21. Northwest

Convening Lead Authors
Philip Mote, Oregon State University
Amy K. Snover, University of Washington

Lead Authors
Susan Capalbo, Oregon State University
Sanford D. Eigenbrode, University of Idaho
Patricia Glick, National Wildlife Federation
Jeremy Littell, University of Washington
Richard Raymondi, Idaho Department of Water Resources
Spencer Reeder, Cascadia Consulting Group

Key Messages

1. **Changes in the timing of streamflow related to changing snowmelt are already observed and will continue, reducing the supply of water for many competing demands and causing far-reaching ecological and socioeconomic consequences.**
2. **In the coastal zone, the effects of erosion, inundation, threats to infrastructure and habitat, and increasing ocean acidity collectively pose a major threat to the region.**
3. **The combined impact of increasing wildfire, insect outbreaks, and diseases is virtually certain to cause additional forest mortality by the 2040s and long-term transformation of forest landscapes. Almost complete loss of subalpine forests is expected by the 2080s.**
4. **While the agriculture sector's technical ability to adapt to changing conditions can offset some of the adverse impacts of a changing climate, there remain critical sector-specific concerns with respect to costs of adaptation, development of more climate resilient technologies and management, and availability and timing of water.**

Introduction

With craggy shorelines, volcanic mountains, and high sage deserts, the Northwest's complex and varied topography contributes to the region's rich climatic, geographic, social, and ecologic diversity. Abundant natural resources – timber, fisheries, productive soils, and plentiful water – remain important to the region's economy.

Snow accumulates in mountains, melting in spring to power both the region's rivers and economy, creating enough hydropower (40% of national total) (NWPCC 2010) to export 2 to 6 million megawatt hours/month (EIA 2011). Snowmelt waters crops in the dry interior, helping the region produce tree fruit (#1 in the world) and almost $17 billion worth of agricultural commodities including 55%, 15%, and 11% of U.S. potato, wheat, and milk production respectively (USDA 2012a, 2012b).

Seasonal water patterns shape the region's flora and fauna, including iconic salmon and steelhead, and forested ecosystems, which cover 47% of the landscape (Smith et al. 2009). Along more than 4,400 miles of coastline, regional economic centers are juxtaposed with diverse habitats and ecosystems that support thousands of species of fish and wildlife, including commercial fish and shellfish resources valued at $480 million in 2011 (NOAA 2012).

Adding to the influence of climate, human activities have altered natural habitats, threatened species, and extracted water to the limits in dry years. More recently, efforts have multiplied to balance environmental restoration and economic growth while evaluating climate risks. As conflicts and trade-offs increase, the region's population continues to grow – and the regional consequences of climate change continue to unfold. The need to seek solutions to these conflicts is becoming increasingly urgent.

Observed Climate Change

Temperatures have increased across the region over the past century, with a regionally averaged warming of about 1.5°F (Kunkel et al. 2012; Mote 2003). Trends in precipitation have varied among locations, seasons, and time periods of analysis, but precipitation has generally increased, especially in spring. Studies of extreme precipitation use different time periods and definitions of extreme, but most conclude that extreme precipitation (heavy downpours) increased somewhat in the Northwest, as in the rest of the country (Groisman et al. 2004; Madsen and Figdor 2007; Rosenberg et al. 2010). These and other climate trends include as yet unquantified contributions from both human influences (chiefly heat-trapping or "greenhouse" gases) and natural climate variability, and the trends are consistent with expected changes from human activities (Ch 2: Our Changing Climate, Key Message 1). Additional aspects of observed climate change in the region appear under the key messages below.

Projected Climate Change

Over the period from 1970-99 to 2070-99, an increase in average annual temperature of 3.3°F to 9.7°F is projected, depending largely on whether global emissions eventually decline (B1 scenario) or continue to rise (A1B, A2 scenarios), and is projected to be largest in summer. Change in annual average precipitation, averaged over the Northwest, is projected to be within a range of –11% to +12% for the B1, A1B, and A2 scenarios for 2030-2059 and –10% to +18% for 2070-99 (Mote and Salathe 2010). Seasonally, model projections range from modest decreases to large increases in winter, spring, and fall (Kunkel et al. 2012; Mote and Salathé 2010; Ch. 2: Our Changing Climate; Key Message 5). Projections of precipitation are less certain than those for temperature (Kunkel et al. 2012), yet one aspect of seasonal changes in precipitation is largely consistent across climate models: for scenarios of continued growth in global emissions, summer precipitation is projected to decrease by as much as 30% by the end of the century (Kunkel et al. 2012; Mote and Salathé 2010). Although Northwest summers are already dry, so that a 10% reduction is a small amount of precipitation, unusually dry summers have many noticeable consequences, including low streamflow west of the Cascades (Bumbaco and Mote 2010) and greater extent of wildfires throughout the region (Littell et al. 2010).

Ongoing research on the implications of these changes largely confirms projections and analyses made over the last decade while providing more information about how climate impacts are likely to vary from place to place within the region. In addition, new areas of concern like ocean acidification have arisen.

Water-related Challenges

Changes in the timing of streamflow related to changing snowmelt have been observed and will continue, reducing the supply of water for many competing demands and causing far-reaching ecological and socioeconomic consequences.

Description of observed and projected changes

Observed regional warming has been linked to hydrologic changes in basins with significant snowmelt contributions to streamflow. Since around 1950, area-averaged spring snowpack decreased 0% to 30% (depending on method and period of analysis) (Mote 2006; Pierce et al. 2008), spring snowmelt occurred 0 to 30 days earlier (Stewart et al. 2005), late winter/early spring streamflow increased (Hidalgo et al. 2009) and summer flow decreased 0% to 15% as a fraction of annual total flow (Luce and Holden 2009; Stewart et al. 2005), and winter flow increased, (U.S. Bureau of Reclamation 2011a) with exceptions in smaller areas and shorter time periods (Mote et al. 2008a).

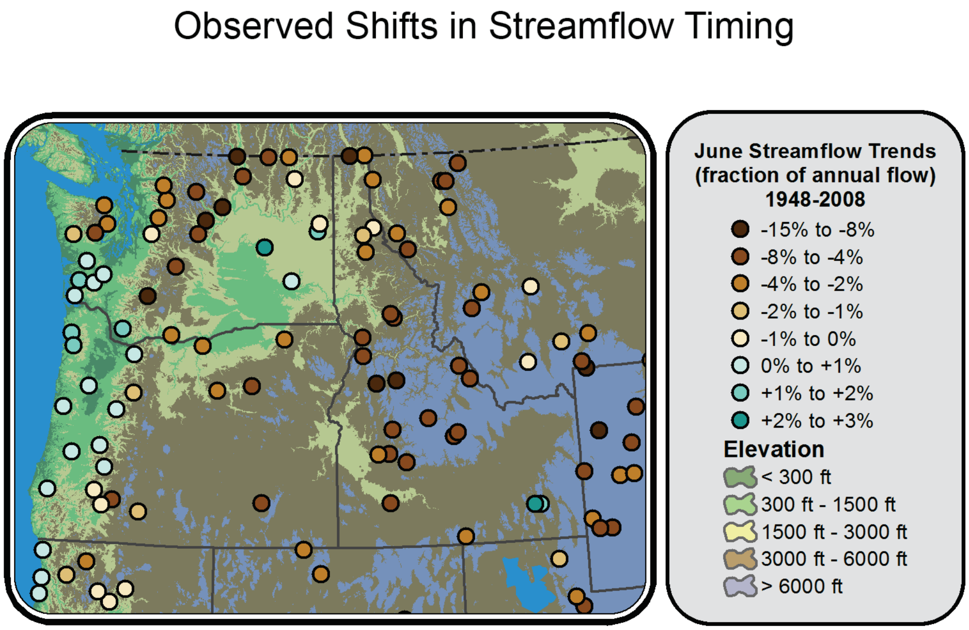
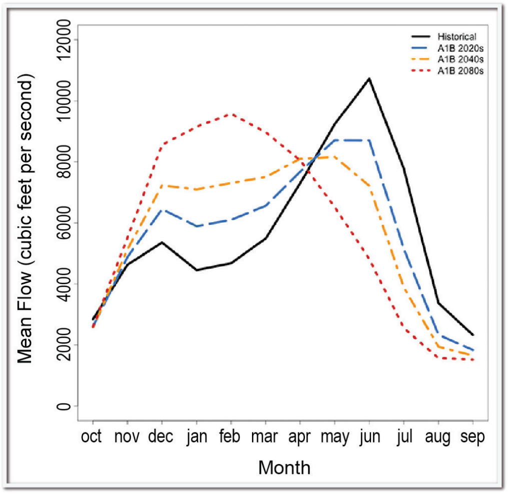


Figure 21.1: Observed Shifts in Streamflow Timing

Caption: Reduced June flows in many Northwest snow-fed rivers is a signature of warming in basins with a significant snowmelt contribution. The fraction of annual flow arriving in June increased slightly in rain-dominated coastal basins and decreased in mixed rain-snow basins and snowmelt dominated basins for 1948-2008 (Fritze et al. 2011). June is during the high flow period for most Northwest river basins; decreases in summer flows can make it more difficult to meet a variety of competing human and natural demands for water.

