SUB-SECTION CLIMATE CHANGE TAB 2

Climate Change And Our Natural Resources

A Report from the Treaty Tribes in Western Washington

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CLIMATE CHANGE AND OUR NATURAL RESOURCES

A Report from the Treaty Tribes in Western Washington

Front cover images (Top left, clockwise):

Mary Leitka, Hoh tribal member, bundles cedar bark for use in weaving baskets; Quinault tribal fisherman Sam Goodman works his fishing net on the Quinault River early in the blueback, or sockeye, fishing season; the Pacific Ocean. Photos: Debbie Preston, NWIFC. Adult chum. Photo: Fran Wilshusen, NWIFC.

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PRINCIPAL MESSAGE

This report from the twenty member tribes of the Northwest Indian Fisheries Commission focuses on the impacts of climate change to our homelands, waters, and ways of life. We have a historical and contemporary relationship with the watersheds and ecosystems of the Pacific Ocean coast, the Strait of Juan de Fuca, Hood Canal, and Puget Sound. Virtually all of the resources and activities that our treaties protect—fishing, gathering, and hunting—are impacted by the effects of climate change. In this report, we present our collective concerns and an overview on the regional scale of changes in natural systems and the challenges we face:

- Interference or reduction in opportunities to exercise our treaty rights as resources decline, disappear, or are pushed out of our traditional fishing, hunting, and gathering areas due to changing environmental conditions;
- Loss of important cultural sites and infrastructure to substantial physical disturbance; and
- Negative societal outcomes due to the direct effects of climate change and the indirect effects on cultural continuity and community cohesion.

Each tribe is unique in its culture, geography, and priorities in response to climate change. Each tribe is conducting scientific research to assess impacts to the species and ecosystems of greatest concern. As individual tribes and in collaboration with our tribal and non-tribal partners, we are bolstering the resilience of natural systems and our communities to adapt to change.

EXECUTIVE SUMMARY

INTRODUCTION

Our ancestral territories stretch from the Cascade Mountains westward to the Pacific Ocean. They encompass diverse sub-regions with distinct ecosystems that face both shared and unique challenges in the face of climate change. A wide variety of plants and animals have sustained our communities for thousands of years, providing food, fuel, shelter, medicines, and materials for commerce. Our natural resources form the foundation for our spiritual life, sacred ceremonies, and community cohesion.

In the last 150 years our homelands and waters have profoundly changed. Salmon and steelhead runs that are central to our culture and economy are at a fraction of their historical populations.[1] Many lowland old-growth forests have been logged.[2] In some parts of the region, natural shorelines have been replaced by concrete[3] and hundreds of acres of shellfish beds are too polluted for harvest.[4] These changes have contributed to declines in natural resources important to our communities.[5]

Today climate change is affecting our environment and the natural resources we depend upon in countless ways. This report focuses on climate impacts to the ecosystems that play central roles in our cultures, health, identity, and lifeways. It also introduces a selection of potential responses and adaptation strategies.

CLIMATE CHANGE IMPACTS TO TRIBAL RIGHTS AND RESOURCES

In the 1850s, we entered into treaties with the U.S. government. In exchange for ceding vast tracts of land, the tribes retained the right to fish, hunt, and gather as we have always done throughout our traditional territories. Major federal court decisions have upheld our treaty rights as the law of the land.[6] The ability to exercise our rights is diminished if species productivity drops too low or if species are no longer available in our gathering, hunting, and fishing grounds.

Individual species will respond to climate change depending on their characteristics and the local conditions. A detailed analysis of the response of each species that is important to each tribe is beyond the scope of this report. Nonetheless, there are overarching concerns that have the potential to challenge our ability to exercise our treaty-reserved rights. An overview of potential threats to treaty-protected resources associated with climate change is as follows:

Declining runs of salmon and steelhead due to changes in streamflow, stream temperature, levels of dissolved oxygen, amount of sediment in streams, susceptibility to disease, ocean temperatures, ocean chemistry, timing of prey availability, prey type, and competition from warm-water species.[7]
Migration of marine fish away from historical fishing grounds as they seek out cooler ocean temperatures.[8]
Replacement of traditional fish runs with invasive species and new species that have migrated from the south.[9]
Declining populations of shellfish (both mollusks and crustaceans) due to changing ocean chemistry.[10]
Closing of shellfish harvest areas due to harmful algal blooms.[11]
Loss of traditional shellfish harvesting areas, forage fish spawning grounds, and important cultural sites to sea level rise or increased coastal erosion.[12]
Loss of water supplies for drinking and other needs due to saltwater intrusion from sea level rise, or changes to precipitation, streamflow, and/or groundwater availability.[13]
Declining populations of wildlife and birds due to habitat changes, loss of food sources, disease, and competition with invasive species.[14]
Migration of wild game and birds out of traditional hunting grounds as they move farther north or to higher elevations.[15]
Decreased plant productivity and shifts in species ranges due to heat stress, drought, invasive species encroachment, or increasing pests.[16]
Loss of traditional hunting grounds, plant gathering areas, and sacred sites due to wildfire, landslides, or invasive species.[17]
Loss of access routes to important cultural sites due to flooding, bridge damage, permanent road closures, or landslides.[18]

Changes in the timing of key life stages in a variety of species, such as the migration of salmon, fruiting of berries, or optimal time to harvest cedar bark.[19]

Negative health outcomes from poor air quality, heat stress, spread of diseases, loss of nutrition from traditional foods, and loss of opportunities to engage in traditional cultural activities.[20]

GLOBAL WARMING AND REGIONAL CLIMATE CHANGE

Global warming is the increase in global average temperatures that has been recorded around the world. Rising temperatures cause changes to long-term patterns and variability of climate factors such as wind, humidity, and the type and amount of precipitation.[21] The dominant driver is the human-caused buildup of greenhouse gases such as carbon dioxide (CO_2), methane, and other heat-trapping gases in the atmosphere, largely due to burning fossil fuels and changing land use.[22]

The impacts of climate change are already happening. These impacts are projected to continue or accelerate into the future. In the Pacific Northwest (PNW), the observed and projected trends in physical systems include the following:

- Warmer air temperatures;[23]
- Shrinking glaciers;[24]
- Less snowfall;[25]
- Decreasing summer streamflows;[26]
- Increasing winter peak flows;[27]
- Changes to timing of peak and base flows;[28]
- Higher stream and lake temperatures;[29]
- Lower levels of dissolved oxygen in streams;[30]
- More sediment delivered into, carried by, and deposited in streams;[31]
- Drying out of wetlands;[32]
- Increased frequency and size of wildfires;[33]
- Greater probability of landslides;[34]
- Warmer ocean temperatures;[35]
- Rising sea levels;[36]
- Stronger storms and greater storm surge;[37] and
- Changing ocean chemistry, including ocean acidification.[38]

Figure 1 (on page ix) illustrates the relationships among the primary changes to physical systems in our region and the types of treaty resources affected by those changes.

MOVING FORWARD

The combination of direct habitat alteration and global climate change creates a challenge for tribes in maintaining tribal lifeways and inherent sovereign rights. Tribal leaders and communities face difficult decisions in order to sustain the species and ecosystems that form the basis of our treaty rights, and to maintain our livelihoods, feed our families, and pass on our culture in the face of ongoing environmental changes.

Climate change programs that work toward sustaining tribal treaty rights and resources call for the following:

- Development of tribal capacity to assess on- and off-reservation climate change impacts and to promote resilience to these impacts at multiple scales.
- Management of natural resources using practices that incorporate climate change impacts into long-term plans.
- Coordination between tribes and among departments within each tribe, such as natural resources, planning, public health, emergency management, and community outreach.
- Partnerships between tribal and non-tribal scientists on research, modeling, and tracking environmental trends.

- Partnerships with federal, state, and local governments to work together on local concerns and solutions.
- Access to funding sources that assist in the implementation of adaptation projects that protect tribal people, homelands, and resources.

Moving forward entails efforts on two fronts. The first focuses on the reduction of harmful greenhouse gas emissions at local, regional, national, and international levels in order to prevent the worst-case scenarios of climate change impacts from occurring. Around the world, indigenous communities are promoting renewable energy sources, better energy efficiency, and the choice to leave fossil fuels in the ground.[39] The second type of effort enhances the ability of ecosystems and the communities that rely on them to adapt to changing conditions. Strategies the tribes are using to foster ecosystem resilience to environmental change center on the following:

- Developing approaches to natural resources management that include innovative solutions and consider landscape-scale processes;
- Working together to restore natural physical processes and ecological function, and to reduce existing stressors, such as water quality impairment, fish-passage barriers, noxious invasive weeds, and habitat fragmentation;
- Promoting biological diversity, protecting intact ecosystems, and creating climate refuges—areas where changes are expected to be less severe or to occur more slowly;
- Tracking changes to local environmental conditions, including the use of tribal traditional knowledge of climate patterns and ecosystems as a source for early warning signals;
- Promoting cultural resilience through tribal citizen engagement and education, especially K-12 education; and
- Sharing knowledge and expertise with tribes and non-tribal entities within and outside of the PNW.

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FIGURE 1: CLIMATE CHANGE IMPACTS AND TREATY-PROTECTED RESOURCES

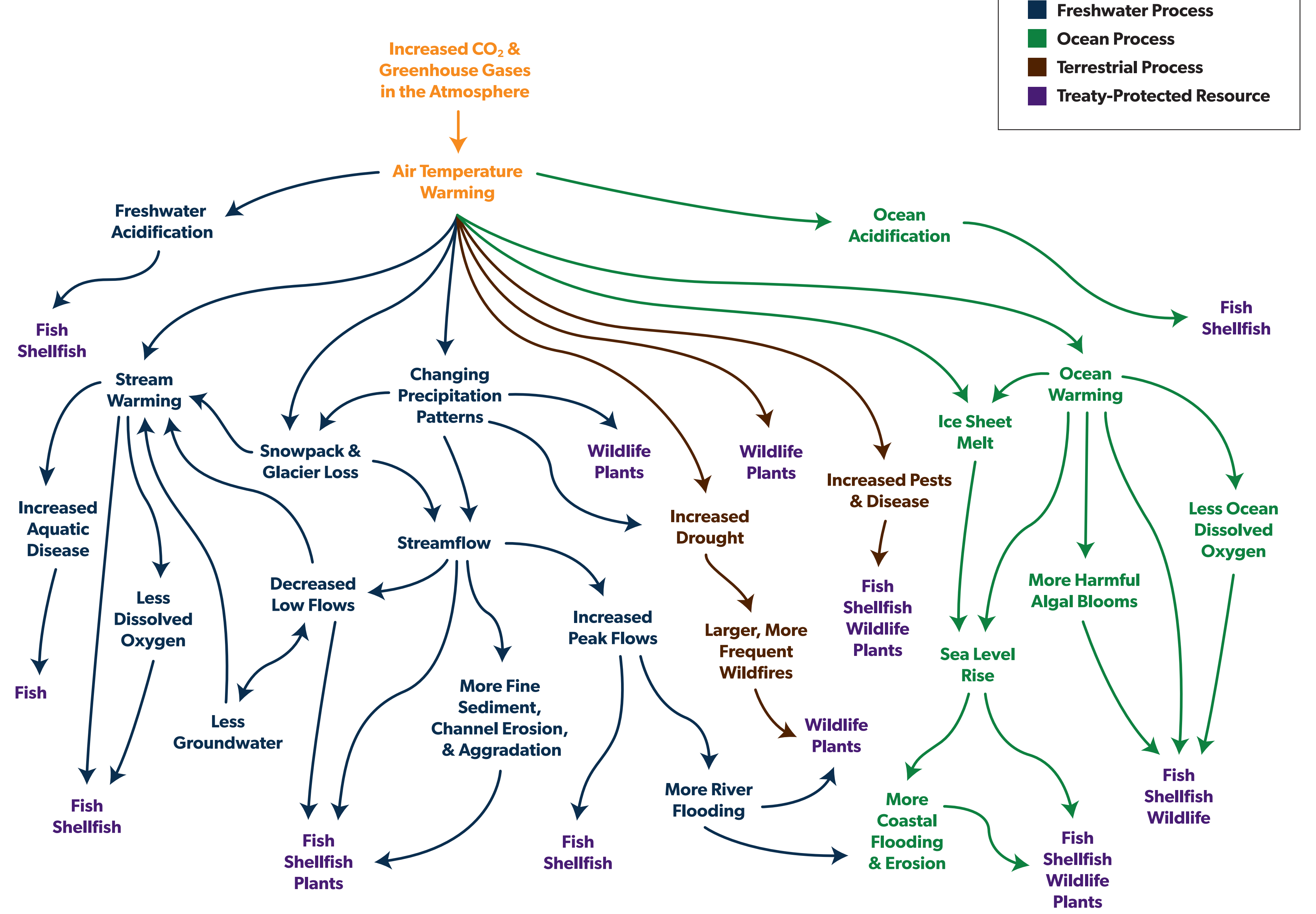

Illustration: Eliza Ghitis, Northwest Indian Fisheries Commission

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1. INTRODUCTION

This report from the treaty tribes in western Washington presents a synthesis of the impacts of climate change to the natural systems that sustain our treaty rights. Species of great importance, including fish, shellfish, terrestrial plants, and wildlife, are already facing negative effects due to climate change. These species provide food security and ensure economic survival for tribal families. They also form the foundation for our spiritual life, sacred ceremonies, traditional medicine, and community cohesion. Human activities, both past and present, have degraded ecosystem function in many areas. Our ability to protect and restore natural ecosystem function is threatened by climate change.

The document begins with background information on the treaty tribes in western Washington and our homelands (Chapter 2). After an overview of global and regional climate trends (Chapter 3), Chapters 4 through 7 describe existing and projected climate change impacts to aquatic, marine, and terrestrial environments. Also presented in these chapters is a brief summary and a discussion of factors that contribute to resilience, or the ability to adapt to change. Chapter 8 describes potential next steps for moving forward and presents a collection of research questions for consideration. The report concludes with a series of appendices that contain additional information and resources. Throughout this document, sections labeled *Taking Action* present examples of individual tribes taking action to understand or address the impacts of climate change to treaty-protected resources.

Many species are important to our communities, and a complete accounting of the climate change impacts and biological response of each one is beyond the scope of this report. Instead, we present an overview of our greatest common concerns on the regional scale. The information presented here is a synthesis of a number of notable studies that describe the impacts and future projections of climate change in the Pacific Northwest (PNW) and the implications for biological communities. This report presents a snapshot for this moment in time, but new information about climate change and the subsequent biological responses continues to emerge. For further reading, see *Appendix A: Selected References*. Additional explanations of terms used in this report can be found in *Appendix B: Glossary of Terms.*

2. THE TREATY TRIBES AND OUR HOMELANDS

The scope of this impact assessment covers the area of interest to the 20 member tribes of the Northwest Indian Fisheries Commission (NWIFC). This geographical area includes the reservations, trust lands, traditional territories, Usual and Accustomed (U&A) places, and historic hunting and gathering areas of the member tribes:

- Hoh Tribe
- Jamestown S'Klallam Tribe
- Lower Elwha Klallam Tribe
- Lummi Nation
- Makah Tribe
- Muckleshoot Indian Tribe
- Nisqually Indian Tribe
- Nooksack Indian Tribe
- Port Gamble S'Klallam Tribe
- Puyallup Tribe of Indians
- Quileute Tribe
- Quinault Indian Nation
- Sauk-Suiattle Indian Tribe
- Skokomish Indian Tribe
- Squaxin Island Tribe
- Stillaguamish Tribe of Indians
- Suquamish Tribe
- Swinomish Indian Tribal Community
- Tulalip Tribes
- Upper Skagit Indian Tribe

Additional regional tribal consortiums are actively involved in this area: the Point No Point Treaty Council and the Skagit River System Cooperative.

2.1 PHYSICAL SETTING

Our homelands extend from the Cascade Mountains westward to several miles off the Pacific coast of Washington (Figure 2). They encompass the watersheds of four different saltwater bodies: Puget Sound, Hood Canal, the Strait of Juan de Fuca, and the Pacific Ocean, each with distinct ecosystems and unique problems in the face of climate change. Over the course of millions of years, tectonic forces have given rise to the Olympic and Cascade mountains and the complex topography of the region. A sequence of Ice Age glaciations over the last 2 million years blanketed the region in ice. In the most recent glaciation, continental ice sheets spread from the north into the Puget lowlands and portions of the Olympic Peninsula, as far south as the area around present-day Centralia. At the peak of this glacial episode, the ice over what is now Seattle was 3,000 feet thick, and nearly 6,000 feet thick over present-day Bellingham.[40] Along with carving out many of the topographic features visible today, the ice also deposited vast amounts of clay, sand, gravel, and boulders. The last glaciation ended about 10,000 to 12,000 years ago, leaving glaciers to persist only in the high mountains of the Olympics and Cascades. During the last glaciation, sea levels were hundreds of feet lower than they are today. Over the course of thousands of years, the melting ice sheets released the water that had been locked up back to the world's oceans. Sea levels in our region have been relatively stable for about 6,000 years.

Figure 2: The 20 member tribes of the NWIFC in western Washington. Map: Ron McFarlane, NWIFC.

Today the climate of the region is temperate, with relatively cool, dry summers and wet winters that are mild at low elevations. The elevation of this area ranges from sea level to over 14,000 feet. The great variety of topographic relief causes temperature and precipitation to vary between and within each watershed. The average maximum temperature in July ranges from 65°F near the Pacific coast to 80°F in the Cascade Mountain foothills. Average minimum temperatures in January range from 20°F at higher elevations to 38°F along the Pacific coast. Precipitation ranges from 24 inches per year to over 120 inches per year in the mountains. In general, most precipitation occurs between October and March and this wet period has a dominant influence on the hydrology of the region.

