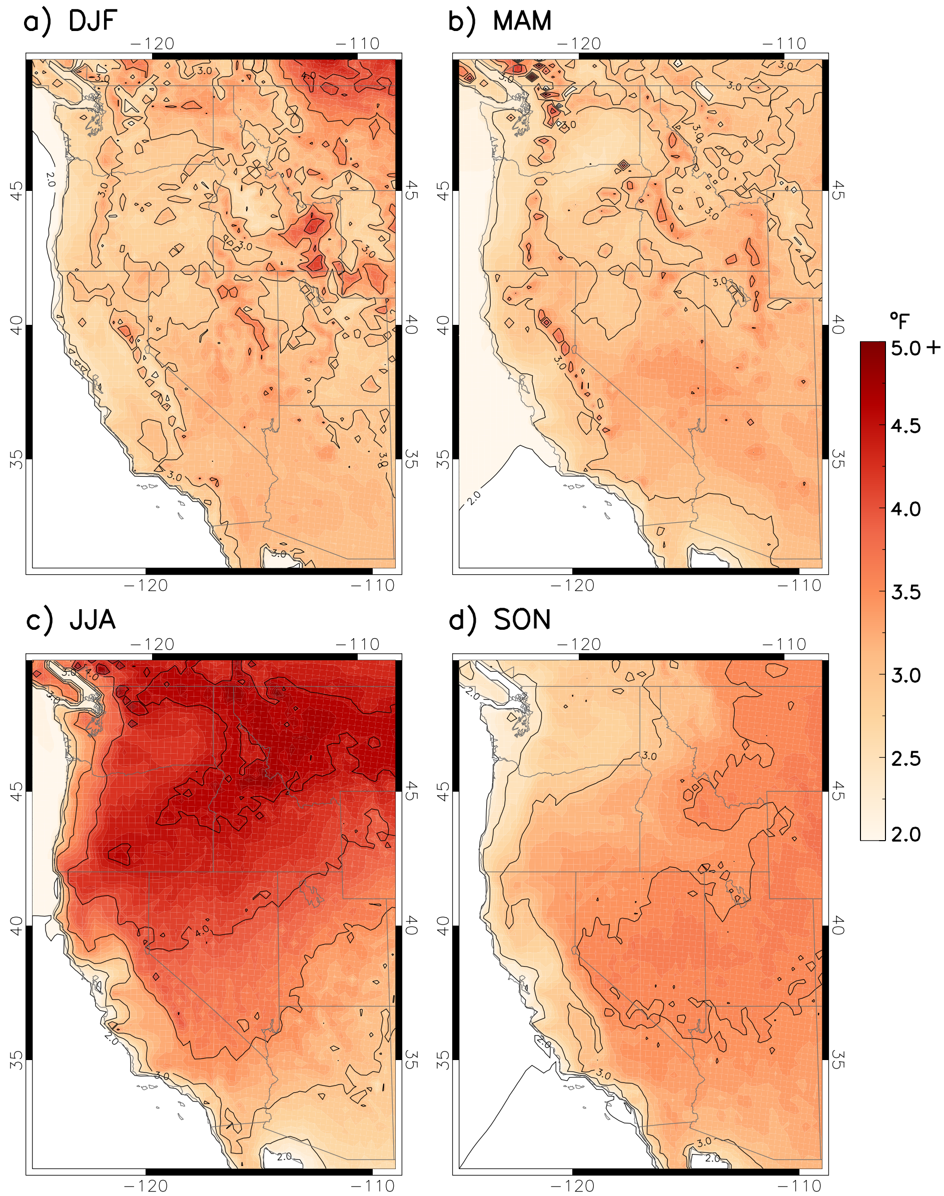

Figure 4. Projected change in mean temperature, 1985-2014 to 2030-59, from a regional superensemble using the low (RCP4.5) emissions scenario for (a) Dec-Jan-Feb (winter), (b) Mar-Apr-May (spring), (c) Jun-Jul-Aug (summer), and (d) Sep-Oct-Nov (fall). Adapted from (Rupp et al. 2017) and used by permission.

For precipitation (not shown), both the set of global models and our regional model suggested modest increases in winter precipitation and modest decreases in summer precipitation. In addition, our regional modeling results for mid-century suggest a weakened rain shadow effect in winter, with larger increases (>20%) in precipitation east of the Cascades and small (<10%) increases west of the Cascades. These changes in seasonal means are matched by changes in extreme precipitation (Figure 5) which are relatively larger east of the Cascades. For example, the 99th percentile (wettest day in 100 days) goes up 6% west of the Cascades but 14% east of the Cascades.

Hydroclimate

Since OCAR3 (Dalton et al. 2017), a new analysis of observed changes in snow resources in the west (Mote et al. 2018) show that nearly every location in Oregon experienced declines in spring snowpack since mid-20th century. Recently, an analysis of atmospheric variability (Siler et al 2018) indicates that the influence

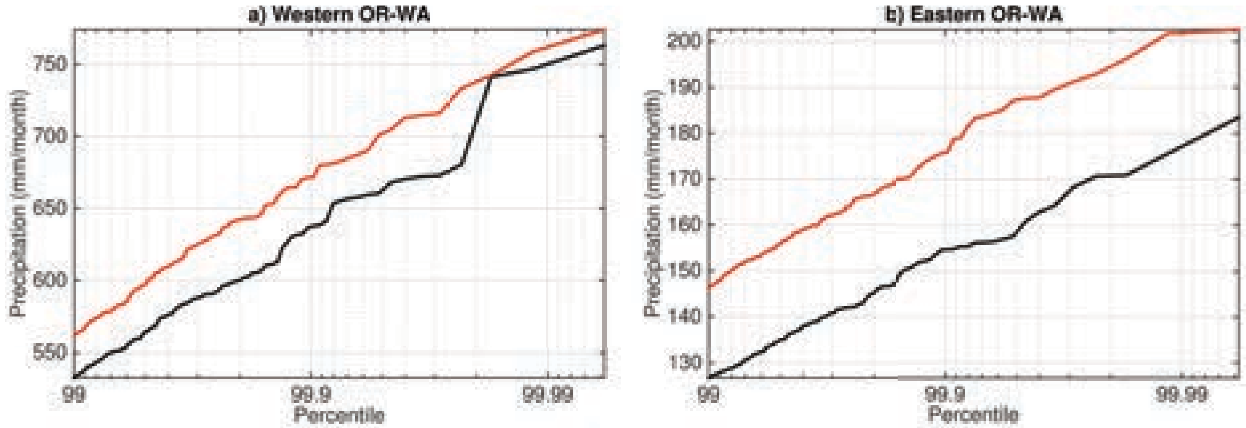

Figure 5. Simulated extreme one-day precipitation are shown by percentile for western Oregon and Washington (left) and eastern Oregon and Washington (left), for 1985-2014 (black) and 2030-59 (red). For example, the 99.9th percentile is the wettest day in 1000 days. Figure from Li (2017) using weather@home data.

of regional warming on the west's snowpack since 1985 has been largely masked by natural variability in ocean temperatures and atmospheric circulation patterns important during the cool season, effectively slowing the rate of spring snowpack decline. The authors expect greatly enhanced response in the snowpack to warming in coming decades as this pattern ebbs.

The climate toolbox depicts how the region's water variables will change. For example, Figure 6 shows the disappearing snowpack expected by the end of the century. Most of the Northwest will see decreases in April 1 snowpack in excess of 56% but the highest peaks in the Cascades are projected to decrease less, only in the 11-33% range. These reductions in snowpack will lead to wintertime increases but summertime decreases in soil moisture in most places (Figure 6). The increases in soil moisture in the driest parts of the region are also seen in the regional superensemble, and are confined to lower soil layers. Upper soil layers also dry substantially there, but the paucity of deep-rooted plants limit the depletion of lower soil layers.

In most basins, the changes in snowmelt timing also alter streamflow (Figure 7). The increases in average wintertime flow (owing to reduced snow accumulation and more rapid runoff) also correspond to increases in flood risk in those basins. Summertime flow is reduced in many basins, by as much as 50% (in June).

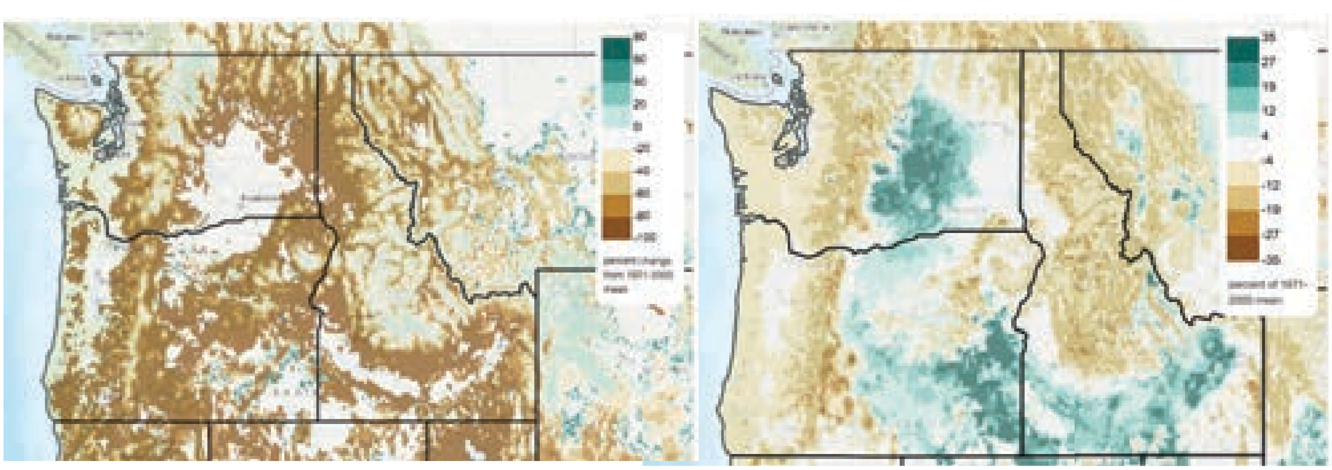

Figure 6. Change in (left) April 1 snow water equivalent and (right) summer soil moisture, for 2040-69 under the high-emissions RCP8.5 scenario, as a percentage of 1971-2000 baseline from a mean of 10 GCMs. Figure prepared using the NW Climate Toolbox, climatetoolbox.org. Data source: VIC hydrologic model.

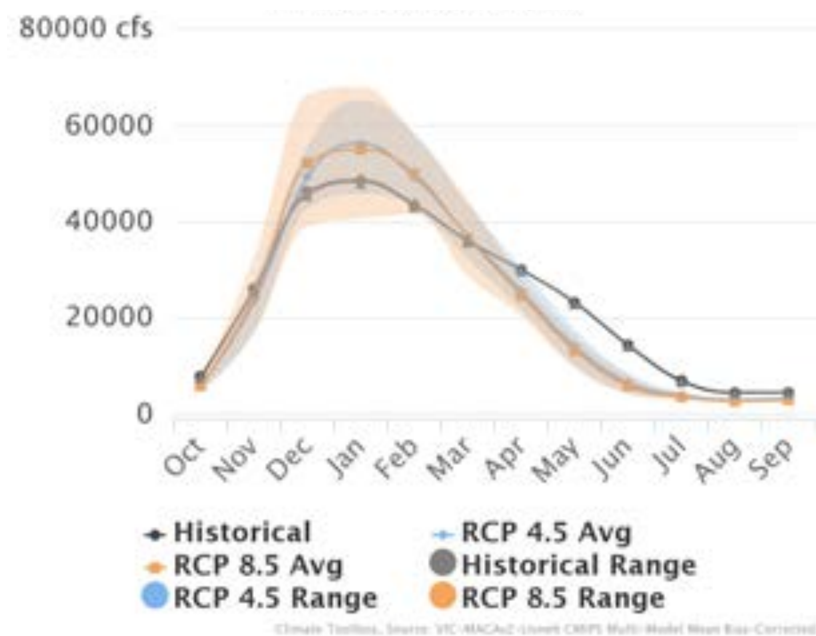

Figure 7. Monthly non-regulated streamflow in the Willamette River at Salem for 2040-2069 under high and low emission scenarios and over the 1971-2000 historical baseline. Shaded regions show the range from 10 climate models. Figure prepared with the NW Climate Toolbox, climatetoolbox.org, data source: streamflow routing of VIC hydrologic model.

Fire-climate risk

Placing weather-related events in a historical context can be a useful exercise, especially when trying to understand the meteorological conditions that certain hazards, e.g. wildfires and drought, favor and how these events may be exacerbated by changing climate. Wildfires have received considerable attention over the past two years, due to their devastation (Camp and Carr Fires in California; Substation Fire near The Dalles) or economically or socially valued location (Eagle Creek Fire in the Columbia River Gorge and Chetco Bar Fire in southwestern Oregon). Statistical analysis shows that warm, dry summers are associated with higher area burned (McKenzie et al 2004, Westerling et al., 2006). Large fires increased in the western US from 1984-2011 in a warming climate (Dennison et al., 2014) and human-caused climate change was responsible for the increase in area burned in forests in the western US from 1984-2015 (Abatzoglou and Williams, 2016).

Fire season in Oregon runs roughly from late July to mid-September, though it can start earlier and end later, as was the case in 2018. Fire activity is dependent on many anthropogenic and natural variables, and warmer or drier seasons can create conditions favorable for wildfires. In Figure 8 we define fire season using a rough definition of the months of July-September. The upper left quadrant represents the warmest and driest years in this historical record; the lower right quadrant shows the wettest and coolest years. Years for the climate analysis are only labeled from 2002-2018, the same period of record as the fire data, to reduce clutter. Circles are meant to show the acres burned in each of these years, binned into groups.

The fire seasons with the most acres burned (2012, 2014, and 2017) are among the warmest in the record, and notably warmer than most of the other years in the upper left quadrant. July-September 2012 and 2017 were drier than normal, but the same time period in 2014 was slightly wetter than the historical average. There are years (2003, 2009) that were in the top 10 warmest July-Septembers on record, but had relatively small areas of wildfire activity. 2002 and 2012 had significant large fires (over 500,000 acres) boosting the overall total; the 2002 Biscuit Fire in southwestern Oregon and the 2012 Long Draw fire in eastern Oregon. Both fire seasons topped 1,000,000 wildland acres burned. 2010 had near-normal precipitation and temperature and 2004 was wetter than normal for the fire season; these two years had the smallest area burned on record. In this typically arid season in Oregon, a few rainfall events can skew the entire season. 2013 was notable as it was Oregon's wettest September on record, owing to two large storms early and late in the month. July-September has consistently been warmer and drier than the 1895-2018 average for most of the past 17 years, creating prime conditions for potentially large wildfire seasons. And while large wildfire seasons can be dominated by single events, warmer conditions tend to be more favorable for an above average area burned in Oregon, consistent with the rest of the western US. None of the years with above-average area burned were near normal in seasonal temperature and precipitation. In a changing climate, fire activity in Oregon will

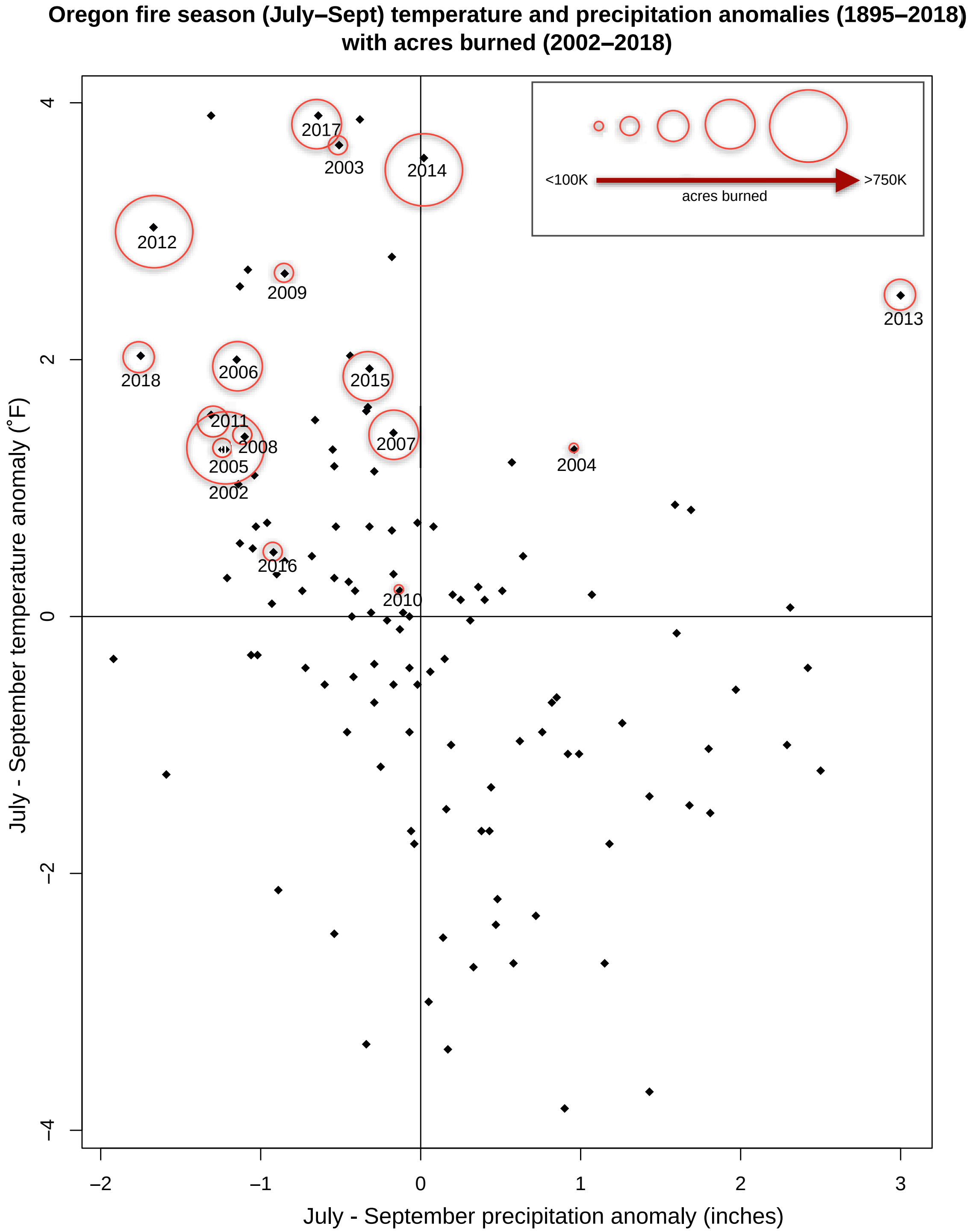

Figure 8. Scatterplot of fire season (July-September) mean precipitation and temperature, with area burned in each year since 2002 indicated by circles. Climate data are from NOAA's National Center for Environmental Information statewide data for Oregon for 1895-2018 (the average for this entire period is used to calculate anomalies). Wildland fire data for 2002-2017 are from the National Interagency Fire Center (NIFC). Preliminary 2018 data are included here, but the final figure was not available from NIFC due to the lapse in federal appropriations. Prescribed fires were excluded from the analysis.