Hydrologic response to climate change varies by type of watershed, with the largest responses in basins with significant snow accumulation, where warming increases winter flows and advances the timing of spring melt (Hamlet and Lettenmaier 2005; Hidalgo et al. 2009). By 2050, snowmelt is projected to shift 3 to 4 weeks earlier than the 20th century average (Barnett et al. 2005; U.S. Bureau of Reclamation 2008), and summer flows are projected to be substantially lower (Elsner et al. 2010). Change in flood risk depends on many factors, but is projected to increase the most in mixed basins (those with both winter rainfall and summer snowmelt-related runoff peaks) and decrease in higher basins (Hamlet and Lettenmaier 2007; Mantua et al. 2010). Regional climate models project increases of 0% to 20% in extreme daily precipitation depending on location and definition of "extreme" (for example, annual wettest day), with a 13% regionally averaged increase in number of days with over one inch of precipitation for 2041-2070 compared with 1971-2000 (Kunkel et al. 2012). This increase in heavy downpours could increase future flood risk in transient and rain-dominant basins.

Future Shift in Timing of Stream Flows



Reduced Summer Flows

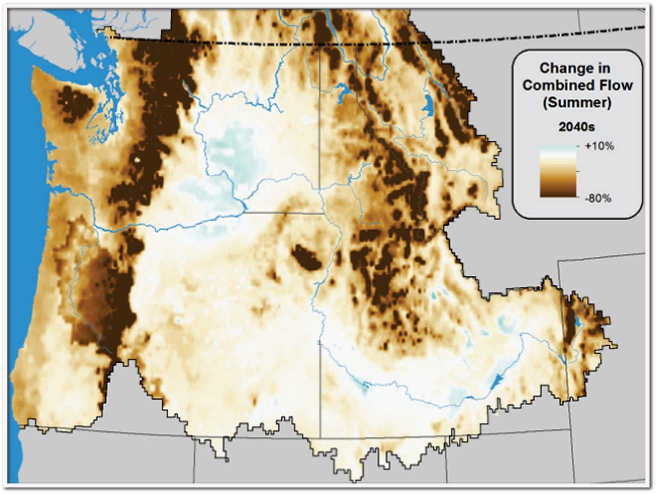


Figure 21.2 (left): Future Shift in Timing of Stream Flows

Left caption: Projected increased winter flows and decreased summer flows in many Northwest rivers will cause widespread impacts. Mixed rain-snow watersheds, such as the Yakima River basin, an important agricultural area in eastern Washington, will see increased winter flows, earlier spring peak flows, and decreased summer flows in a warming climate. Changes in average monthly stream flow from baseline (simulated 1916-2006 average, black) to the 2020s (blue), 2040s (yellow), and 2080s (red) indicate that the Yakima could change from a basin deriving most of its streamflow from snow melt to a rain-dominant basin by the 2080s under a scenario that assumes continued increases in emissions through mid century but declines thereafter (A1B) (Elsner et al. 2010).

Figure 21.2 (right): Reduced Summer Flows

Right caption: Across most of the Northwest, flows during the already low summer flow period would be significantly reduced in the 2040s compared to baseline (1915-2006) conditions under the same scenario (A1B) (Littell et al. 2011). This would put stress on freshwater fish species such as endangered salmon and bull trout and necessitate increasing trade-offs among conflicting users of summer water.

Consequences and likelihoods of changes

Reservoir systems have multiple objectives, including irrigation, municipal and industrial use, hydropower production, flood control, and preserving fish habitat. Modeling studies indicate, with near 100% likelihood, that reductions in summer flow will occur by 2050 in basins with significant snowmelt (Elsner et al. 2010). Combined with summer increases in heat-driven electric power demand for cooling (Hamlet et al. 2010) and evaporative demand from crops and forests (Kunkel et al. 2012; U.S. Bureau of Reclamation 2011b), these reduced flows will require tradeoffs among objectives of the whole system of reservoirs (Isaak et al. 2011). For example, reductions in hydropower production of as much as 20% by the 2080s could be required to preserve in-stream flow targets for fish in the Columbia River basin (Payne et al. 2004). Springtime irrigation diversions increased between 1970 and 2007 in the Snake River basin, as earlier snowmelt led to reduced spring soil moisture (Hoekema and Sridhar 2011). In the absence of adaptation, annual hydropower production is much more likely to decrease than to increase; economic impacts of hydropower changes could be substantial, on the order of hundreds of millions of dollars per year (Markoff and Cullen 2008).

Several aspects of hydrologic change, such as increased flooding in mixed rain-snow basins, region-wide increased winter flows and summer temperatures, and decreased summer flows, will threaten many freshwater species, particularly salmon, steelhead, and trout. Rising temperatures will increase disease and/or mortality in several iconic salmon species, including spring/summer Chinook and sockeye, especially in the interior Columbia and Snake River basins (Mantua et al. 2010) – although some streams are less sensitive to warming because of the temperature buffering provided by snowmelt and groundwater (Mohseni et al. 1999). By the 2080s, suitable habitat for the four trout species of the interior western U.S. is projected to decline 47% on average compared to 1978-97 (Wenger et al. 2011). Some Northwest streams (Isaak et al. 2011) and lakes have already warmed, on average, over the past three decades, contributing to changes such as earlier Columbia River sockeye salmon migration (Crozier et al. 2011) and earlier blooms of algae in Lake Washington (Winder and Schindler 2004). As species respond to climate change in diverse ways, there is a potential for ecological mismatches to occur – such as in the timing of the emergence of predators and their prey (Winder and Schindler 2004).

Adaptive capacity and implications for vulnerability

The ability to adapt to climate changes is strengthened by extensive water resources infrastructure, diversity of institutional arrangements (Slaughter et al. 2010), and management agencies that are responsive to scientific input. However, overallocation of existing water supply, conflicting objectives, limited management flexibility caused by rigid water allocation and operating rules, and other institutional barriers to changing operations continue to limit progress towards adaptation in many parts of the Columbia River basin (Hamlet 2011; Miles et al. 2000).

Vulnerability is probably highest in basins with the largest hydrologic response to warming and lowest management flexibility – that is, fully allocated, mid-elevation, temperature-sensitive, mixed rain-snow watersheds with existing conflicts among users of summer water. Regional power planners have expressed concerns over the existing hydroelectric system's potential inability to provide adequate summer electricity given the combination of climate change, demand growth, and operating constraints (NWPCC 2010). In contrast, vulnerability is probably lowest where hydrologic change is likely to be smallest (in rain-dominant basins), and where institutional arrangements are simple, and current natural and human demands rarely exceed current water availability (EPA 2010; Hamlet 2011; King County Department of Natural Resources and Parks 2009; Palmer and Hahn 2002; Vano et al. 2010b).

The adaptive capacity of freshwater ecosystems also varies and, in managed basins, will depend on the degree to which the need to maintain streamflows and water quality for fish and wildlife is balanced with human uses of water resources. In highly managed rivers, release of deeper, colder water from reservoirs could offer one of the few direct strategies to lower water temperatures downstream (Yates et al. 2008). Actions to improve stream habitat, including planting trees for shade, are being tested. In more natural streams, some species may be able to change behavior or take advantage of cold-water refugia (Goniea et al. 2006; High et al. 2006).

Coastal Vulnerabilities

In the coastal zone, the effects of erosion, inundation, threats to infrastructure and habitat, and increasing ocean acidity collectively pose a major threat to the region.

With diverse landforms (beaches, rocky shorelines, bluffs, estuaries), coastal and marine ecosystems, and human uses (rural communities, dense urban areas, international ports, transportation), the Northwest coast will experience a wide range of climate impacts.