2.2 ECOLOGICAL SETTING

The ecosystems of western Washington support a wide variety of plant and animal species that we have always depended on for food, medicine, tools, crafts, ceremony, and commercial endeavors. Some of the common plants and animal species that we use are listed below. For the scientific names of these and other species mentioned in this report, please see *Appendix C: Common and Scientific Names of Species.*

- Salmonid fish species including chinook salmon (both fall and spring/summer runs), sockeye salmon (including lake-based kokanee), chum salmon, pink salmon, coho salmon, steelhead/rainbow trout, cutthroat trout, bull trout, and Dolly Varden trout.
- Other finfish species including Pacific herring, sand lance, surf smelt, sardines, Northern anchovy, hooligan (also called eulachon or smelt), mackerel, Pacific halibut, black cod (sablefish), Pacific cod, Pacific whiting, lingcod, Pacific lamprey, sturgeon, flatfish, rockfish, grunters, sculpins, and many others.
- Mollusks such as native Olympia and introduced Pacific oysters, butter clam, Manila clam, razor clam, horse clam, littleneck clam, California mussel, blue mussel, geoduck, rock scallop, pinto abalone, and gumboot chiton.
- Crustaceans such as Dungeness crab, shrimp, spot prawn, crawfish, and barnacle.
- Other marine organisms including Pacific octopus, squid, sea urchin, anemone, sea star, sea cucumber, eelgrass, seaweed, and kelp.
- Culturally important marine mammals, such as gray whales, orcas, harbor seals, and northern fur seals.
- Terrestrial mammals and birds such as elk, deer, mountain goat, black bear, cougar, river otter, beaver, fisher, snowshoe hare, turkey, and various waterfowl.
- Tree species for traditional and commercial uses include western red cedar, yellow cedar, Douglas fir, lodgepole pine, western hemlock, silver fir, western white pine, Sitka spruce, red alder, black cottonwood, and big leaf maple.
- Many types of plants and fungi used for food, tools, baskets, nets, medicines, cultural ceremonies, and other traditional practices. Examples include camas root, nodding onion, skunk cabbage, oceanspray, Pacific ninebark, bear grass, and various berries, nuts, herbs, ferns, lichen, and mushrooms.

2.3 THE CHANGING LANDSCAPE

In the last 150 years, the landscapes of western Washington have undergone significant changes. Early settlers from Europe and the East Coast of the United States put pressure on traditional fishing grounds while early logging activities reduced hunting grounds and profoundly changed watershed structures and functions. Habitat was lost and degraded as land was cleared for railroads, agriculture, and residential development. With these endeavors came many ecosystem modifications that continue to this day, including the draining and filling of salt marshes and wetlands; the construction of dams, levees, and revetments; installation of shoreline and stream bank armoring; the straightening and diversion of streams; the removal of downed wood and logjams from streams, the logging of old-growth forests; and the introduction of paved surfaces on prairies and meadows.

Since 1889, Washington state has lost 70 percent of the estuarine wetlands, 50 percent of the riparian habitat, and 90 percent of the old-growth forest.[41] In Puget Sound, only 31 percent of the approximately 2,470 miles of shoreline has not been modified in some way. The freshwater tidal and brackish marshes of Puget Sound have seen a loss of 93 percent—in the Duwamish and Puyallup rivers nearly all of this type of habitat has disappeared.[42] In Grays Harbor on the Pacific coast, 37 percent of the shorelines were modified.[43]

Climate change impacts are occurring within the context of landscape modification that has already degraded function in many ecosystems within our homelands. In some cases, existing impacts compound the negative effects of climate change. For an overview of the ways climate change interacts with landscape modification, please see *Section 7.2: Interactions with Existing Ecological Stressors.*

2.4 TRIBAL SOVEREIGNTY AND TREATY RIGHTS

The impacts of climate change to our natural resources create a challenge for maintaining our treaty rights. When the tribes in what is now known as western Washington ceded vast tracts of our lands in treaties with the United States government in the 1850s, we reserved certain rights to protect our way of life. The treaties specifically and purposefully protected our ability to continue to gather, hunt, and fish on the reservations and outside the reservations—the areas referred to as "usual and accustomed places" for aquatic animal life and "open and unclaimed lands" for hunting and gathering.[44] The rights secured by the treaties are the supreme law of the land, as established by Article VI Section 2 of the U.S. Constitution, and have been consistently upheld by federal courts. These rights cannot be legally curtailed by blocking access nor by undermining the viability of species through habitat destruction. The treaties also do not have any species limitations. We retained the right to harvest any species whether or not they were harvested historically.[45]

Today, tribes provide leadership and participate in nearly all aspects of natural resources management in our region. Tribal leaders and communities face difficult decisions in order to:

- Sustain the species that form the basis of our treaty rights;
- Support species and habitat adaptation to ongoing changes to air, land, and water; and
- Maintain our livelihoods, feed our families, and pass on our culture in the face of environmental loss and change.

3. GLOBAL WARMING AND CLIMATE CHANGE

Around the globe, the burning of fossil fuels, deforestation, cement production, wetland conversion, raising livestock, and other human activities have added greenhouse gases (GHGs) into the atmosphere, leading to warming of the air and oceans. Carbon dioxide (CO_2) is the dominant GHG emitted by human activities, but methane is also a potent GHG, along with nitrous oxide and sulfur hexafluoride. The number of CO_2 molecules in the atmosphere has risen from 280 parts per million (ppm) during the Industrial Revolution to around 400 ppm today.[46] The current CO_2 levels are higher than they have been in 800,000 years and likely the highest they have been in the past 20 million years, based on the geological record.[47]

The National Academies of Science states that "Climate change is occurring, is caused largely by human activities, and poses significant risks for—and in many cases is already affecting—a broad range of human and natural systems."[48]

3.1 OBSERVATIONS OF A WARMING WORLD

Global warming is the increase in global average temperatures in the air and oceans. It contributes to the suite of effects known as climate change. Climate change refers to a significant shift in long-term patterns and variability of climate factors such as temperature, precipitation, humidity, and wind over the course of decades, centuries, or millennia. The science of global warming is well established, as confirmed by data from multiple independent sources around the world.[49] Both direct observations since the 1950s and climate reconstructions from the geological record unequivocally point to changes in the climate system over the last century.[50] Many of the impacts described in the chapters below for the PNW region have also been observed globally. The effects of a changing climate are seen in global ocean temperatures, sea levels, air temperatures, and changing patterns of atmospheric circulation.[51] The CO_2 in the atmosphere is dissolving into the world's oceans and changing the chemistry of sea water.[52]

The year 2015 was the warmest on record since 1880, by the largest margin ever recorded, according to two separate analyses of global climate data by the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA). The 16 warmest years on record have occurred since 1998 and 15 of the 16 warmest years on record have occurred since 2001.[53] The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) states that global averages of land and ocean surface temperatures from multiple datasets show an increase of 1.5°F (0.85°C) between 1880 and 2012, with an increase of about 1.0°F (0.6°C) occurring in the last three decades.[54] The majority of the observed warming since the 1950s is due to human activities.[55] While a warming of 1.5°F may not seem like much, the geological record shows that average global temperatures have been stable over long time periods. Even seemingly small shifts in global average temperature correlate to major environmental changes. For example, at the end of the last ice age that covered our region in thousands of feet of ice, the average global temperatures in the low mid-latitudes were 7 to 11°F colder than today.[56]

While the planet has been warming steadily over time, climate variability can alter the rate of warming for a period of years to decades. Climate variability is an inherent characteristic of the climate system due to the variable nature of interactions between the components (such as the ocean and atmosphere), and variations in external forcing, both natural (such as solar radiation) and human-caused (such as GHGs).[57] Variability in the climate and the random patterns inherent in atmospheric circulation will continue in the future. These factors contribute to uncertainty in climate projections for temperature and precipitation in North America, especially at middle and high latitudes during winter.[58] In addition, climate change will not occur evenly or at the same rate across the landscape. Some climate types will disappear while new types emerge. The rate of change in climate variables will vary across systems and different locations.[59]

The IPCC AR5 confirmed a number of the projections presented in previous assessments.[60] For example, the first IPCC assessment in 1990 projected that higher global temperatures would result in more extreme weather events, in part stemming from changes to the hydrologic cycle with variable effects across the globe. Although extreme events have multiple causes, climate change has played a role in the increasing frequency and intensity of heavy precipitation events, droughts, heat waves, and extreme cold events.[61] In 2013, 41 separate weather disasters across the world each caused more than $1 billion in damages.[62] In 2014, the United States alone experienced 8 weather and climate disaster events that individually exceeded $1 billion in losses. Overall they caused 377 deaths and $110 billion in damages.[63] In addition, many previously predicted impacts are happening sooner and more quickly than expected, such as sea level rise and the melting of the Greenland and Antarctic ice sheets.[64] More information on global impacts can be found in *Appendix A: Selected References*. For more details on the processes involved in global and regional climate projections, see *Appendix D: An Overview of Climate Models.*

3.2 PACIFIC NORTHWEST CLIMATE TRENDS

In the PNW, average air temperatures increased about 1.3°F between 1895 and 2014.[65] The greatest increases were seen in the winter and at lower elevations.[66] Natural variability plays a strong role in air temperature and annual precipitation trends, but the extent of the influence of natural variability in the long term is a subject of debate among scientists.[67] While precipitation naturally varies between years and decades, heavy rainfall events have increased in frequency and intensity beyond the natural variability. For example, the extreme rainfall events that fall in the top 1 percent of all daily events increased in frequency by 12 percent in the PNW during the 20th century.[68]

The local climate variations on the yearly and decadal basis are due in large part to regional climate patterns known as the Pacific Decadal Oscillation (PDO) and the El Niño-Southern Oscillation (ENSO). The PDO is a 20- to 30-year cycle that tends to produce warmer and drier winters in the warm phase and colder and wetter winters in the cool phase in the PNW. In our region, El Niño years tend to produce warmer and drier winters, while the opposite phase, known as La Niña, produces cooler and wetter winters. If ENSO and PDO fall into phase, temperature and precipitation extremes are likely to follow. These regional annual and decadal climate cycles can temporarily mask climate change effects during cooler phases, but the ensuing warming phases will then intensify impacts. Because of these natural climate variations, accurate tracking of the PNW climate change signal requires a time frame covering many decades.

Changes to the PNW climate, along with the increase in CO_2 in the atmosphere and oceans, lead to a host of impacts across the region. These impacts are described in detail in the subsequent chapters of the report. In summary, the observed and projected climate trends in the PNW include the following:

- Warmer air temperatures;[69]
- Shrinking glaciers;[70]
- Less snowfall;[71]
- Decreasing summer streamflows;[72]
- Increasing winter peak flows;[73]
- Changes to timing of peak and base flows;[74]
- Higher stream and lake temperatures;[75]
- Lower levels of dissolved oxygen in streams;[76]
- More sediment delivered into, carried by, and deposited in streams;[77]
- Drying out of wetlands;[78]
- Increased frequency and size of wildfires;[79]
- Greater probability of landslides;[80]
- Warmer ocean temperatures;[81]
- Rising sea levels;[82]
- Stronger storms and greater storm surge;[83] and
- Changing ocean chemistry, including ocean acidification.[84]

3.3 REGIONAL CLIMATE PROJECTIONS

Regional climate models suggest continued changes across the PNW due to global warming. Future climate projections are based on the GHG concentrations already in the atmosphere along with a range of future GHG emission scenarios and the natural variability of the global climate. For more details on how projections are modeled, see *Appendix D: An Overview of Climate Models.*

Air temperatures in the PNW are projected to rise 4.3 to 7.1°F by the middle of the 21st century as compared to what they were at the end of the 20th century based on a high or "business as usual" GHG emission scenario.[85] By the last decades of the 21st century, the average annual temperature will rise even more, with the greatest increase seen in the summer.[86] Projections for the amount of average annual precipitation vary, with some models projecting increases and some projecting decreases. Nonetheless, summers are generally projected to be as much as 30 percent drier by the end of the century.[87] Extreme rainfall events are projected to be more severe—the highest daily rainfall for a given year is projected to increase by 4 to 30 percent by the mid-21st century, depending on the model.[88]

3.4 OVERVIEW OF IMPLICATIONS FOR TREATY-PROTECTED RESOURCES

Changes to climate conditions such as temperature and precipitation drive changes to physical systems that interact with one another in many cases. These changes in environmental conditions drive biological responses that also interact with one another. Organisms respond to environmental change that threatens their survival by altering their behavior, changing the timing of life phases, moving into more favorable locations, or adapting though evolution.[89] Each species and even local populations within a species may respond differently to climate change depending on their sensitivity to environmental change and their ability to adapt. Threats to the persistence of any species are particular to each individual population and will depend on the local conditions.

Species must be able to keep pace with the velocity of climate change, which is how fast climate conditions change.[90] The rate that species must shift their range in order to maintain suitable habitat depends on local climate velocities.[91] Where the rate of change is too rapid, it will be difficult for plants, animals, and human communities to adapt. How well a species is able to persist amid changes to environmental conditions will also depend on its ability to move through the landscape and to take advantage of local variations in conditions.[92] Biological dispersal, or the movement of individuals, seeds, or spores, can affect genetics, species distribution, and population dynamics. Dispersal not only depends on the characteristics of the species in question, but also on the presence of barriers, both natural (e.g. waterfalls) or artificial (e.g. dams). Species interactions such as competition and predator-prey relationships also strongly influence the ways climate change influences species distribution, population decline, and the composition of assemblages.[93]

Although detailed projections of individual biological responses to environmental change are beyond the scope of this report, an overview of the some of the significant threats to treaty-protected resources due to climate change is as follows:

Declining runs of salmon and steelhead due to changes in streamflow, stream temperature, levels of dissolved oxygen, amount of sediment in streams, susceptibility to disease, ocean temperatures, ocean chemistry, timing of prey availability, prey type, and competition from warm-water species.[94]

Migration of marine fish away from historical fishing grounds as they seek out cooler ocean temperatures.[95]

Replacement of traditional fish runs with invasive species and new species that have migrated from the south.[96]

Declining populations of shellfish (both mollusks and crustaceans) due to changing ocean chemistry.[97]

Closing of shellfish harvest areas due to harmful algal blooms.[98]

Loss of traditional shellfish harvesting areas, forage fish spawning grounds, and important cultural sites to sea level rise or increased coastal erosion.[99]

Loss of water supplies for drinking and other needs due to saltwater intrusion from sea level rise, or changes to precipitation, streamflow, and/or groundwater availability.[100]

Declining populations of wildlife and birds due to habitat changes, loss of food sources, disease, and competition with invasive species.[101]

Migration of wild game and birds out of traditional hunting grounds as they move further north or to higher elevations.[102]

Decreased plant productivity and shifts in species ranges due to heat stress, drought, invasive species encroachment, or increasing pests.[103]

Loss of traditional hunting grounds, plant gathering areas, and sacred sites due to wildfire, landslides, or invasive species.[104]

Loss of access routes to important cultural sites due to flooding, bridge damage, permanent road closures, or landslides.[105]

Changes in timing of key life stages in a variety of species, such as the migration of salmon, fruiting of berries, or optimal time to harvest cedar bark.[106]

Negative health outcomes from poor air quality, heat stress, spread of diseases, loss of nutrition from traditional foods, and loss of opportunities to engage in traditional cultural activities.[107]

4. FRESHWATER AQUATIC ENVIRONMENTS

4.1 CHAPTER SUMMARY

Traditions of fishing are essential to our tribal culture. Climate change threatens salmon, trout, and other aquatic species by affecting their growth, reproduction, susceptibility to disease, and timing of key life changes. Individual species and even distinct runs of the same salmonid species will respond uniquely depending on their level of tolerance to changing conditions. Nonetheless, a number of the factors that have historically limited salmon and trout populations are worsened by climate change, including changes in streamflow, increased stream temperature, channel instability, excess fine sediment loading, and lack of habitat complexity.[108] These legacy impacts in combination with climate change have repercussions for the natural systems that we rely upon for subsistence, economy, culture, and spiritual identity. The ability of freshwater systems to adapt to climate change is improved where natural processes can promote optimal ecosystem health and function.

The key impacts of climate change to freshwater systems include the following:

- Decreasing snowpack and the melting of mountain glaciers;[109]
- Decreasing summer streamflows, increasing winter peak flows, and changes to the timing and profile of annual hydrographs;[110]
- Warming stream temperatures;[111]
- Increased sediment loads in streams;[112]
- Changes to wetland hydrology;[113]
- Altered aquatic food webs;[114] and
- Conditions that favor non-native, invasive species.[115]

4.2 PEOPLE OF THE SALMON

The importance of freshwater systems to our lives cannot be overstated. Archaeological evidence suggests that salmon were used consistently by indigenous peoples in the PNW for the last 7,500 years despite the natural disturbances that periodically put pressure on salmon populations.[116] Today, salmon and trout are valuable sources of nutrition, income, and cultural continuity for our communities. Salmonids are rich in essential fatty acids, protein, and nutrients associated with reduced risk of heart disease, diabetes, and cancer. Fishing also provides a source of spiritual fulfillment and an opportunity to connect with family, friends, the land, and the water.[117] In traditional belief systems, water itself is sacred and connects humans, animals, plants, and the land through the continuous flow of the hydrological cycle.[118]

A Skokomish tribal fisherman hauls his net during a fishery in Hood Canal. Photo: Tiffany Royal, NWIFC.

“It’s not just fish survival, but our own.”

Terry Williams, Treaty Rights Office Commissioner, Tulalip Tribes and NWIFC Commissioner

Salmon and trout populations have declined from historical levels throughout western Washington. Although direct counts are not available, it is estimated that native salmonid runs are less than 10 percent of the runs in the late 1800s.[119] Under the Endangered Species Act (ESA), Puget Sound spring chinook, Lake Ozette sockeye, and Hood Canal/Strait of Juan de Fuca summer chum were listed as threatened in 1999. Steelhead were listed as threatened under the ESA in 2007, and bull trout were listed as threatened by the U.S. Fish and Wildlife Service in 1999.

4.3 SNOWPACK AND GLACIERS

Snowpack and glaciers act as storage for water that is released gradually with melting in the spring and summer. The climate change impacts to snowpack and glaciers are closely linked to stream temperatures, streamflows, and sediment dynamics. These aspects of climate change impacts to freshwater systems are discussed below in *Section 4.4: Stream Temperatures, Section 4.5: Streamflow Patterns,* and *Section 4.6: Sediment in Streams.*

As snowpack and glaciers decline due to climate change, rivers will see lower flows and higher stream temperatures in the summer, during critical salmonid life stages.[120] With the reduced area of snow accumulation, increased winter precipitation in the form of rain on the exposed landscape will lead to more runoff and increasing winter peak flows.[121] Less summer precipitation and loss of snowpack may reduce availability of water at the same time that human population growth creates greater demand for water. This demand can further reduce streamflows unless minimum instream flows are protected. Lower summer flows will also have an impact on hydropower generation, sediment transport, and nutrient loading in streams.

Observed and Projected Changes

The area and depth of snow accumulation are declining in western Washington. Warming trends are the main driver, but regional climate variability also plays a role.[122] Snowpack quantity is commonly represented by the snow-water equivalent (SWE), or the amount of water held in the snowpack on April 1. In the western U.S., the SWE decreased by approximately 20 percent between 1950 and 2000.[123] The largest declines in snow accumulation were in areas where winters are mild, such as the Cascade Mountains.[124]

Warmer temperatures melt more snow earlier in the spring and cause more precipitation to fall as rain instead of snow. An example of the effects of warming air temperatures on snowpack can be seen in the extremely low snowpack of the winter of late 2014 and early 2015. Although total precipitation was at near normal levels, record-breaking temperatures from October 2014 to March 2015 were 4.7°F above the 20th century average. More precipitation fell as rain rather than snow in the zones where snow usually accumulates during winter. By May 15, 2015, Governor Jay Inslee declared a statewide drought emergency and the average snowpack in western Washington was at 10 percent of the median value for 1981 to 2010, with the lowest levels measured in the Olympic and Central Puget Sound basins.[125] Although the causes of this event are tied to regional climate variability, the results offer an indication of future snowpack conditions in a warmer PNW.