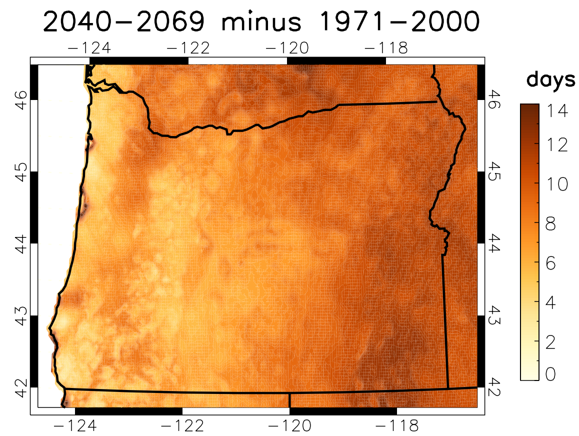

Figure 9. Projected change in extreme fire risk days, defined as the number of days when the 100-hour fuel moisture in June-July-August (JJA) is below the 3rd percentile of days in the baseline period. Figure prepared with data on the NW Climate Toolbox, climatetoolbox.org. Data source: MACA

continue to be influenced by warming temperatures and longer fire seasons. Projections using vegetation models (previously published in OCAR3, Dalton et al. 2017) highlighted spatial differences in changing fire risk, emphasizing that more frequent fires could be expected even in the wet western third of the state, and indeed as the Eagle Creek fire (summer 2017) showed, that prediction is coming true.

Weather data can be used to calculate fire risk in various ways. Operational agencies often use the energy release component (ERC) as well as measures of fuel moisture and wind speeds. One measure of the fuel moisture is the '100-hr' fuels moisture, which is the amount moisture within vegetation (the 'fuel'), averaged over 100 hours. Figure 9 shows the '100-hour' fuel moisture, specifically the number of days per summer when the fuel moisture is below the 3rd percentile ("extreme"). The largest increases in the frequency of extreme fire risk are in the eastern third of Oregon and in the Willamette Valley.

Sea level rise: long term view

Projections for sea level rise to 2050 have not changed substantially in recent years, but new estimates of the maximum physically plausible sea level rise by 2100 are now 8.2 feet (2.5m) (USGCRP 2017, p. 343). Intermediate estimates are also higher than some previous assessments, 3.3 feet (1.0m) by 2100. Moreover, an improving understanding of the behavior of the Antarctic ice sheet especially in past glacial-interglacial cycles has advanced the understanding of its future response to warming. A crucial point about both Greenland and Antarctica is that *even after global temperatures are stabilized, melting will continue until a new equilibrium is reached.* In the case of Greenland, there is growing concern that any warming beyond 1.5-2°C could lead to the irreversible melting of the entire ice sheet: once the melting reduces the altitude enough, the ice sheet cannot accumulate enough new snow in winter to offset the melting in summer. In the case of Antarctica, recent research by Oregon scientists (Clark et al. 2018) shows that the equilibration to a new climate would take thousands of years. Their analysis suggests that stabilizing global climate at 2°C above preindustrial would limit sea level rise to less than 3.3 ft (1m) by 2300, but even so, it could reach 9m by the year 9000. Higher emissions scenarios could lead to increases in global mean sea level of almost 10m by the year 2500 and over 50m by the year 9000. The authors note that the policy consequences of limiting emissions now will last for millennia.

Potential surprises

The Climate Science Special Report includes a chapter (Kopp et al. 2017) on potential surprises, compound extremes and tipping elements. The key findings are worth paraphrasing here:

1. Positive feedbacks (self-reinforcing cycles) within the climate system have the potential to accelerate human-induced climate change and even shift the Earth's climate system, in part or in whole, into new states that are very different from those experienced in the recent past (for example, ones with greatly diminished ice sheets or different large-scale patterns of atmosphere or ocean circulation). Some feedbacks and potential state shifts can be modeled and quantified; others can be modeled or identified but not quantified;

and some are probably still unknown. (*Very high confidence* in the potential for state shifts and in the incompleteness of knowledge about feedbacks and potential state shifts).

2. The physical and socioeconomic impacts of compound extreme events (such as simultaneous heat and drought, wildfires associated with hot and dry conditions, or flooding associated with high precipitation on top of snow or waterlogged ground) can be greater than the sum of the parts (*very high confidence*). Few analyses consider the spatial or temporal correlation between extreme events.

3. While climate models incorporate important climate processes that can be well quantified, they do not include all of the processes that can contribute to feedbacks, compound extreme events, and abrupt and/or irreversible changes. For this reason, future changes outside the range projected by climate models cannot be ruled out (*very high confidence*). Moreover, the systematic tendency of climate models to underestimate temperature change during warm paleoclimates suggests that climate models are more likely to underestimate than to overestimate the amount of long-term future change (*medium confidence*).

All of these points are highly relevant for Oregon as it considers policies to reduce emissions and prepare for future challenges to its climate-sensitive natural resource economy, natural world and cultural heritage, infrastructure, health, and frontline communities. These are covered in the Northwest chapter of NCA4, available here:

https://nca2018.globalchange.gov/downloads/NCA4_Ch24_Northwest_Full.pdf

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Recommended Citation for Chapter

May C., 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: Northwest. 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, pp. 1036–1100. doi: 10.7930/NCA4.2018.CH24

On the Web: https://nca2018.globalchange.gov/chapter/northwest

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Four Lakes basin in White Cloud Peaks, Sawtooth National Forest, Idaho

Key Message 1

Natural Resource Economy

Climate change is already affecting the Northwest's diverse natural resources, which support sustainable livelihoods; provide a robust foundation for rural, tribal, and Indigenous communities; and strengthen local economies. Climate change is expected to continue affecting the natural resource sector, but the economic consequences will depend on future market dynamics, management actions, and adaptation efforts. Proactive management can increase the resilience of many natural resources and their associated economies.

Key Message 2

Natural World and Cultural Heritage

Climate change and extreme events are already endangering the well-being of a wide range of wildlife, fish, and plants, which are intimately tied to tribal subsistence culture and popular outdoor recreation activities. Climate change is projected to continue to have adverse impacts on the regional environment, with implications for the values, identity, heritage, cultures, and quality of life of the region's diverse population. Adaptation and informed management, especially culturally appropriate strategies, will likely increase the resilience of the region's natural capital.

Key Message 3

Infrastructure

Existing water, transportation, and energy infrastructure already face challenges from flooding, landslides, drought, wildfire, and heat waves. Climate change is projected to increase the risks from many of these extreme events, potentially compromising the reliability of water supplies, hydropower, and transportation across the region. Isolated communities and those with systems that lack redundancy are the most vulnerable. Adaptation strategies that address more than one sector, or are coupled with social and environmental co-benefits, can increase resilience.

Key Message 4

Health

Organizations and volunteers that make up the Northwest's social safety net are already stretched thin with current demands. Healthcare and social systems will likely be further challenged with the increasing frequency of acute events, or when cascading events occur. In addition to an increased likelihood of hazards and epidemics, disruptions in local economies and food systems are projected to result in more chronic health risks. The potential health co-benefits of future climate mitigation investments could help to counterbalance these risks.

Key Message 5

Frontline Communities

Communities on the front lines of climate change experience the first, and often the worst, effects. Frontline communities in the Northwest include tribes and Indigenous peoples, those most dependent on natural resources for their livelihoods, and the economically disadvantaged. These communities generally prioritize basic needs, such as shelter, food, and transportation; frequently lack economic and political capital; and have fewer resources to prepare for and cope with climate disruptions. The social and cultural cohesion inherent in many of these communities provides a foundation for building community capacity and increasing resilience.

Executive Summary

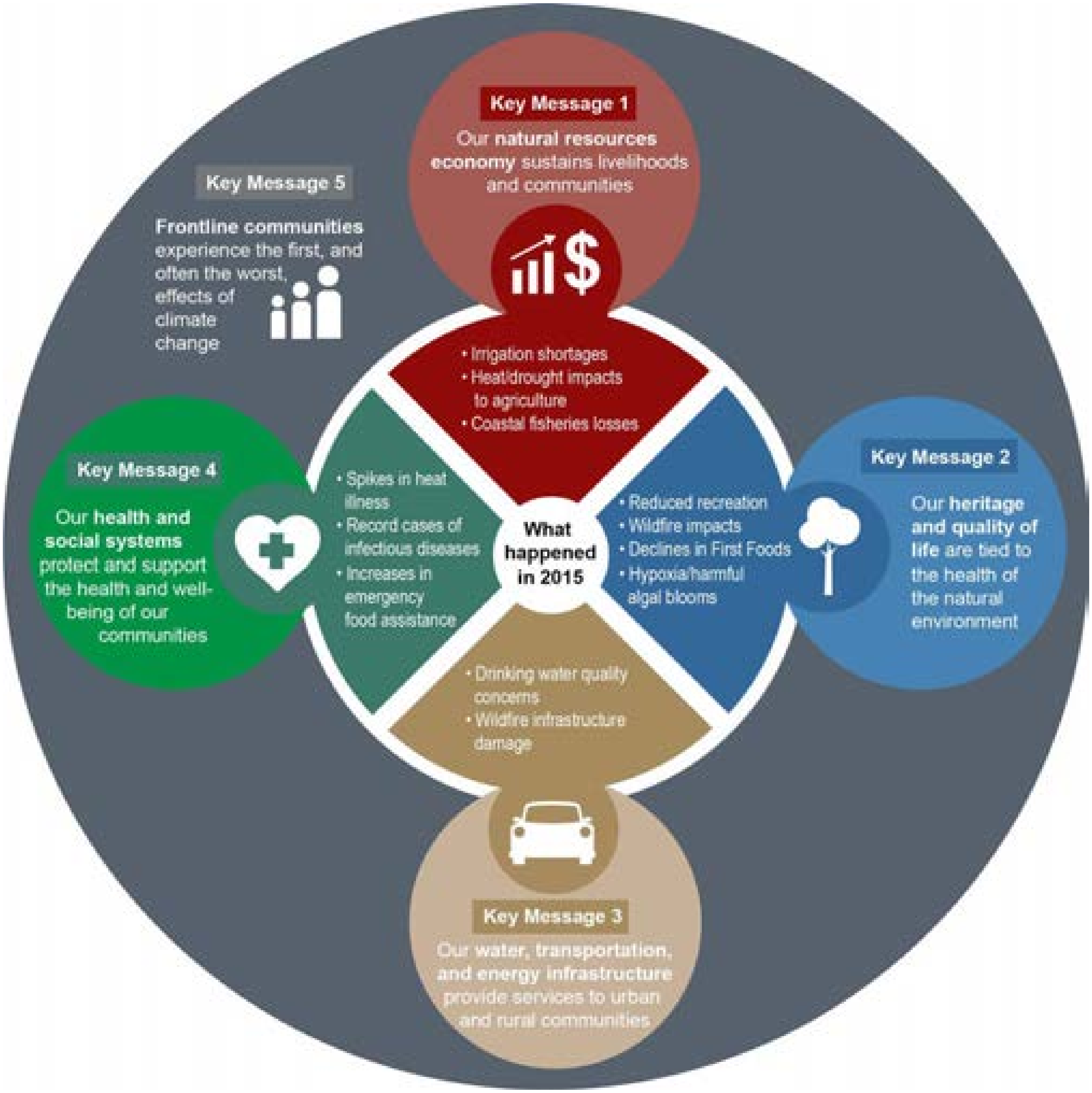
Residents of the Northwest list the inherent qualities of the natural environment among the top reasons to live in the region. The region is known for clean air, abundant water, low-cost hydroelectric power, vast forests, extensive farmlands, and outdoor recreation that includes hiking, boating, fishing, hunting, and skiing. Climate change, including gradual changes to the climate and in extreme climatic events, is already affecting these valued aspects of the region, including the natural resource sector, cultural identity and quality of life, built infrastructure systems, and the health of Northwest residents. The communities on the front lines of climate change—tribes and Indigenous peoples, those most dependent on natural resources for their livelihoods, and the economically disadvantaged—are experiencing the first, and often the worst, effects.

In the Third National Climate Assessment, the Key Messages for the Northwest focused on projected climate impacts to the region.[1] These impacts, many of which are now better understood in the scientific literature, remain the primary climate concerns over the coming decades. In this updated assessment, the Key Messages explore how climate change could affect the interrelationships between the environment and the people of the Northwest. The extreme weather events of 2015 provide an excellent opportunity to explore projected changes in baseline climate conditions for the Northwest. The vast array of climate impacts that occurred over this record-breaking warm and dry year, coupled with the impacts of a multiyear drought, provide an enlightening glimpse into what may be more commonplace under a warmer future climate. Record-low snowpack led to water scarcity and large wildfires that negatively affected farmers, hydropower, drinking water, air quality, salmon, and recreation. Warmer than normal ocean temperatures led to shifts in the marine ecosystem, challenges for salmon, and a large harmful algal bloom that adversely affected the region's fisheries and shellfish harvests.

Strong climate variability is likely to persist for the Northwest, owing in part to the year-to-year and decade-to-decade climate variability associated with the Pacific Ocean. Periods of prolonged drought are projected to be interspersed with years featuring heavy rainfall driven by powerful atmospheric rivers and strong El Niño winters associated with storm surge, large waves, and coastal erosion. Continued changes in the ocean environment, such as warmer waters, altered chemistry, sea level rise, and shifts in the marine ecosystems are also expected. These changes would affect the Northwest's natural resource economy, cultural heritage, built infrastructure, and recreation as well as the health and welfare of Northwest residents.

The Northwest has an abundance of examples and case studies that highlight climate adaptation in progress and in practice—including creating resilient agro-ecosystems that reduce climate-related risks while meeting economic, conservation, and adaptation goals; using "green" or hybrid "green and gray" infrastructure solutions that combine nature-based solutions with more traditional engineering approaches; and building social cohesion and strengthening social networks in frontline communities to assist in meeting basic needs while also increasing resilience to future climate stressors. Many of the case studies in this chapter demonstrate the importance of co-producing adaptation efforts with scientists, resource managers, communities, and decision-makers as the region prepares for climate change impacts across multiple sectors and resources.

Climate Change Will Impact Key Aspects of Life in the Northwest



The climate-related events of 2015 provide a glimpse into the Northwest's future, because the kinds of extreme events that affected the Northwest in 2015 are projected to become more common. The climate impacts that occurred during this record-breaking warm and dry year highlight the close interrelationships between the climate, the natural and built environment, and the health and well-being of the Northwest's residents. *From Figure 24.2 (Source: USGCRP).*

Background

Residents of the Northwest list the inherent qualities of the natural environment among the top reasons to live in the region. The Northwest is known for clean air, abundant water, low-cost hydroelectric power, vast forests, extensive farmlands, and an array of outdoor recreation that includes hiking, boating, fishing, hunting, and skiing. Warming and related changes in climate are already affecting aspects of the Northwest's identity such as its natural resource economy and its cultural heritage that is deeply embedded within the natural environment. The built systems that support Northwest residents and the health of residents themselves are also already experiencing the effects of climate change. The communities on the front lines of climate change experience the first, and often the worst, effects. Frontline communities in the Northwest include tribes and Indigenous peoples, the economically disadvantaged, and those most dependent on natural resources for their livelihoods.

The region has warmed substantially—nearly 2°F since 1900—and this warming is partially attributable to human-caused emissions of greenhouse gases.[2,3,4] Warmer winters have led to reductions in the mountain snowpack[5,6] that historically blanketed the region's mountains, increasing wildfire risk (Ch. 6: Forests, KM 1)[7,8] and speeding the usually slow release of water for communities, agriculture, rivers, and soils. In 2015, record winter warmth led to record-low snowpack in much of the Northwest's mountains as winter precipitation fell as rain instead of snow,[9] resulting in drought, water scarcity, and large wildfires that negatively affected farmers, hydropower, drinking water, salmon, and recreation. In addition, warmer ocean temperatures led to shifts in the marine ecosystem, challenges for salmon, and a large harmful algal bloom.[10] The extreme climate-related events of 2015 have prompted Northwest states, cities, tribes, and others to increase and prioritize climate preparedness efforts, as evidenced by the presentations at the 6th and 7th annual Northwest Climate Conference (http://pnwclimateconference.org/CdA2015/ and http://pnwclimateconference.org/Stevenson2016/).