Description of observed and projected changes

Along much of the coast in the Northwest, tectonic uplift reduces apparent sea level rise below the currently observed global average, though a major earthquake in the subduction zone, expected within the next few hundred years, would immediately reverse centuries of uplift and increase relative sea level about 40 inches or more (Atwater and Yamaguchi 1991; NRC 2012). Global sea levels have risen 8 inches since 1880 and are projected to rise another 1 to 4 feet by 2100 (Ch. 2: Our Changing Climate, Key Message 9). Many local factors can modify the global trend, including vertical land movement, oceanic circulation and local effects of ice loss in southeast Alaska, sediment compaction, subterranean fluid withdrawal (groundwater, natural gas), and other geophysical factors. Taking into account all of these factors and considering a wider range of emissions scenarios than are used in this assessment, a recent evaluation focused on the west coast calculated projected sea level rise and ranges for specific sites in the Northwest by 2100, relative to 2000 (NRC 2012). This type of evaluation can provide local decision-makers with the most relevant information specific to their coastline. In addition to the range of sea level rise projected for specific locations within the Northwest, El Niño conditions alone could temporarily increase sea level by about 4 to 12 inches across the region (NRC 2012).

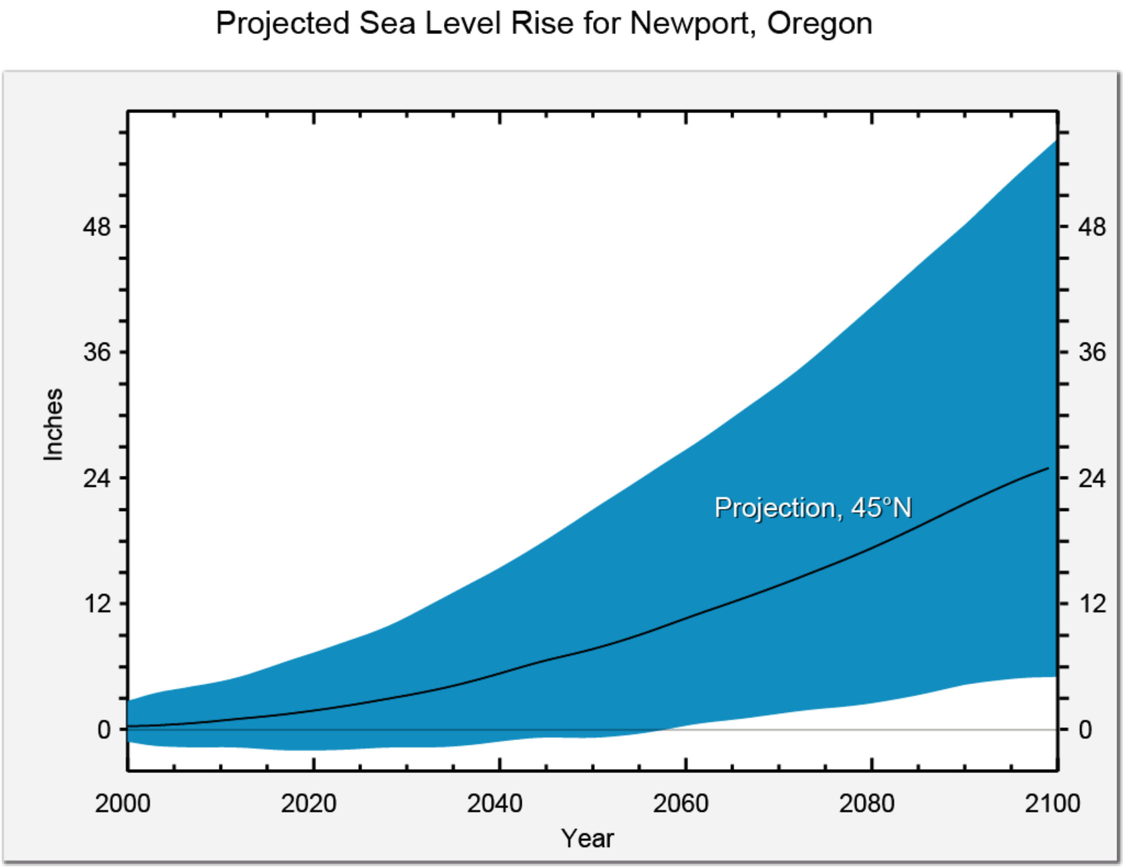


Figure 21.3: Projected Sea Level Rise for Newport, OR

Caption: Projected sea level rise for Newport, OR (in inches relative to the year 2000) is based (NRC 2012) on a broader suite of emissions scenarios (B1-A1F1) and a more detailed calculation than in this assessment (See Ch. 2: Our Changing Climate). The blue area shows the range of sea level rise and the black line shows the projection based on the methodology used in the NRC report, which incorporates global and local effects of warming oceans, melting land ice, and vertical land movements. Given the impossibility of assigning likelihood to any one possible trajectory of sea level rise at this time, a reasonable risk assessment for local adaptation planning would consider multiple scenarios within the full range of possible outcomes. (Source: Plotted with data from NRC 2012).

Northwest coastal waters, some of the most productive on the West Coast (Hickey and Banas 2008), have highly variable physical and ecological conditions as a result of seasonal and inter-annual (year-to-year) changes in upwelling of deeper marine water that make changes over time difficult to detect. Coastal sea surface temperatures have been shown to have increased since the 1900s (Deser et al. 2010; Field et al. 2006), and summertime fog has declined, both of which could be consequences of weaker upwelling winds (Johnstone and Dawson 2010). Projected future changes include increasing but highly variable acidity (Butorac et al. 2010; Feely et al. 2008; Feely et al. 2010), increasing surface water temperature (2.2°F from 1970-99 to 2030-59) (Mote et al. 2010), and possibly changing storminess (Gemmrich et al. 2011; Ruggiero et al. 2010). Climate models show inconsistent projections for the future of Northwest coastal upwelling (Mote and Salathé 2010; Wang et al. 2010).

Consequences and likelihoods of changes

In Washington and Oregon, more than 140,000 acres of coastal lands lie within 3.3 feet in elevation of high tide (Strauss et al. 2012). As sea levels continue to rise, these areas will be inundated more frequently. Many coastal wetlands, tidal flats, and beaches will probably decline in quality and extent as a result of sea level rise, particularly where inland shifting of habitats is precluded. Species such as shorebirds and forage fish (small fish eaten by larger fish, birds, or mammals) would be harmed, and coastal infrastructure and communities would be at greater risk from coastal storms (Drut and Buchanan 2000; Krueger et al. 2010).

Ocean acidification threatens culturally and commercially significant marine species directly affected by changes in ocean chemistry (like oysters) and those affected by changes in the marine food web (like Pacific salmon) (Ries et al. 2009). Northwest coastal waters are among the most acidified worldwide, especially in spring and summer with coastal upwelling (Butorac et al. 2010; Feely et al. 2008; Hickey and Banas 2003; NOAA's Northwest Fisheries Science Center) combined with local factors in estuaries (Butorac et al. 2010; Feely et al. 2010).

Increasing coastal water temperatures and changing ecological conditions may alter the ranges, types, and abundances of marine species (Hollowed et al. 2001; Tillmann and Siemann 2011). Recent warm periods in the coastal ocean, for example, saw the arrival of subtropical and offshore marine species from zooplankton to top predators such as striped marlin, tuna, and yellowtail more common to the Baja area (Pearcy 2002; Peterson and Schwing 2003). Warmer water in Puget Sound may contribute to a higher incidence of harmful blooms of algae linked to neurotoxic shellfish poisoning (Feely et al. 2010; Huppert et al. 2009; Moore et al. 2008).

Many human uses of the coast – for living, working, and recreating – will also be negatively affected by the physical and ecological consequences of climate change. Erosion, inundation, and flooding will threaten: public and private property along the coast; infrastructure, including wastewater treatment plants (Solecki and Rosenzweig 2012); stormwater outfalls (Fleming and Rufo-Hill 2012; Haub 2012, personal communication); ferry terminals (WSDOT 2011); and coastal road and rail transportation, especially in Puget Sound (MacArthur et al. 2012). Municipalities from Seattle (Fleming and Rufo-Hill 2012) and Olympia (Haub 2012, personal communication), Washington, to Neskowin, Oregon, have mapped risks from the combined effects of sea level rise and other factors.