With few exceptions, glaciers are diminishing throughout the mountain ranges of Washington. Glaciers are decreasing in number, surface area, depth, and surface mass balance (the difference between snow accumulation and loss). In Olympic National Park, glacier surface area decreased 34 percent from 1980 to 2009.[126] The Anderson Glacier, one of the sources of the Quinault River, lost more than 90 percent of its surface area between 1927 and 2009 (Figure 3).[127] The glacier has essentially lost its ability to survive without its zone of accumulation of snow and ice. The Blue Glacier, which drains into the Hoh River, retreated about 325 feet (100 m) between 1995 and 2006.[128]

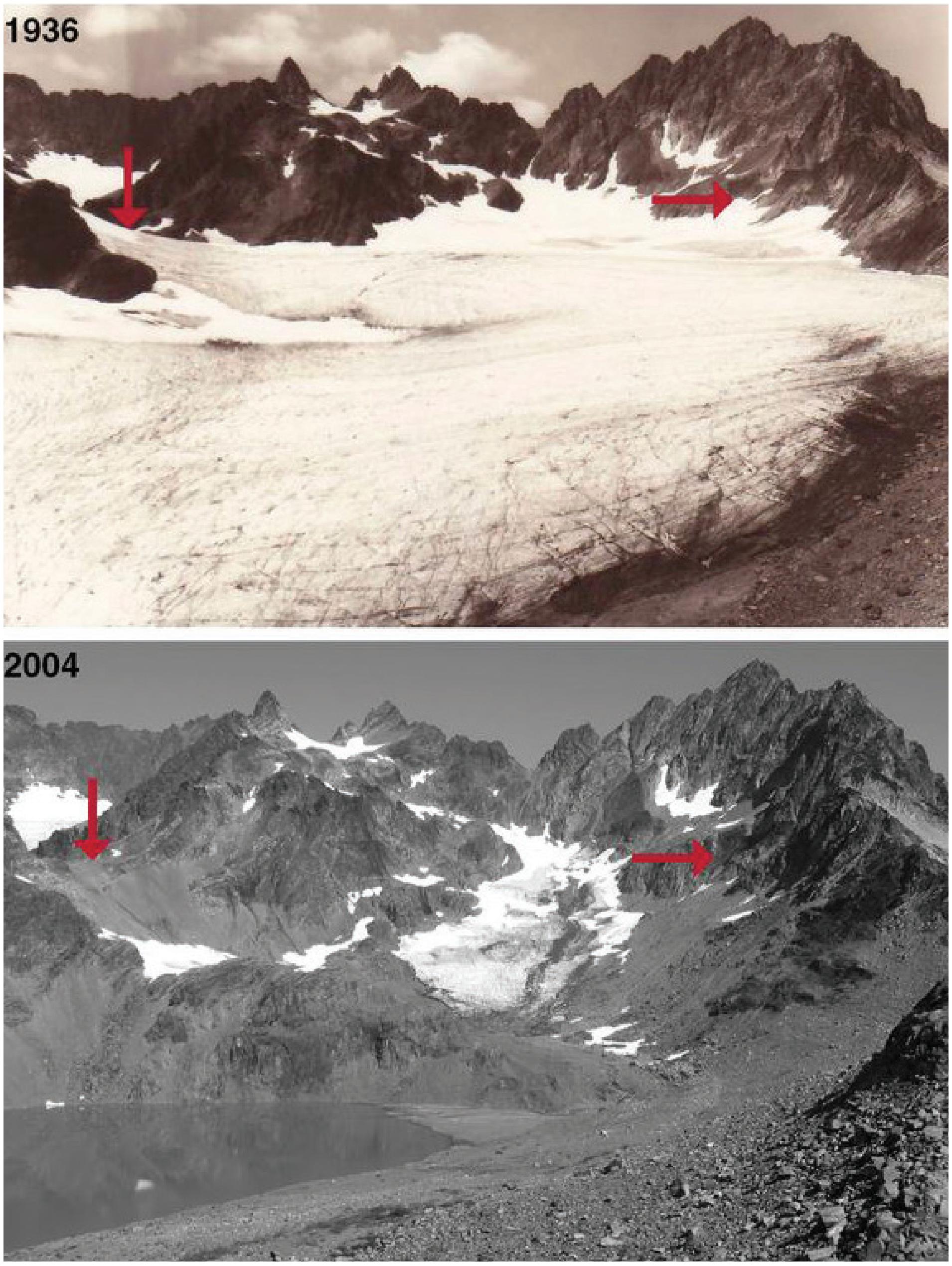


Figure 3: Photographs of Anderson Glacier show its significant retreat in the 20th century. The arrows mark the edges of the glacier in 1936 in both images. Source: ONP 2015 (1936: Asahel Curtis, 2004: Matt Hoffman, Portland State Univ.)[129]

In the North Cascades National Park Service Complex, glaciers have shown substantial losses.[130] The glaciers of Mount Baker, which feed the Skagit and Nooksack rivers, have receded by an average of 957 feet between 1993 and 2013.[131] In the Skagit River basin, total loss of glacier area since 1900 is estimated at around 50 percent.[132] The Nooksack Indian Tribe monitored glacier ablation of the Sholes Glacier on Mount Baker in the Nooksack River basin in 2015. The tribe measured 12.5 feet of total ice ablation from mid-July to mid-September, with a daily ablation rate as high as 8.3 inches.[133] The amount of ablation was greater than the amount of accumulation by the equivalent of 11 feet of SWE, the greatest of any season over the last 31 years.[134]

Projected increases in air temperature will result in a shorter snow season as more precipitation falls as rain and snow melts earlier in the spring. Average spring snowpack in Washington state is projected to decline by 65 percent by the 2080s for a moderate GHG emissions scenario.[135] In a study of four Puget Sound watersheds (the Cedar, Green, Tolt, and Sultan), the largest SWE reduction was projected for lower elevations. For example, the low-lying valleys of the Upper Green and Cedar watersheds were projected to see 90 percent less SWE starting in the 2020s. By the 2080s, the SWE is projected to completely disappear at high elevations for all four watersheds. Peak spring snowmelt is projected to occur three weeks earlier by the 2040s and six weeks earlier by the 2080s for these basins.[136] Projections for the Middle Fork Nooksack River basin show a 69 percent and 87 percent decrease of ice extent by the end of the century for a moderate and high GHG emissions scenario, respectively. In the North Fork Nooksack River basin, which has the largest area of glacial ice within the Nooksack River basin (12 square miles), ice extent is projected to decrease by approximately 66 percent and 88 percent for moderate and high scenarios, respectively, by 2099.[137]

4.4 STREAM TEMPERATURES

As air temperature rise, so do stream temperatures. Warmer stream temperatures threaten salmonids, which are cold-water species with narrow temperature requirements in all life phases. If stream temperatures warm by even a few degrees above their optimal range, salmonids can experience negative effects unless they can adapt or find thermal refugia, the cooler zones within the channel. The species that are most vulnerable are those that spend the most time in fresh water before out-migration, such as chinook, coho, steelhead, and bull trout.[138] As cold-blooded fish, salmonids experience higher metabolic rates in warm water. They can grow more quickly or they can experience reduced growth if there is not enough food available.[139] Faster growth rates can leave them physiologically ready for out-migration before the streamflows are high enough to carry them downstream.[140] Temperatures in the range of 70 to 75°F (21 to 24°C) interfere with the physiological transition from fresh water to salt water and result in greater vulnerability to predators.[141]

High water temperatures leave salmonids with greater susceptibility to diseases and parasites. *Columnaris* and freshwater ich, diseases lethal to salmonids, are more prevalent in warmer water.[142] Salmonids also have greater susceptibility to the effects of toxic chemicals in the water when temperatures are high.[143] Warmer water can hold less dissolved oxygen (DO), which is critical for the health of fish and other aquatic organisms. Rising stream temperatures also accelerate aquatic food web processes and decomposition, which further lowers DO. The combination of these processes can create hypoxic zones that are lethal to aquatic life. DO levels can also affect growth, swimming behavior, and susceptibility to disease and other environmental stressors.[144] DO in streambed gravel is critical for salmonid egg and embryo development and survival.[145] DO levels in the gravel may be lower than in the water column, especially in locations with low stream slope, fine channel bed sediment, or where there are multiple, superimposed redds.[146]

Warmer summer stream temperatures may alter aquatic food webs and can create favorable conditions for non-native fish species that compete with salmonids for habitat and prey.[147] High stream temperatures can also create barriers that salmonids will not cross. For example, water temperatures in the White River, a tributary to the Puyallup River, reached 72°F in early July 2015. Russ Ladley, Resources Protection Manager for the Puyallup Tribe of Indians, explained that, "if the water in the lower river is too warm, it's likely [that] fish will delay entry or go somewhere else. Even if some fish do try to head upstream, they might die before they spawn because of the warm water."[148] Thermal barriers can limit connectivity of habitat and reduce fish population resilience to environmental change.

Observed and Projected Changes

Stream temperatures in many western Washington locations regularly exceed the optimal temperatures for fish in all life phases, particularly during summer. Temperatures in PNW streams warmed by about 0.4°F (0.22°C) per decade from 1980 to 2009.[149] Air temperature was the dominant driving force in the long-term stream temperature trends, but low streamflow accounted for 52 percent of the change during the summer.[150] Human modifications to watersheds also play a role. Removal of streamside forests, channel straightening, runoff from impervious surfaces in the watershed, and subsequent changes to channel geometry all contribute to elevated temperatures. Studies in the South Fork Nooksack River suggest that legacy impacts could have caused an increase in stream temperature of 2.9°F (1.6°C) in addition to the impacts of climate change.[151]

Projected conditions of increased air temperatures, lower streamflow, and loss of ice and snow all point to warmer stream temperatures. Below is a summary of projections for stream temperatures in the PNW:

- Compared to the average stream temperature from 1993 to 2011, mean August stream temperatures in western Washington are projected to increase 2.5°F (1.4°C) on average by the 2040s and 4.25°F (2.4°C) by 2080 for a moderate GHG emissions scenario.[152]
- Warmer air temperatures will result in 16 percent more stream locations with weekly summer stream temperatures in excess of 67°F, which is stressful to salmonids, by the 2080s under a moderate GHG scenario (Figure 4).[153] For example, summer stream temperatures in the South Fork Nooksack are projected to increase 12.6°F (7°C) by the 2080s for a moderate GHG emissions scenario. River temperatures may reach 77.2°F (25.1°C), which is above the lethal limit for adult spring chinook.[154]
- The length of time that rivers exceed salmonid thermal thresholds will be longer. By the 2080s, many stream locations will exceed salmonid temperature tolerances for the entire summer—even locations that did not exceed these temperatures in the past.[155]
- Temperature increases are greatest at low elevations, where rivers are slower and wider, and where air temperatures are warmer.

4.5 STREAMFLOW PATTERNS

Salmonids and other aquatic organisms are adapted to seasonal cycles of streamflow to which they synchronize their life phases. Disruption of the timing and quantity of water in streams can have repercussions for these species and for the tribes that rely upon them.[156] Large annual peak flows are correlated with low chinook salmon productivity.[157] The Stillaguamish Tribe has found a correlation between increasing annual peak flows and low juvenile chinook survival rates (Figure 5).[158] This is likely due to harmful effects to egg incubation and survival. Greater frequency and magnitude of flood flows also increase the amount of sediment transported by the stream, subjecting salmonid redds to suffocation and entombment by fine sediment (discussed in *Section 4.6: Sediment in Streams*).[159] Heavier storm events can also increase the discharge of pollution from runoff into streams, including pesticides, herbicides, and excess nutrients.[160]

Increasing peak flows can also wash out salmonid redds. For example, chum bury their eggs just below the typical depths of streambed scour. A small increase in scour depth due to higher flows can wash out eggs before the fry emerge.[161] Higher winter flows can also wash juvenile salmon downstream before they are ready, forcing them to compete for limited habitat.[162]

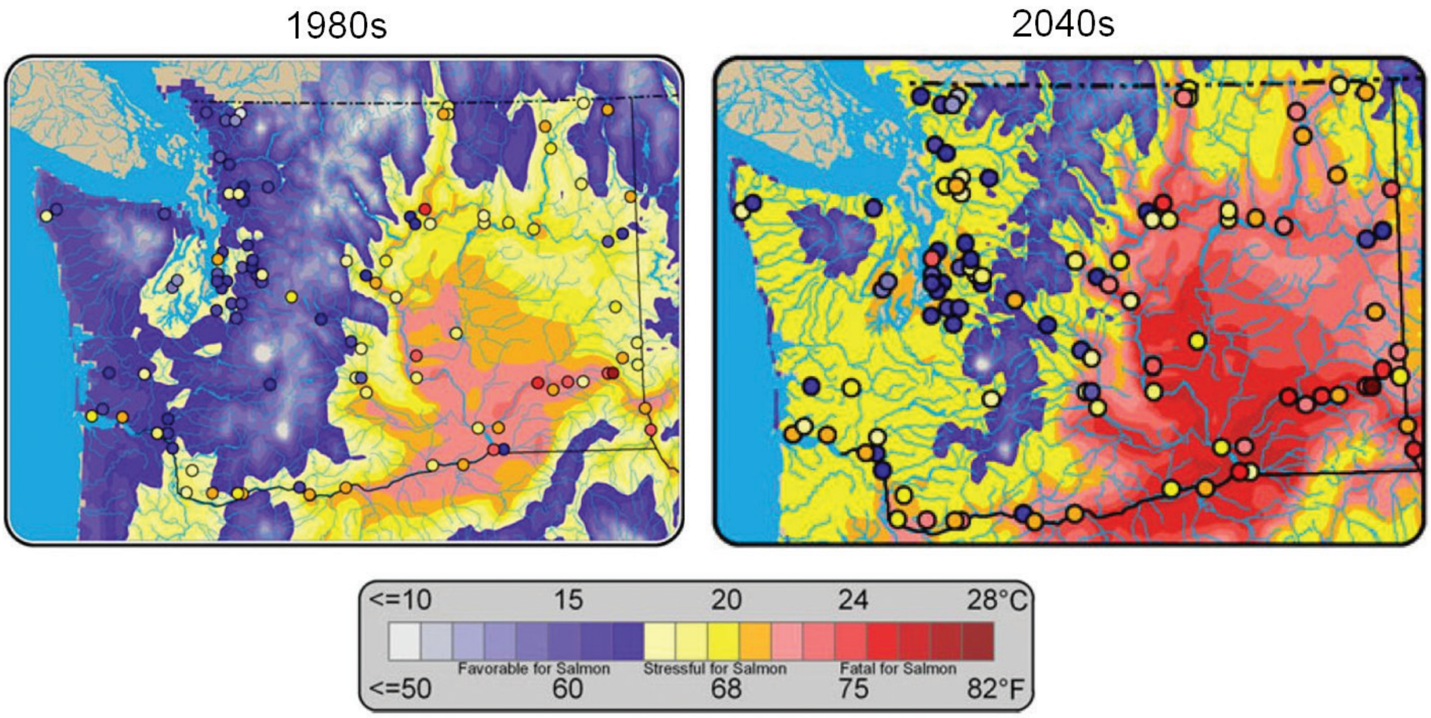


Figure 4: Average summer temperatures and salmon thresholds as observed in the 1980s (left) and projected for the 2040s under a moderate GHG emission scenario (right). The dots represent water temperature monitoring sites and the continuous color represents air temperatures. Source: Mantua et al. 2010.

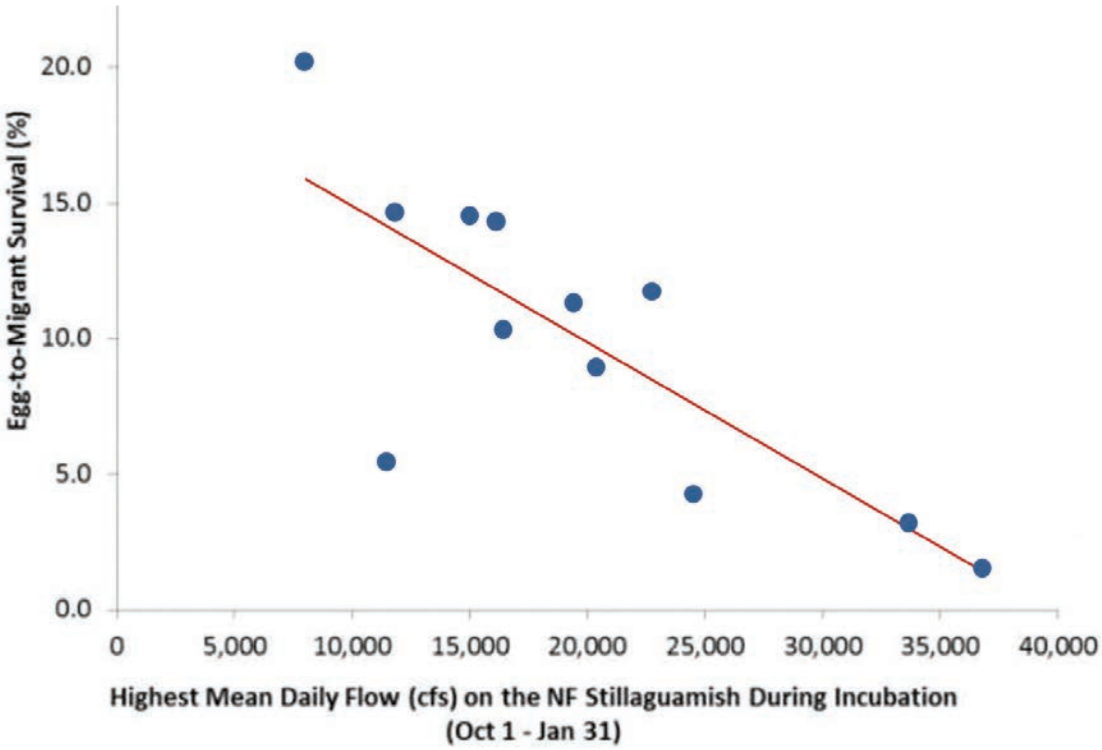


Figure 5: Egg-to-migrant survival for juvenile chinook in the Stillaguamish River under a range of annual peak flow magnitudes. Source: Stillaguamish Tribe of Indians.