Detroit Lake Reservoir During Multiyear Drought

Figure 24.1: Detroit Lake Reservoir in Oregon at record-low levels in 2015. Photo credit: Dave Reinert, Oregon State University.

Climate change affects the interrelationships between the environment and the people of the Northwest, and extreme climate events, such as those that occurred during 2015, provide a preview of what may be more commonplace under a warmer future climate (Figure 24.2). The Northwest is projected to continue to warm during all seasons under all future scenarios, although the rate of warming depends on current and future emissions.[11] The warming trend is projected to be accentuated in certain mountain areas in late winter and spring,[9] further exacerbating snowpack loss and increasing the risk for insect infestations and wildfires.[12] In central Idaho and eastern Oregon and Washington, vast mountain areas have already been transformed by mountain pine beetle infestations, wildfires, or both, but the western Cascades and coastal mountain ranges have less experience with these growing threats.[13]

Climate Change Will Impact Key Aspects of Life in the Northwest

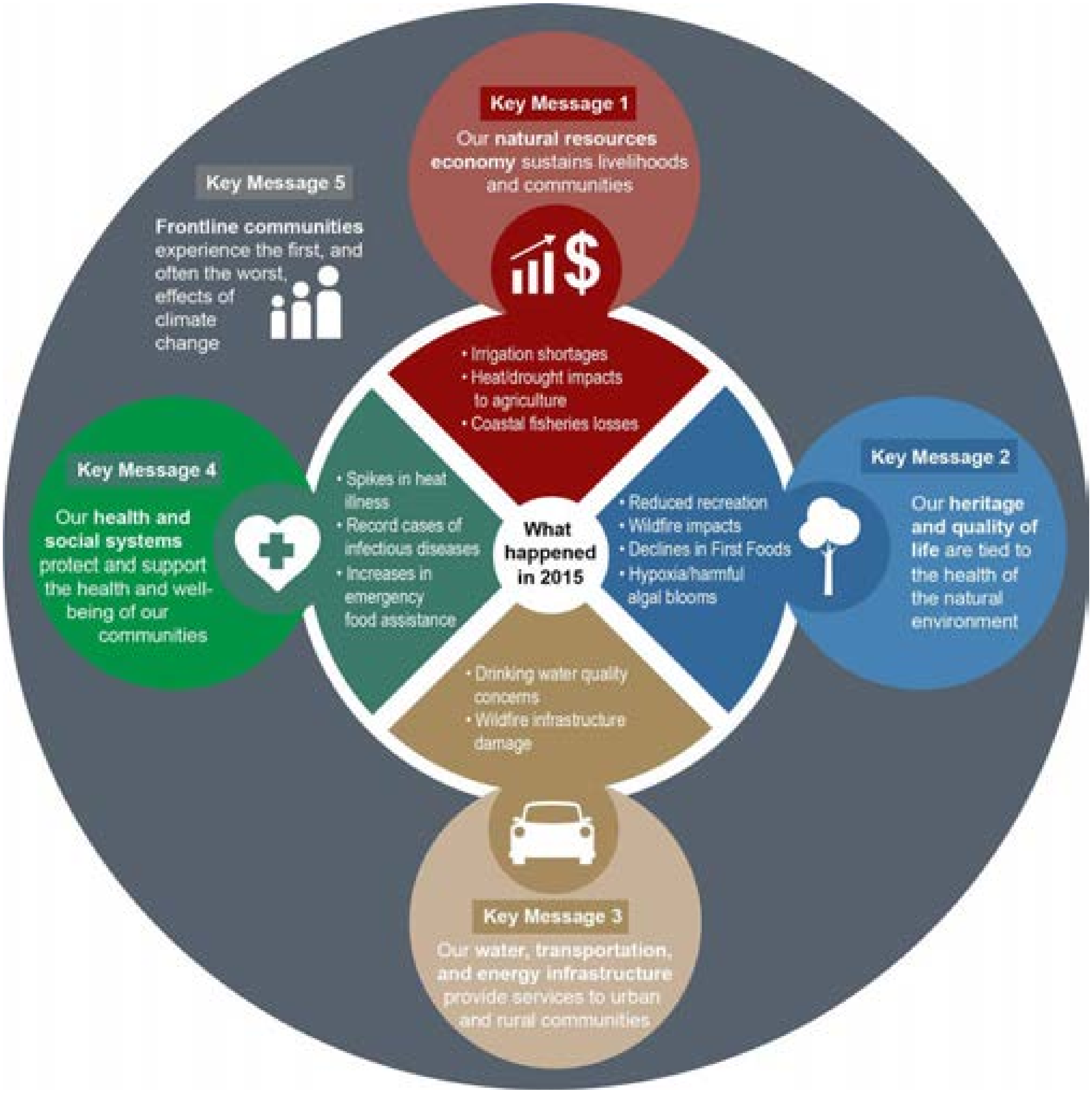


Figure 24.2: The climate-related events of 2015 provide a glimpse into the Northwest's future, because the kinds of extreme events that affected the Northwest in 2015 are projected to become more common. The climate impacts that occurred during this record-breaking warm and dry year highlight the close interrelationships between the climate, the natural and built environment, and the health and well-being of the Northwest's residents. Source: USGCRP.

Average winter precipitation is expected to increase over the long term, but year-to-year variability in precipitation is also projected to increase.[11] Years of abnormally low precipitation and extended drought conditions are expected to occur throughout the century,[11] and extreme events, like heavy rainfall associated with atmospheric rivers, are also anticipated to occur more often.[14] Along the coast, severe winter storms are also projected to occur more often, such as occurred in 2015 during one of the strongest El Niño events on record.[15] El Niño winter storms contributed to storm surge, large waves, coastal erosion, and flooding in low-lying coastal areas (Ch. 8: Coastal, KM 1).[16] Changes in the ocean environment, such as warmer waters, altered chemistry, sea level rise, and shifts in the marine ecosystems are also expected (Ch. 9: Oceans). These projected changes affect the Northwest's natural resource economy, cultural heritage, built infrastructure, recreation, and the health and welfare of Northwest residents.

Key Message 1

Natural Resource Economy

Climate change is already affecting the Northwest's diverse natural resources, which support sustainable livelihoods; provide a robust foundation for rural, tribal, and Indigenous communities; and strengthen local economies. Climate change is expected to continue affecting the natural resource sector, but the economic consequences will depend on future market dynamics, management actions, and adaptation efforts. Proactive management can increase the resilience of many natural resources and their associated economies.

Linkage Between Observed Climate and Regional Risks

The Northwest provides for a diverse natural resource economy, from coastal fisheries, to Douglas fir plantations, to vineyards, to semiarid rangelands, to dryland and irrigated farms. The region is the Nation's top producer of 28 agricultural products, one of the leading national producers of timber products, and is widely recognized for salmon and shellfish fisheries. The agriculture, forestry, and fisheries sectors accounted for over 700,000 jobs and more than $139 billion in sales in 2015 (in 2015 dollars; Figure 24.3).[17]

Natural Resource Industry Jobs and Sales Revenues

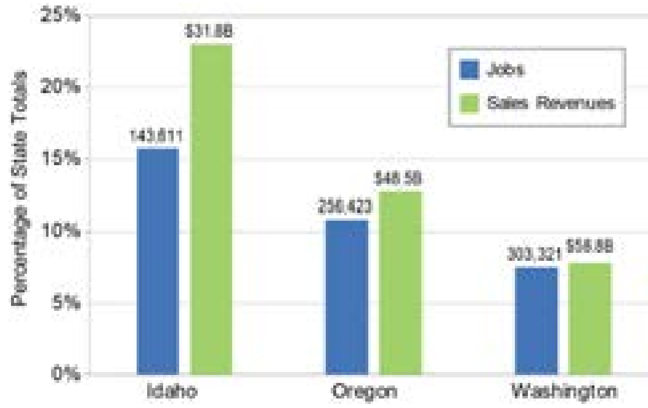


Figure 24.3: Natural resources are a key part of the Northwest economy. Climate change is putting natural resource sector jobs and sales revenues at risk. Jobs and sales figures include the agriculture, forestry, and fisheries sectors only, and are presented based on 2015 data for Idaho, Oregon, and Washington.[17] Source: U.S. Forest Service and Boise State University.

The outdoor recreation sector is another important contributor to local economies in the Northwest. The Outdoor Industry Association (2017)[18] estimates that the region's outdoor recreation economy generates $51 billion (based on 2017 data, dollar year not reported) in consumer spending each year and provides around 451,000 jobs. These economic benefits are particularly important in rural and tribal communities whose income base is largely dependent on natural resource economies and supporting industries (Ch. 10: Ag & Rural, KM 4; Ch. 15: Tribes). Outdoor activities, including skiing, boating, rafting, hunting, fishing, hiking, and backpacking, are impacted by climate variability, whether through less summer water, warmer streams, less snowfall, or loss of forests. Comparing high-snowfall to low-snowfall years in the Northwest between 1999 and 2009, each low-snowfall year resulted in more than 2,100 fewer employees and a $173 million reduction in ski resort revenues ($189 million in 2015 dollars) compared to the high-snowfall years.[19] Impacts on the skiing industry were especially prominent during the warm 2015 winter, when snowpack was at record lows (see Box 24.7).

Both the natural resource commodity sector and the outdoor recreation industry are sensitive to short- and long-term climate variability. The record-setting 2015 drought and above-average temperatures were a challenge for agriculture. The reduced availability of water for irrigation coupled with heat stress impacted production and livestock health (see Box 24.7) (see also Ch. 10: Ag & Rural, KM 2 and 3; Ch. 3: Water, KM 3). In Northwest forests, tree mortality driven by wildfires, insects, and disease have been more prevalent over the last two decades due to drought conditions and increased temperatures (e.g., Hicke et al. 2013[13]), and timber managers are adjusting to increased risk of loss by shortening rotation rates, reducing investment in some areas, and changing planted species.[20,21]

Commercial fisheries are also sensitive to climate variability. River temperatures increase during warm and dry years, resulting in fish kills of migrating and spawning salmon; these fish kills have consequences several years in the future.[22,23,24] In 2015, July water temperatures in the lower Columbia River and its tributaries were higher than in any other year on record, leading to a high rate of mortality for endangered sockeye and threatened Chinook.[25,26] The record temperatures in 2015 were part of a long-term trend of declining low flows[27] and warming streams.[28,29] Increasing ocean temperatures and acidity also impact fish survival, species abundance, and predator–prey distribution and timing.[30] In 2015, the increased ocean temperatures were part of an ocean heat wave coined "the Blob," which fueled a coast-wide harmful algal bloom that affected commercial, recreation, and tribal subsistence fisheries (see Box 24.7) (see also Ch. 9: Oceans).[10]

Future Climate Change Relevant to Regional Risks

Shifts in timing of water supply, such as earlier snowmelt and declining summer flows, can adversely impact irrigated crop productivity, particularly where access to reservoir water storage and/or groundwater is limited (Ch. 10 Ag & Rural, KM 2).[31] Planning studies for Northwest reservoirs suggest a significant increased need for reservoir storage to meet future summer irrigation demands under climate change scenarios.[32,33] Irrigation demands among farmers in the Columbia River Basin are projected to increase 5% in response to climate change by the 2030s; however, actual water demands will vary depending on adaptive management decisions and crop requirements.[34] For dryland wheat production, shifting planting dates and rising temperatures coupled with increased atmospheric carbon dioxide (CO_2) and associated increases in plant water use efficiency are projected to lead to improved wheat yields under both lower and higher scenarios (RCP4.5 and RCP8.5) through the end of the century.[35,36]

Specialty crops, including apples and other tree fruits, are already experiencing changes. Higher spring temperatures have led to earlier flowering, which can lead to a mismatch with the availability of pollinators required for fruit setting (the process of flowers becoming fruit)[37] and can affect fruit quality as well as yield. Additionally, summer heat stress can lead to sunburn scald on apples and softer berry crops that can be damaged in transport and harvest,[37] which can decrease fruit quality and the farmers' selling price. Heat stress can also decrease livestock health and increase parasite abundance.[38] Projected warmer and drier summer seasons will likely reduce forage quality and quantity,[39] with varied impacts across forage and rangeland types.[40] Impacts to the quality and quantity of forage will also likely impact farmers' economic viability as they may need to buy additional feed or wait longer for their livestock to put on weight, which affects the total price they receive per animal.

Forests in the interior Northwest are changing rapidly because of increasing wildfire[8] and insect and disease damage,[41,42] attributed largely to a changing climate (Ch. 5: Land Changes).[43] These changes are expected to increase as temperatures increase[44] and as summer droughts deepen.[45] For forests that grow in areas with snowpack, the declining snowpack is projected to worsen summer drought conditions, increasing vulnerability to drought caused by year-to-year precipitation variability.[46] Some forests in the region will increase in potential productivity (growth without consideration of increased disturbance) due to a combination of increased CO_2 and a longer growing season length, while others will decrease due to reduced availability of summer moisture (Ch. 6: Forests).[47] Timber supplies from the drier eastern Northwest forests are the most affected by climate-related disturbances,[48] resulting in intermittent and unpredictable timber supplies and depressed timber prices[49] in an already difficult global market. This could affect mill investments and the long-term viability of forestry as an economic activity, particularly in the more remote areas of the region where transportation costs to mills are high.

The negative impacts on Northwest fisheries associated with ocean warming, acidification, and harmful algal blooms are expected to increase (Ch. 9: Oceans).[50] This could lead to extensive fisheries closures across all of the region's coastal fisheries, with severe economic and cultural effects on commercial and subsistence shellfish industries. The warming ocean is projected to result in range shifts, with some Northwest species shifting as far north as the Bering Sea.[51] However, these range shifts may also open up new fishing opportunities in the Northwest,[51,52] depending on interstate and international coordination between management agencies. As the marine ecosystems respond to climate change, there will likely be consequences to existing place-based fisheries resources, as well as potential benefits and new resources. How the shifting resources will be managed and how existing fishing rights and allocations will change over time is currently not known (Ch. 9: Oceans, KM 2).

Projections for increased stream temperature indicate a 22% reduction in salmon habitat in Washington by late century under a high emissions future (the A1F1 scenario).[53] This habitat loss corresponds to more than $3 billion in economic losses due to reductions in salmon populations and decreases in cold-water angling opportunities ($3.3 billion in 2015 dollars, discounting method not specified).[53] Freshwater trout are sensitive to habitat connectivity and wildfire, so land management practices will affect how trout respond to climate change.[54] Overall, commercial fishing performance and abundance are expected to decline as the climate changes.[50,55,56,57]

Decreases in low- and mid-elevation snowpack and accompanying decreases in summer streamflow are projected to impact snow- and water-based recreation, such as downhill and cross-country skiing, snowmobiling, boating, rafting, and fishing. Climate change could decrease snow-based recreation revenue by more than 70% annually in the Northwest under a higher scenario (RCP8.5).[58] Impacts to snowpack and, consequently, winter recreation will likely occur later in the colder, higher-elevation mountains in southern Idaho.[59]

Challenges, Opportunities, and Success Stories for Reducing Risk

Climate change will likely have both positive and negative effects on the natural resource sector; however, cost-effective adaptation approaches that build agro-ecosystem resilience are likely needed to maintain agricultural livelihoods (see Box 24.1). A shift in plant hardiness zones, or the ability of a given plant to thrive in a specific location, is expected, changing the suitability of growing certain crops in specific locations;[60,61] such shifts may change land uses entirely (Ch. 5: Land Changes, KM 2). For example, Northwest wine producers may see the potential for growing higher-quality and higher-value wine grape varietals,[62] but changing hydrologic regimes are projected to limit available water supplies for irrigation, requiring water storage or alternative water sources to maintain productivity. Over the longer term, changes to average growing season temperatures and the number of severe hot days are projected to reduce premium wine grape production in the Northwest, potentially shifting prime growing areas further north.[63] To take advantage of shifting opportunities, farmers would need to consider costly changes and investments in new farming practices and territories in advance of projected climate change.[37,64]

Livestock producers in the Northwest have an advantage over those in other U.S. regions where climate change impacts are likely to be more severe (Ch. 10: Ag & Rural, KM 3).[65] However, livestock production costs are still likely to increase in the Northwest due to supplemental feeding and watering requirements and the need for reducing livestock numbers in response to warmer and drier summers.[40]

The prevalence of wildfires, insect infestations, disease epidemics, and drought-induced dieback of Northwest forests have heightened forestry managers' awareness of potential climate change impacts. Over the long term, these sustained impacts are projected to fundamentally alter forest composition and land cover (Ch. 6: Forests, KM 1; Ch. 5: Land Changes). Forest management adaptation strategies are being developed,[21,66] including strategies

Supplemental Watering of Livestock During Drought

Figure 24.4: Supplemental watering of livestock in Eastern Oregon during the 2015 drought. Photo credit: Sonia A. Hall.

that address drought-related risks, improve the reliability of forest transportation infrastructure, and protect forest-related ecosystem services (Ch. 6: Forests, KM 3).[67] Vulnerability assessments and adaptation plans have been completed, or are in progress, for almost every National Forest and Park in the region.[68]

Marine and ocean environments of the Northwest are projected to continue to change gradually in response to climate change, but the full extent of the potential effects on fisheries is not well understood.[69] In the near term, the fisheries industry can use existing strategies that work within the limits of the natural environment to maintain species abundance, avoid extinction, or increase harvests, such as limited fishing seasons, developing quota systems, and expanding aquaculture (Ch. 9: Oceans, KM 2). In the longer term, particularly as large-scale range shifts occur, species-dependent management changes and alternative management systems are likely to be needed to maintain fisheries and open up new fisheries opportunities.[70]

Despite the many strategies for reducing risks, adaptive capacity is not uniform across the natural resource sector. Given the heterogeneity across climatic and natural resource industries in the region, it is not likely that productivity gains and losses will be felt equally across the broad diversity in the region.[71,72]

Emerging Issues

Climate stressors such as increased temperatures, CO_2 fertilization, and precipitation changes are projected to impact pest, disease, and weed pressures (Ch. 10: Ag & Rural).[77,78] Improved modeling of climate stressors on yields and crop quality will likely enhance the understanding of climate change effects and inform adaptation options[36] and assist in addressing farmers' concerns about future pest and pathogen impacts in the region.[79,80] Water shortfalls are also likely to continue during drought periods despite adaptation efforts focused on water efficiency and reducing water usage (Ch. 3: Water, KM 1). Western water law assigns a priority date to each right based on seniority, so junior (or more recent) water rights are more likely to be adversely affected under shortage conditions than

Box 24.1: Adaptive Agricultural Approaches in Practice

Farmers and ranchers across the Northwest are creating resilient agro-ecosystems to reduce weather- and climate-related risks while meeting economic, conservation, and adaptation goals. Below are a few examples of these efforts from the region.