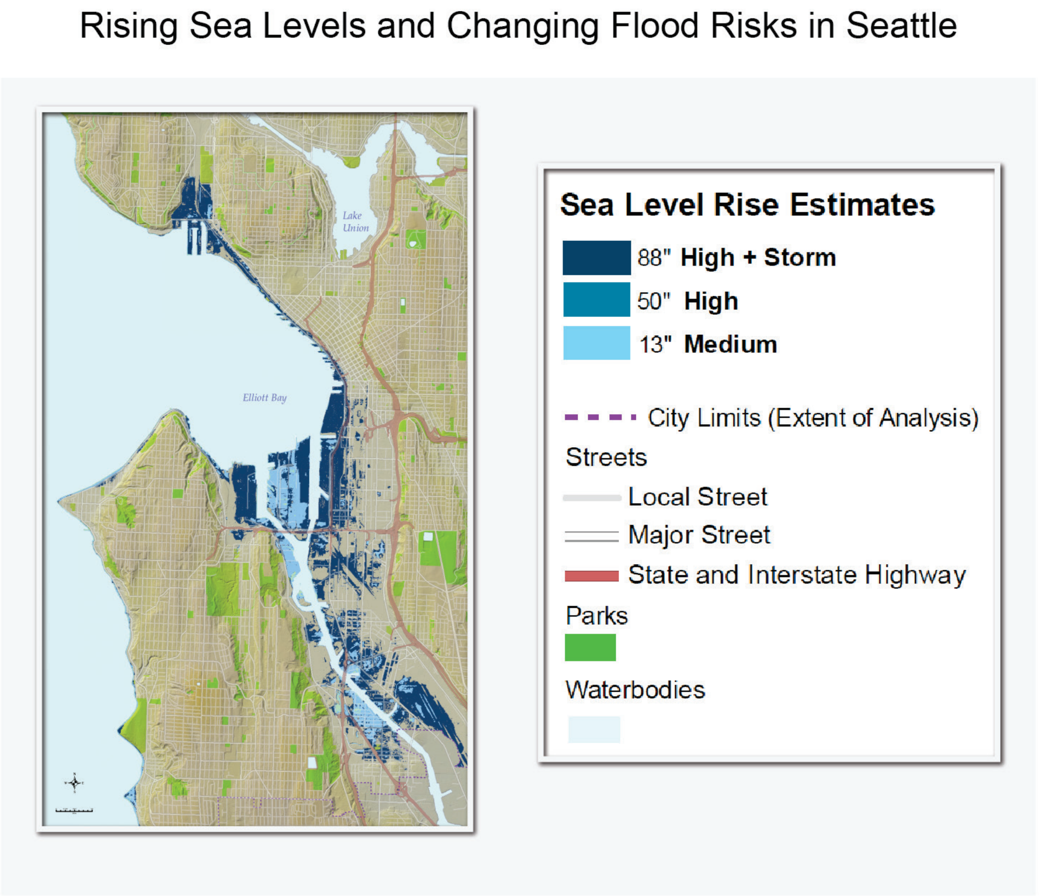


Figure 21.4: Rising Sea Levels and Changing Flood Risks in the City of Seattle

Caption: Areas of Seattle projected by Seattle Public Utilities to be below sea level during high tide (Mean Higher High Water) and therefore at risk of flooding or inundation are shaded in blue under three levels of sea level rise, (Mote et al. 2008b), assuming no adaptation (Fleming and Rufo-Hill 2012; Seattle Public Utilities 2010). (High [50 inches] and medium [13 inches] levels are within the range projected for the Northwest by 2100; the highest level incorporates the compounding effect of storm surge). Unconnected inland areas shown to be below sea level may not be inundated, but could experience problems due to areas of standing water caused by a rise in the water table and drainage pipes backed up with sea water. (Figure source: Courtesy of Seattle Public Utilities)

Adaptive capacity and implications for vulnerability

Human activities have increased the vulnerability of many coastal ecosystems, by degrading and eliminating habitat (Good 2000; WDNR 1998) and by building structures that, along with natural bluffs, thwart inland movement of many remaining habitats. In Puget Sound, for example, an estimated one-third of the shoreline has been modified by seawalls, bulkheads, and other structures (Fresh et al. 2011), though some restoration has occurred. Human response to erosion and sea level rise, especially shoreline armoring, will largely determine the viability of many shallow-water and estuarine ecosystems (Huppert et al. 2009; Puget Sound Nearshore Ecosystem Restoration Project 2011; Tillmann and Siemann 2011). In communities with few alternatives to existing coastal infrastructure, such as parts of Highway 101 in Oregon, sea level rise and storm surges will pose an increasing threat to local commerce and livelihoods. Finally, there seem to be few options for ameliorating projected ocean acidification (Washington Governor's Blue Ribbon Panel on Ocean Acidification 2012).

Figure 21.5: Adapting the Nisqually River Delta to Sea Level Rise

Caption: In the Nisqually River Delta in Washington, estuary restoration on a large scale to assist salmon and wildlife recovery provides an example of adaptation to climate change and sea level rise. After a century of isolation behind dikes (left), much of the Nisqually National Wildlife Refuge was reconnected in 2009 with tidal flow by removal of a major dike and restoration of 762 acres (right), with the assistance of Ducks Unlimited and the Nisqually Indian Tribe. This reconnected more than 21 miles of historical tidal channels and floodplains with Puget Sound (U.S. Fish and Wildlife Service 2010). A new exterior dike was constructed to protect freshwater wetland habitat for migratory birds from tidal inundation and future sea level rise. Combined with expansion of the authorized Refuge boundary, ongoing acquisition efforts to expand the Refuge will enhance the ability to provide diverse estuary and freshwater habitats despite rising sea level, increasing river floods, and loss of estuarine habitat elsewhere in Puget Sound. This project is considered a major step in increasing estuary habitat and recovering the greater Puget Sound estuary.

Figure credits/sources: Left (backhoe): Jesse Barham/U.S. Fish and Wildlife Service http://www.flickr.com/photos/usfwspacific/5791362738/in/set-72157626745822317); Right (aerial): Jean Takekawa/U.S. Fish and Wildlife Service (http://www.flickr.com/photos/usfwspacific/5790804083/in/set-72157626745822317)

Impacts on Forests

The combined impact of increasing wildfire, insect outbreaks, and diseases is virtually certain to cause additional forest mortality by the 2040s and long-term transformation of forest landscapes. Almost complete loss of subalpine forests is expected by the 2080s.

Evergreen coniferous forests are a prominent feature of Northwest landscapes, particularly in mountainous areas. Forests support diverse fish and wildlife species, promote clean air and water, stabilize soils, and store carbon. They support local economies and traditional tribal uses, and provide recreational opportunities.

Description of observed and projected changes

Climate change will alter Northwest forests by increasing wildfire risk, insect and disease outbreaks, and by forcing longer-term shifts in forest types and species. Many impacts will be driven by water deficits, which increase tree stress and mortality, tree vulnerability to insects, and fuel flammability. The cumulative effects of disturbance – and possibly interactions between insects and fires – will cause the greatest changes in Northwest forests (Littell et al. 2010; McKenzie et al. 2008). A similar outlook is expected for the Southeast region (See Ch. 20: Southeast, Key Message 3).

Although wildfires are a natural part of most Northwest forest ecosystems, warmer and drier conditions have helped increase the number and extent of wildfires in western U.S. forests since the 1970s (Littell et al. 2010; McKenzie et al. 2008; McKenzie et al. 2004; Westerling et al. 2006). This trend is expected to continue under future climate conditions. By the 2080s, the median annual area burned in the Northwest would quadruple relative to the 1916-2007 period to 2 million acres (range 0.2 to 9.8 million acres) under a scenario that assumes continued increases in emissions through mid century but declines thereafter (A1B). The probability of a very large fire year would increase from 1 in 20 to 1 in 2 (Littell et al. 2010).

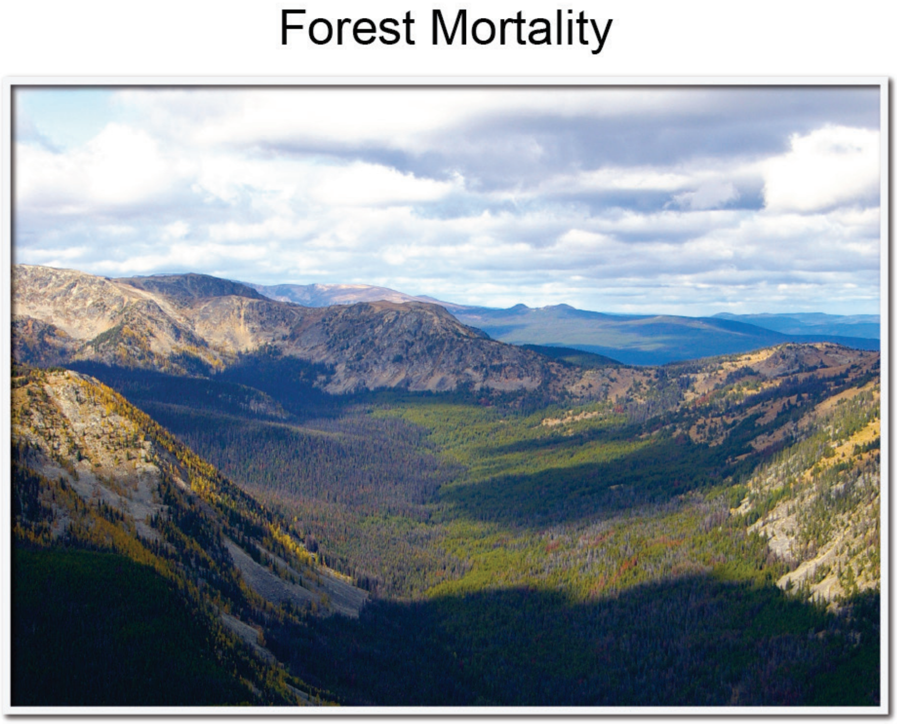


Figure 21.6: Forest mortality

Caption: Forest mortality due to fire and insect activity is already evident in the Northwest, and continued changes in climate in coming decades are expected to increase these effects. Recent burn (left side of watershed) and trees killed by mountain pine beetle and spruce beetle infestations (right side of watershed) in subalpine forest in the Pasayten Wilderness, Okanogan Wenatchee National Forest, Washington. Figure source: Jeremy Littell, USGS.