Lower summer streamflow reduces water availability for aquatic habitat, fish hatcheries, irrigation, and drinking water. Available habitat is reduced and fish passage is limited.[163] Low flows during spawning season also force fish to build their spawning redds in the main channel of the river where they are more vulnerable to scour during winter peak flows.[164] Extremely low flows in the Dungeness River in August 2015 posed a challenge for salmon migrating upstream, especially chinook, whose large body size requires deeper water. The Jamestown S'Klallam Tribe partnered with the Washington State Department of Fish and Wildlife (WDFW) and Washington Conservation Corps to construct temporary channels and pools in the river bed to enable fish passage. Simultaneously, low flows in the Sol Duc River of the Quillayute River system required that WDFW and the Quileute Tribe take action to help fish access their spawning grounds.

Lower water levels can disconnect streams from their floodplains, restricting fish access to off-channel habitat. Less water availability can also cause tributaries that are important for salmonid rearing to lose all surface flow and go dry. When all flow goes below the surface, the stream loses connectivity to the rest of the river system and fish can become stranded. Lower flows can reduce survival of juvenile salmon.[165] Slower flows increase the time of out-migration, exposing the juveniles to predation. Low flows also concentrate pollutants and exacerbate water quality impairments in streams.[166] Less water increases water temperatures, which reduces dissolved oxygen and promotes the spread of disease in aquatic organisms (discussed in *Section 4.4: Stream Temperatures*).[167]

Lower streamflows also have the potential to impact salmon and steelhead hatcheries. These hatcheries play a role in the exercise of tribal treaty rights by mitigating the loss of natural fish production due to habitat degradation and other human-caused disturbances. In Puget Sound, hatcheries contribute 70 to 80 percent of the coastal salmon and steelhead catch.[168] Changes to freshwater systems can affect hatchery operations in multiple ways, from reducing the quality and amount of available water to worsening the conditions of the waters into which the fish are released.[169]

Observed and Projected Changes

Changes in precipitation patterns, increasing air temperatures, decreasing snowpack, and loss of mountain glaciers are altering hydrological processes in many watersheds. Streamflow trends vary considerably in the PNW, depending on location and the characteristics of the watershed. Rivers in western Washington generally fall into three hydrological categories based on their response to the precipitation type in winter (Figure 6):

Rain-dominated rivers run primarily through elevations below the snowline where most precipitation falls as rain. These rivers usually have a single peak in flow during the wet winter months since they respond directly to rainfall.

Transient snow, also called mixed rain-snow, systems flow through moderate elevations where precipitation alternates as snow and rain over the course of the winter. Rivers in these areas generally show two peak flows—one in early winter during storm events and one in spring and early summer during snowmelt.

Snow-dominated rivers have sources at high elevations where precipitation falls mainly as snow in the winter and is stored as snowpack or on glaciers. These rivers exhibit a large peak flow in spring and early summer as the snow and ice melt.

Observed changes since the middle of the 20th century include the following:

- Summer streamflows in snow-dominated and transient snow watersheds are declining, especially in areas such as western Washington where temperatures during the snow season do not fall far below freezing.[170]
- From 1950 to 2010, summer streamflows decreased 33 percent in snow-dominated watersheds and 36 percent in transient snow watersheds.[171] For example, summer flows decreased 28 percent in the Nooksack River and 21 percent in the North Fork Nooksack from 1963 to 2003.[172]
- Across western North America, the date of annual peak flows in rivers shifted 10 to 30 days earlier in the spring between 1948 and 2002. The signal was largest in PNW watersheds influenced by snowmelt.[173]

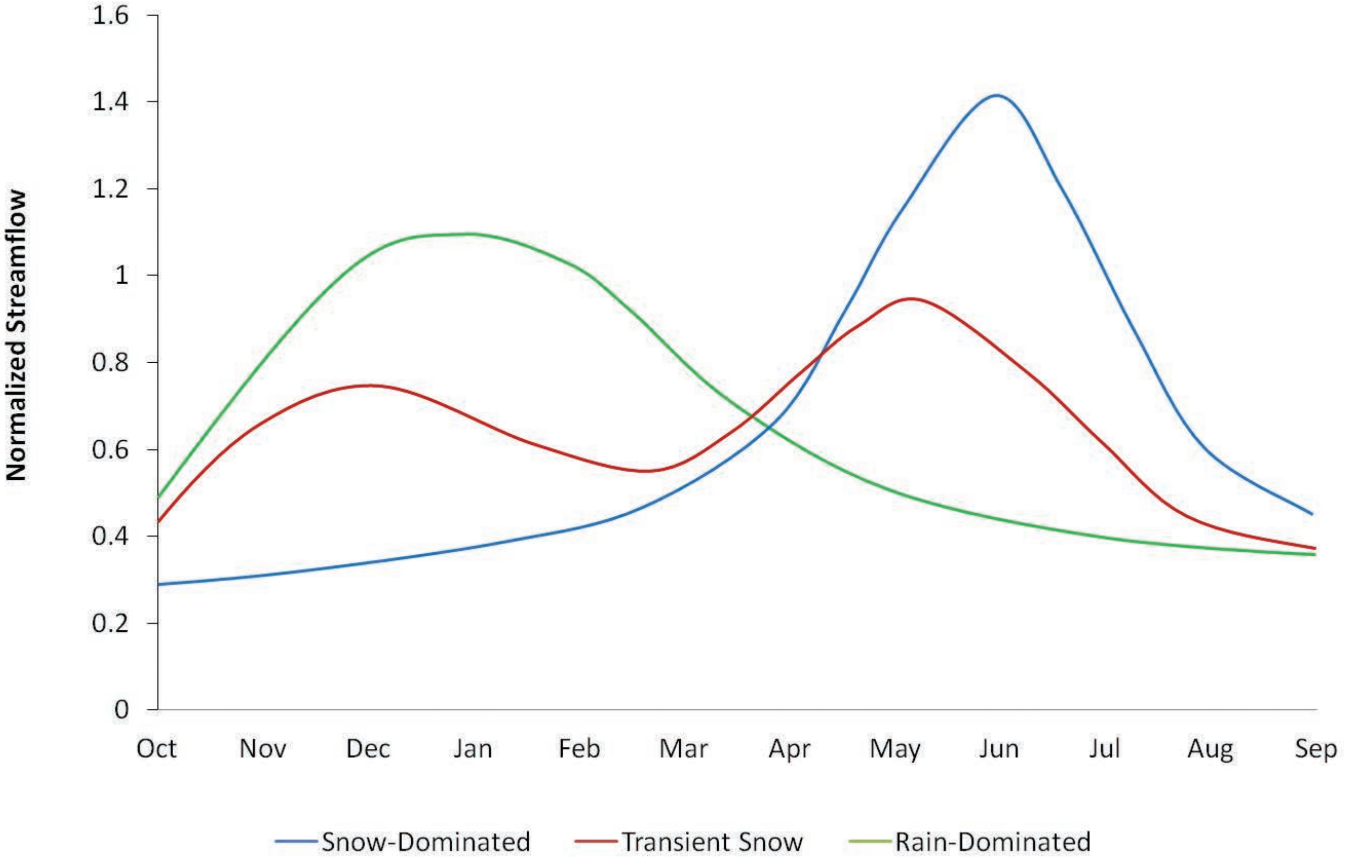


Figure 6: Typical hydrological regimes of PNW rivers showing representative peak and base flow timing in rain-dominated, transient snow (or rain- and snow-dominated), and snow-dominated watersheds. Source: after Elsner et al. 2010.

Projections of regional climate change impacts in western Washington indicate a shift in the timing of hydrological patterns. The projected changes are as follows:

- By the 2080s the timing of streamflow will shift in snow-dominant and transient-snow watersheds. For example, peak streamflow will occur 4 to 9 weeks earlier by the 2080s for four Puget Sound watersheds (Green, Cedar, Tolt, and Sultan).[174] Timing of peaks will remain largely unchanged in rain-dominated watersheds.
- The double peak hydrograph of transient watersheds will shift toward a single-peak, rain-dominant profile as more precipitation falls as rain rather than snow and with earlier melt of the snow that does fall. For example, the Quinault River is projected to shift to a single-peak hydrograph by the 2040s (Figure 7).[175]
- Winter flood risk will increase due to heavy precipitation events increasing in both frequency and intensity. Annual runoff in Washington will increase 2 to 3 percent by the 2040s driven mainly by more winter precipitation.[176] Rising snowlines also increase winter flood risk by exposing more watershed area that can contribute to runoff.
- Summer base flows will decrease, particularly for rain-dominated and transient-snow watersheds west of the Cascades.[177] Low flow conditions will become more severe for about 80 percent of watersheds in Washington.[178] For example, considerable low flow impacts are projected across most of the Olympic Peninsula, regardless of watershed type.[179]
- Future projections indicate that glacier melt contribution to summer base flows will continue to increase, until the glaciers disappear entirely.[180]
- Warmer air temperatures will increase evaporation and evapotranspiration by vegetation, the process by which plants draw water out of the soil and release it into the atmosphere. This will also worsen summer low flows.[181]

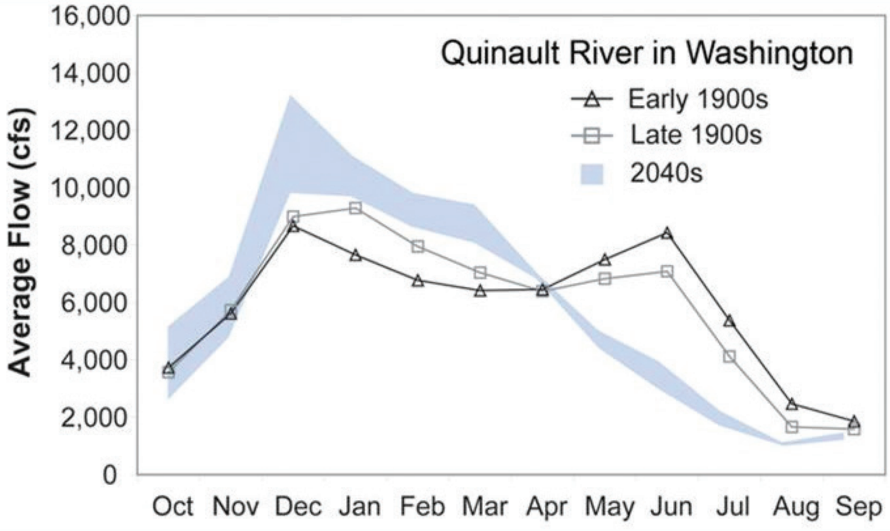


Figure 7: Streamflow changes in the Quinault River during the 20th century. Projections for the 2040s show a shift from two periods of high flows to one. The 2040s curve is shaded to represent a range across a number of different climate scenarios. Source: University of Washington Climate Impacts Group cited in USGCRP 2009.[182]

Taking Action: Jamestown S'Klallam Tribe's Strategy for Dungeness River Floodplain Protection and Restoration

The Dungeness River in the northern Olympic Peninsula is the ancestral river of the Jamestown S'Klallam Tribe. Four salmon and char species in the Dungeness River watershed are currently listed as threatened under the ESA: Puget Sound chinook, Hood Canal/Strait of Juan de Fuca summer chum, Puget Sound steelhead, and bull trout. In the Jamestown S'Klallam Tribe's 2013 Climate Change Vulnerability Assessment and Adaptation Plan, salmon were ranked as a Very High Priority.[183] Recovery of Dungeness River salmon and char will require the restoration of a significant amount of floodplain that has been disconnected from the main channel by dikes, roads, and other infrastructure.[184] Reconnecting the floodplain to the river will also help ameliorate the impacts of climate change. Negative impacts to salmon are expected as river temperatures rise and flows increase during rearing and egg incubation life phases. Along with the shade provided by floodplain forests, hydrological connectivity with floodplains allows high flows to spread and dissipate energy. Restoring side-channel connectivity will provide off-channel refugia for juvenile salmon during winter months and may provide access to spawning areas outside the deepest parts of the main channel during summer low flows, so salmon redds are not located where they will be most vulnerable to scour during high flows. Events such as a series of damaging floods between December 2014 and February 2015 and the record-breaking low flows of the summer of 2015 are increasing the importance and urgency of implementing a floodplain restoration and protection strategy.

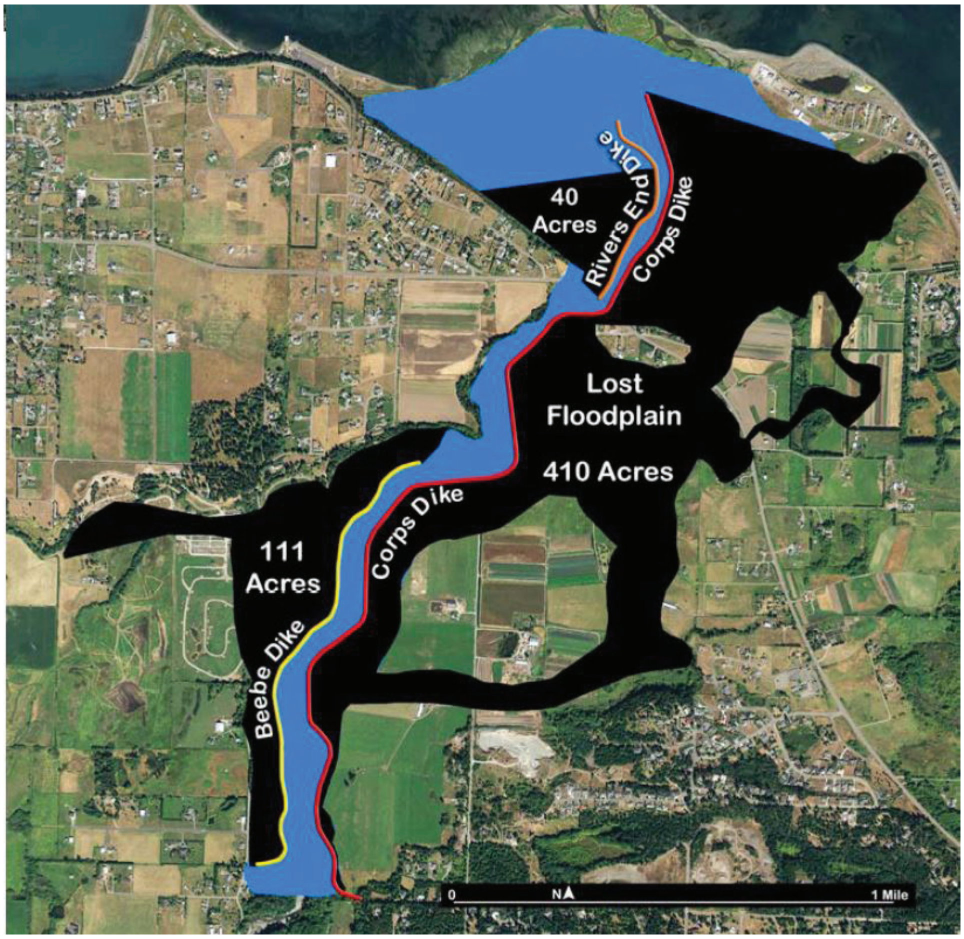


Figure 8: The contemporary floodplain of the lower 2.8 miles of the Dungeness River covers 169 acres (shown in blue), whereas the pre-1963 floodplain extended over 730 acres (shown in black). Source: Jamestown S'Klallam Tribe.

The tribe has identified a number of projects to reconnect 340 acres of the 561 acres of floodplain that have been disconnected from the river by infrastructure since 1963 (Figure 8). The projects focus on the removal, setback, or reconfiguration of dikes, roads, and undersized bridges in the floodplain. Over the last two decades the tribe has purchased 140 acres of floodplain properties in the Dungeness River corridor to protect high-quality habitat or to restore degraded habitat for the benefit of ESA-listed and culturally significant salmon. The tribe also intends to establish native riparian forests and restore large logjams in the river. In 2015, the tribe replaced a historic railroad bridge and approach trestle, which had degraded Dungeness River geomorphic function by constricting the natural processes of channel migration. The trestle bridge, which has important historical, cultural, and recreational value for the tribe, was also vulnerable to flooding. After the trestle was damaged by a flood in February 2015, it was replaced with a new 750-foot structure that spans the entire floodplain and channel migration zone. The trestle replacement restored salmon habitat-forming processes to approximately 20 acres of floodplain, numerous side channels, and 2,000 feet of the Dungeness River main channel.

4.6 SEDIMENT IN STREAMS

The rivers of western Washington transport sediment from a variety of sources, such as weathering of bedrock, erosion of soils, landslides, channel bank erosion, mudflows originating on volcanoes, and erosion of glacially derived sediment. Accurate and up-to-date data for the amount of sediment transported by rivers in western Washington are incomplete for many watersheds.[185] Several member tribes have initiated studies aimed at assessing current sediment dynamics as well as projecting sediment dynamics with continued climate change. For more discussion of issues related to landslides and other forms of mass movement, please see *Section 6.8: Landslides and Mass Movement.*

Sediment delivery into and transport through streams are natural processes that build vital habitat in aquatic and coastal systems. However, when land use, river modifications, or changing hydrological regimes lead to excessive sediment delivery, the results can be harmful to fish and other aquatic organisms. Many rivers in western Washington are degraded by excessive amounts of sediment, particularly fine-grained sediment suspended in the water. Excessive fine sediment loads in rivers can be caused by mass wasting and surface erosion from managed forestlands entering streams. It can also be caused by increased levels of bank erosion after removal of the riparian vegetation that enhances bank stability and traps fine sediment from upland runoff. High sediment loads can also occur due to the disconnection of the channel from adjacent floodplains and wetlands, where fine sediments settle out during overbank flows. In agricultural and urban areas, increases in fine sediment delivery can also occur through dredging, bank erosion from livestock access, and surface erosion of cropland, construction sites, and unlined ditches. These legacy impacts have altered the natural habitat-forming geomorphic processes and sediment dynamics in many western Washington rivers.

Increased fine sediment in rivers can harm salmonids in multiple ways. It reduces survival from the egg-to-fry phase and increases juvenile salmonid mortality.[186] Excess fine sediment can cause gill trauma and disrupt internal fluid regulation, blood chemistry, and reproduction. It reduces insects and other invertebrates living in the substrate that are critical for the aquatic food web.[187] High turbidity can reduce the feeding efficiency for juvenile salmonids, which are visual predators, thereby reducing growth rates.[188] It can also cause the fish to avoid habitats or delay their migration.[189]

Where sediment supply exceeds sediment transport capacity, sediment collects on the channel bed through a process called aggradation. Aggradation of coarse-grained sediment like gravel and cobbles changes the configuration of the channel by raising the elevation of the channel bed. This exacerbates stranding and other barriers to fish movement during low flows. This sediment can also directly bury salmonid redds and can increase the risk of flooding, especially where floodplains have been disconnected from the channel.