- A dryland farmer in Eastern Oregon is implementing flexible cropping methods, which allows the farmer to plant additional crops, instead of leaving the field uncultivated (fallow), when soil moisture conditions allow. By intensifying production and reducing fallow periods, profits have increased while also improving weed management, reducing erosion, and improving soil quality.[73]

- A vegetable, grain, and livestock farmer in Washington is caring for the soil by using conservation tillage, direct seeding, and double cropping to reduce soil erosion, improve soil health, and increase revenues.[74]

Figure 24.5: A farmer in Oregon surveys his no-till field, a practice used to build climate resilience. Photo credit: Sylvia Kantor, Washington State University Extension.

- A cattle ranching family in Washington is using holistic management, a comprehensive approach for ranch decision-making, to reduce environmental risks and improve pasture productivity and profitability.[75]

- Farmers in Oregon's Willamette Valley are using dry farming methods to reduce reliance on irrigation water. This Dry Farming Collaborative is developing and implementing approaches that reduce drought risks during dry summer growing seasons.[76]

those with senior water rights. More studies would enhance the understanding of which watersheds are at the greatest risk and what, if any, changes could address water limitations in the future. The development of more robust water markets may facilitate adaptation to climate change in the arid and semiarid Pacific Northwest; however, considerable institutional barriers currently prevent their full implementation.[81]

Although much is being researched with respect to the effects of climate change on forests and associated ecosystem services, far less has been explored with respect to timber markets. Even then, most of the focus has been on changes in forest productivity overall (e.g., Latta et al. 2010[47]) and less on the consequences of disturbance. Research is absent on the effects of potential increases in supply volatility and the consequences for investment and ultimately on harvest and milling jobs.

Ocean acidification poses a direct threat to shellfish and other calcifying species that are at the base of the food web (Ch. 9: Oceans, KM 1). The prominence of the impact on shellfish farms in the Northwest led to the installation of an ocean monitoring system to track ocean acidity. Although calcium carbonate can be used to increase seawater pH in a hatchery setting,[82] the same approach cannot be used in the open ocean to prevent shell dissolution.[83] The broader food web consequences of decline in calcifying species is an area of active research (Ch. 9: Oceans).

There is a great deal of uncertainty regarding impacts on the economic viability of primarily rural, natural-resource-based economies in the region, particularly the degree to which individual sectors are integrated into global commodity markets, which are likely to vary immensely and be difficult to predict (Ch. 10: Ag & Rural; Ch. 16: International, KM 4).[50]

Key Message 2

Natural World and Cultural Heritage

Climate change and extreme events are already endangering the well-being of a wide range of wildlife, fish, and plants, which are intimately tied to tribal subsistence culture and popular outdoor recreation activities. Climate change is projected to continue to have adverse impacts on the regional environment, with implications for the values, identity, heritage, cultures, and quality of life of the region's diverse population. Adaptation and informed management, especially culturally appropriate strategies, will likely increase the resilience of the region's natural capital.

Linkage Between Observed Climate and Regional Risks

The intangible values and aspects of the Northwest's natural environment that support a high quality of life for its residents—wildlife, habitat, and outdoor recreation—are at risk in a changing climate. Tribes and Indigenous communities that rely heavily on the natural environment for their culture and heritage are also at risk.

The Northwest's native wildlife is impacted by climate variability and change *directly* through temperature shifts, water availability, and extreme events, and *indirectly* through loss or fragmentation of habitat.[84] Changes in climate can alter the balance among competing species or predator–prey relationships (e.g., Wenger et al. 2011[52]). Three wildlife categories are of principal concern: already sensitive or endangered species, snow-dependent species, and game species. While the first two groups of animals are generally negatively impacted by changes in climate, some game species, such as deer and elk, may thrive. Game species are

First Salmon Ceremony of the Lummi Tribe, Washington

Figure 24.6: Tribes in the Northwest typically honor the fi salmon caught in the season through tribal ceremonies. Photo credit: Northwest Indian Fisheries Commission (CC BY 3.0).

of concern not because of their sensitivity to changes in climate and habitat but because of their notable value for recreational hunting and as key cultural resources for tribes. Climate change is also projected to impact First Foods, or foods that tribes have historically cultivated for subsistence, economic, and ceremonial purposes. First Foods vary among tribes but often include berries, roots, water, fish, and local wildlife.[85,86] Additionally, nearly half of all adults in the region participated in wildlife-related recreation in 2010.[87] As temperatures increase, the demand for warm-weather outdoor and water-based recreation increases, and visitation rates at local, state, and national parks increase.[88,89,90] However, boating and other water-based recreation opportunities are likely to decline in the future when summer streamflows and reservoir levels are low. Additionally, popular winter sports and snow-based recreational activities, such as downhill skiing, cross-country skiing, and snowmobiling, have been dramatically impacted by reduced snowfall (see Box 24.7). In low-snowfall years, Washington and Oregon show the highest percentage drop of skier visits, meaning that residents and visitors are losing desirable skiing opportunities.[91]

Future Climate Change Relevant to Regional Risks

Wildlife responses to a changing climate are varied and complex (Ch. 7: Ecosystems). Some species, such as cavity nesting birds, will very likely benefit from greater disturbance.[92,93] Others, particularly snow-dependent species, will likely be unable to persist under climate change.[94]

Game species are expected to have diverse responses to climate change. Longer dry seasons and more pronounced droughts are projected to reduce wetland habitat extent and duration, causing changes in waterfowl movement. Increased fire disturbance, on the other hand, will likely increase shrub cover, a preferred food for deer and elk;[95] reduced winter snowpack may increase food availability in winter; and warmer temperatures reduce winter stress, all of which would support higher deer and elk populations. The primary climate-related impact on game species will likely come from increases in disease and disease-carrying insects and pests.[96]

Temperature-sensitive bull trout, salmon, and other water-dependent species, such as amphibians, are most vulnerable to increased habitat fragmentation.[97,98,99] Increased frequency of extreme events such as flooding, debris flows, and landslides are projected to alter habitats and likely cause local extinctions of aquatic species.

Increased winter streamflow and decreased summer flow are projected to threaten salmon spawning,[100] compromising salmon hatchery and reintroduction efforts.[101] Projected increases in winter storm intensity will likely lead to higher river flows and increased sediment loading that can bury salmon eggs and reduce salmon survival.[101] Rising stream temperatures, ocean acidification, and loss of nearshore and estuarine habitat also increase salmon mortality across all phases of the salmon life cycle.[102]

Shellfish beds are threatened by sea level rise, storm surge, and ocean acidification.[85,103] Species moving out of traditional hunting, gathering, and fishing areas are projected to impact resource access for many tribes.[101,104] Increasing wildfire frequency and intensity are changing foraging patterns for elk and deer, and increased prevalence of invasive species and disease will likely diminish both wildlife and foraging for traditional plants, berries, roots, and seeds.[105]

In winter, continued decreases in lower-elevation snowpack are projected to impact snow-based recreation.[19] Less snowpack and earlier melting of snowpack will likely result in decreased water availability, reducing the quality, quantity, and availability of water-based recreational opportunities, such as boating, rafting, and fishing.[18]

Increased wildfire occurrence is projected to degrade air quality and reduce the opportunity for and enjoyment of all outdoor recreation activities, such as camping, biking, hiking, youth sports, and hunting. Degraded air quality also directly impacts human health and quality of life (see Key Message 4).

Razor Clamming in Washington State

Figure 24.7: Razor clamming draws crowds on the coast of Washington State. This popular recreation activity is expected to decline due to ocean acidification, harmful algal blooms, warmer temperatures, and habitat degradation. Photo courtesy of Vera Trainer, NOAA.

Wildfires Affect Outdoor Recreation

Figure 24.8: Wildfires impact outdoor wilderness activities and recreation. Reduced air quality and closed trails and camping grounds are projected to increase as wildfire occurrences increase. Photo credit: Charles Luce.

Recreational ocean fishing opportunities are expected to decline under future climate change scenarios,[55,56,57] and it is likely that fishery ranges will change.[51] Recreational razor clamming on the coast is also expected to decline due to cumulative effects of ocean acidification, harmful algal blooms, higher temperatures, and habitat degradation (see Figure 24.7 and Key Message 1).

Challenges, Opportunities, and Success Stories for Reducing Risk

Historical and projected changes in amenities affecting the quality of life in the Northwest, such as wildlife, recreation opportunities, and edible plants, form a key challenge for managers of these resources. Informed management, however, can reduce the consequences to those who enjoy and value these resources. Sensitive and endangered plant and animal species currently require special management considerations due to historical habitat changes and past species declines. Management of these species can substantially constrain land and water management options, and the protection of these species will likely become more difficult as suitable habitat is lost.

Game species are already managed. Further management of waterfowl habitat is projected to be important to maintain past hunting levels. If deer and elk populations increase, the pressures they place on plant ecosystems (including riparian systems) may benefit from management beyond traditional harvest levels.

The cultural practice of harvesting and consuming First Foods is integral to tribes and Indigenous health (Ch. 15: Tribes).[106] Many tribes, such as the Confederated Tribes of the Umatilla Indian Reservation are using climate change vulnerability assessments and climate change adaptation plans to alter how First Foods are managed.[107] Tribes can exercise their sovereign rights to manage their resources in a self-determined and culturally appropriate manner, thereby increasing each tribe's adaptive capacity to respond to climate change impacts on tribal lands, foods, health, and cultures (see Box 24.2).[85,108,109] Tribes can also increase their adaptive capacity through regional networks, such as the Columbia River Inter-Tribal Fish Commission, that support tribal and Indigenous planning and management (see Key Message 5).

As fisheries become stressed due to climate change, additional management strategies are likely to be needed to maintain fish populations. Strategies that focus on habitat quality and quantity are likely to be the most successful.[110]

Box 24.2: Pacific Salmon and the Identity and Culture of Northwest Tribes

For most Northwest tribes and Indigenous peoples, salmon fishing is more than a cultural, subsistence, and economic act. The tribes view salmon as an extension of life and an indicator of environmental health, and loss of salmon is equated with the loss of tribal identity and culture. As a testament of the importance of salmon, Julia Davis-Wheeler, a Nez Perce elder, stated: "We need the salmon because it is part of our lives and part of our history. The salmon is a part of us, and we are a part of it. Our children need to be able to feel what it is like to catch and eat salmon. They need to be able to experience that sense of respect that many of us have felt in past years."[111]

Figure 24.9: Pacific salmon are essential to most Northwest Tribes' identity and culture. Typically, the first salmon caught is displayed, cleaned, and cooked for the community to share. The skeleton is returned to the water to show respect to the salmon. This photo shows the First Salmon ceremony of the Puyallup Tribe. Pacific salmon—a keystone species in the Northwest—are at risk because of climate change. Economic, social, and cultural values are also at risk if salmon populations continue to decline. Recreational salmon fishing contributes to the quality of life and well-being for many Northwest residents. Photo credit: Matt Nagle, Puyallup Tribal News.

Adaptation strategies aimed at restoring and enhancing salmon fisheries can be more successful when traditional knowledge is coupled with modern science.[112,113] For example, the Nez Perce Tribe used local tribal knowledge to construct "natural" rearing ponds in the Columbia River coupled with introducing wild salmon as broodstock to enhance and restore a culturally significant salmon population.[109] Adaptation and informed management can reduce the consequences to those who enjoy and value these resources.

Emerging Issues

Some of the species likely to be affected by climate change are already imperiled by population declines, extirpations, or even extinction as a result of historical changes in habitat and other factors. Climate change adds urgency to addressing existing and emergent challenges. Research is already active in identifying resilient habitats (e.g., Morelli et al. 2016, Luce et al. 2014, Isaak et al. 2016[114,115,116]) and the means for maintaining and improving habitat resilience in the face of increasing climate and disturbance pressure.[117] Habitat modeling that includes projections of natural resource shifts, fragmentation, and identification of new wildlife corridors are projected to be beneficial in supporting land and water management decisions that benefit people, recreation, and the Northwest's varied wildlife.

An institutional network of land, wildlife, and fishery management agencies, tribes, and non-governmental conservation organizations has already successfully reversed negative trends in many fish and wildlife populations caused by other human activities.[118] These same groups are exploring methods to improve fish and wildlife resilience in a changing climate. Many habitat improvement activities, a cornerstone of conservation biology, also provide flood mitigation, climate mitigation, adaptation, and ecosystem service co-benefits (Ch. 6: Forests).[119,120] Despite proactive management and adaptation, it is likely that species not currently listed as endangered could become endangered over the next century, and eventual extinctions are likely, yet challenging to predict.[121]

First Foods are an important aspect of tribal and Indigenous health and well-being,[122] and they can be used as indicators in tribal health assessments and climate adaptation plans.[112,123]

The loss or decline of First Foods is projected to have cascading physical and mental health impacts for tribes and Indigenous peoples (see Key Message 5) (see also Ch. 15: Tribes, KM 2).[124,125] However, more research to refine these indicators would better support decision-making (see Box 24.2).[123,126]

Social indicators link a decline in quality of life in the Northwest to loss of recreational opportunities due to climate change impacts,[127] but the causal links are not well understood. Additionally, future human migration and population increases may alter the relationship and nature of recreation in the Northwest.[128] As the population increases, the demand for snow-based recreation is likely to also increase. However, it is not clear how the limited availability of snow-based recreation (for example, a shorter ski season) in the Northwest over the long term can influence interest in snow sports in contrast to alternatives.

Key Message 3

Infrastructure

Existing water, transportation, and energy infrastructure already face challenges from flooding, landslides, drought, wildfire, and heat waves. Climate change is projected to increase the risks from many of these extreme events, potentially compromising the reliability of water supplies, hydropower, and transportation across the region. Isolated communities and those with systems that lack redundancy are the most vulnerable. Adaptation strategies that address more than one sector, or are coupled with social and environmental co-benefits, can increase resilience.

Linkage Between Observed Climate and Regional Risks

Infrastructure plays a critical role in keeping the Northwest's economy running smoothly. Roads, highways, railways, and ports facilitate the movement of people and goods within the region and support valuable import and export markets. Powerlines and substations maintain the reliable supply of electricity to homes, businesses, schools, and hospitals. Dams and reservoirs manage streamflow to minimize flood risks, generate electricity, and provide water supply for irrigation and human consumption. Groundwater wells act as an important water source for agriculture and drinking supplies across much of the region. Levees and seawalls prevent damage to homes and property along rivers and the coast. Culverts manage water flows to protect roadways from flooding and assist with fish passage, including for migrating salmon. Storm water and wastewater systems help minimize flooding, especially in urban areas, and are critical for maintaining water quality. However, most infrastructure is designed for a historical climate, and damage and disruptions caused by extreme events demonstrate existing infrastructure vulnerabilities that are likely to increase in a changing climate (Ch. 3: Water, KM 2; Ch. 4: Energy, KM 1; Ch. 11: Urban, KM 2; Ch. 12: Transportation, KM 1; Ch. 28: Adaptation, KM 2).