Higher temperatures and drought stress are contributing to outbreaks of mountain pine beetle that increase pine mortality in drier Northwest forests (Carroll et al. 2003; Logan and Powell 2001; Oneil 2006). This trend is projected to continue with ongoing warming (Bentz et al. 2010; Hicke et al. 2006; Littell et al. 2010; Mitchell and Buffam 2001). The proportion of Northwest pine forests where mountain pine beetles are most likely to survive is projected to first increase (27% higher in 2001-2030 compared to 1971-2000) and then decrease (about 49% to 58% lower by 2071-2100) (Bentz et al. 2010). Between now and the end of this century, the elevation of suitable beetle habitat is projected to increase, exposing higher elevation forests to the pine beetle but ultimately limiting available area (Bentz et al. 2010; Hicke et al. 2006; Littell et al. 2010).

The areas most climatically suited for many tree species will shift from their current locations, increasing vulnerability to insects, disease, and fire in areas that become unsuitable. Eighty-five percent of the current range of three species that are host to pine beetles is projected to be climatically unsuitable for one or more of those species by the 2060s (Littell et al. 2010; Rehfeldt

2006), while 21 to 38 currently existing plant species may no longer find climatically appropriate habitat in the Northwest by late this century (McKenney et al. 2011).

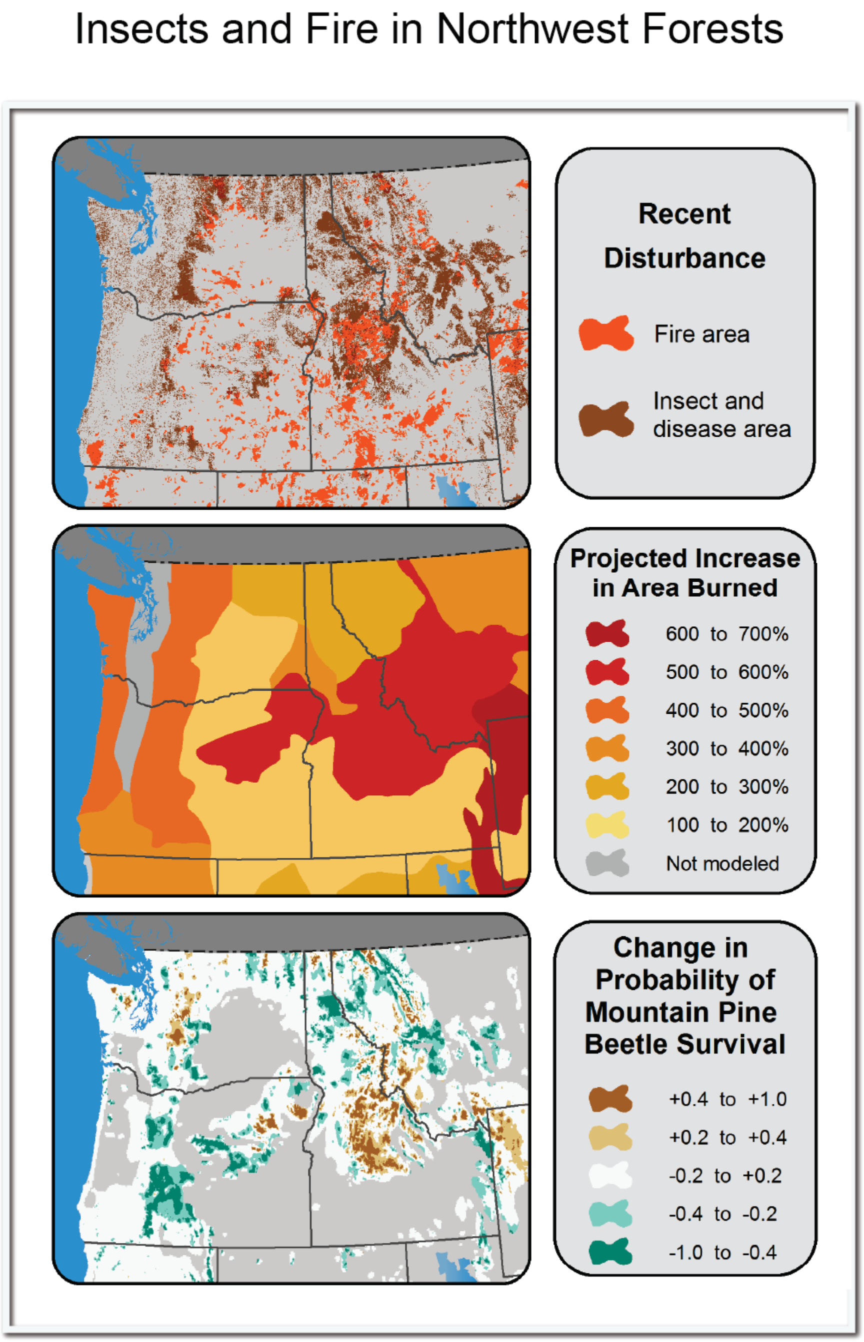


Figure 21.7: Insects and Fire in Northwest Forests

Caption Top: Insects and fire have cumulatively affected large areas of the Northwest, and are projected to be the dominant drivers of forest change in the near future. Map shows areas recently burned (1984-2008)(Eidenshink et al. 2007; USGS 2012) or affected by insects or disease (1997-2008) (USFS 2012).

Caption Middle: Large increases in area burned by wildfire are projected for most of the Northwest. Projected changes in area burned associated with a 2.2°F global warming, including both the expected temperature and precipitation changes (NRC 2011). The divisions are areas that share common climatic and vegetation characteristics (Bailey 1995).

Caption Bottom: Projected changes in the probability of mountain pine beetle climatic suitability for the period 2001-2030 relative to 1971-2000, where brown indicate areas where pine beetles are projected to increase in the future and green indicates areas where pine beetles are expected to decrease in the future. Changes in probability of survival are based on climate-dependent factors important in beetle population success, including cold tolerance (Régnière and Bentz 2007), spring precipitation (Safranyik et al. 1975), and seasonal heat accumulation (Bentz et al. 2010; Logan and Powell 2001).

Consequences and likelihoods of changes

The likelihoods of increased disturbance and altered forest distribution are very high in areas dominated by natural vegetation, and the resultant changes in habitat would affect native species and ecosystems. Subalpine forests and alpine ecosystems are especially at risk, and may undergo almost complete conversion to other vegetation types by the 2080s (Rogers et al. 2011). Changes in the risk of very large, high-intensity, stand-replacing fires cannot yet be predicted, but such events could have enormous impacts for forest dependent species (McKenzie et al. 2004). Increased wildfire could exacerbate respiratory and cardiovascular illnesses in nearby populations due to smoke and particulate pollution (Baron et al. 2008; Karl et al. 2009; Washington State Department Ecology 2012). The economic impacts of climate change in Northwest forests would be moderate for the region as a whole, but could significantly affect local timber revenues and bioenergy markets (Capalbo et al. 2010).

Adaptive capacity and implications for vulnerability

Ability to prepare for these changes varies with land ownership and management priorities. Adaptation actions that decrease forest vulnerability exist, but none is appropriate across all of the Northwest's diverse climate threats, land-use histories, and management objectives (Littell et al. 2012; Millar et al. 2007; Peterson et al. 2011). Surface and canopy thinning can reduce the occurrence and effects of high severity fire in previously low severity fire systems, like drier eastern Cascades forests (Peterson and Johnson 2007; Prichard et al. 2010), but may be ineffective in historically high severity fire forests, like the western Cascades, Olympics, and some subalpine forests. It is possible to use thinning to reduce tree mortality from insect outbreaks (Chmura et al. 2011; Littell et al. 2012), but not on the scale of the current outbreaks in much of the West.