Observed and Projected Changes

The USGS has estimated that about 6.5 million tons of sediment are transported by rivers into Puget Sound and adjacent waters.[190] Estimates for each major river system range from 330,000 tons for the Lake Washington Ship Canal to 2,800,000 tons for the Skagit River. While changes brought about by global warming may worsen the impacts of sediment impairment in streams, land use and changes to land cover continue to play a major role. Globally, soil erosion is projected to increase about 14 percent by the 2090s relative to the 1980s. Of this amount, 9 percent is due to climate change and 5 percent to land-use changes.[191] For example, on a heavily regulated river such as the Columbia River, the impacts of human modification to flow far outweigh the effects of climate change when it comes to sediment transport rates.

Projections of climate change impacts to sediment in streams are not well documented. Nonetheless, potential effects can be inferred from the impacts to the temperature and hydrological regimes that drive geomorphic processes in the PNW. For example, the effects of climate on sediment transport rates are expected to be greater than on streamflow because the relationship between increasing flow and increasing sediment discharge is not linear.[192] Sediment loads have increased in the Skagit River basin due to glacier retreat, especially in the Sauk and Cascade rivers, and are expected to continue to rise due to glacier loss, reduced snowpack, and larger peak flows, especially in rivers without dams that trap sediment such as the Sauk.[193] In the Skagit River, average annual sediment loads are projected to increase by 149 percent and peak winter sediment loads by 335 percent by the 2080s.[194] At the local watershed scale, land use and management practices will also determine changes in sediment loads.

Most streams and rivers in western Washington flow through glacial sediments that are easily eroded and transported. As glaciers recede, they expose vast quantities of sediment that are then readily washed down into rivers. For example, a USGS study of the rivers arising from the glaciated slopes of Mount Rainier found that pronounced aggradation between 1984 and 2009 in the Puyallup, White, and Carbon rivers had increased the average channel bed elevations by 7.5, 6.5, and 2 feet, respectively.[195] Melting glaciers leave behind over-steepened valley slopes that are susceptible to mass failure as the protective snow cover disappears. These rock avalanches and debris flows temporarily increase sediment loads.[196] For example, Mount Rainier received 18 inches of rain in 36 hours in November 2006, resulting in glacial outburst floods that triggered debris flows. The accumulation of the transported material increased the elevation of the channel bed by 4 feet.[197] Sediment sources from the surface and inside glaciers can also provide substantial sediment loading as glaciers melt. The Nooksack Indian Tribe has documented conditions in glacier-fed streams of Mount Baker using turbidity as a surrogate for suspended sediment in the water column. They found that the turbidity spikes during glacier melt periods on the Sholes Glacier, which has receded over 190 feet in the last five years.[198]

Warmer air temperatures increase the amount of sediment available for delivery into streams by speeding the breakdown of soils and reducing the amount of snow cover protecting the ground from runoff. Heavier and more frequent rain events enhance soil erosion and sediment loading.[199] These rain events will increase river flows and hence, sediment inputs into lakes and streams.[200] More precipitation falling as rain instead of snow can also increase the risk of landslides. Saturated soils are more likely to fail, potentially delivering more sediment into streams. Increased sedimentation in streams can also result from erosion during rainfall after wildfires.

4.7 FRESHWATER WETLANDS

Chinook salmon returning to the North Fork Stillaguamish River in 2015 faced record high temperatures and low flows. Photo: Kari Neumeyer, NWIFC.

Wetlands serve many critical functions in freshwater systems. They provide habitat for a variety of animal and plant species, absorb floodwaters, stabilize stream banks, and filter sediment, nutrients, and pollutants before water enters a stream. Wetland plants are a food source for the aquatic insects and fish that are prey for larger fish, mammals, birds, amphibians, and reptiles. Seasonal floodplain wetlands provide rearing habitat for a variety of fish, including salmonids.[201] Juvenile salmon and steelhead use floodplain wetlands as a refuge from high flows during winter. One study of the floodplain wetlands of the Chehalis River found high fish utilization, including coho, chinook, chum, and cutthroat trout.[202] Juvenile sturgeon and Pacific lamprey may use wetlands as rearing habitat for several years before migrating to the ocean. Adult sturgeon feed in freshwater and brackish wetlands. Seasonal wetlands can also provide critical habitat for non-game species such as three-spine stickleback, sculpins, and the Olympic mudminnow. The Olympic mudminnow is only found in limited areas of Washington and is listed as a sensitive species by the state. It is completely dependent on healthy wetland habitat for all life phases, including spawning.[203] Amphibians also use seasonal wetlands in high numbers.[204]

Warmer temperatures due to climate change can hasten drying of wetlands through direct evaporation of surface water or through increased evapotranspiration of wetland plants. Changes to streamflows alter the hydrological characteristics of floodplain wetlands, affecting nutrient availability, productivity, and species composition. Conversely, loss of wetlands leads to loss of surface water storage and groundwater recharge areas. As wetlands diminish, so do habitats for wetland-dependent species and fish that use wetlands for spawning and rearing. Warmer temperatures can also increase disease, including the fungal and bacterial infections that can decimate fish, amphibian, and reptile populations in wetlands.[205]

Observed and Projected Changes

The vulnerability of a wetland to climate change depends on the interactions of precipitation, streamflow, snowmelt, and groundwater. The hydrological characteristics determine the depth and extent of a wetland, along with the hydroperiod, or the duration, frequency, and seasonality of inundation. Loss of snowpack and projected changes in precipitation patterns that lead to drier summers will cause wetlands to decline.[206] Ephemeral wetlands, those that dry out periodically, are especially vulnerable if the dry periods last longer and occur more frequently in the future. Wetlands at high elevations are particularly at risk because they are dependent on snowmelt. Declining snowpack and earlier snowmelt will reduce the extent of these mountain wetlands.[207]

Wetlands that depend primarily on precipitation for their water supply are highly vulnerable to the impacts of climate change, while those that are dependent primarily on groundwater flow can be less vulnerable.[208] Groundwater flows can potentially buffer these systems to changes to surface water regimes, unless the watershed is too small to support sufficient groundwater discharge.[209] Increased human demand for water can further decrease the amount of surface and ground water available to maintain wetland systems. Climate change impacts to freshwater wetland hydrology occur in tandem with existing effects from human activities. Wetlands that are already diminished or degraded by pollution, water use, and habitat fragmentation will be especially vulnerable.

Freshwater wetlands located on the coast can be vulnerable to conversion to saltwater marshes due to sea level rise. One study of multiple sites in Puget Sound and the Pacific coast of Washington and Oregon estimated a loss of 13 percent of inland freshwater marshes and 25 percent of tidal freshwater marshes for all sites by 2100 under a moderate GHG emission scenario.[210] For more information on coastal impacts from sea level rise, see *Section 5.4: Sea Level Rise*.

4.8 RESILIENCE IN FRESHWATER ENVIRONMENTS

Resilience is the capacity of an individual or a system to recover from significant disturbances without major changes to its state or functions. In relation to climate change it can be described as the capacity to maintain biological diversity and ecological function as the environment changes.[211]

Natural flow, sediment, and temperature regimes in wetlands, floodplains, and riparian areas improve resilience to climate change impacts such as low flows, floods, and stream temperature for salmonid populations and river ecosystems.

Fully functioning floodplains and riparian zones provide resilience to a number of the impacts of climate change. Floodplain forests and wetland complexes promote groundwater recharge, store water during high flows, and slowly release water during low flows. Floodplains also allow fine sediment to settle out of flood flows before the water returns to the main river channel. Floodplain forests help stabilize off-channel habitat, which functions as a refuge for salmonids during periods of high temperatures or high flows.[212]

Riparian forests improve water quality through filtration of nutrients, sediment, and chemical pollutants. Riparian forests provide sources for large woody debris. Large wood that falls into the river provides instream shade, increases groundwater exchange, and promotes channel forms like pools that can provide fish with refuge from warm temperatures.[213] Streambank vegetation adds to bank stability, preventing excessive erosion and sediment impairments in hydrologically modified stream systems. Terrestrial vegetation is an important source of insects and organic material that supports aquatic food webs and provides food for salmonids. In addition, wildlife, amphibians, and birds use riparian zones as habitat and migration corridors. The loss of connectivity and diversity of habitat in riparian zones limits the time and space that organisms and assemblages have to adjust to changing environmental conditions.[214]

A dynamic mosaic of freshwater habitats helps salmonids cope with environmental disturbance.[215] Habitat complexity helps salmonids adapt to a warmer climate.[216] For example, in the mountains of the northwestern U.S. (including the Rocky Mountains), the rate that stream

An adult coho. Photo: Debbie Preston, NWIFC.

warming is occurring is relatively lower in steep headwaters even though air temperatures are generally warming faster at high elevations.[217] Cold-water species are finding refuge in parts of the stream network that are cold and have low velocity of change.[218]

An important feature in the resilience of salmonids is their phenotypic plasticity—that is, they are able to shift their physiological characteristics in response to environmental factors without genetic changes.[219] There are many instances of salmon altering the timing of their life history phases in order to adapt to unfavorable conditions in stream temperature or flow.[220] Nonetheless, salmonid responses to climate change will be mixed depending on the stock and location. For example, in a laboratory experiment two stocks of steelhead from Hood Canal rivers only 50 miles apart responded differently to changes in water temperature.[221] Overall, populations occupying the warmest and most degraded habitats will be at greater risk for extirpation (local extinction).[222]

In some cases, evolutionary rescue, or relatively rapid genetic change, allows population recovery in the face of environmental disturbance that could have caused extinction.[223] One study of Columbia River sockeye found that two-thirds of the observed shift toward earlier adult migration is due to genetic evolution and the process of natural selection acting against late migrants when stream temperatures become too warm for their survival.[224] The remainder of the shift is attributed to phenotypic plasticity in response to river flows.[225] The average migration of pinks into Auke Creek in Alaska is occurring nearly two weeks earlier than it did 40 years ago, and evidence suggests a genetic basis for the decrease in the late-migrating individuals.[226] While some species may be able to adapt to changing conditions, our understanding of this process is limited by uncertainty around species interactions and climate change velocity.[227]

Taking Action: Nooksack Indian Tribe Climate Change Research

The salmon and trout stocks of the Nooksack River watershed provide sustenance and commerce for the Nooksack Indian Tribe, along with vital elements of traditional cultural and spiritual identity and practices. Habitat degradation is the leading cause of the decline of the two Nooksack River populations of spring chinook, which are at 0.8 percent and 1.8 percent of estimated historical levels. In addition, climate change has caused and will continue to cause impacts including an increase in winter peak flows, reduced area and depth of snow accumulation, earlier snowmelt, decrease in summer low flows, and an increase in water temperatures that exceed salmon tolerance or survival.

The Nooksack Indian Tribe has initiated a comprehensive study throughout the Nooksack River watershed to establish baseline conditions, characterize legacy impacts, model future impacts of climate change on fish habitat and survival, and develop restoration strategies that promote resiliency in the aquatic ecosystem. The tribe has contracted with the University of Washington and Western Washington University to model historic and future glacier behavior, stream temperature, streamflow, and sediment dynamics under various climate change scenarios.

Glacier Ablation: The tribe is currently measuring glacier ablation in terms of reduced area, melt rate, and amount of melt water discharge.

Stream Temperature: The tribe measures stream temperature at 66 seasonal and year-round stations throughout the Nooksack River watershed. Water temperatures in the South Fork Nooksack River frequently exceed optimal temperature ranges and approach lethal limits for salmonids. In partnership with the U.S. Environmental Protection Agency's Office of Research and Development, the tribe has initiated a pilot project using the temperature total maximum daily load (TMDL) designation. The objective of the assessment was to characterize climate change impacts to salmonids and to identify and prioritize restoration strategies to ameliorate those impacts.

Stream Hydrology: The tribe measures stream discharge at six sites within the watershed. Some of these sites are part of the NWIFC Tribal Water Technical Group base flow measurement project. This information, along with three USGS gauge stations in the basin, establish a baseline as reference for future streamflow changes due to climate change.

Sediment and Turbidity: The tribe measures turbidity and suspended sediment at 16 sites throughout the upper Nooksack River watershed. In addition, they collect bedload and suspended sediment samples at three bridges and with an automatic suspended sediment sampler. This network of sampling stations allows them to determine baseline sediment dynamics under current conditions and to identify the major sources of sediment in the watershed.

Adaptation: The tribe has analyzed each reach of the South Fork Nooksack River and prioritized adaptation actions based on the highest level of positive impacts expected.[228] Floodplain reconnection was identified as a high-priority action, including removal or setback of hydromodifications such as levees. Installation of logjams was also identified as a means to reconnect rivers to their floodplains. Other priorities included riparian revegetation, removal of invasive vegetation, and rehabilitation of channel modifications through installation of engineered logjams and narrowing of over-widened channels. Restoration of streamflow regimes though the reduction of water withdrawals and the restoration of floodplain wetlands was identified as a priority as well. The assessment also addresses increased sediment delivery into streams, especially due to landslides or forest roads. Actions focus on monitoring sediment dynamics over the long term, evaluating impacts to fish habitat, and working with local landowners and federal agencies to limit sediment inputs to streams from forested lands.

Nooksack Tribe water resources manager Oliver Grah hikes up Sholes Glacier to measure how much it is melting. Photo: Kari Neumeyer, NWIFC.

5. COASTAL AND MARINE ENVIRONMENTS

5.1 CHAPTER SUMMARY

Marine ecosystems provide us with food, employment, and a host of cultural, social, and health benefits. Shellfish (both mollusks and crustaceans) and other marine fish play an important role in ocean ecosystems and the lifeways of the tribes. Salmonids can spend years of their lives at sea, depending on the species, so their survival is also closely dependent on marine conditions. Climbing GHG emissions are changing several key chemical and physical properties of the ocean systems, and marine and coastal ecosystems face challenges from the effects of the following:

- Warmer ocean temperatures;[229]
- Rising sea levels;[230]
- Flooding and coastal erosion due to greater storm surge effects from sea level rise; and[231]
- Changing ocean chemistry due to ocean acidification and hypoxia, or low dissolved oxygen.[232]

5.2 WHEN THE TIDE IS OUT, THE TABLE IS SET

We have a traditional saying that conveys the significance of coastal species to our people: "When the tide is out, the table is set." We harvest coastal species for food and to use in tools and ornaments. Marine shorelines also contain many archeological sites that hold great cultural and spiritual importance to our peoples.[233] Some tribes historically expanded and actively managed shellfish beds known as "clam gardens."[234] Today, shellfish harvests continue to be important culturally, nutritionally, and economically.[235] Shellfish harvest provides physical activity in a culturally and spiritually nourishing way. Shellfish also have high levels of protein, essential fatty acids, and nutrients needed to maintain health.

While marine fish, mollusks, and crustaceans are important traditional foods, other types of shore species such as dune grasses, seaweed, and kelp also are used for food and crafts. Marine mammals such as otters, seals, and whales have great cultural importance. Whales and whaling are central to the culture of the Makah Tribe. For the Treaty of Olympia tribes (Quileute Tribe, Quinault Indian Nation, and Hoh Tribe), gray whales, orcas, Pacific harbor seals, and northern fur seals are among the most culturally important marine mammals.[236]

A Skokomish elder observes a chinook and pink fishery in Hood Canal. Photo: Tiffany Royal, NWIFC.

5.3 OCEAN TEMPERATURES

The effects of warming ocean temperatures ripple through the entire marine food web. Warm temperatures bring warm water species to our region and challenge species that need cold water to survive. Lower ocean productivity is linked to warmer water. Warming can increase phytoplankton biomass if enough nutrients are available, but this effect could be reversed by a loss of nutrient supply due to seasonal vertical stratification in the upper ocean.[237] Nutrient supply into the upper ocean is projected to decrease by over 40 percent by 2100 relative to 1800 under a high GHG emissions scenario.[238] For example, warm ocean conditions off the PNW coast in 2005 reduced surface phytoplankton biomass by about 50 percent and primary productivity by about 40 percent.[239]

Ocean temperatures influence salmon migration routes. The Fraser River sockeye and pink salmon that return from the ocean to their natal streams in Canada usually take one of two routes: either they go north around Vancouver Island through Johnstone Strait,

or they go south through the Strait of Juan de Fuca. When these fish divert their migration to the north and out of U.S. waters, the tribes that fish this run in the Strait of Juan de Fuca lose their access. From 1990 to 2014 the average rate of diversion for Fraser River sockeye to the north was 62 percent, and for pink the average northern diversion rate since 1997 has been 56 percent. In 2015, the estimated diversion rates into Johnstone Strait for sockeye and pink salmon were 99 percent and 91 percent, respectively.[240] In the past, northern diversion has been very strongly correlated with warmer water off of Vancouver Island. Between 1906 and 1983, large northern diversions of Fraser sockeye have occurred after El Niño years.[241] Unusually warm ocean conditions in 2015 may have spurred the Fraser runs toward the north and away from our fishing grounds.

Warm ocean waters can also affect salmon population size, their age of return, and timing of return. When ocean temperatures are warm, chinook are smaller in length, weigh less for their size, and have lower return rates than in cold ocean conditions.[242] In our region, cold waters tend to bring nutrients that feed plankton, which are eaten by forage fish, which are in turn eaten by salmonids, birds, and marine mammals. For example, cold-water conditions favor certain species of copepods, a type of plankton. The cold-water copepods are rich in lipids (such as fatty acids) that are beneficial to marine fish growth and survival. Warm-water copepod species are smaller and have fewer lipids, so when warm-water conditions dominate, the marine fish that salmon eat carry less fat and the salmon have a lower probability of marine survival.[243]

Temperature-related patterns have also been observed with chinook and coho salmon returning to Oregon rivers. High returns of chinook and coho corresponded with the cool phase of the Pacific Decadal Oscillation (PDO) from 1947 to 1976. When PDO switched to a warm phase from 1977 to 1998, salmon returns below the average were more common.[244] Chinook salmon that entered the ocean along the Oregon and Washington coast during warm conditions due to the PDO were smaller and weighed less for their size.[245] The coho runs of 2015 in western Washington were less than half of what was expected in most areas and most of the fish that did return were 20 to 30 percent smaller than normal.[246] This has been attributed to poor ocean conditions such as warm waters in the Pacific, compounded by the ongoing loss of high-quality habitat in the freshwater environment. The consequences will be low production in these coho populations for years to come.