Services provided by infrastructure can be disrupted during extreme weather and climate events, illustrating the sensitivity of these systems to climate variability and change (see Box 24.3). During the 2015–2016 extreme El Niño winter, wave energy along the West Coast was about 50% above normal.[16] Several major storms hit northwestern Oregon, bringing record-breaking rainfall, high winds, and high tides. Tillamook County in Oregon experienced a state of emergency that included major highway and road closures due to flooding, failed culverts, landslides, and sinkholes. Disruptions in transportation networks affected access to food, healthcare, and social services (see Key Message 2) (see also Ch. 12: Transportation, KM 2).[130] The event highlighted the need to maintain detour routes that were valuable in reaching communities that could become isolated. Wave and storm surge energy

Box 24.3: Tribal Relocation as a Last Resort

The Quinault Indian Nation (QIN), located on the southern coast of Washington's Olympic Peninsula, has experienced repeated flood disasters, as described in the U.S. Climate Resilience Toolkit.[129] In March 2014, coastal storm surge breached the seawall protecting the town of Taholah, flooding the lower village. In January 2015, heavy rainfall washed out roads, including the Highway 109 bridge, a main access road to and from QIN, and threatened wastewater treatment facilities. With more severe impacts anticipated with climate change, combined with risks from tsunamis, QIN's leadership developed a master plan to relocate the lower village to higher ground. The master plan is considered the first step toward realizing QIN's vision for relocation based on sustainable practices and cultural values. Other Washington tribes have also relocated or begun relocation efforts, including the Hoh Tribe, Quileute Tribe, Makah Tribe, and Shoalwater Bay Tribe. Relocation of a tribe is considered a last resort.

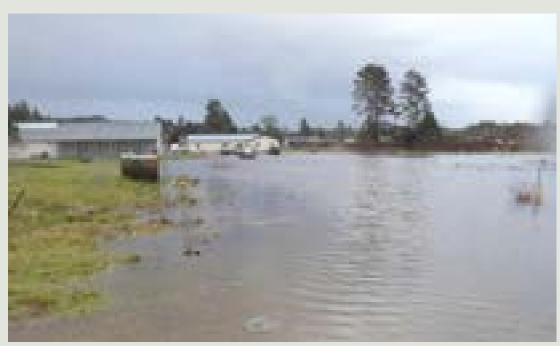


Figure 24.10: Coastal floodwaters inundated the Quinault Indian Nation's lower village of Taholah in March 2014. This event, and continuing concerns about future climate change, prompted the village to begin relocation to higher ground. Photo credit: Michael Cardwell.

along the Pacific Northwest coast is expected to increase with climate change.[131] Continuing efforts to build resilience within the health and transportation sectors in response to flooding hazards will likely help the county weather future storms.[130]

Heavy rainfall can lead to slope instabilities and landslides, which can close roadways and railways. Along the Amtrak Cascades Corridor, more than 900 coastal bluff landslides have blocked the tracks and shut down rail service since 1914, with over 240 disruptions occurring between 2009 and 2013.[132] Each landslide results in a minimum 48-hour moratorium on commuter rail service. The Washington State Department of Transportation is implementing a Landslide Mitigation Action Plan to proactively address the climatic and other factors contributing to landslide-based rail closures.[132]

Landslides during winter storms have also closed major Interstates, such as the December 2015 closure of eastbound Interstate 90 near Snoqualmie Pass and the February 2017 closure of westbound Interstate 90 near Issaquah.

Wildfires can result in road and railway closures, reduced water quality in reservoirs, and impacts on the energy sector. The Goodell wildfire in August 2015 forced Seattle City Light to de-energize transmission lines around its Skagit River Hydroelectric Project for several days.[133] The combined impact of damages and lost power production totaled nearly $3 million (in 2015 dollars).[134] The Eagle Creek fire along the Washington–Oregon border in 2017 led to the closure of Interstate Highway 84 and an adjacent railway, likely increasing shipping costs and creating negative economic impacts on tourism and regional small businesses.[135]

Drought conditions also present challenges for infrastructure, especially water supplies. In Washington, the Department of Ecology allocated almost $7 million in drought relief funds in 2015 (in 2015 dollars). Relief grants were used to provide backup or emergency water supplies for irrigation or human consumption where wells were failing or pumping capacity was inadequate.[136] These small and typically rural systems are relatively more vulnerable to drought impacts when compared to larger urban systems (Ch. 10: Ag & Rural, KM 4).

Future Climate Change Relevant to Regional Risks

Climate change is expected to increase the frequency and/or intensity of many extreme events that affect infrastructure in the Northwest. Available vulnerability assessments for infrastructure show the prominent role that future extremes play. Since much of the existing infrastructure was designed and is managed for an unchanging climate, changes in the frequency and intensity of flooding, drought, wildfire, and heat waves affect the reliability of water, transportation, and energy services.

Hydrologic change will likely be an important driver of future climate stress on infrastructure. As higher temperatures increase the proportion of cold season precipitation falling as rain rather than snow, higher streamflow is projected to occur in many basins, raising flood risks.[137,138,139,140] An increased risk of landslides is also expected, as more mixed rain and melting snow events occur in low- to mid-elevation mountains.[141] Increases in the amount of precipitation falling in heavy rainfall events (including atmospheric rivers)[142] are anticipated to magnify these risks. Along the coast, sea level rise is projected to increase flood risks in low-lying areas and will likely magnify the potential for coastal erosion (Ch. 5: Land Changes) and infrastructure damage during extreme events with high storm surge and wave hazards. By the end of the century, the upper sea level rise projection of 4.3 feet[143] would impact significant infrastructure investments throughout the Northwest, particularly in the low-lying urban areas of the Puget Sound and Portland (Ch. 8: Coastal).

Multiple Climate Stressors Affect Vulnerable Infrastructure

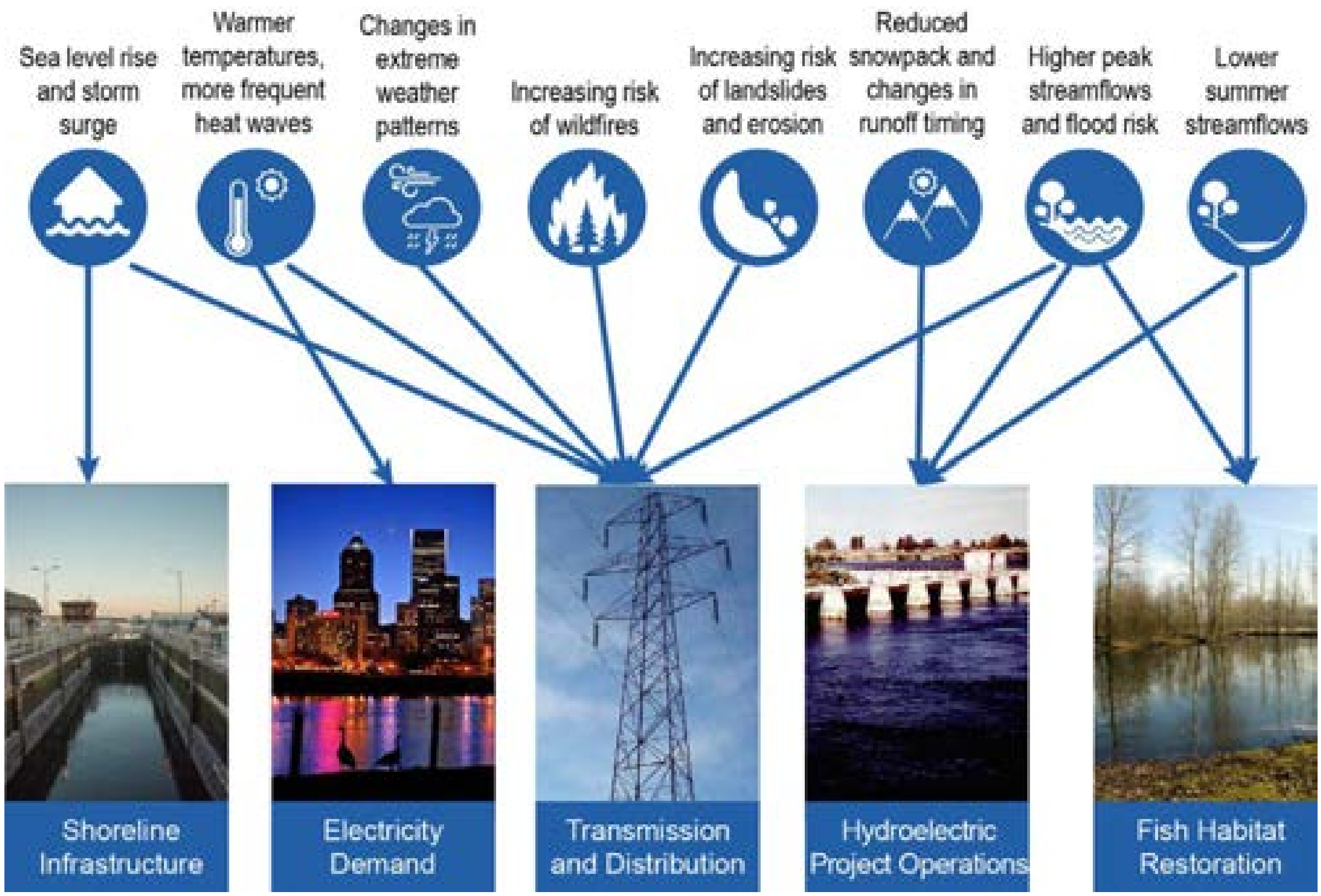


Figure 24.11: Extreme events such as fl heat waves, wildfi landslides, and drought play an important role in the vulnerability of infrastructure. The fi from Seattle City Light's Vulnerability Plan,[133] illustrates how the utility's assets, operations, and management goals are affected by a broad range of climate impacts and extreme events. Adaptation strategies to increase the resilience of the energy system must focus on multiple potential risks as well as environmental considerations. Source: adapted from Raymond 2015.[133] Photo credits (from left to right): Emmet Anderson (Flickr, CC BY-NC 2.0), Justin Miller (Flickr, CC BY-NC 2.0), photojojo3 (Flickr, CC BY 2.0), U.S. Department of Energy, Rick Swart, Oregon Department of Fish & Wildlife.

Spring and summer streamflows are anticipated to decline in basins that have historically relied on snowmelt, and low flow periods are projected to be more prolonged and more severe. If observed declines in higher elevation precipitation continue,[144] this would exacerbate low streamflow conditions,[27] resulting in decreased water supply and reservoir storage. Climate change can affect water quality as well (Ch. 3: Water, KM 1). Higher air temperatures, lower streamflow, and decreases in rainfall are expected to raise summer stream temperatures, making it more difficult to meet water quality standards. In coastal areas, sea level rise will likely lead to saltwater intrusion into groundwater supplies.

Challenges, Opportunities, and Success Stories for Reducing Risk

Anticipated future impacts on infrastructure create opportunities for addressing existing environmental and social goals. For example, actions by the city of Boise, Idaho, to improve water quality are likely to minimize some of the impacts associated with a warmer climate. In Boise, a phosphorous removal facility reduces the amount of phosphorous entering rivers, thereby reducing the need for water treatment facility upgrades[145] and perhaps also preventing downstream algal blooms, which are anticipated to become more common in a warmer climate.

The Northwest has several examples of successful cross-sector collaboration between resource managers and scientists to plan and prepare for climate impacts across multiple sectors (Ch. 17: Complex Systems, KM 3). In Portland and Multnomah County, Oregon, the 2030 Climate Change Preparation Strategy and 2050 Climate Action Plan have incorporated strategies across multiple sectors including water systems, natural and built infrastructure, and human health, with specific social equity considerations woven throughout.[146,147] For many socially vulnerable populations, limited access to transportation, businesses, and other community resources can inhibit their ability to cope with climate impacts. Addressing these disparities can have the added benefit of bolstering resilience (see Key Message 5). Building and strengthening partnerships across sectors will continue to be important in addressing these complex challenges.

Infrastructure managers in larger urban areas like Seattle and Portland have invested in building climate resilience for their systems (e.g., Vogel et al. 2015, Mauger et al. 2015[139,148]) (see also Ch. 11: Urban, KM 4), often partnering with researchers to develop tailored climate risk information and adaptation strategies. However, in many parts of the Northwest, especially areas outside urban centers, the lack of redundancy within infrastructure systems will likely be an important factor in limiting adaptive capacity (Ch. 12: Transportation, KM 2; Ch. 10: Ag & Rural, KM 4). Understanding the risks associated with these systems remains a challenge, as impacts could emerge directly from climate events or from the interaction of non-climate and climate stressors (such as equipment failure making a water system more susceptible to subsequent drought). For example, in the Washington Department of Transportation's vulnerability assessment, lifeline roadways that serve as the only means to access communities often emerged as highly vulnerable.[149] Disruptions to these roadways could cut off communities, preventing supplies or first responders from arriving. The lack of redundancy in transportation networks has also been noted for several of the region's National Parks, contributing to their vulnerability.[141] In a similar vein, the Washington Department of Health is examining aspects of groundwater systems that contribute to climate vulnerability. They have found that many groundwater systems are single source and lack any back-up supplies (see Figure 24.12). If supplies are disrupted, either by climate or non-climate stressors, surrounding communities may be forced to transport water to their area or relocate to a place with a more reliable supply (Ch. 3: Water, KM 2).

An additional challenge in addressing future impacts to infrastructure is cost. Projects for replacing, retrofitting, or improving dams, reservoirs, pipelines, culverts, roadways, electrical transmission and distribution systems, and shoreline protection can have costs in the billions (e.g., Wilhere et al. 2017[150]).

Managing water in the face of a changing climate also presents an opportunity for transboundary collaboration and coordination. For the Columbia River, projections of future streamflow have been generated for use by U.S. federal agencies, in partnership with Canadian agencies.[151] The information about future hydrology can support infrastructure decisions about water supply management, flood risk management, and hydropower production (Ch. 3: Water, KM 3; Ch. 16: International, KM 4).

Emerging Issues

Infrastructure managers are beginning to consolidate planning for the combined risks of sea level rise, flooding, and seismic hazards, as well as tsunami risks that can also arise from a major earthquake event. Going forward, it could be useful to identify strategies that enhance community resilience and emergency

Single-Source Water Systems in Washington

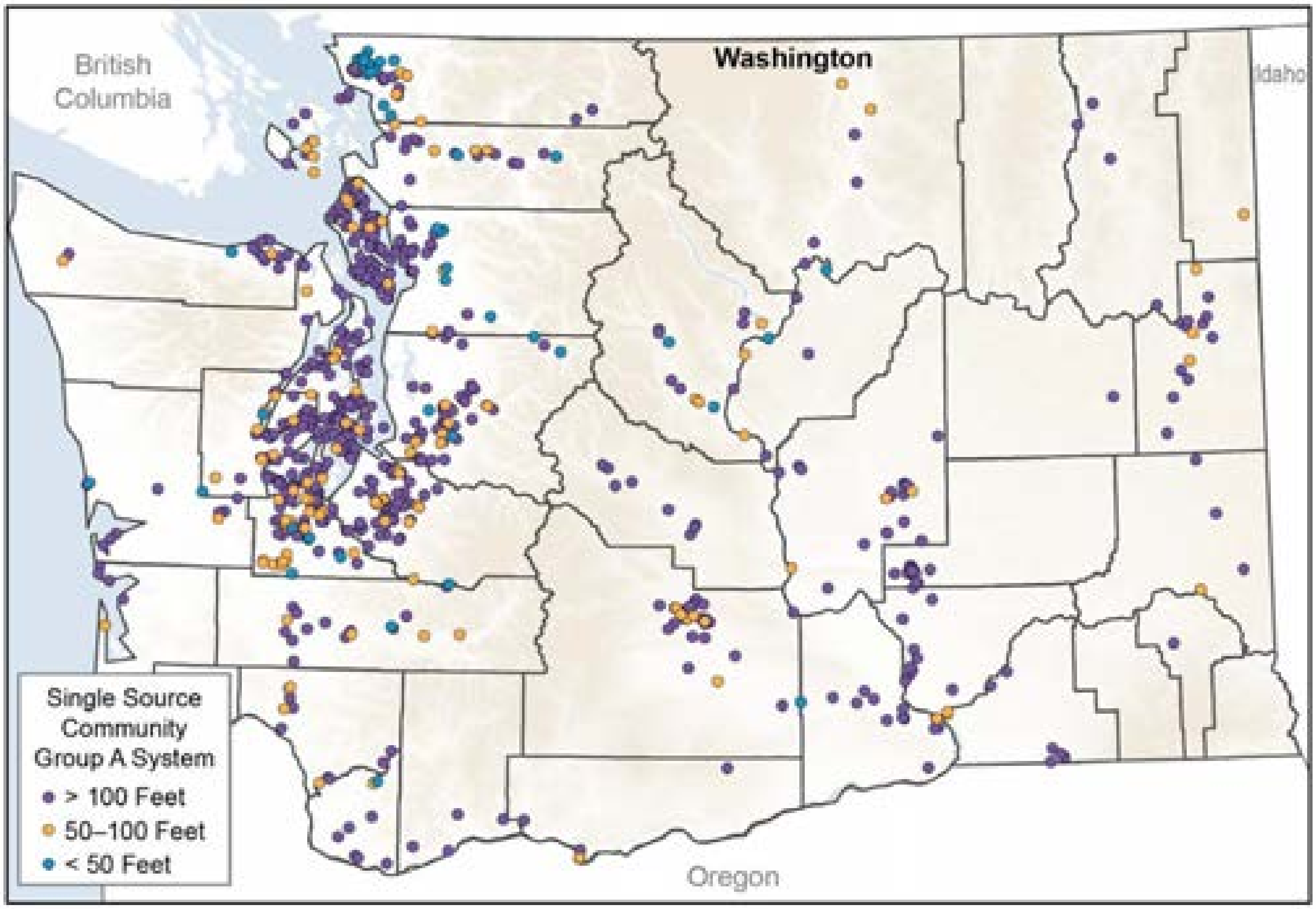


Figure 24.12: The map shows public water systems in Washington that are single source, meaning they lack a backup supply, and service at least 25 people per day or have 15 or more connections. Smaller public water systems exist but are not shown. For operators of single source systems, it will likely be particularly difficult to deal with climate-related disruptions such as flooding, drought, and saltwater intrusion. Approximate well depth is indicated by color; shallower wells (less than 100 feet in blue and orange) are projected to be more vulnerable to impacts, although aquifer type also influences vulnerability. Although similar impacts will likely occur in Oregon and Idaho, the data are not readily available to assess at a statewide level. Source: Washington Department of Health.

response capacity to many types of hazards and potential disruptions.