Adapting Agriculture

While the agriculture sector's technical ability to adapt to changing conditions can offset some of the adverse impacts of a changing climate, there remain critical sector-specific concerns with respect to costs of adaptation, development of more climate resilient technologies and management, and availability and timing of water.

Agriculture provides the economic and cultural foundation for Northwest rural populations and contributes substantively to the overall economy. Agricultural commodities and food production systems contributed 3% and 11% of the region's GDP, respectively in 2009 (Brady and Taylor 2011; ODA 2009; U.S. Government Revenue 2012; USDA 2011a, 2011b, 2011c). Although the overall consequences of climate change will probably be lower in the Northwest than in certain other regions, sustainability of some Northwest agricultural sectors is threatened by soil erosion (Kok et al. 2009; Mulla 1986) and water supply uncertainty, both of which could be exacerbated by climate change.

Description of observed and projected changes

Northwest agriculture's sensitivity to climate change stems from its dependence on irrigation water, a specific range of temperatures, precipitation, and growing seasons, and the sensitivity of crops to temperature extremes. Projected warming will reduce the availability of irrigation water in snowmelt-fed basins, as described above, and increase the probability of heat stress to field crops and tree fruit. Some crops will benefit from a longer growing season (Stöckle et al. 2010) and/or higher atmospheric CO_2, at least for a few decades (Hatfield et al. 2011; Stöckle et al. 2010). Longer-term consequences are less certain. Changes in plant diseases, pests, and weeds present additional risks but are species-specific, preventing general projections. In general, higher temperatures are coupled with greater pressure from insect pests, stemming from changes in geographic ranges and dates of spring arrival (Parmesan 2006; Trumble and Butler 2009).

Consequences of changes

Because much of the Northwest has low annual precipitation, many crops require irrigation. Reduction in summer flows in snow-fed rivers ("Reduced Summer Flows" figure above), coupled with warming that could increase agricultural and other demands, potentially produces irrigation water shortages (Washington State Department of Ecology 2011). The risk of a water-short year – when Yakima basin junior water rights holders are allowed only 75% of their water right amount – is projected to increase from 14% in the late 20th century to 32% by 2020 and 77% by 2080, assuming no adaptation and under a scenario (A1B) that assumes emissions of heat-trapping gases continue to increase through mid century but decline thereafter (Vano et al. 2010b).

Projected increases in average temperature and hot weather episodes and decreases in summer soil moisture would reduce yields of wheat and other cereals in irrigated and rain-fed production zones. Potential yield losses are expected to reach 25% for some crops by the end of this century, depending upon location, relative to 1975-2005; yields of fully irrigated potatoes are projected to decline by 2% to 3% under the A1B scenario, because the fertilization effect of CO_2 mostly offsets direct climate-related losses (Stöckle et al. 2010). Tuber quality could also be reduced (Alva et al. 2002).

Fully irrigated apple production is projected to increase in Washington state by 6%, 9%, and 16% in the 2020s, 2040s, and 2080s (Stöckle et al. 2010), again with some offsetting between effects of CO_2 and climate. However, because tree fruit requires chilling to ensure uniform flowering and fruit set, and wine grape varieties have specific chilling requirements for maturation (Jones 2005), warming could adversely affect currently grown varieties of these commodities. The economic consequences for Northwest agriculture will be influenced by input and output prices driven by global economic conditions as well as by regional and local changes in productivity.

Adaptive capacity and implications for vulnerability

Of the four areas of concern discussed here, agriculture is perhaps best positioned to adapt to climate trends without explicit planning and policy, because it already responds to annual climate variations and exploits a wide range of existing climates across the landscape (Reilly and Schimmelpfennig 1999). Nonetheless, rapid climate change could present difficulties. Adaptation could occur slowly if substantial investments or significant changes in farm operations and equipment are required. Shifts to new varieties of wine grapes and tree fruit, if indicated, and even if ultimately more profitable, are necessarily slow and expensive. Breeding for drought- and heat-resistance requires long-term effort. Irrigation water shortages that necessitate shifts away from more profitable commodities could exact economic penalties (Washington State Department of Ecology 2011). Risk aversion among farmers, although prudent under typical circumstances, could hamper responsiveness to climatic changes.

Traceable Accounts

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Key Message Process: A central component of the assessment process was the NW Regional Climate Risk Framing workshop that was held December 2, 2011 in Portland with approximately 50 attendees. Participants included representatives from all sectors, affiliations, and states and communities within the region to ensure that the outcomes were representative of the region. The workshop consisted of four main components: 1) introduction to risk-based framing of climate impacts; 2) a panel of experts presenting on the likelihood of eight climate risks; 3) an online, real-time survey collecting, from each participant, responses to questions about the consequences of those risks; and 4) breakout group discussions. The survey outcomes and workshop discussions began the process leading to a 79-page Technical Input Report (TIR) that was assembled by 8 authors (Dalton et al. 2012).

The NCA NW chapter author team engaged in multiple technical discussions via regular teleconferences and two all-day meetings. These included careful review of the foundational TIR (Dalton et al. 2012) and of approximately 80 additional technical inputs provided by the public, as well as the other published literature, and professional judgment. They also drew heavily from two state climate assessment reports (CIG 2009; Oregon Climate Change Research Institute 2010). These discussions were followed by expert deliberation of draft key messages by the authors wherein each key message was defended before the entire author team before this key message was selected for inclusion in the Report. These discussions were supported by targeted consultation with additional experts by the lead author of each message, and they were based on criteria that help define "key vulnerabilities."

Key message #1/4	**Changes in the timing of streamflow related to changing snowmelt are already observed and will continue, reducing the supply of water for many competing demands and causing far-reaching ecological and socioeconomic consequences.**
Description of evidence base	This message was selected because of the centrality of the water cycle to many important human and natural systems of the NW (hydropower production and the users of this relatively inexpensive electricity; agriculture and the communities and economies dependent thereon; coldwater fish, including several species of threatened and endangered salmon, the tribal and fishing communities and ecosystems that depend on them, and the adjustments in human activities and efforts necessary to restore and protect them), these impacts and any societal adjustments to them will have far-reaching ecological and socioeconomic consequences. Evidence that winter snow accumulation will decline under projected climate change is based on 20th century observations and theoretical studies of the sensitivity of NW snowpack to changes in precipitation and temperature. There is good agreement on the physical role of climate in snowpack development, and projections of the sign of future trends are consistent (many studies). However, climate variability creates disagreement over the magnitude of current and near-term future trends. Evidence that projected climate change would shift the timing and amount of streamflow deriving from snowmelt is based on 20th century observations of climate and streamflow and hydrologic model simulation of streamflow responses to climate variability and change. There is good agreement on the sign of trends (many studies), though the magnitude of current and near-term future trends is less certain because of climate variability. Evidence that declining snowpack and changes in the timing of snowmelt-driven streamflow will reduce water supply for many competing and time-sensitive demands is based on: (1) hydrologic simulations, driven by future climate projections, that consistently show reductions in spring and summer flows in transient and some snow-dominant watersheds;

	(2) documented competition among existing water uses (irrigation, power, municipal, in stream flows) and inability for all water systems to meet all summer water needs all of the time, especially during drier years; (3) empirical and theoretical studies that indicate increased water demand for many uses under climate change; (4) policy and institutional analyses of the complex legal and institutional arrangements governing NW water management and the challenges associated with adjusting water management in response to changing conditions. Evidence for far-reaching ecological and socioeconomic consequences of the above is based on: (1) model simulations showing negative impacts of projected climate and altered streamflow on many water resource uses at scales ranging from individual basins (for example, Skagit, Yakima) to the region (for example, Columbia River basin); (2) model simulations of future agricultural water allocation in the Yakima, showing increased likelihood of water curtailments for junior water rights holders; (3) model and empirical studies documenting sensitivity of coldwater fish to water temperatures, sensitivity of water temperature to air temperature, and projected warming of summer stream temperatures; (4) regional and extra-regional dependence on NW-produced hydropower; (5) legal requirements to manage water resources for threatened & endangered fish as well as for human uses. Evidence that water users in managed transient basins (mix of snow and rain) are likely to be the most vulnerable to climate change and less vulnerable in rain dominated basins is based on: (1) observed, theoretical, and simulated sensitivity of watershed hydrologic response to warming by basin type (2) historical observations and modeled simulations of trade-offs required among water management objectives under specific climatic conditions (3) analyses from water management agencies of potential system impacts and adaptive responses to projected future climate (4) institutional and policy analyses documenting sources and types of management rigidity (for example, difficulty adjusting management practices to account for changing conditions)
New information and remaining uncertainties	A key uncertainty is the degree to which current and future interannual and interdecadal variations in climate will enhance or obscure long-term anthropogenic climate trends. Uncertainty over local groundwater or glacial inputs and other local effects may cause overestimates of increased stream temperature based solely on air temperature. However, including projected decreases in summer streamflow would increase estimates of summer stream temperature increases above those based solely on air temperature. Uncertainty in how much increasing temperatures will affect crop evapotranspiration affects future estimates of irrigation demand. Uncertainty in future population growth and changing per capita water use affects estimates of future municipal demand and therefore assessments of future reliability of water resource systems. A major uncertainty is the degree to which water resources management operations can be