The marine food web could experience negative effects if changes in the distribution and timing of plankton growth causes a lack of synchrony, or a mismatch in timing, with the many species that graze upon them.[247] This could change the distribution of marine species, including but not limited to Pacific salmonids.[248] An illustrative example occurred along the West Coast in 2005, when a delayed onset of the upwelling season caused major plankton productivity to occur three to four months later than usual. This produced a cascade of negative consequences on plankton-dependent fish, seabirds, and marine mammals. That year saw recruitment failure of many species of rockfish, low chinook and coho survival rates, nesting failure for Cassin's auklet, and mortality of common murres, sooty shearwaters, and other seabirds.[249]

Warmer waters cause marine species to shift their ranges toward the poles in search of colder water. The average rates of northward migration in 28 marine fish in the northeast Pacific Ocean are projected to be about 18 miles (30 km) per decade under a high GHG emissions scenario.[250] At the same time, warm-water species will become more common, bringing substantial changes to ecological and economic systems by 2050.[251] Population shifts can lead to mismatches between species that have evolved together and that depend on each other. It can also lead to fishing grounds shifting away from historical or established locations. Some species may become extirpated, or locally extinct, in areas where the tribes have traditionally fished for them, but we will not be able to follow the fish. These projected patterns will have a significant impact on treaty rights, resources, and cultural practices for tribes, especially when considering Pacific salmonid species.

Warmer water temperatures also have negative impacts on shellfish harvest. Warm water may increase the incidence of the harmful algal blooms that produce toxins in shellfish. Although individual species respond differently to environmental conditions, blooms of one dinoflagellate responsible for paralytic toxins in Puget Sound shellfish increase with warmer air and water temperatures in Puget Sound.[252] Projected future conditions indicate that harmful algal blooms in Puget Sound will become more frequent and will last longer.[253]

The largest and most toxic bloom ever recorded of *Pseudo-nitzschia*, the marine algae that produces domoic acid poisoning in shellfish and crabs, covered the West Coast in the summer of 2015.[254] Domoic acid can be harmful or even fatal to humans if consumed. Levels exceeded health safety standards, prompting closure of shellfish harvests in Washington, Oregon, and California. This was the largest closure of razor clam harvest and of the multi-million-dollar crab fishery in Washington state history. The toxin bioaccumulates in fish such as sardines and anchovy that eat the algae and other plankton. This in turn can poison other fish, birds, and marine mammals such as sea lions. These blooms typically last only a few weeks, but this one lasted from April through early October and stretched from Santa Barbara, California, to Alaska. The dinoflagellates that produce Paralytic Shellfish Poisoning were also detected in some places in a rare co-occurrence with domoic acid. A combination of warm water and the availability of nutrients enabled the bloom. Generally these two conditions do not occur together, since the upwelling of cold, deep water is usually the source for nutrients in the California Current Ecosystem, which flows along the west coast of North America from British Columbia to Baja California.

An analogy of the effect on marine life of warmer ocean temperatures can be seen in an unusually long-lived and exceptionally warm expanse of water that appeared across the Gulf of Alaska in autumn 2013. By 2015, it spanned the North Pacific from Alaska to Japan with water temperatures at the sea surface as much as 7°F (3.9°C) higher than average for months at a time. Several theories have been proposed to explain this phenomenon, nicknamed "the blob." In the Gulf of Alaska it is related to a persistent ridge of high atmospheric pressure that reduced westerly winds in the autumn and winter of 2013 to 2014.[255] This meant fewer and weaker storms in the PNW and less mixing and cooling of surface ocean waters. By January 2016, the warm blob had weakened, due to strong winds from the north and cooler ocean temperatures brought about by El Niño conditions in the Pacific Ocean.[256] However, temperature anomalies persist down to a depth of about 980 feet (300 m), so impacts to marine ecosystems and weather could continue for some time.[257]

The warm-water blob is a phenomenon not seen before, and while it may not be linked to climate change, it does provide a life-size laboratory of the ecological effects of warm surface water. The changes in wind patterns reduced the primary production of the marine food web as phytoplankton biomass plummeted in the winter of 2013–2014.[258] The decrease in krill and other plankton resulted in the starvation and death of sea birds like Cassin's auklets from California to British Columbia between October 2014 and February 2015. Warm-water species like sunfish, sardines, and certain types of jellyfish appeared in uncharacteristic places. Salmon returns to Puget Sound were particularly low in 2015 due to a combination of warm ocean conditions and hydrological drought in the region's streams. Projections for 2016 were low enough to prompt closure of many salmon fisheries.[259]

Observed and Projected Changes

The upper 2,300 feet (700 meters) of the global oceans have been warming, with the greatest amount of warming occurring in the upper 250 feet (75 meters). Since 1971 this uppermost 250 feet has warmed about 1°F on average. Records before that time are sparse, but it is likely that warming was occurring during the first half of the 20th century as well.[260] Because the ocean has so much mass, and water has a high heat capacity, the ocean can store vast amounts of energy. Of all the heat absorbed by air, sea, and land since 1971, about 93 percent has been stored in the ocean. The high heat capacity and slow circulation of the world's oceans means that while the surface ocean takes about a decade to adjust to warming from GHG emissions, the deep ocean will continue to warm for centuries or millennia.[261]

Average annual sea surface temperatures in the California Current System warmed during the 20th century by about 1 to 2°F (0.6 to 1.0°C).[262] In Puget Sound, long-term temperature data is limited. Water temperature records from Hood Canal, Admiralty Inlet, and Point Jefferson show an increase of 0.8 to 1.6°F from 1950 to 2009.[263] At the Race Rocks Lighthouse in the Strait of Juan de Fuca, the waters warmed by 1.7°F (0.9°C) between 1921 and 2005.[264]

Oceans are projected to continue to warm, and this heat will penetrate into the deeper oceans. The waters off the Washington Pacific coast are projected to increase by another 2°F by the 2040s under a moderate GHG emissions scenario.[265] Natural variability in our region from climate phenomena like El Niño and the PDO will continue to play a role, but how these short-term cycles will be affected is

Sea level rise of the Pacific Ocean off the coast of Washington state is a significant concern of the tribes. Photo: Debbie Preston, NWIFC.

not well known.[266] In addition, the amount of warming in any specific location may depend on circulation patterns or topography. For example, shallow areas with minimal circulation such as Lynch Cove in Hood Canal can be susceptible to greater warming.[267]

5.4 SEA LEVEL RISE

The elevation of the sea surface varies geographically and over time. It is controlled by a number of factors including water density; the amount of water locked up globally in ice caps, ice sheets, and glaciers; and changes in land surface elevation. Warming oceans actually take up more space in a process called thermal expansion, one of the main drivers of sea level rise. Another global source of sea level rise is the water released by the melting of the great ice sheets of Antarctica and Greenland and of glaciers on land.

Thermal expansion and ice melt contribute to absolute sea level rise, but relative sea level includes the effects of vertical land movement. Upward land movement can occur due to sediment accretion or plate tectonics causing uplift. Downward land movement can also occur due to plate tectonics or from subsidence due to sediment compaction, organic material decomposition, or groundwater withdrawal.[268] Because these local conditions vary, the amount of relative sea level rise is not consistent throughout Washington. Vertical land movement in western Washington is dominated by tectonic forces. The general trend along the Pacific coast is tectonic uplift that increases toward the north, and Puget Sound exhibits subsidence that increases to the south, but these rates vary over time and location.[269]

Sea level rise changes coastal habitat types, which changes the abundance and distribution of coastal species that have specific tolerances for depth, frequency, and duration of inundation.[270] The number and types of invertebrates, including but not limited to shellfish, can change. In just one example, the Swinomish Indian Tribal Community found that at least 27 percent of the shellfish harvest area at Lone Tree Point is vulnerable to the effects of sea level rise due to inundation of habitat.[271] As more tribes conduct sea level rise assessments, other tribal shellfish harvest sites will be found to be vulnerable to sea level rise as well. Sea level rise can also accelerate coastal erosion. While the erosion of shorelines is a natural process that plays a role in the formation and maintenance of many types of shore forms, excess coastal erosion can change the distribution and viability of biological communities in the nearshore.

Many organisms spend the early part of their life in the nearshore, including the larvae or juveniles of species that have commercial and cultural importance to tribes, such as salmon, Pacific herring, and Dungeness crab. The nearshore encompasses the shoreline from the top of the upland bank or bluff on the landward side down to the depth of water that light can penetrate and where plants can photosynthesize, called the photic zone. Marine water, fresh water, and terrestrial landscapes interact in a complex mosaic of habitats and processes in the nearshore. For juvenile salmon, estuaries provide cover from predators, sources of prey, places to wait out the low tide, and opportunities for the physiological transition that occurs in migration between freshwater and marine environments.[272] This is especially true for chinook, whose overall survival rates decrease without estuary access,[273] and for chum, whose estuarine rearing phase is a major factor in the size of the adult population.[274] The nearshore is also critical for forage fish—the small, schooling fish that act as a link in the marine food web between plankton and the larger fish, birds, marine mammals, and squid that prey upon them.

Impacts to the coastal environments of Washington occur in the context of development and modification of shoreline habitats over the past 150 years. These modifications have disrupted natural habitat-forming processes with destructive effects on ecological function and structure in all segments of the nearshore. When the rate of sea level rise is not too fast, nearshore ecosystems can adapt by migrating upland to maintain the same amount of tidal inundation, as long as the substrate is suitable. Shoreline development prevents the landward migration of nearshore habitat. This is known as coastal squeeze—coastal habitats are hemmed in by rising water levels on one side and hardened shorelines on the other. Habitat is lost for birds, fish, shellfish, and plants. The narrowing and loss of surf smelt habitat will probably be among the first negative effects of climate change to the Puget Sound nearshore.[275] Coastal squeeze will also destroy marsh habitat necessary for juvenile chinook and chum as they migrate through estuaries. In modified shorelines, sea level rise and storm surge can also expose sources of pollutants that then enter the water and destabilize infrastructure such as freshwater and sewer pipes, power transmission, and roads. Saltwater intrusion associated with sea level rise can also cause contamination of shoreline freshwater aquifers and can escalate on-site septic system issues.

Observed and Projected Changes

Global mean sea level rise is estimated at 7.3 inches (0.19 m ± 0.02 m) for the period between 1901 and 2010.[276] Off the Washington coast, observations from satellite altimetry and tide gauges indicate a long-term increase in sea level rise with large seasonal and decadal variability.[277] Estimates of relative sea level rise based on analysis of tide gauge records average 0.8 mm per year in Friday Harbor and 2.3 mm per year in Seattle. In the northwest corner of the Olympic Peninsula, upward vertical land movement outpaces sea level rise, so relative sea levels are actually decreasing slightly in the area (Table 1).[278]

Table 1: Observed relative mean sea level (MSL) trends in Washington. Since tide gauge measurements are made with respect to a local fixed reference level on land, these measurements record relative MSL trends that combine the rates of global sea level rise and local vertical land motion. Source: NOAA (2013)[279] and Craig (1993, for Olympia).[280]

Location	Mean Sea Level Historical Trend (mm/year)	100-Year Change Equivalent (inches per 100 years)
Olympia	2.4	9.6
Seattle	1.99 +/- 0.16	7.8
Port Townsend	1.69 +/- 0.84	6.6
Port Angeles	-0.06 +/- 1.0	-0.2
Neah Bay	-1.76 +/- 0.31	-7.0
Toke Point (Willapa Bay)	0.35 +/- 1.01	1.3

Sea level is also influenced by storms and atmospheric conditions. When large storms at sea move inland, a storm surge can occur, especially when high astronomical tides combine with a wind direction perpendicular to the shore.[281] Extreme ocean levels brought about by a combination of storm surge, high tides, or El Niño events occur regularly on the west coast of the United States. El Niño storms commonly raise water levels 20 to 30 inches (50 to 70 centimeters), and one extreme storm in March 1999 raised the tide almost 6 feet (1.75 meters) above the predicted level.[282] Rising sea levels can increase the effects of storm surge, high tides, and high flows in rivers, leading to extreme flooding.

In the next decade, sea level rise will continue along the West Coast but the amount varies among sources depending on the type of analysis conducted. In addition, vertical land motion is difficult to predict since it varies spatially and is not necessarily consistent over time. Studies that combine low rates of sea level rise with high rates of vertical uplift show that some areas could see a decline in sea level.[283] Other studies indicate that sea levels in Washington state could increase by a range of 4 inches to 4.6 feet by 2100.[284]

Projections of future sea levels also vary depending on the level of GHG emissions and different estimates of the future contribution of melting ice sheets. The rate of ice sheet melt could vary depending on how quickly melting accelerates as temperatures warm and what happens when substantial parts of the ice sheets collapse. Recent studies have concluded that the West Antarctica Ice Sheet has begun to disintegrate and that there is enough water held just in that section of ice to ultimately raise global sea levels by 16 feet in the next few centuries.[285] The future behavior of the Antarctic Ice Sheet is not well known, but temperatures in Antarctica are rising more quickly than predicted and the topography of the seabed below the ice, the presence of warm ocean currents, and the configuration of the ice sheet all could contribute to catastrophic and irreversible collapse. In addition, a glacier that covers 16 percent of the Greenland Ice Sheet has been receding three times faster since 2012, with an additional 410 feet (125 meters) of retreat every year.[286]

Table 2: Comparison of sea level rise projections for Washington state relative to 2000.

Region	2030 Sea Level Rise Projection (inches)	2050 Sea Level Rise Projection (inches)	2100 Sea Level Rise Projection (inches)
Puget Sound:			
Puget Sound[a] (Mote et al. 2008)	NA	+6	+13
Seattle[b] (USACE 2015)	+4.7	+8.3	+21.2
Olympic Peninsula:			
NW Olympic Peninsula[a] (Mote et al. 2008)	NA	+0	+2
Port Townsend[c] (Petersen et al. 2015)	+2.4	+4.8	+12
Port Angeles[c] (Petersen et al. 2015)	+1.2	+1.2	+6
Neah Bay and Clallam Bay-Sekiu[c] (Petersen et al. 2015)	-1.2	-2.4	-1.2
Pacific Coast of Washington:			
Central and South Pacific Coast of Washington[a] (Mote et al. 2008)	NA	+5	+11
Pacific Coast of Washington[d] (NRC 2012)	+2.6	+6.5	+24.3

[a] Medium sea level rise estimates relative to the end of the 20th century. No values for 2030 given.

[b] High sea level rise scenario relative to 1992 levels.

[c] Projections relative to 2000 for a high GHG emissions scenario at the 99% confidence limits using the probabilistic approach to sea level rise developed by Kopp et al. (2014).[287]

[d] Mean values at the latitude of Seattle relative to 2000 based on a high sea level rise scenario.

Taking Action: Storm Surge at the Quinault Indian Nation Village of Taholah

The village of Taholah on the Pacific coast of the Olympic Peninsula is home to the Quinault Indian Nation's school, courthouse, police station, and the homes of 700 tribal members. The 2,000-foot-long sea wall built to protect the village was breached by storm waves in March 2014, causing flooding, erosion, and property damage. The tribe declared a state of emergency and the sea wall was rebuilt by the U.S. Army Corps of Engineers. Taholah is still vulnerable; the wall has been breached before and such flood events are expected to increase in frequency and severity. The village of Taholah was partially evacuated in December 2015 due to the possibility of another sea wall collapse.[288] In response, the tribe has a plan to move the entire village to upland property. The move is estimated to cost $350 million and the tribe is exploring a collaborative approach to funding. Moves such as this can be difficult because tribal culture and identity are place-based and because of the painful history of the forced relocation of Native Americans. David Underwood, a Quinault tribal member, told KUOW Earthfix News in Seattle, "This place, right here, where we are, is where my people have lived for thousands of years and each and every member of this tribe, we're all proud Quinault tribal members, proud Native Americans. I don't ever want to leave this place, but if the ocean keeps rising we're going to have to."[289]

Quinault tribal member Sonny Curley canoes through Sea Breeze Field on the Quinault Reservation. Photo: Larry Workman, Quinault Indian Nation.

5.5 OCEAN ACIDIFICATION

Changing ocean chemistry has the potential to alter the range and distribution of marine species along the Pacific coast. The world's oceans have absorbed about 30 percent of the atmospheric CO_2 emitted by humans.[290] When CO_2 dissolves in seawater, it causes a sequence of chemical reactions that leads to ocean acidification. The acidity of a substance is measured by the concentration of hydrogen ions, or pH. The lower the pH, the more acidic the substance. Because pH is a logarithmic scale, each whole number increment represents a tenfold difference. Ocean pH can vary widely in time and space due to local factors. In Hood Canal, pH as low as 7.39 has been measured.[291] Where aquatic vegetation is present, pH can fluctuate as plants take up CO_2 during photosynthesis during the day and release CO_2 during respiration at night. Besides pH, ocean acidification can also be measured through the total dissolved inorganic carbon in seawater and by the partial pressure of CO_2, which is the amount of CO_2 dissolved in seawater.

The chemical processes that cause ocean pH to decrease also reduce the saturation state of the minerals aragonite and calcite, two forms of calcium carbonate that marine species such as crabs, clams, oysters, and certain types of plankton use to build their shells and skeletons. The saturation state is a measure of the likelihood that a mineral will form or dissolve in seawater. Low saturation states interfere with the ability of organisms to form shells and dramatically lower their survival rates. A meta-analysis of studies that measured biological response to the projected changes in global mean surface ocean pH by 2100, found that mollusk survival was reduced by 34 percent, calcification by 40 percent, growth by 17 percent, and development by 25 percent.[292]

Tribal clam and oyster harvest areas are replenished by natural recruitment of larvae or locally produced seed. If reproduction of these species is hampered by ocean acidification, we may have to explore other ways of keeping shellfish beds viable. However, solutions such as obtaining seed from hatcheries located in other regions might not be feasible for some species such as crab. In addition, the shellfish that we rely upon may not be available due to domoic acid, a toxin that is harmful to humans and wildlife and that has caused widespread shellfish closures on Washington beaches. Laboratory experiments with the *Pseudo-nitzschia* diatoms that produce domoic acid found that higher levels of CO_2 in the water resulted in greater growth rates and increased toxin production in the diatoms.[293]

Each level of the marine food web, from plankton to fish to mammals, is susceptible to changes in reproduction, growth, and species distribution from changing ocean chemistry. Phytoplankton response to increased ocean acidification will vary, with some species spurred to grow faster, while others will grow more slowly or die out.[294] As calcifying species decline, they could be replaced by non-calcareous species, changing the structure of the marine food web. By 2100, the plankton species distribution could be very different in response to ocean acidification in combination with warmer ocean temperatures.[295] One type of calcifying zooplankton that is already showing the impacts of ocean acidification are the pteropods, tiny swimming snails that are a food source for salmon, herring, and other fish. A 2011 study of waters off the coasts of Washington, Oregon, and California showed severe shell dissolution in 53 percent of onshore pteropods and in 24 percent of those offshore.[296] The authors estimate that the amount of severe shell dissolution of pteropod shells in the region has doubled since pre-industrial times due to ocean acidification.