Infrastructure management is traditionally oriented to protecting assets and services in place. The use of "green" or hybrid "green and gray" infrastructure (e.g., Kittitas County Flood Control Zone District 2015, City of Portland 2010[152,153]) that utilizes nature-based solutions is emerging as a potential adaptation option. However, in some locations and for some impacts, it may be more efficient to remove or abandon infrastructure and find alternatives (for example, relocating communities and distributing water or energy systems). The knowledge and experience are just emerging to identify thresholds when such transformative decisions might be appropriate (Ch. 11: Urban, KM 3; Ch. 17: Complex Systems, KM 4).

Key Message 4

Health

Organizations and volunteers that make up the Northwest's social safety net are already stretched thin with current demands. Healthcare and social systems will likely be further challenged with the increasing frequency of acute events, or when cascading events occur. In addition to an increased likelihood of hazards and epidemics, disruptions in local economies and food systems are projected to result in more chronic health risks. The potential health co-benefits of future climate mitigation investments could help to counterbalance these risks.

Linkage Between Climate Change and Regional Risks

Over the last few decades, an increase in climate-related extreme events has led to an increase in the number of emergency room visits and hospital admissions. Warmer and drier conditions during summer have contributed to longer fire seasons.[140] Wildfire smoke can be severe, particularly in communities in the eastern Northwest.[154] Smoke events during 2004–2009 were associated with a 7.2% increase in respiratory hospital admissions among adults over 65 in the western United States.[155] In Boise, Idaho, 7 of the last 10 years have included smoke levels considered "unhealthy for sensitive groups" (including children) for at least a week during the fire season,[154] causing some cancellation of school-related sports activities (Ch. 13: Air Quality, KM 2).

During extreme heat events in King County, Washington, from 1990 to 2010, heat-related hospital admissions were 2% higher and deaths 10% higher than the average for that period,[156,157] with an increased demand for emergency medical services for children, outdoor laborers, and the elderly.[158] The state of Oregon has also recorded spikes in heat-related emergency room visits.[159] In particular, agricultural workers are at increased risks for heat-related injuries because they work outside during the summer harvest season.[160]

In the last several years, the region has seen an increase in some infectious diseases. An increase in Lyme disease cases is associated with rising temperatures and changing tick habitat.[161] The Washington Department of Health's vector surveillance program has observed an earlier onset of West Nile virus-carrying mosquitoes, likely associated with higher temperatures, and an increasing number of human infections, with some resulting in fatalities.[162] Before 1999, cryptococcal infections were limited to the tropics, but *Cryptococcus gatti*, the species that causes these infections, is now established in Northwest soil, with 76 cases occurring in Oregon in 2015.[163] The Oregon Health Authority recorded spikes in cases of Salmonella and *E. coli* during months with extreme heat in 2015.[163] A large outbreak of Shigellosis (a bacterial diarrheal disease) occurred in late 2015, affecting a large number of homeless people in the Portland Metro region; this outbreak was associated with unusually extreme precipitation.[164]

Changes in drought conditions and increased water temperatures have increased the potential for freshwater harmful algal blooms in recreational waters,[165] although there is little capacity among state health departments to monitor and track harmful algal blooms. Toxins from marine harmful algal blooms can accumulate in shellfish, leading to illnesses for those who eat them.[166] In 2015, during the largest harmful algal bloom ever observed off the West Coast from California to Alaska, high levels of domoic acid led to the closure of shellfish harvesting in much of the Northwest (Box 24.7).[167]

Children and youth, in general, will likely experience cumulative physical and mental health effects of climate change over their lifetimes[168] due to increased exposure to extreme weather events (such as heat stress, trauma from injury, or displacement) and increased toxic exposures (such as increased ground-level ozone pollution in urban areas or increased risk of drinking water contamination in rural areas). Beginning at the fetal development stage, environmental exposures to air or water pollution can increase the risk of impaired brain development,[169] stillbirth,[170] and preterm births.[171,172] Infants and children can be disproportionately affected by toxic exposures because they eat, drink, and breathe more in proportion to their body size.[173] Natural disasters, as well as gradual changes (like changing landscapes and livelihoods) caused by climate stressors, increase the risk of anxiety, depression, and post-traumatic stress disorder (PTSD).[174] Evidence shows that exposure to both pollution and trauma early in life is detrimental to near-term health, and an increasing body of evidence suggests that early-childhood health status influences health and socioeconomic status later in life.[175,176]

Future Climate Change Relevant to Regional Risks

More frequent wildfires and poor air quality are expected to increase respiratory illnesses in the decades to come (Ch. 13: Air Quality, KM 2). Airborne particulate levels from wildfires are projected to increase 160% by mid-century under a lower scenario (RCP4.5),[177] creating a greater risk of smoke exposure through increasing frequency, length, and intensity of smoke events.[177]

Projected increases in ground-level ozone (smog), small particulate matter ($PM_{2.5}$), and airborne allergens[178] can further complicate respiratory conditions (Ch. 13: Air Quality, KM 1). There is a well-documented link between exposure to air pollution and risk of heart attack, stroke, some types of cancer, and respiratory diseases,[179] all of which are leading causes of death in the Northwest.[180] The portion of each health condition attributed to air pollution is unknown, but the social and economic costs of these diseases are large. In Oregon, the medical costs associated with heart attacks in 2011 alone were over $1.1 billion, and those associated with stroke were $254 million ($1.2 billion and $269 million, respectively, in 2015 dollars).[181]

Increases in average and extreme temperatures are projected to increase the number of heat-related deaths.[182,183] Mid-century climate in Portland, Oregon, under a mid-high scenario (RCP6.0) may result in more than 80 additional heat-related deaths per year, although this figure does not account for future population growth or possible adaptations.[184]

Future extreme precipitation events could increase the risk of exposure to water-related illnesses as the runoff introduces contaminants and pathogens (such as *Cryptosporidium, Giardia*, and viruses) into drinking water.[185] In the Puget Sound, under a mid-high emissions scenario (SRES A1B), local atmospheric heating of surface waters is projected to result in 30 more days per year that are favorable to algal blooms and an increased rate of bloom growth.[186]

Income loss associated with climate impacts will likely increase the risk of people experiencing food insecurity (see Key Message 1).[187] As an example, in early 2016 a harmful algal bloom impacted the local economy in Long Beach, Washington, which is largely dependent on shellfish, tourism, and service industries. The local Food Bank recorded an almost 25% increase in the number of families requesting assistance in the six months that followed.[188] Climate-driven hardships can also affect mental health, resulting in outcomes ranging from stress to suicide.[189] Oregon, Washington, and Idaho all rank among the top 10 states in terms of prevalence of mental illness and lowest access to mental health care.[190] Serious mental illness costs the U.S. economy more than $193 billion in lost earnings each year ($224 billion in 2015 dollars).[191] Tribes and Indigenous peoples face multiple physical and mental health challenges related to climate change, with impacts to subsistence and cultural resources (see Key Messages 2 and 5) (see also Ch. 15: Tribes, KM 2). Some of these health concerns are described in a recent project created by members of the Confederated Tribes of Warm Springs.[192] Tracking climate stressors and training related to climate anxiety and post-disaster trauma is not widespread among the region's health workforce.[193]

Challenges, Opportunities, and Success Stories for Reducing Risk

Existing environmental health risks are expected to be exacerbated by future climate conditions,[187] yet over 95% of local health departments in Oregon reported having only partial-to-minimal ability to identify and address environmental health hazards.[194]

With funding from the Centers for Disease Control and Prevention, Oregon has been able to make some headway on assessing climate change vulnerabilities[195] and recently released a statewide climate and health resilience plan.[196] Five local health jurisdictions in Oregon are some of the first in the country to complete local climate and health adaptation plans. Interventions to address community-identified priorities range from providing water testing for domestic well users in drought-prone areas to quantifying the health co-benefits of proposed transportation investments. The Washington Department of Health has also added a climate program to begin integrating climate considerations into the state's public health system. In addition, the Drinking Water State Revolving Fund has made it possible for water system managers and utilities to apply for low interest loans that support resilience projects. Washington's Marine Biotoxin Program, also housed within the Department of Health, operates an early warning system in partnership with academics, organizations, and citizen scientists to increase the geographic breadth and frequency of sampling for harmful algal blooms that could compromise the safety of shellfish. Public health practitioners in southeastern Idaho have formed a new working group with tribes, universities, local jurisdictions, businesses, and nonprofits to develop strategies for mitigating health impacts of wildfire smoke and water insecurity.

Together, Northwest states have launched the Northwest Climate and Health Network for public health practitioners to share resources and best practices. Idaho, Oregon, and Washington all have syndromic surveillance systems that provide near-real-time data from emergency room visits. These health data have the potential to be layered with climate and environmental data (such as temperature and air quality data), but such analysis has not been carried out on a broad scale.

Incorporating more health and wellness considerations into climate decision-making can increase a community's overall resilience (Ch. 14: Human Health, KM 3). For example, preserving the ecological functions of an area can also promote tribal and Indigenous health, while investing in active transportation and green infrastructure can also improve air quality and increase physical activity.[197]

Box 24.4: Healthcare Partnerships That Increase Resilience

A new International Transformational Resilience Coalition (ITRC) has grown out of the Northwest and is engaging cross-sector partners in pilot projects to build psycho-social resilience in some communities. The initiative uses neuroscience and mindfulness to train leaders and organizations on how to cope with, and use, climate-related adversities to catalyze collective adaptation.[193] Composed of more than 250 mental health, trauma treatment, resilience, climate, and other professionals, the ITRC is working to enhance the ability of organizations and communities to heal, grow, and flourish during economic, social, and environmental stress and adversity.

Figure 24.13: Participants at the 2017 Northwest International Transformational Resilience Coalition Conference on Building Psycho-Social Resilience to Climate Change. Photo Credit: The Resource Innovation Group/International Transformational Resilience Coalition.

Emerging Issues

Communities with higher rates of illness and death often have less adaptive capacity and are more vulnerable to climate stressors.[198] Many people living in the Northwest already struggle to meet basic needs that could serve as protective factors—and these numbers could increase. For example, roughly 1 in 5 children in the region live in a food-insecure household[199,200,201] and are already at higher risk of poor health outcomes like asthma and diabetes.[202] Both the states of Washington and Idaho have had some of the largest increases in homeless populations in the United States, and in 2016, Oregon had the highest rate of unsheltered homeless families with children.[203] People lacking adequate shelter face increased climate risks (such as direct exposure to extreme heat or winter storms) while also having increased vulnerability (such as poorer health and less access to resources).

Displacement and increased migration to the Northwest could place increasing pressures on housing markets, infrastructure, and health and social service systems.[128] However, the role of climate as a driver for migration to the Northwest is speculative; current population forecasts do not yet account for climate factors.[204]

Public health leaders in the Northwest are working to modernize health systems to better respond to and prepare for complex and emerging health risks. Coordinated Care Organizations (CCOs) in Oregon, which serve as Medicaid insurance providers, are beginning to invest in certain climate protections for members. For example, some are covering the cost of air conditioning units for patients at risk of heat-related illnesses, ensuring patients can remain in their homes.[205] More studies would be needed to fully account for the cost savings associated with these kinds of health-related services.

Key Message 5

Frontline Communities

Communities on the front lines of climate change experience the first, and often the worst, effects. Frontline communities in the Northwest include tribes and Indigenous peoples, those most dependent on natural resources for their livelihoods, and the economically disadvantaged. These communities generally prioritize basic needs, such as shelter, food, and transportation; frequently lack economic and political capital; and have fewer resources to prepare for and cope with climate disruptions. The social and cultural cohesion inherent in many of these communities provides a foundation for building community capacity and increasing resilience.

Linkage Between Observed Climate and Regional Risks

Because people care about the place they live, a focus on places serves to highlight the local material and symbolic contexts in which people create their lives and through which those lives derive meaning.[206,207] This is true for communities across the Northwest whether or not they are on the frontline of dealing with climate change. While there are many types of frontline communities (those communities likely to experience climate impacts first and worst) in the region, this chapter highlights three sets of communities: tribes (Ch. 15: Tribes), farmworkers, and low-income populations in urban and rural (Ch. 10: Ag & Rural) environments.

The effects of climate variability and extreme events are not felt equally across communities in the Northwest. Frontline communities have higher exposures, are more sensitive, and are less able to adapt to climate change for a variety of reasons (Ch. 14: Human Health, KM 1),[187,208,209] including enhanced occupational exposure,[210] dependence on natural and cultural resources (Ch. 15: Tribes, KM 1),[124] fewer economic resources,[209] other demographic factors,[211,212] and gender.[213] In addition, frontline communities frequently must overcome cumulative exposures[125] and intergenerational and historical trauma.[125,214] It is the interconnected nature of legacy exposure, enhanced exposure, higher sensitivity, and less capability to adapt that intensifies a community's climate vulnerability.[187,215,216] Climate change can affect the health, well-being, and livelihoods of these communities directly by increasing the risk of acute health impacts, such as physical injury during severe weather,[189,209] and indirectly through chronic impacts, such as food insecurity or mental health conditions like PTSD (see Key Message 4) (see also Ch. 15: Tribes, KM 2; Ch. 14: Human Health, KM 1).

Future Climate Change Relevant to Regional Risks

Frontline communities generally prioritize meeting existing basic needs, such as shelter, food, and transportation. While climate-related risks vary from community to community, neighborhood to neighborhood, and even person to person, for frontline communities, climate variability, change, and extreme events can exacerbate existing risks, further limiting their ability to meet basic needs.[217]

Northwest tribes directly depend on natural resources, both on and off reservations, and are among the first to experience climate impacts. In the United States, the history of colonization, coupled with ongoing management barriers (such as land fragmentation and limited authority and control over natural resources), has led to many challenges for tribal and Indigenous climate adaptation (see Box 24.5) (see also Ch. 15: Tribes, KM 3).[124,218] The loss or reduced availability of First Foods (Key Message 2) can have broad physical, cultural, and spiritual impacts, including diabetes, heart disease, mental health impacts, and loss of cultural identity.[125,209] This is likely to be coupled with mental health impacts associated with intergenerational and historical trauma, alcohol abuse, suicide, and other impacts (see Key Message 2) (see also Ch. 15: Tribes, KM 2).[209]

Farmworkers are vital to the region, yet they often earn very low wages and face discrimination and workplace hazards. Farmworkers and their families often deal with both chronic and acute health impacts because of the high cost of healthcare and physically demanding work environments. Overall, farmworkers, who are largely immigrant laborers from Mexico, Central America, and South America, face distinct challenges and are more vulnerable due to structural causes that can lead to exploitation, discrimination, and violence.[219] Climate change is projected to exacerbate these existing stressors.

While the Northwest is not typically considered a high-risk area for heat-related illness, heat waves (defined as 5-day, 1-in-10-year events) across the country are projected to increase in frequency and intensity.[3] In the Northwest, nighttime heat waves (defined as 3-day, 1-in-100-year events) have a greater influence on human health than daytime heat waves[220] and have increased in frequency since 1901.[221] These changes are projected to make heat-related illness more common in the future. Farmworkers can be particularly vulnerable to heat-related illness due to occupational exposure (heavy exertion and working outdoors)[210] and to air quality concerns associated with wildfires, yet they often do not seek healthcare because of high costs, language barriers, and fear of deportation.[222] Working conditions, as well as cooling and hydration practices, vary across the region.[223]

In urban environments, economically disadvantaged communities and communities of color live in neighborhoods with the greatest exposure to climate and extreme weather events[224] and are, therefore, disproportionately affected by climate stressors.[225,226] Urban heat islands, worsening air quality,[227] less access to transit, increasing demands for food and energy, and proximity to pollution sites can lead to injury, illness, and loss of life for the urban poor (Key Message 4).[225,228] For instance, in the Northwest, increased risk of heat-related illnesses and deaths has been associated with socioeconomic status, age, race, and occupation (for example, outdoor labor).[156,182,229]

Challenges, Opportunities, and Success Stories for Reducing Risk

Many frontline communities are taking actions that begin to address these challenges. Indigenous peoples and Northwest tribes have demonstrated a high degree of resilience by adapting to changing environmental and social conditions for thousands of years (Ch. 15: Tribes).[124] The strong social networks and connectivity, present in many tribes and Indigenous communities, can reduce vulnerability to climate change (Ch. 15: Tribes, KM 3).[230] Efforts to enhance communication and strengthen network connections between tribes and their partners can be seen across the region.

Box 24.5: Collaborations Can Use Existing Social Cohesion to Build Resilience

Social cohesion, social networks, and other forms of social capital can help communities be more resilient to climate change.[231] The Pacific Northwest Tribal Climate Change Network is a regional collaboration aimed at supporting tribal and Indigenous climate resilience by better understanding and communicating the impacts of climate change on Indigenous peoples, tribal sovereignty, and culture. The Network does this by sharing resources such as case studies, tools, and funding opportunities through the Online Tribal Climate Change Guide (https://tribalclimateguide.uoregon.edu/); bringing together a diverse group of tribes, agencies, and nonprofit and private sector organizations; and discussing key actions and initiatives that are building resilience among tribes in the region.