	adjusted to account for climate driven changes in the amount and timing of streamflow, and how competing resource objectives will be accommodated or prioritized. Based on current institutional inertia, significant changes are unlikely to occur for several decades. There is uncertainty in economic assessment of the impacts of hydrologic changes on the NW because much of the needed modeling and analysis is incomplete. Economic impacts assessment would require quantifying both potential behavioral responses to future climate-affected economic variables (prices of inputs, products) and to climate change itself. Some studies have sidestepped the issue of behavioral response to these and projected economic impacts based on future scenarios that do not consider adaptation, which lead to high estimates of "costs" or impacts.
Assessment of confidence based on evidence and agreement or, if defensible, estimates of the likelihood of impact or consequence	Confidence is **very high** based on strong strength of evidence and **high** level of agreement among experts. See specifics under "description of evidence" above.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Key Message Process: See Key Message #1

Key message #2/4	**In the coastal zone, the effects of erosion, inundation, threats to infrastructure and habitat, and increasing ocean acidity collectively pose a major threat to the region.**
Description of evidence base	Given the extent of the coastline, the importance of coastal systems to the region's ecology, economy, and identity, and the difficulty of adapting in response, the consequences of sea level rise, ocean acidification, and other climate driven changes in ocean conditions and coastal weather are expected to be significant and largely negative, which is why this message was included. Evidence for observed global (eustatic) sea level rise and regional sea level change derives from satellite altimetry and coastal tide gauges. Evidence for projected global sea level rise is described in Ch.2: Our Changing Climate, in the recent NRC report (2012) that includes a detailed discussion of the U.S. west coast, and Parris et al. (2012). Evidence of erosion associated with coastal storms is based on observations of storm damage in some areas of the Northwest. Evidence for erosion and inundation associated with projected sea level rise is based on observations and mapping of coastal elevations and geospatial analyses of the extent and location of inundation associated with various sea level rise and storm surge scenarios. Evidence for climate change impacts on coastal infrastructure derives from geospatial analyses (mapping infrastructure locations likely to be affected by various sea level rise scenarios, storm surge scenarios and/or river flooding scenario), such as those undertaken by various local governments to assess local risks of flooding for the downtown area (Olympia), of sea level rise and storm surge for marine shoreline inundation and risk to public utility infrastructure (Seattle), and of sea level rise for wastewater treatment plants and associated infrastructure (King County). Vulnerability of coastal transportation infrastructure to climate change has been assessed by combining geospatial risk analyses with expert judgment of asset sensitivity to climate risk and criticality to the transportation system in Washington state and by assessing transportation infrastructure exposure to climate risks associated with sea level rise and river flooding in the region as a whole. Evidence for impacts of climate change on coastal habitat is based on: Model-based studies of projected impacts of sea level rise on tidal habitat showing significant changes in the composition and extent of coastal wetland habitats in WA & OR. Observations of extent and location of coastal armoring and other structures that would potentially impede inland migration. Observed changes in coastal ocean conditions (upwelling, nutrients, sea surface temperatures); biogeographical, physiological and paleoecological studies indicating a historical decline in coastal upwelling; global climate model projections of future increases in sea surface temperatures (SST). Modeled projections for increased risk of harmful algal blooms (HAB) in Puget Sound associated with higher air and water temperatures, reduced streamflow, low winds, and small tidal variability (i.e., these conditions offer a favorable HAB window of opportunity). Observed changes in the geographic ranges, migration timing, and productivity of marine species due to changes in sea surface temperatures associated with cyclical events, such as the interannual El Niño Southern Oscillation (ENSO) and inter-decadal Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO).

	Evidence for historical increases in ocean acidification is from observations of changes in coastal ocean conditions, which also indicate high spatial and temporal variability. Evidence for acidification's effects on various species and the broader marine food web is still emerging but is based on observed changes in abundance and size of marine calcifying organisms and laboratory based and in situ acidification experiments. Evidence for marine species responses to climate change derives from observations of shifts in distribution and abundance of marine plankton, fish, and seabird species associated with historical changes in ocean conditions, including temperature and availability of preferred foods. Evidence for low adaptive capacity is from observations of extent of degraded or fragmented coastal habitat, existence of few options for mitigating changes in marine chemical properties, observed extent of barriers to inland habitat migration, narrow coastal transportation corridors, and limited transportation alternatives for rural coastal towns. Evidence for low adaptive capacity is also based on the current limitations (both legal and political) of local and state governments to restrict and/or influence shoreline modifications on private lands.
New information and remaining uncertainties	There is significant but well characterized uncertainty about the rate and extent of future sea level rise at both the global and regional/sub-regional scales. However, there is virtually no uncertainty in the direction (sign) of global sea level rise. There is also a solid understanding of the primary contributing factors and mechanisms causing sea level rise. Other details concerning uncertainty in global sea level rise are treated elsewhere (e.g., NRC 2012) and in Ch.2: Our Changing Climate. Regional uncertainty in projected NW sea level rise results primarily from uncertainty over local vertical land movement (i.e., affecting relative sea level rise). An accurate determination of vertical land deformation requires a sufficient density of monitoring sites (for example, NOAA tide gauges and permanent GPS deformation sites) to capture short wavelength variability, and in most NW coastal locations such dense networks do not exist. There is also considerable uncertainty about potential impacts of climate change on processes that influence storminess and affect coastal erosion in the Northwest. These uncertainties relate to system complexity and the limited number of studies and lack of consensus on future atmospheric and oceanic conditions that will drive changes in regional wind fields. Continued collection and assessment of meteorological data at ocean buoy locations and via remote sensing should improve our understanding of these processes. Uncertainty in future patterns of sediment delivery to the coastal system limit projections of future inundation, erosion and changes in tidal marsh. For example, substantial increases in riverine sediment delivery, due to climate-related changes in the amount and timing of streamflow, could offset erosion and/or inundation projected from changes in sea level alone. However, there are areas in the NW where it is clear that man-made structures have interrupted sediment supply and there is little uncertainty that shallow water habitat will be lost. Although relatively well-bounded, uncertainty over the rate of projected relative sea level rise limits our ability to assess whether any particular coastal habitat will be able to keep pace with future changes through adaptation (for example, through accretion). The specific implications of the combined factors of sea level rise, coastal climate change, and ocean acidification for coastal ecosystems and specific individual species remain uncertain due to the complexity of ecosystem response. However, there is general agreement throughout the peer-reviewed literature that negative impacts for a number of marine calcifying organisms are very likely, particularly during juvenile life stages. Projections of future coastal ocean conditions (for example, temperature, nutrients, pH, productivity) are limited, in part, by uncertainty over future changes in upwelling – climate

	model scenarios show inconsistent projections for likely future upwelling conditions. Considerable uncertainty also remains in whether and how higher average ocean temperatures will influence geographical ranges, abundances, and diversity of marine species, although evidence of changes in pelagic fish species ranges and production associated with Pacific Ocean temperature variability during cyclical events have been an important indicators for potential species responses to climate change in the future. Consequences from ocean acidification for commercial fisheries and marine food web dynamics are potentially very high – while the trend of increasing acidification is very likely, the rate of change and spatial variability within coastal waters are largely unknown and are the subject of ongoing and numerous nascent research efforts. Additional uncertainty surrounds non-climate contributors to coastal ocean chemistry (for example, riverine inputs, anthropogenic carbon, and nitrogen point and non-point source inputs) and society's ability to mitigate these inputs.
Assessment of confidence based on evidence and agreement or, if defensible, estimates of the likelihood of impact or consequence	There is **very high** confidence in the global upward trend of sea level rise and ocean acidification. There is **high** confidence that SLR over the next century will remain under an upper bound of approximately 2 meters. Projections for SLR and OA at specific locations are much less certain (**medium to low**) because of the high spatial variability and multiple factors influencing both phenomena at regional and sub-regional scales. There is **medium** confidence in the projections of species response to sea level rise and increased temperatures, but **low** confidence in species response to ocean acidification. Uncertainty in upwelling changes result in **low** confidence for projections of future change that depend on specific coastal ocean temperatures, nutrient contents, dissolved oxygen content, stratification, etc. There is **high** confidence that significant changes in the type and distribution of coastal marsh habitat are likely, but **low** confidence in our current ability to project the specific location and timing of changes. There is **high** confidence in the projections of increased erosion and inundation.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 21: Northwest