Crustaceans such as Dungeness crab and spot prawns are most vulnerable to ocean acidification as larvae and juveniles because it can slow their growth. Laboratory tests of Dungeness crab found that larvae took longer to hatch and develop under pH 7.1, the projected future condition during upwelling events.[297] Under the low-pH conditions, crab larval survival was reduced by more than half relative to the open ocean pH of 8.0.[298] Crab larvae are important forage for marine finfish and a decline in larvae could have ramifications through the marine food web. Since crustaceans like crab use chitin along with calcium carbonate for their shells, some species may be buffered against the corrosive effects of ocean acidification.[299] This depends on species type, life history strategy, the type of habitat they are accustomed to, and the exact chemical composition of their exoskeletons. [300]

Rockfish and flatfish could experience impacts due to the decline of some of the echinoderms that they prey upon.[301] Larval fish show behavioral changes, such as less effective predator detection and avoidance.[302] As abundance of pteropods decline, the fish that normally feed on them may turn to juvenile fish such as salmon instead.[303] Orcas are sensitive to changing ocean conditions such as temperature, pH, DO, and shifts in food web structure.[304]

Observed and Projected Changes

Before the industrial revolution, ocean pH averaged 8.2; today ocean pH is 8.1.[305] The 0.1-unit drop in pH represents a 26 percent increase in hydrogen ion concentration.[306] Our region is experiencing accelerated rates of ocean acidification due to natural factors such as cold water (which can absorb more CO_2) and upwelling ocean currents that bring deeper high CO_2/low DO waters to the surface. In addition, human activities can increase local acidification through nutrient pollution from agricultural runoff carried by rivers, failing septic systems, and wastewater treatment plants. Nutrients stimulate phytoplankton growth and when those organisms die, their decomposition by bacteria lowers dissolved oxygen, pH, and aragonite saturation state. The rate of decomposition is accelerated by increased sea surface and air temperatures.

The pH of surface waters in Puget Sound and the Pacific coast has decreased between 0.05 to 0.15 units since the dawn of the Industrial Age.[307] Overall in Puget Sound, 24 percent of the pH decrease in the summer and 49 percent of the decrease in the winter can be attributed to ocean acidification.[308] The amount of undersaturated water in the top 328 feet (100 meters) of the ocean off the coasts of Washington, Oregon, and California has increased by 6 times since the pre-industrial era (Figure 9).[309] Marine waters entering Puget Sound were above saturation for aragonite in pre-industrial times, but today they are undersaturated.[310]

Models indicate that the surface of the global oceans will continue to acidify as atmospheric CO_2 continues to rise. Water at depth will also acidify as CO_2 in surface waters penetrates deeper into the ocean. By the end of the 21st century, the global mean surface ocean pH is projected to decrease by 0.31 to 0.5 units for high emissions scenarios.[311] Seasonal cycles of the ocean's dissolved inorganic carbon and pH in seawater are projected to cause large-scale undersaturation of aragonite if atmospheric CO_2 reaches 496 ppm above the North Pacific and 511 ppm above the Southern Ocean.[312] In Washington, seasonal upwelling and upland sources of nutrients and organic carbon will continue to promote more acidification of coastal waters. The combination of ocean acidification and warmer ocean temperatures creates a stronger response together in biological factors such as calcification, photosynthesis, reproduction, and survival.[313]

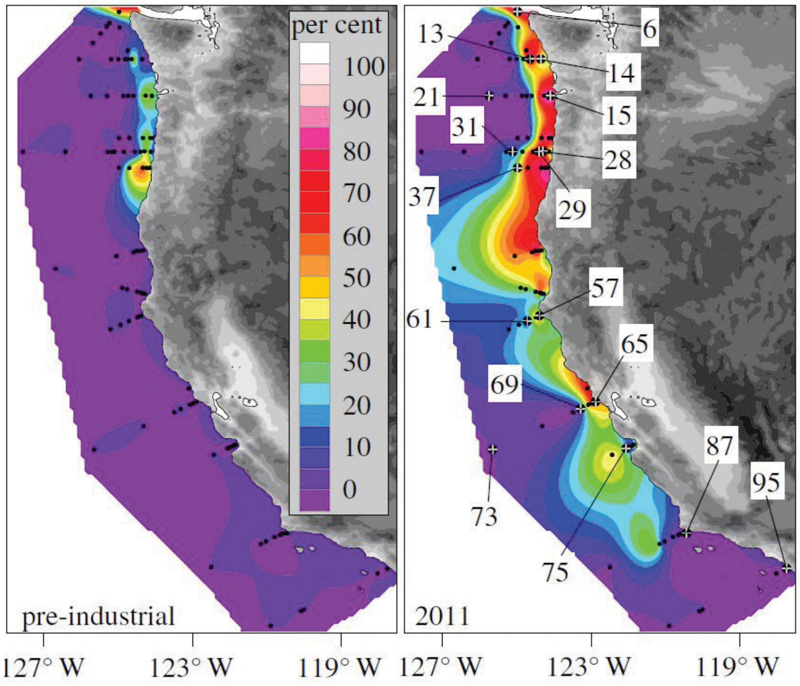
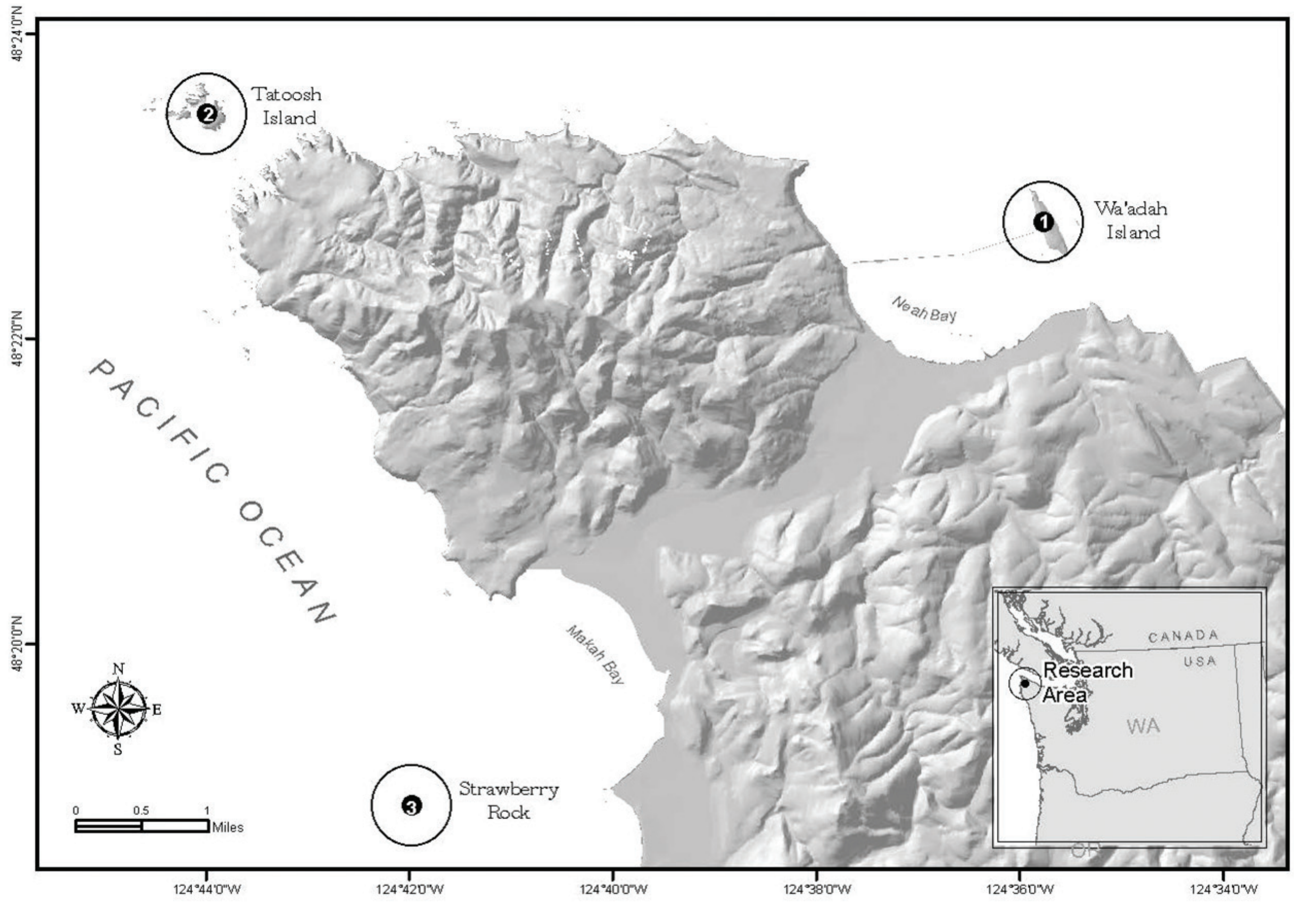


Figure 9: Percent of the upper 100 m of the water column off the U.S. Pacific coast estimated to be undersaturated with aragonite (a form of calcium carbonate used by marine organisms to form shells): during pre-industrial times (left) and from August to September 2011 (right). Numbers in the squares denote pteropod monitoring stations. Source: modified from Bendaršek et al. 2014.[314]

Taking Action: Makah Tribe Ocean Acidification Research

The Makah Tribe is using a novel approach to an established scientific method to detect the effects of ocean acidification in Neah Bay. The analysis of stable carbon and oxygen isotopes in fish otoliths (or ear bones) has been used to track the fish's life histories and their environmental conditions. At the Makah Tribe, analysis of carbon isotope ratios ($^{13}C/^{12}C$ or $\delta^{13}C$) in bivalve shells is helping the tribe to make informed decisions about shellfish resource protection and economic development. Previous research based on eight years of observation of pH at Tatoosh Island in Neah Bay concluded that the pH decline is proceeding 10 times more quickly than expected and that the decline has ecological consequences for nearshore ecosystems.[315] However, people living on the Makah Reservation have noticed that modern mussels are different in size and shape between Neah Bay, Makah Bay, and Tatoosh Island (Figure 10). Because these locations are within five miles of one another and share similar water characteristics, it is possible that the different growth rates of California mussels in Neah Bay may come from the different food sources or supplies. Along with samples of California mussels from Neah Bay, Makah Bay, and Tatoosh Island, the tribe conducts water quality monitoring for temperature, salinity, pH, dissolved oxygen concentration, and the isotope ratios of dissolved inorganic carbon and oxygen.

Figure 10: California mussel samples were collected from three locations: (1) Wa'adah Island; (2) Tatoosh Island; and (3) Strawberry Rock. These locations represent the different environmental conditions where mussels grow in Neah Bay. Source: Makah Tribe.



5.6 COASTAL HYPOXIA

Ocean acidification is occurring alongside warmer ocean temperatures and lower levels of dissolved oxygen. All three of these stressors on marine organisms are expected to increase as the climate changes.[316] As in fresh water, warmer salt water can hold less dissolved oxygen. Hypoxia (low dissolved oxygen) and anoxia (the lack of dissolved oxygen) in marine waters can have a profound effect on ecological processes and fisheries. Fish and shellfish need oxygen and will change their behavior when levels decrease. Mobile species will leave a hypoxic area in search of more oxygenated waters, but if mobility is low or when levels drop too low or too quickly, "fish kills" can occur. Lower dissolved oxygen also reduces growth, reproduction, and availability of prey and habitat.[317] Low oxygen supply can lower the tolerance of some species to high temperatures and their defense against disease.[318]

The amount of dissolved oxygen in the marine waters of the PNW naturally varies throughout the day, seasonally, and annually. Hypoxic conditions regularly occur in some locations in Puget Sound, particularly in Hood Canal and the southern inlets.[319] This is often primarily due to natural factors, such as circulation patterns that result in slow flushing rates in some areas. On the Pacific coast, strong winds from the north can push surface waters offshore causing upwelling of deeper, low-oxygen ocean water. Human sources of nutrients also lower dissolved oxygen levels and increase ocean acidification. The combination of hypoxia and ocean acidification can be highly stressful to organisms.

While some marine species are adapted to periodic hypoxia, other species cannot tolerate such conditions. A number of fish kills have occurred in Hood Canal in the last 15 years, predominantly affecting copper rockfish and lingcod.[320] In 2006, an exceptionally large and long-lasting hypoxic event struck the Pacific coast of Oregon and much of Washington, stretching across about 1,160 square miles (3,000 km^2), encompassing 80 percent of the water column in shallow shelf waters and persisting from June to October.[321] Surveys conducted that August in Oregon waters found that the rocky reefs that normally support diverse species of rockfish were completely devoid of fish.[322]

Observed and Projected Changes

Oxygen levels in global oceans are decreasing. This is due in part to warming ocean temperatures. Warmer waters hold less oxygen and also increase stratification, where ocean layers mix less and oxygen in surface waters does not descend into deeper waters. Warm water also encourages the growth of phytoplankton, which depletes dissolved oxygen at depth during decomposition.

The frequency and severity of hypoxic events are increasing in the California Current Ecosystem due to changes in the oxygen levels in upwelling water, the intensity of winds that cause upwelling, and increases in productivity and respiration of marine plants and phytoplankton.[323] This is placing added pressure on fish populations that are already stressed by loss of habitat, pollution, warmer oceans, and ocean acidification. One study of the relative influence of ocean acidification, hypoxia, and temperature in global ocean ecosystems found that the variation in species diversity is most strongly explained by oxygen levels.[324]

By 2030, the climate change signal will be evident in hypoxia around the world's oceans.[325] The dissolved oxygen levels in the North Pacific have been decreasing for the last 50 years. The continuation of this trend combined with increased nutrients from human sources, warming ocean temperatures, and changes to the timing and amount of freshwater inputs will cause widespread decreases in dissolved oxygen levels in Puget Sound and the Strait of Juan de Fuca.[326] Low dissolved oxygen will cause habitat fragmentation and reduction in habitat for some species.[327]

5.7 RESILIENCE IN COASTAL AND MARINE ENVIRONMENTS

The resilience of coastal environments to sea level rise and storm surge is greatly enhanced by the presence of salt marshes and coastal wetlands. Natural shorelines improve coastal resilience by allowing landward migration of habitats and by maintaining the geomorphic processes that build and sustain nearshore ecological function. The natural topographical and hydrological variability in coastal wetlands also improves ecosystem function.[328]

Human modifications that alter natural geomorphic and hydrological function can reduce the resilience of nearshore environments. The presence of shoreline armoring structures such as bulkheads can limit the natural ability of the beach to

Eelgrass and kelp are vital to the coastal ecosystem as habitat and food for marine species. Photo: Tiffany Royal, NWIFC.

adjust to changes in sea level, increase wave energy scour, and block the delivery of sediment from upland sources. Levees and revetments in river systems can also detract from nearshore geomorphic function. For example, the levees that currently constrain the lower Skagit River concentrate flows enough to push a substantial amount of the sediment carried by the river past the delta into the deeper waters offshore. The presence of distributary channels on the Skagit River delta would allow river flows to spread sediment across the delta where it can build up the ground surface as sea levels rise.[329]

Although ocean acidification is a global process, local conditions can vary greatly. Spatial variability along with individual species characteristics may buffer some locations from the corrosive effects of ocean acidification.[330] Because high-CO_2, low-DO conditions occur regularly in our region, some species are naturally resilient to a limited amount of exposure to these conditions. However the combination of ocean acidification, warmer ocean temperatures, and decreasing levels of dissolved oxygen will work together to reduce resilience of species, particularly those that are not mobile and cannot move away from adverse conditions.

Eelgrass meadows and kelp beds play an important role in the coastal ecosystem as habitat and food for marine species and they may be able to enhance the resilience of coastal species to ocean acidification at the site scale. As they photosynthesize, they decrease the amount of CO_2 dissolved in seawater locally. The presence of eelgrass and kelp could provide refuge from corrosive waters for coastal species. Eelgrass and salt marshes also provide carbon sequestration—that is, they store carbon in their leaves and in the substrate.

Changing marine food webs will have variable effects on marine mammals. Generalist species such as gray whales, Pacific harbor seals, and California sea lions may be able to adapt to new or different food sources and changing habitat.[331] Other species are more vulnerable, such as the northern fur seal populations, which are declining in part due to changing climate.[332] The ESA-listed southern resident orca populations that spend spring, summer, and autumn in the Salish Sea are also vulnerable to decreases in the availability of Pacific salmon, their major food source.[333]

Taking Action: Lummi Nation Wetland and Habitat Mitigation Bank

The coastal wetlands of the Lummi Indian Reservation form where rivers and streams meet the sea. They provide vital ecosystem goods, functions, and services, including stormwater attenuation, floodwater storage, water quality enhancement, fish habitat, wildlife habitat, and plants with traditional cultural importance. Protecting and enhancing coastal wetlands and the functions they provide has become increasingly important in the face of global climate change—particularly accelerated sea level rise. The tribe has developed the Lummi Nation Wetland and Habitat Mitigation Bank to protect and improve function on large tracts of estuarine and floodplain wetlands of the Lummi and Nooksack rivers. In 2009, the Lummi Nation approved an acquisition and land use plan for approximately 2,770 acres of wetland habitat on the reservation's riverine and coastal floodplains for mitigation banking and restoration purposes. These areas will be protected into perpetuity through conservation easements.

The mitigation bank will be developed in phases. The first phase, which encompasses most of the Nooksack River estuary, became operational in 2012. Enhancement activities underway in this area include removing invasive species and planting native species (e.g. willows, conifers). At the Lummi River estuary sites, where acquisition of properties is ongoing, rehabilitation will focus largely on restoring direct tidal input to areas that have been isolated from tidal hydrology by shoreline dikes. Restoration at these sites will include removing existing tide gates or replacing them with self-regulating tide gates, removing portions of existing dikes, and opening remnant sloughs and distributary channels—actions which will facilitate shoreward migration and help to prevent coastal squeeze. By implementing this extensive wetland protection and enhancement project, the Lummi Nation has taken an important step to guard against coastal wetland losses due to climate change.

Lummi tribal technicians plant conifers in the Nooksack delta where the tribe is enhancing habitat for a wetland mitigation bank. Photo: Kari Neumeyer, NWIFC.

6. TERRESTRIAL AND UPLAND ENVIRONMENTS

6.1 CHAPTER SUMMARY

Terrestrial environments provide us with an abundant array of wild game, greens, roots, nuts, berries, and other fruit. Terrestrial plants and animals are also used for medicine, ceremony, and artistic expression. Terrestrial ecosystems are responding to warmer air temperatures, less snowpack, higher snowlines, more frequent and severe flooding, shifts in precipitation patterns, and drier summers. These changes occur within the context of human land and water use that already have diminished the quantity, connectivity, and ecological integrity of vital habitat for terrestrial animal and plant species.