Figure 24.14: Social cohesion and social networks can help communities adapt to changing climate conditions. One example is the Pacific Northwest Tribal Climate Change Network (https://tribalclimate.uoregon.edu/). The Network provides a forum for tribes to work together and with universities, federal agencies, and private and nonprofit organizations to share information, strengthen connections, and build resilience through events such as the 2017 Tribes and First Nations Climate Summit (http://atnitribes.org/climatechange/events/) hosted by the Tulalip Tribes and co-sponsored by the Affiliated Tribes of Northwest Indians, the North Pacific Landscape Conservation Cooperative, and the Pacific Northwest Tribal Climate Change Project. Photo credit: Peggy Harris, Affiliated Tribes of Northwest Indians.

Acknowledging the risk of heat-related illness for outdoor workers, the state of Washington issued rules requiring employers to make specific changes to job sites during the summer season (from May 1 through September 30). For temperatures above certain thresholds, the employer is required to provide at least one quart of water per employee per hour, relieve employees from duty if they are showing signs of heat-related illness, and provide training for employees and supervisors about heat-related illness.[232]

Economically disadvantaged populations and communities of color often face multiple barriers to participating in public processes where decisions about future climate-related investments are made. Organizations representing these frontline communities have found some success prioritizing leadership development through workshops and training that enable new and emerging voices to be heard in more formal policy settings. Engagement has partly been made possible by providing transportation, childcare, meals, and accessibility and by using a relational worldview and trauma-informed approach to community capacity-building. Cities and counties have also made concerted efforts at the policy level to explicitly acknowledge and address race and social inequities alongside environmental concerns.[147,228,233,234,235] Example actions include targeting investments in frontline communities and providing job training and employment opportunities that help limit displacement and enhance resilience.[147]

Box 24.6: Community Organizations Empower Frontline Communities

Community-based organizations in the Northwest's two most urban centers, Seattle and Portland, have engaged communities of color to assess priorities for building climate resilience. Our People, Our Planet, Our Power[236] and Tyee Khunamokwst: Leading Together[237] both emphasize that any efforts to build climate resilience will be undermined if low-income people and people of color continue to be displaced. Both community-driven efforts indicate strong support for strategies that reduce emissions and simultaneously build community resilience, such as increasing access to active transportation options and installing green infrastructure within under-resourced communities. The cities of Seattle and Portland have made progress in placing equity more centrally in municipal climate planning. The Portland-Multnomah Climate Action through Equity report[147] documents how these efforts led to a more inclusive and accountable climate action plan, and the Seattle Equity & Environment Agenda[228] articulates current disparities and a commitment to ensuring that people most affected by environmental injustices have a strong voice in finding solutions moving forward.

Emerging Issues

There is an emerging understanding of the importance of not only prioritizing climate change preparedness efforts in frontline communities but also involving and empowering these groups in the decision-making and implementation of climate change plans and actions.

The physical and psychological connections people have with natural resources are complex, and additional research would aid understanding of how changing climate conditions are likely to affect not only those natural resources but also the people who depend on them. How intersecting vulnerabilities, driven by a confluence of climatic, social, and economic factors, will compound and accelerate risks in frontline communities is not yet fully understood (Ch. 17: Complex Systems, KM 1). Additional research would help to measure and evaluate how supporting frontline communities in the implementation of community-identified strategies might improve outcomes and increase not only climate resilience but also equity and economic vitality in the Northwest and across the country.

Box 24.7: 2015—A Prelude of What's to Come?

In 2015, the Northwest experienced its warmest year on record.[238] Severe drought, large wildfires, heat waves (on land and in the ocean), and record harmful algal blooms occurred. An exceptionally warm winter led to record-low mountain snowpack across the region as precipitation fell largely as rain instead of snow.[9] The lack of snowpack and a dry spring led to dry fuel conditions that primed the largest wildfire season recorded in the region.[239]

Extreme climate variability provides a preview of what may be commonplace in the future.

In the Northwest, 2015 temperatures were 3.4°F above normal (as compared to the 1970–1999 average),[238] with winter temperatures 6.2°F above normal.[240] The warm 2015 winter temperatures are illustrative of conditions that may be considered "normal" by mid-century (higher scenario, RCP8.5) or late century (lower scenario, RCP4.5).[11]

Winter, spring, and summer precipitation during 2015 for the Northwest were below normal (as compared to the 1970–1999 average) by 25%, 35%, 14%, respectively (NOAA 2017).[241,242,243] Precipitation from January to June 2015 was the 7th driest on record for the region (4.6 inches below the 20th century average).[244] In general, most climate models project increases in future Northwest winter and spring precipitation with decreases in the summer, although some models project increases and others decreases in each season.[11] The 2015 spring precipitation deficits are similar to the largest decreases (−34%) in summer precipitation projected for the end of the century (2070–2099) under a higher scenario (RCP8.5).[11]

Snowpacks in Oregon and Washington in 2015 were the lowest on record at 89% and 70% below average, respectively.[9] These levels are more extreme than projected under the higher scenario (RCP8.5) by end of century (65% below average).[245] However, with continued warming, this type of low snowpack drought is expected more often. For example, the 2015 extreme low snowpack conditions in the McKenzie River Basin (which sits largely in the middle elevation of the Oregon Cascades) could occur on average about once every 12 years under 3.6°F (2.0°C) of warming.[246] For each 1.8°F (1°C) of warming, peak snow-water equivalent in the Cascades is expected to decline 22%–30%.[247]

What happened? How were systems tested? What vulnerabilities were highlighted?

Impacts from the 2015 "snow drought" were widespread, including irrigation shortages, agricultural losses, limited snow- and water-based recreation, drinking water quality concerns, hydropower shortages, and fish die-offs from impaired stream water quality. Many farmers received a reduced allocation of water, and irrigation water rights holders had their water shut off early; senior water rights holders had their water shut off early for the first time ever.[248] For example, Treasure Valley farmers in eastern Oregon received only a third of their normal irrigation water because the Owyhee Reservoir received inadequate river inflows to fill the reservoir for the third year in a row.[249]

Box 24.7: 2015—A Prelude of What's to Come? *continued*

Agricultural-related impacts of the drought were numerous, including damaged crops, reduced yields, altered livestock management, fewer planted crops, and land left idle (for example, 20% of farm acres in Treasure Valley, Oregon, were left idle).[248] Estimated agricultural economic losses were between $633 million and $773 million in Washington, including losses of over $7.7 million in blueberries, nearly $14 million in red raspberries, $500 million in a selection of 15 crops that make up more than three-quarters of Washington's cultivated acreage, and more than $33 million in the dairy industry (losses reported in 2015 dollars).[250]

Low-elevation ski areas struggled to stay open during the 2014–2015 season. Hoodoo Ski Area in the Oregon Cascades had its shortest season in 77 years of operations after closing for the season in mid-January;[246] Stevens Pass Mountain Resort in Washington's North Cascades only opened for 87 days, down from an average of 150;[251] and Silver Mountain Resort in Idaho closed its ski lifts by the end of March, a month earlier than usual.[252] Summer water recreation also suffered. Visitation at Detroit Lake, a reservoir in the Cascade foothills, decreased by 26% due to historically low water levels—70 feet (21 meters) below reservoir capacity in July—and unusable boat ramps.[246,253]

Low summer stream levels and warm waters, which amplified a naturally occurring fish disease, resulted in widespread fish die-offs across the region, including hundreds of thousands of sockeye salmon in the Columbia and Snake River Basins.[136,248,254] And for the first time ever, Oregon implemented a statewide daily fishing curtailment beginning in July 2015 to limit added stress on the fish from fishing.[248]

The lack of snowpack in 2015 in concert with extreme spring and summer precipitation deficits led to the most severe wildfire season in the Northwest's recorded history with more than 1.6 million acres burned across Oregon and Washington, incurring more than $560 million in fire suppression costs (in 2015 dollars).[239] In Oregon, the cost of large fires in 2015 was 344% of the 10-year average of large-fire costs.[248] The wildfire season resulted in transmission shutdowns for Seattle City Light during the Goodell Fire (see Key Message 3) and infrastructure damage for Idaho Power Company following the Soda Fire.[255] Smoke from the wildfires caused significant air quality and health concerns from late July through September, particularly in eastern Oregon and Washington, Idaho, Colorado, and Canada.[256,257]

The ocean heat wave referred to as "the Blob" was first detected off the Pacific coast in 2013, and by 2014 it spanned the coast from Alaska to California.[10] In 2015, the largest harmful algal bloom recorded on the West Coast was associated with the Blob. High levels of multiple toxins, including domoic acid and paralytic shellfish toxins, closed a wide range of commercial, recreational, and tribal fisheries, including salmon, shellfish, and Dungeness crab along the entire Northwest coast.[172,258,259,260]

Box 24.7: 2015—A Prelude of What's to Come? *continued*

Who is doing what to increase resilience? What success stories are there?

The conditions in 2015 tested the capacity of existing systems and provided insights into potential future adaptation priorities. Several actions to increase resilience have already begun across multiple levels of governance. For example, the Oregon Drought Task Force was created to "review the State's existing drought response tools, identify potential gaps, and make recommendations on tools and information needed to ensure that the State is prepared to respond during a drought in the future."[261] Washington assessed the economic impact on agriculture and recommended developing a plan "to assist growers and plan for a future that will include increased incidence of severe weather events such as the 2015 drought."[250]

At the onset of the drought, anticipated agricultural losses were much higher than what occurred because of actions at the federal and state levels, and actions implemented by the farmers themselves (Box 24.1).[250] This highlights the adaptive capacity of some producers in the agricultural sector (Key Message 1). However, as conditions experienced in 2015 become more regular as a result of climate change, some farms will likely struggle to stay solvent despite adaptation interventions (Ch. 10: Ag & Rural, KM 1).[250]

After the lack of snow during the previous winter season prevented Mount Ashland Ski Area in southwest Oregon from opening at all, the ski area instituted several adaptation strategies that helped it open and stay open during the 2015 busy winter holidays. Strategies included snow-harvesting and thinning vegetation, among others. Future plans include diversifying the business by creating more summer recreation opportunities, so that the ski area's revenue depends less on snow-related recreation.[249]

In the Yakima Basin, irrigators, conservation groups, and state and federal agencies worked together to replenish the diminished tributary flows to bolster the salmon runs and riparian habitat during the drought. Water from the Yakima River was redirected through farm irrigation canals to seven tributaries. Although this further reduced the farmers' irrigation water, they agreed to continue rerouting water to sustain the fish.[262]

Acknowledgments

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Opening Image Credit
Sawtooth National Forest, Idaho. Photo credit: Mark Lisk/USDA Forest Service.

Traceable Accounts

Process Description

This assessment focuses on different aspects of the interaction between humans, the natural environment, and climate change, including reliance on natural resources for livelihoods, the less tangible values of nature, the built environment, health, and frontline communities. Therefore, the author team required a depth and breadth of expertise that went beyond climate change science and included social science, economics, health, tribes and Indigenous people, frontline communities, and climate adaptation, as well as expertise in agriculture, forestry, hydrology, coastal and ocean dynamics, and ecology. Prospective authors were nominated by their respective agencies, universities, organizations, or peers. All prospective authors were interviewed with respect to the qualifications, and selected authors committed to remain part of the team for the duration of chapter development.

The chapter was developed through technical discussions of relevant evidence and expert deliberation by the report authors at workshops, weekly teleconferences, and email exchanges. The author team, along with the U.S. Global Change Research Program (USGCRP), also held stakeholder meetings in Portland and Boise to solicit input and receive feedback on the outline and draft content under consideration. A series of breakout groups during the stakeholder meetings provided invaluable feedback that is directly reflected in how the Key Messages were shaped with respect to Northwest values and the intersection between humans, the natural environment, and climate change. The authors also considered inputs and comments submitted by the public, interested stakeholders, the National Academies of Sciences, Engineering, and Medicine, and federal agencies. For additional information on the overall report process, see Appendix 1: Process. The author team also engaged in targeted consultations during multiple exchanges with contributing authors for other chapters, who provided additional expertise on subsets of the Traceable Accounts associated with each Key Message.

The climate change projections and scenarios used in this assessment have been widely examined and presented elsewhere[11,50,263,264] and are not included in this chapter. Instead, this chapter focuses on the impact of those projections on the natural resources sector that supports livelihoods (agriculture, forestry, fisheries, and outdoor recreation industry), the intangible values provided by the natural environment (wildlife, habitat, tribal cultures and well-being, and outdoor recreation experiences), human support systems (built infrastructure and health), and frontline communities (farmworkers, tribes, and economically disadvantaged urban communities). The literature cited in this chapter is largely specific to the Northwest states: Washington, Oregon, and Idaho. In addition, the authors selected a series of case studies that highlight specific impacts, challenges, adaptation strategies and successes, and collaborations that are bringing communities together to build climate resilience. The most significant case study is the 2015 case study (Box 24.7), which cuts across all five Key Messages and highlights how extreme climate variability that is happening now may become more normal in the future, providing important insights that can help inform and prioritize adaptation efforts.

Key Message 1

Natural Resource Economy

Climate change is already affecting the Northwest's diverse natural resources (*high confidence*), which support sustainable livelihoods; provide a robust foundation for rural, tribal, and Indigenous communities; and strengthen local economies (*high confidence*). Climate change is expected to continue affecting the natural resource sector (*likely*, *high confidence*), but the economic consequences will depend on future market dynamics, management actions, and adaptation efforts (*very likely*, *medium confidence*). Proactive management can increase the resilience of many natural resources and their associated economies (*very likely*, *medium confidence*).

Description of evidence base

Multiple studies suggest that Northwest natural resource sectors will likely be directly affected by climate change, including increased temperatures, changes in precipitation patterns, and reduced snowpack (see NOAA State Climate Summaries for Oregon, Washington, and Idaho).[265,266,267] The direct and indirect consequences of these climate drivers are projected to impact regional natural resource sectors in varied ways. In many cases, the secondary and tertiary effects of climatic changes have larger consequences on the natural resource sector, such as increased insect and pest damage to forests,[41] increased wildfire activity,[8] changes to forage quality and availability for livestock,[38,39,40] reductions in water availability for irrigation and subsequent impacts to water rights,[268,269] and increasing temperatures and ocean acidity limiting the viability of existing commercial and recreational fisheries;[30,55,56,57] lower snowfall is also expected to reduce the economic benefits associated with the recreational skiing industry.[19,58]

There is good evidence that natural resource managers are attempting to build more resilient production systems in the face of climate change through the adoption of adaptation practices (see Box 24.1), particularly those that build soil resources to increase resilience in the face of more extreme and variable weather; however, in some cases not all adaptation strategies will necessarily lead to broader soil benefits.[270,271] There is also evidence that adaptive strategies coupled with increased warming will likely shorten the growing season in some parts of the Northwest due to earlier crop maturation, coupled with earlier plantings, leading to lower irrigation demand during low flow periods.[34] Forest managers are also incorporating adaptation strategies focused on addressing drought and fire risks as well as broader efforts to protect and maintain key forest ecosystem services.[67] While adapting to changing ocean conditions is challenging,[83] some in the industry are improving monitoring and hatchery practices to reduce risks.[82] And some in the outdoor recreation industry are looking for ways to benefit from increased temperatures;[88] for instance, many ski resorts are diversifying their recreational opportunities to take advantage of warmer weather and earlier snowmelt.[272,273]

Yet, how individual actors respond to changes in climate is a source of uncertainty, particularly if these actions do not reduce climate risks or capitalize on potential benefits as expected.[64] Additionally, many adaptive actions, at least in the short term, will likely be costly for individual producers to implement.[37,274]

Major uncertainties

Climate impacts, such as increased temperatures, reduced snowpack, and more variable precipitation and subsequent impacts on pests, disease, fire incidence, and other secondary impacts will very likely indirectly affect livelihoods and the economic viability of natural resource sectors, with more severe impacts to rural, tribal, and Indigenous communities (Ch. 10: Ag & Rural). There is, however, greater uncertainty as to how precisely these impacts are projected to affect natural resource managers' financial security and their subsequent land-use decisions (Ch. 5: Land Changes), as well as other factors important to sustainable livelihoods and community well-being.

This is particularly relevant for key commodities that are integrated with national and international markets that are influenced by multiple factors and are difficult to predict (Ch. 10: Ag & Rural; Ch. 16: International). National and global market dynamics will likely be influenced by broader climate change effects on other natural resource sectors in the United States and across the globe,[50] while also being impacted by a broad array of factors that include technological developments, laws, regulations and policies affecting trade and subsidies, and security issues. There are instances where the economic consequences will likely be positive, particularly in comparison to other regions in the United States, such as found in the dairy production sector.[65] The economic impacts to regional fisheries are much less certain as iconic species and industries in the Northwest struggle to maintain viability.[51,52,53] Although much is being researched with respect to the effects of climate change on forests and associated ecosystem services (e.g., Vose et al. 2016[275]), far less has been explored with respect to timber markets and attendant infrastructure and processing.

Description of confidence and likelihood

There is *high confidence* that climate change, through reductions in snowpack, increased temperatures, and more variable precipitation, is already affecting the Northwest's diverse natural resource base. There is *high confidence* that these natural resource sectors provide critical economic benefits, particularly for rural, tribal, and Indigenous communities who are more dependent on economic activities associated with natural resource management. There is *high confidence* that climate change will have a large impact on the natural resource sector throughout this century; however, there is *medium confidence* that these impacts will negatively impact rural, tribal, and Indigenous livelihoods, particularly about how projected changes will economically impact specific natural resource sectors due to large uncertainties surrounding global market dynamics that are influenced by climatic and non-climatic factors. It is *very likely* that proactive management efforts will be required to reduce climate risks, yet there is *medium confidence* that these adaptation efforts will adequately reduce negative impacts and promote sector-specific economic benefits.