Key Message Process: See Key Message #1

Key message #3/4	**The combined impact of increasing wildfire, insect outbreaks, and diseases is virtually certain to cause additional forest mortality by the 2040s and long-term transformation of forest landscapes. Almost complete loss of subalpine forests is expected by the 2080s.**
Description of evidence base	Evidence that the area burned by fire has been high relative to earlier in the century since at least the 1980s is strong. Peer-reviewed papers based on federal fire databases (for example, National Interagency Fire Management Integrated Database (NIFMID)1970/1980-2011) and independent satellite data (Monitoring Trends in Burn Severity (MTBS), 1984-2011) indicate increases in area burned. Evidence that the interannual variation in area burned is at least partially controlled by climate during the period 1980-2010 is also strong. Statistical analysis has shown that increased temperature (related to increased potential evapotranspiration, relative humidity, and longer fire seasons) and decreased precipitation (related to decreased actual evapotranspiration, decreased spring snowpack, and longer fire seasons) are moderate to strong (depending on forest type) correlates of the area and number of fires in the Pacific Northwest. Future projections of area burned with climate change are documented in peer-reviewed literature, and different approaches (statistical modeling and dynamic global vegetation modeling) agree on the order of magnitude changes for Pacific Northwest forests, though the degree of increase depends on the climate change scenario and modeling approach. Evidence that the area of forest mortality from insect outbreaks and diseases (including the mountain pine beetle) is increasing is from aerial disease and detection surveys jointly coordinated by the U.S. Forest Service and state level government. Evidence that mountain pine beetle and spruce bark beetle outbreaks are climatically controlled is from a combination of laboratory experiments and mathematical modeling reported in peer-reviewed literature. Peer-reviewed future projections of climate have been used to develop projections of mountain pine beetle and spruce beetle habitat suitability based these models, and show increases in the area of climatically suitable habitat (particularly at mid- to high elevations) by the mid-21st century, but subsequent (late 21st century) declines in suitable habitat, particularly at low- to mid-elevation. There is considerable spatial variability in the patterns of climatically suitable habitat. Evidence for long term changes in the distribution of vegetation types and tree species comes from statistical species models, dynamic vegetation models, and other approaches and uses the correlation between observed climate and observed vegetation distributions to model future climatic suitability. These models agree broadly in their conclusions, that future climates will be unsuitable for historically present species over significant areas of their ranges and that broader vegetation types will likely change, but the details depend greatly on climate change scenario, location within the region, and forest type. Evidence that subalpine forests are likely to undergo almost complete conversion to other vegetation types is moderately strong (relatively few studies, but good agreement), and comes from both dynamic global vegetation models that include climate and individual statistical species distribution models based on climatic variables.

New information and remaining uncertainties	The key uncertainties are primarily the timing and magnitude of future projected changes in forests, rather than the direction (sign) of changes. The rate of expected change is affected by the rate of climate change – higher emissions scenarios have higher impacts earlier in studies that consider multiple scenarios. Most impacts analyses reported in the literature and synthesized here use A1B or A2. Projections of changes in the proportion of NW pine forests where mountain pine beetles are likeliest to survive and of potential conversion of subalpine forests used A2. Statistical fire models do not include changes in vegetation that occur in the 21st century due to disturbance and other factors such as land-use change and fire suppression changes. As conditions depart from the period used for model training, projections of future fire become more uncertain, and by the latter 21st century (beyond about the 2060s-2080s), statistical models may over-predict area burned. Despite this uncertainty, the projections from statistical models are broadly similar to those from dynamic global vegetation models, which explicitly simulate changes in future vegetation. Only a few insects have had sufficient study to understand their climatic linkages, and future insect outbreak damage from other insects currently unstudied could increase the estimate future areas of forest mortality due to insects. Fire-insect interactions and diseases are poorly studied – the actual effects on future landscapes could be greater if diseases and interactions were considered more explicitly. For subalpine forests, what those forests become instead of subalpine forests is highly uncertain – different climate models used to drive the same dynamic global vegetation model agree about loss of subalpine forest, but disagree about what will replace it.
Assessment of confidence based on evidence and agreement or, if defensible, estimates of the likelihood of impact or consequence	The observed effects of climate on fires and insects combined with the agreement of future projections across modeling efforts warrants **very high** confidence that increased disturbance will increase forest mortality due to area burned by fire, and increases in insect outbreaks also have very high confidence until at least the 2040s in the Pacific Northwest. The timing and nature of the rates and the sources of mortality may change, but current estimates may be conservative for insect outbreaks due to the unstudied impacts of other insects. But in any case, the rate of projected forest disturbance suggests that changes will be driven by disturbance more than by gradual changes in forest cover or species composition. After that, uncertainty about the interactions between disturbances and landscape response limits confidence to **high** because total area disturbed could begin to decline as most of the landscape becomes outside the range of historical conditions.

CONFIDENCE LEVEL			
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Chapter 21: Northwest

Key Message Process: See Key Message #1

Key message #4/4	**While agriculture's technical ability to adapt to changing conditions can offset some of the adverse impacts of a changing climate, there remain critical sector-specific concerns with respect to costs of adaptation, development of more climate resilient technologies and management, and availability and timing of water.**
Description of evidence base	NW agriculture's sensitivity to climate change stems from its dependence on irrigation water, adequate temperatures, precipitation and growing seasons, and the sensitivity of crops to temperature extremes. Projected warming trends based on GCMs and emissions scenarios potentially increase temperature-related stress on annual and perennial crops in the summer months. Evidence for projected impacts of warming on crop yields consists primarily of published studies using crop models indicating increasing vulnerability with projected warming over 1975-2005 baselines. These models also project that thermal-stress related losses in agricultural productivity will be offset or overcompensated by fertilization from accompanying increases in atmospheric CO_2. These models have been developed for key commodities including wheat, apples, and potatoes. Longer term, to end of century, models project crop losses from temperature stress to exceed the benefits of CO_2 fertilization. Evidence for the effects of warming on suitability of parts of the region for specific wine grape and tree fruit varieties are based on well-established and published climatic requirements for these varieties. Evidence for negative impacts of increased variability of precipitation on livestock productivity due to stress on range and pasture consists of a few economic studies in states near the region; relevance to NW needs to be established. Evidence for negative impacts of warming on dairy production in the region is based on a published study examining projected summer heat-stress on milk production. Evidence for reduction in available irrigation water is based on peer reviewed publications and state and federal agency reports utilizing hydrological models and precipitation and snowpack projections. These are outlined in more detail in the traceable account for the hydrology section of the NW region chapter. Increased demands for irrigation water with warming are based on cropping systems models and projected increases in acres cultivated. These projections, coupled with those for water supply, indicate that some areas will experience increased water shortages. Water rights records allow predictions of the users most vulnerable to the effects of these shortages. Projections for surface water flows include decreases in summer flow related to changes in snowpack dynamics and reductions in summer precipitation. Although these precipitation projections are less certain than those concerning temperatures, they indicate that water shortages for irrigation will be more frequent in some parts of the region, based especially on a Washington State Department of Ecology sponsored report that considered the Columbia Basin. Other evidence for these projected changes in water is itemized in the Hydrology report for the NW chapter of this report. Evidence that agriculture has a high potential for autonomous adaptation to climate change, assuming adequate water availability, is inferred primarily from the wide range of production practices currently being used across the varied climates of the region.

New information and remaining uncertainties	Although increasing temperatures can affect the distribution of certain pest, weed, and pathogen species, existing models are limited. Without more comprehensive studies, it is not possible to project changes in overall pressure from these organisms, so overall effects remain uncertain. Some may be adversely affected by warming directly or through enhancement of their natural enemy base, while others become more serious. Uncertainty exists in models in how increasing temperatures will impact crop evapotranspiration affects future estimates of irrigation demand (from hydrology) (extracted from Hydrology uncertainty) Shifting international market forces including commodity prices and input costs, adoption of new crops, which may have different heat tolerance or water requirements and technological advances are difficult or impossible to project, but may have substantial effects on agriculture's capacity to adapt to climate change. Estimates of changes in crop yields as a result of changing climate and CO_2 are based on very few model simulations, so the uncertainty has not been well quantified.
Assessment of confidence based on evidence and agreement or, if defensible, estimates of the likelihood of impact or consequence	Confidence is **very high** based on strong strength of evidence and high level of agreement among experts. See specifics under "description of evidence" above.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
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