Key Message 2

Natural World and Cultural Heritage

Climate change and extreme events are already endangering the well-being of a wide range of wildlife, fish, and plants (*high confidence*), which are intimately tied to tribal subsistence culture (*very high confidence*) and popular outdoor recreation activities (*high confidence*). Climate change is projected to continue to have adverse impacts on the regional environment (*very likely*), with implications for the values, identity, heritage, cultures, and quality of life of the region's diverse population (*high confidence*). Adaptation and informed management, especially culturally appropriate strategies, will likely increase the resilience of the region's natural capital (*medium confidence*).

Description of evidence base

Since the Third National Climate Assessment, there have been significant contributions within the literature in relation to climate impacts to Northwest communities, with specific focus on how values and activities, such as recreation, iconic wildlife, management, and tribal and Indigenous cultures, will likely be impacted.

Wildlife are projected to have diverse responses to climate change.[94,96,121] Droughts, wildfires, reduced snowpack and persistence, shifted flood timing, and heat stress can cause habitat loss or fragmentation[84] and increase mortality of waterfowl; trout, salmon, and other coldwater fish;[52,98,276,277,278] amphibians; wolverines; lynxes; and snowshoe hares.[94] Other species, such as elk and deer, may benefit from future climate conditions.[96]

Multiple studies also demonstrate that climate change impacts will likely affect other iconic, Northwest species. Wildfires will affect berries, roots, and plants;[85,105] ocean acidification is increasing shellfish mortality, and ocean acidification and warmer ocean temperatures are altering marine food webs;[279,280,281] and aquatic acidification is affecting salmon physiology and behavior.[282] These impacts are project to have direct negative impacts on traditional Sacred First Foods.[85,86] Droughts and reduced snowpack will also reduce tribal water supplies.[101,283] The loss of these First Foods is projected to have cascading physical health impacts, such as diabetes,[125] and mental health impacts.[124,125,189,209,214]

Salmon is one of the most iconic Northwest species and important First Foods for Tribes. Salmon are at high risk to climate change because of decreasing summer flows due to changes in seasonal precipitation and reduced snowpack,[284,285,286,287,288] habitat loss through increasing storm intensity and flooding,[100,287] physiological and behavioral sensitivity and increasing mortality due to warmer stream and ocean temperatures, and cascading food web effects due to ocean acidification.[29,281,289,290] These impacts can be amplified due to human-placed impediments (culverts, dams), contaminants, and diseases.[291,292,293]

There are multiple lines of evidence verifying that reduced snowfall and snowpack in the future will adversely impact winter and snow-based recreation, including a reduction in ski visitation rates.[19,58,91] This will also adversely affect summer water-based recreation such as boating and rafting,[277] although warmer temperatures in the future can increase demand for water-based recreation and visitations rates to parks.[88,89,90] Future habitat shifts in marine species[51] and warmer ocean temperatures are projected to lead to declines in opportunities for ocean fishing recreation.[55,56,57,294] Ocean acidification and harmful algal blooms are also projected to reduce recreational shellfish gathering.[55] Increased wildfire frequency[8] will reduce air quality, and some evidence suggests that this can reduce outdoor recreation opportunities and enjoyment. Regional case studies highlight climate impacts to snow-based recreation, ocean fishing, water-based recreation, and decreased air quality.[28,53,276]

Adaptation and management strategies in response to climate impacts on the natural capital and Northwest heritage are extremely varied across the region. Many tribes have begun managing First Foods and other important cultural resources through climate change vulnerability assessments and adaptation plans that incorporate both traditional knowledge and western science.[85,107,109,112,113,123] Efforts to manage wildlife, habitats, and species are variable in their approaches to increasing climate resilience, with limited uncertainty in how these strategies can collectively result in increased climate resilience of the region's natural capital.[54,110,114,117,118,119,120]

Major uncertainties

There is strong evidence to suggest that recreational opportunities are an important quality of the Northwest,[87] but there is uncertainty around the perceived importance of future recreation opportunities' prioritization in people's quality of life despite the direct reduction of many recreational opportunities.[127]

The effects of climate change on game species are uncertain, with large potential forcing in both directions and a lack of information on which processes will dominate consequences for game species and how managers might be able to effectively adapt to changing climate.

Description of confidence and likelihood

There is *high confidence* that climate change and extreme events have already endangered the well-being of a wide range of wildlife, fish, and plants. There is *very high confidence* that these impacts will directly threaten tribal subsistence and culture and *high confidence* that these impacts will threaten popular recreation activities. Future climate change will *very likely* continue to have adverse impacts on the regional environment. There is *high confidence* that future climate change will have negative impacts on the values, identity, heritage, cultures, and quality of life of the diverse population of Northwest residents. There is *medium confidence* that adaptation and informed management, especially culturally appropriate strategies, will increase the resilience of the region's natural capital.

Key Message 3

Infrastructure

Existing water, transportation, and energy infrastructure already face challenges from flooding, landslides, drought, wildfire, and heat waves (*very high confidence*). Climate change is projected to increase the risks from many of these extreme events, potentially compromising the reliability of water supplies, hydropower, and transportation across the region (*likely*, *high confidence*). Isolated communities and those with systems that lack redundancy are the most vulnerable (*likely*, *medium confidence*). Adaptation strategies that address more than one sector, or are coupled with social and environmental co-benefits, can increase resilience (*high confidence*).

Description of evidence base

There is a growing body of evidence suggesting that climate change will likely increase the frequency and/or intensity of extreme events such as flooding, landslides, drought, wildfire, and heat waves.[27,139,142,295,296,297,298,299,300,301,302] Several investigations have highlighted the vulnerability of water supply, hydropower, and transportation to such changes.[33,139,303,304,305,306,307]

Infrastructure redundancy is widely accepted as a means to enhance system reliability. Multiple investigations cite the importance of system redundancy for transportation, energy, and water supply.[136,146,308] Several studies describe the ways that agencies tasked with water, energy, and transportation management are exploring climate change impacts and potential adaptation options.[133,146,148,151,309,310,311,312,313,314]

Major uncertainties

Many analyses and anecdotal evidence link the risk of infrastructure disruption or failure to extreme events. However, the attribution of specific infrastructure impacts to climate variability or climate change remains a challenge. In many cases, infrastructure is subject to multiple climate and non-climate stressors. Non-climate stressors common to many parts of the region include increases in demand or usage from growing populations and changes in land use or development. In addition, much infrastructure across the region is beyond its useful lifetime or may not be in a state of good repair. These factors typically enhance sensitivity to many types of stressors but add uncertainty when trying to draw a direct connection between climate and infrastructure impacts.

Demographic shifts remain an important uncertainty when assessing future infrastructure impacts as well as the relative importance of certain types of infrastructure. Migration to and within the region can fluctuate on timescales shorter than those of climate change. As people move, the relative importance of different types of infrastructure are likely to change, as are the consequences of impacts.

Lastly, there is considerable uncertainty in quantitatively assessing the role of redundancy in minimizing or managing impacts. Metrics for determining the extent to which networking or emergency/backup systems yield adaptive capacity are not currently available at the regional scale.

Description of confidence and likelihood

There is *very high confidence* in the link between extreme events and infrastructure impacts. Most of the existing vulnerability assessments in this region, as well as those at larger spatial scales, emphasize extreme events as a key driver of past impacts. Most infrastructure is planned and designed to withstand events of a specified frequency and magnitude (for example, the 100-year flood, design storms), underscoring the importance of extreme events to our assumptions about infrastructure reliability and function. There is *high confidence* that rising temperatures, increases in heavy rainfall, and hydrologic changes are projected for the region.[5,71,139] These changes are anticipated to raise the risk of flooding, landslides, drought, wildfire, and heat waves. There is *medium confidence* about the role of redundancy in determining vulnerability. Although this link has been exhibited in many case studies, quantitative evidence at the local and regional scale has yet to be developed.

Impacts discussed in this chapter (e.g., WSDOT 2014, ODOT and OHA 2016, Withycomb 2017, US Climate Resilience Toolkit 2017[129,130,132,135]), within other chapters (see Ch. 11: Urban; Ch. 12: Transportation; Ch. 17: Complex Systems; Ch. 28: Adaptation), and elsewhere[139] highlight the connections among infrastructure systems, or between infrastructure reliability, and access to critical services. In addition, infrastructure systems are faced with a host of non-climate stressors (for example, increased demands from growing population, land-use change). As a result, there is *high confidence* that adaptation efforts designed to address climate impacts across multiple sectors (e.g., Portland-Multnomah County 2014, 2016[146,147]), as well as those that will yield social environmental co-benefits, will build resilience.

Key Message 4

Health

Organizations and volunteers that make up the Northwest's social safety net are already stretched thin with current demands (*very likely*, *high confidence*). Healthcare and social systems will likely be further challenged with the increasing frequency of acute events, or when cascading events occur (*very likely*, *high confidence*). In addition to an increased likelihood of hazards and epidemics, disruptions in local economies and food systems are projected to result in more chronic health risks (*very likely*, *medium confidence*). The potential health co-benefits of future climate mitigation investments could help to counterbalance these risks (*likely*, *medium confidence*).

Description of evidence base

Cascading hazards could occur in any season; however, the summer months pose the biggest health challenges. For example, wildfire could occur at the same time as extreme heat and could damage electrical distribution systems, thereby simultaneously exposing people to smoke and high temperatures without the ability to pump water, filter air, or control indoor temperatures. Although some work is being done to prepare, responses to emergency incidents continue to show that there are considerable gaps in our medical and public health systems.[315] Public health departments are in place to track, monitor, predict, and develop response tactics to disease outbreaks or other health threats. In the case of cascading hazards, the public health system has a role in communicating risks to the public as well as strategies for self-care and sheltering-in-place during a crisis. Unfortunately, local health departments report inadequate capacity to respond to local climate change-related health threats, mainly due to budget constraints.[316] Hospitals in the United States routinely operate at or above capacity. Large numbers of emergency rooms are crowded with admitted patients awaiting placement in inpatient beds, and hospitals are diverting more than half a million ambulances per year due to emergency room overcrowding.[317]

Existing environmental health risks are expected to be exacerbated by future climate conditions,[187] yet over 95% of local health departments in Oregon reported having only partial-to-minimal ability to identify and address environmental health hazards.[194] The capacity of our public health systems is largely inadequate and unable to meet basic responsibilities to protect the health and safety of people in the Northwest.[162,194] Public health leaders from state and local health authorities, state advisory boards, and public health associations have been working together for over five years to develop a plan for rebuilding, modernizing, and funding the region's public health systems.

Socioeconomic income levels can be a predictor of environmental health outcomes in the future.[187,195] Food systems face continued increases in environmental pressures, with climate change influencing both the quality of food and the ability to distribute it equitably. The capacity to ensure food security in the face of rapidly changing climate conditions will likely be a major determinant of disease burden.[318]

Climate mitigation strategies can in some cases have substantial health co-benefits, with evidence pointing toward active transportation[319] and green infrastructure improvements.[320] This evidence of health co-benefits provides an additional and immediate rationale for reductions in greenhouse gas emissions beyond that of climate change mitigation alone. Recognition that mitigation strategies can have substantial benefits for both health and climate protection offers the possibility of strategies that are potentially both more cost effective and socially attractive than are those that address these priorities independently.[321] The Oregon Health Authority's Climate Smart Strategy Health Impact Assessment found that almost all climate mitigation policies under consideration by the Metro Regional Government could improve health, and that certain policy combinations were more beneficial, namely those that reduced vehicle miles traveled.[322] For example, according to 2009 data available on the National Environmental Public Health Tracking Network, a 10% reduction in $PM_{2.5}$ could prevent more than 400 deaths per year in a highly populated county and about 1,500 deaths every year in the state of California alone. Working across sectors to incorporate a health promotion approach in the design and development of built environment components could mitigate climate change, promote adaptation, and improve public health.[323]

Major uncertainties

Preparing and responding to cascading hazards is complex and involves many organizations outside of the medical and public health systems. There is not a common set of metrics or standards for measuring surge capacity and emergency preparedness across the region.

There is uncertainty in whether domestic migration will place further stress on social safety net systems.

Description of confidence and likelihood

There is *high confidence* that there will be increased hazards and epidemics, which will *very likely* disrupt local economies, food systems, and exacerbate chronic health risks, especially among populations most at risk. There is *high confidence* that these acute hazards will increase due to future climate conditions and will *very likely* increase the demand on organizations and volunteers that respond and form the region's social safety net. There is *medium confidence* that mitigation investments can help counterbalance these risks and *likely* result in health co-benefits for the region.

Key Message 5

Frontline Communities

Communities on the front lines of climate change experience the first, and often the worst, effects. Frontline communities in the Northwest include tribes and Indigenous peoples, those most dependent on natural resources for their livelihoods, and the economically disadvantaged (*very high confidence*). These communities generally prioritize basic needs, such as shelter, food, and transportation (*high confidence*); frequently lack economic and political capital; and have fewer resources to prepare for and cope with climate disruptions (*very likely*, *very high confidence*). The social and cultural cohesion inherent in many of these communities provides a foundation for building community capacity and increasing resilience (*likely*, *medium confidence*).

Description of evidence base

Multiple lines of research have shown that the impacts of extreme weather events and climate change depend not only on the climate exposures but also on the sensitivity and adaptive capacity of the communities being exposed to those changes.[187,230,324,325] For frontline communities in the Northwest, it is the interconnected nature of legacy exposure, enhanced exposure, higher sensitivity, and less capability to adapt that intensifies a community's climate vulnerability.[187,216]

There are multiple lines of evidence that demonstrate that tribes and Indigenous peoples are particularly vulnerable to climate change. Climate stressors, such as sea level rise, ocean acidification, warmer ocean and stream temperatures, wildfires, or droughts, are projected to disproportionately affect tribal and Indigenous well-being and health,[106,187,326,327] economies,[85,124] and cultures.[105,106] These losses can affect mental health and, in some cases, trigger multigenerational trauma.[125,189,209,214]

There is limited research on how climate change is projected to impact farmworkers, yet evidence suggests that occupational health concerns, including heat-related concerns[210,223] and pesticide exposure,[328] could increase, thus exacerbating health and safety concerns among economically and politically marginalized farmworker communities.

Particularly relevant to economically disadvantaged urban populations, extensive work has been done evaluating and analyzing social vulnerability[211] and applying that work to the Northwest.[195] There has also been work completed considering both relative social vulnerability and environmental health data (see WSDOH 2018[162]).

Strong evidence through reports and case studies demonstrates that tribes are active in increasing their resilience through climate change vulnerability assessments and adaptation plans (see https://

www.indianaffairs.gov/WhoWeAre/BIA/climatechange/Resources/Tribes/index.htm and http://tribalclimateguide.uoregon.edu/adaptation-plans for a list of tribal and Indigenous climate resilience programs, reports, and actions) and through regional networks (for example, Pacific Northwest Tribal Climate Change Network, Affiliated Tribes of Northwest Indians, Northwest Indian Fisheries Commission, Columbia River Inter-Tribal Fish Commission, Point No Point Treaty Council, Upper Snake River Tribes Foundation).

There are also many community organizations across the region focusing on engaging, involving, and empowering frontline communities, including communities of color, immigrants, tribes and Indigenous peoples, and others to design plans and policies that are meaningful (for example, Front and Centered, Got Green, Puget Sound Sage, Coalition of Communities of Color).

Major uncertainties

Actual climate change related vulnerabilities will vary by community and neighborhood.[187,208] Therefore, the scale of any vulnerability assessment or adaptation plan will matter greatly in assessing the uncertainties.

The secondary and tertiary impacts of changing climate conditions are less well understood. For example, climate change may increase the amount and frequency of pesticides used, and the variety of products used to manage crop diseases, pests, and competing weeds.[328] This is likely to increase farmworker exposure to pesticides and ultimately affect their health and well-being. Further, it is unclear how the altered timing of agricultural management of key crops across the United States (for example, the timing of cherry picking) due to increased temperatures and altered growing seasons may influence the demand for farmworker labor, particularly migrant labor, and how this might impact their livelihoods and occupational health.

There is emerging evidence that there are overlaps between environmental justice concerns and climate change impacts on these communities,[233,237] and that solutions designed to address one issue can provide effective solutions for the other issue if done well.[147]

No systematic catalogue of the actions and efforts of frontline communities in the region to address their climate-related challenges exists. Thus, at this point, most examples of adaptation and climate preparedness are anecdotal, but these examples suggest an increasing trend to link adaptation efforts that simultaneously address both climate and equity concerns. However, this approach is still used sporadically based on the interests, needs, and resources of the communities.

Description of confidence and likelihood

There is *very high confidence* that frontline communities are the first to be affected by the impacts of climate change. Due to their enhanced sensitivity to changing conditions, direct reliance on natural resources, place-based limits, and lack of financial and political capital, it is *very likely* that they will face the biggest climate challenges in the region. However, there is a significant amount of uncertainty in how individuals and individual communities will respond to these changing conditions, and responses will likely differ between states, communities, and even neighborhoods. Thus, it is the complex interaction between the climate exposures and the integrated social-ecological systems as well as the surrounding policy and response environment that will ultimately determine the challenges these communities face.

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