The impacts of climate change to terrestrial ecosystems include:

- Changes to species ranges as they migrate to higher elevations and latitudes;[334]
- Decreased productivity due to temperature or drought stress;[335]
- Changes to the timing of key life cycle events tied to temperature or other climate variables and subsequent changes in species interactions;[336]
- Increased frequency and size of wildfires;[337]
- Escalating disease, parasite loads, pest populations, and invasive species; and[338]
- Greater probability of disturbance from landslides.[339]

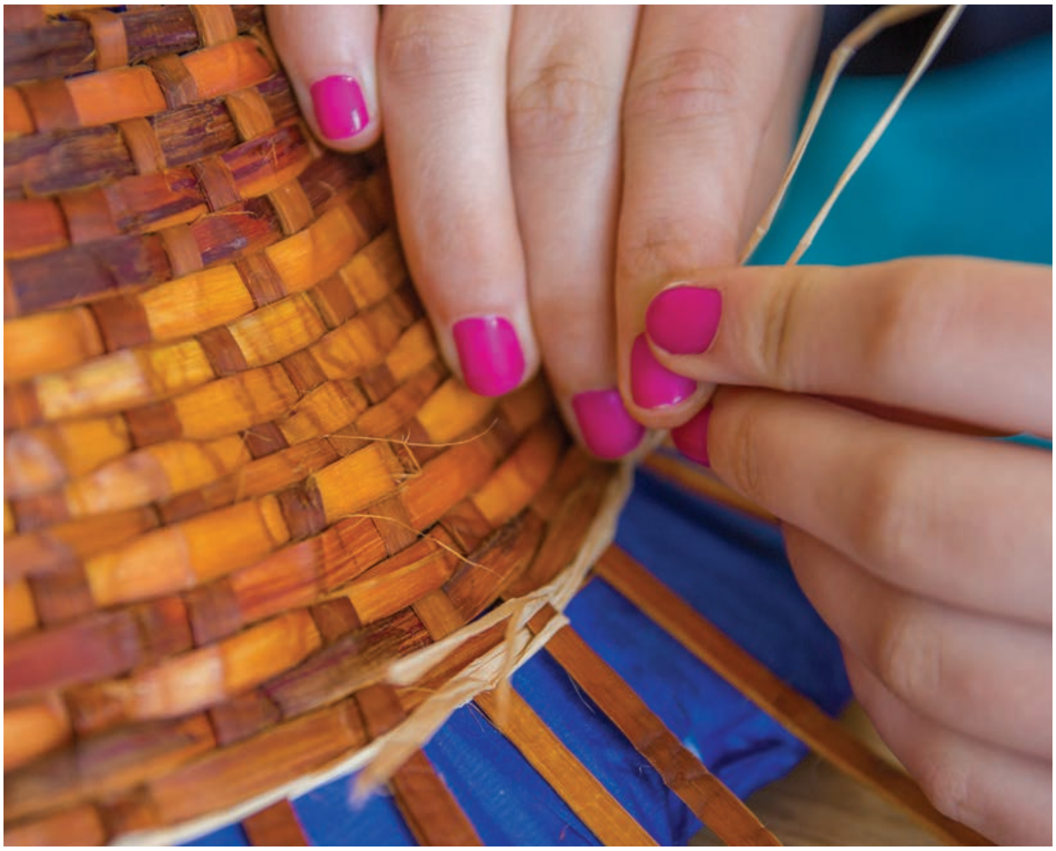
6.2 THE TREE OF LIFE

Many plants have foundational importance to tribes. For example, the western red cedar has been called the Tree of Life because of its contributions to all areas of tribal life.[340] Along with its commercial value, western red cedar is used in making regalia items, baskets, canoes, paddles, rattles, vests, hats, drums, masks, and totem poles.[341] The cedar is regarded as sacred and is used for ceremony, prayer, and healing. Because of its importance and potential vulnerability to climate change, western red cedar has been identified as a key concern for the Jamestown S'Klallam Tribe in their Climate Vulnerability Assessment and Adaptation Plan.[342] Yellow cedar, although rare on the western Olympic Peninsula, is highly valued by the Treaty of Olympia tribes for commercial use and for carving canoe paddles and masks.[343]

Every type of vegetation found in the terrestrial environment has a traditional use: trees, flowering plants, ferns, fern allies (horsetails and clubmosses), mosses, liverworts, lichens, and fungi. Working collaboratively, the Tulalip Tribes, the Muckleshoot Indian Tribe, the Suquamish Indian Tribe, King County, and the Burke Museum of Natural History and Culture at the University of Washington have been researching the nutritional value of traditional foods. Archaeological excavations of 130 sites in King, Kitsap, and Snohomish counties have found over 280 kinds of plants and animals that were used as far back as 5,000 years ago. Unfortunately, many of these species are difficult to obtain today as the environment has become urbanized. At the community roundtable discussion for the Traditional Foods of Puget Sound Project in 2009, one family recounted that one of the most abundant prairie areas for camas bulb harvest had been paved over for a housing development.[344]

> **"In the Squaxin Island Tribe of the Medicine Creek Nation it was common for our people to live beyond 100 years old. Tribal elders attribute this longevity to knowledge about traditional foods and medicines that was passed down from generation to generation. Their powerful traditional science included understanding techniques for gathering, knowing when was the most potent time to harvest, how food was processed for everyday use and how plants were used for ceremonial purposes. This knowledge was highly regarded as a sacred gift that contributed to living a long and fulfilling life."**
>
> – Charlene Krise, Tribal Council Secretary, Squaxin Island Tribe[345]

Foods such as roots, greens, and berries provide vital nutrients recognized for their antioxidant and immune system supporting roles. Big huckleberry formed a major part of traditional diets for many PNW tribes due to its high yield, sweetness, and nutritional content. Berry gathering was one of the main reasons for extended trips into the mountains in the summer. Berries were smoked or dried in the sun and preserved for use all year. Specific berry grounds belonged to women or their families and a network of trails connected the fields.[346]



Students in the Chief Kitsap Academy's Lushootseed Language and Culture class learn how to weave traditional hats and baskets using dried cedar strips harvested by tribal members. Photo: Tiffany Royal, NWIFC.

Today, most of the huckleberry habitat is on public, federally owned lands, which can sometimes limit access, despite treaty-protected rights to gather. In the past century, management practices like fire suppression have caused huckleberry meadows to decline or disappear.

Wild game includes deer, elk, mountain goat, black bear, rabbit, waterfowl, wild turkey, mink, beaver, and river otter. Tribal hunting practices have strong spiritual underpinnings. Deer and elk are essential foods at potlatches, funerals, and naming ceremonies. Their hooves and antlers are used for ceremonial tools and clothing, as is the wool of mountain goats. Wildlife provides a stable source of high-quality protein on reservations where unemployment rates are high and some tribal members struggle to feed their families. The importance of traditional foods to our health and well-being underscores the central role of protecting and restoring ecosystem health.

We have always actively managed our terrestrial hunting and gathering grounds. Our forebears maintained highly valued gathering areas through controlled burns, planting seeds, transplanting bulbs and plants, pruning, harvest rotation, and redirecting water pathways.[347] Prairies were intentionally preserved from forest incursion for plants like camas, notably in the south Puget Sound region,[348] but also on the Olympic Peninsula on the Quillayute Prairie.[349] Controlled burns maintained biodiversity and helped create a mosaic of habitat types.[350] The fires were carefully managed to prevent them from spreading beyond the targeted area. The fire practitioners were skilled at understanding and predicting weather conditions and finding the optimal time for burning.[351] Fire was used to enhance big huckleberry harvest, since it sprouts well after fire and produces more fruit when the tree canopy is not completely closed.[352] Burning was also used to enhance the quality and quantity of basketry materials like bear grass, beaked hazelnut, and willow. Keeping meadows and clearings open also promoted forage for deer and elk.

In the PNW, commercial timber production on tribal lands began in the late 1800s and continues to this day. Douglas fir and western hemlock are dominant species for timber harvest. Following a period of Bureau of Indian Affairs controlled forestry on reservation lands, the 1975 Indian Self-Determination and Education Assistance Act enabled tribes to establish our own natural resources departments and independent forestry programs.[353]

6.3 SHIFTS IN VEGETATION RANGES

Many terrestrial plants and animals are shifting their geographic distributions to higher latitudes or higher elevations due to climate change. At the same time, plants and animals may be unable to migrate if their rate of dispersal cannot keep pace with the rate of change in environmental conditions or if their distribution is limited by other factors, such as light.[354] The impacts to tribes could be enormous if traditional resources die off or move out of established gathering areas and become inaccessible to tribal members. Traditional practices built around certain plants and animals may not be easily transferred to the species of the new ecosystems that arise in a changing environment.

Forests play an important role in tribal life and in Washington state overall. Forests comprise 52 percent of the total area of Washington, with 56 percent publicly owned by federal and state agencies and the rest under tribal, private, and corporate ownership. Conifer species dominate the forest ecosystems, but hardwood species are abundant in riparian areas and in disturbed sites after avalanches or logging.[355] Along with these species, forest ecosystems include understory species—an array of woody shrubs, herbaceous plants, ferns, mosses, lichens, and fungi.

Observed and Projected Changes

In the long term, the composition of plant species present in forest ecosystems depends on the topography, soil type, moisture availability, type of precipitation (snow or rain), temperature, and length of the growing season. As snow cover declines and melts earlier, high elevations will be snow-free for longer periods. Some species may be able to expand into those areas. For example, trees may be able to encroach into existing meadows, especially wet mountain meadows, where temperature, snow cover, and moisture will no longer limit tree establishment.[356]

While vegetation models for the forests west of the Cascade Mountains show that the forest type will shift from conifer to mixed conifer-deciduous, responses to changing environmental conditions vary among species and locations.[357] The moist maritime forests of the west side North Cascades are projected to shift to the dry temperate forest types seen on the east side of the mountains, but not all tree species will be able to make the transition and areas suitable for lodgepole pine will decrease.[358] In models with increased temperatures and changing precipitation, the high elevation ecosystems of the Olympic Peninsula do not respond uniformly because of local variations in topography and the rain-shadow effect of the mountains. In the wet southwest region of the peninsula, the models show forest communities shifting toward higher elevations, but in the dry northeast the same future conditions result in an entirely new combination of tree species.[359]

Shifts in plant species take time and depend on the ability of each species to disperse their seeds. In the rainforests of British Columbia, tree species such as Sitka spruce and western hemlock that are widespread and genetically diverse are better able to colonize new habitats, while other species like cedars and many understory plants may not be able migrate as quickly.[360] Dispersal ability plays an important role in the sensitivity of a number of tree species to climate change. An assessment of tree species that are important to the Treaty of Olympia tribes on the Pacific coast (Quinault Indian Nation, Quileute Tribe, and Hoh Tribe) classified western white pine, western red cedar, Douglas fir, Pacific yew, and lodgepole pine as moderately sensitive to the impacts of climate change.[361] Although Sitka spruce was found to be able to colonize new habitats in B.C., the Treaty of Olympia assessment rated its sensitivity to climate change as moderately high. Sitka spruce is restricted to coastal areas that have cool, foggy summers and it is sensitive to disturbances and changes in temperature and precipitation patterns. In the southern parts of its range, even small decreases in fog and air moisture in the summer could have severe effects on survival and reproduction, especially in combination with pest outbreaks and disturbances such as wildfire and windstorms.

These changes can bring about cascading effects through ecosystems as species relationships shift, and they can create new communities, called novel ecosystems. Douglas fir is a widespread and economically important species. Conditions projected for 2060 indicate that about 32 percent of current Douglas fir habitat would be lost, mainly due to low elevation water shortfalls (Figure 11).[362] However, Douglas fir may be able to spread into high elevation areas made accessible by warmer temperatures and less snow, so the overall amount of area covered would not change greatly, provided there is enough water.[363]

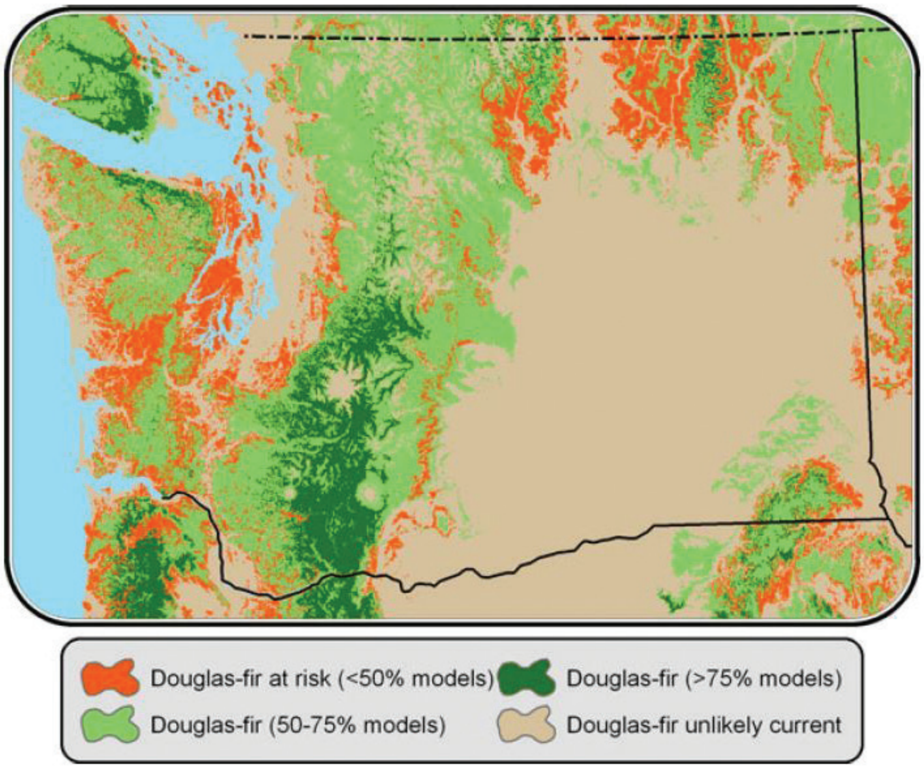


Figure 11: Change in areas of Washington where the climate will be suitable for Douglas fir by the 2060s. The map colors indicate the percentage of statistical models that suggest the climate will support Douglas fir, so orange areas are at greatest risk while dark green areas are at the lowest risk. Note that the decline is centered at lower elevations and that in western Washington decline is most widespread in the south Puget Sound region and the southern Olympic Mountains. Source: Littell et al. 2010.

6.4 SHIFTS IN WILDLIFE RANGES

Increasing temperatures and changing precipitation patterns will affect many wildlife behaviors and physiological processes. Warm-blooded species may need to seek out cooler areas in the summer, while animals that burrow under snow in the winter may be at risk for freezing without adequate snow cover.[364] Terrestrial animals that cannot adapt to changing conditions or that cannot easily migrate into more favorable areas face the possibility of extirpation or extinction. This can further induce a cascade of effects within terrestrial ecosystems, including loss of biological diversity. Those species that occur at the limits of their geographic and elevation ranges are especially vulnerable. For example, moving into habitat at higher elevations may not be an option for species that already live at high altitudes.

Observed and Projected Changes

Individual species response to changing climate conditions depends on their unique characteristics and the particular external factors at work, but overall range shifts can be quite rapid. An analysis of multiple species and locations around the world estimated that shifts to higher elevations have been occurring at 36 feet (11.0 meters) per decade on average, and that shifts to higher latitudes have occurred at 10.5 miles (16.9 kilometers) per decade on average.[365] Natural topographic barriers can restrict species from migrating to a more suitable climate as can a poor ability to migrate. Migration corridors are required, as is the availability of food sources in the new locale. Without areas of suitable climate to migrate to, a species may experience the death of individuals, extirpation, or extinction.

Waterfowl are responding to climatic changes in their habitat, food sources, and migration routes. Drought conditions in the wetland breeding areas of the northern Great Plains could lead to a reduction in the number of breeding ducks throughout North America's flyways of up to 69 percent.[366] Half of the species that winter along the Pacific Flyway breed in Alaska. Earlier onset of spring and warmer air and ocean temperatures in Alaska may favor some species while others experience declines. Some species like mallards and Canada geese tend to remain in the northern part of their range if warmer temperatures keep water from freezing and they have open water and food sources available in the north. The waterfowl that migrate south through the Pacific Flyway rely on coastal marshes and estuaries that are at risk from sea level rise and changes in freshwater inputs. Diving ducks like canvasbacks and ruddy ducks are especially sensitive to loss of estuary habitat because their habitat has already been greatly reduced by human modifications.[367]

6.5 PRODUCTIVITY AND PHENOLOGY

Plant productivity is predicted by the availability of light, temperature, water, and nutrients. Phenology describes the timing of events in an organism's life cycle, such as reproduction or migration. Warmer winter and spring conditions can cause woody plants to experience bud burst (when the first new buds grow in the spring) sooner, but the effects will not be the same for all species. Many tree species in the PNW require cold temperatures in the fall and winter to burst bud properly in the spring. Douglas fir, western hemlock, western larch, pines, and true firs all have a chilling requirement and will not burst bud without cold temperatures, even when the days get longer in the spring.[368] Pacific madrone and western red cedar benefit from chilling, but can still burst bud normally without it.[369] The date when plants begin to flower and the appearance of the insects and birds that pollinate those flowers has been occurring earlier as temperatures warm.[370] While the responses of plants and their pollinators often happen in parallel, in some cases mismatches in timing may occur.[371]

Changes to the timing of the seasons can impact wildlife cycles of migration, hibernation, and mating. Some of the greatest potential impacts to wildlife will come from changes in habitat type, migration patterns, and the phenology of food sources. Animals with specialized diets will be negatively impacted if the timing of their life cycles falls out of synchrony with their food sources. Shifts in phenology also threaten important and long-standing tribal cultural traditions. For example, members of the Sauk-Suiattle Indian Tribe traditionally collected mountain goat wool in close timing with the animals' life cycles and the melting of the snowpack in high-altitude environments of the North Cascades. The timing of these events are shifting and mountain goats are rated as being extremely vulnerable to changes occurring by the 2080s under moderate and high GHG emissions scenarios.[372]

Observed and Projected Changes

Increases in winter temperatures projected for 2080 indicate that bud burst for Douglas fir would occur up to 74 days earlier, except in the southern part of their range where bud burst is expected to occur later due to the lack of chilling. Other species also were projected to burst bud earlier, except where lack of chilling would cause the opposite effect.[373]

Where forest productivity is limited by cold temperatures, climate warming may increase growth. Most western Washington forest systems are water-limited because of our dry summers. These areas will respond negatively to warmer and drier summers because the water demands on the plants will be greater at the same time that less water will be available.[374] Drier meadows may see less tree encroachment, but lower soil moisture will reduce huckleberry production.[375]

Along with available moisture, changes to the length of the growing season can also reduce the productivity of plants.[376] For example, Douglas fir and western hemlock, conifers that dominate western Washington forests, are expected to decline in growth and vigor as environmental conditions change.[377] While increases in atmospheric CO_2 can initially fertilize and accelerate plant growth, the stress of higher temperatures will dominate plant productivity in the long term.

Brian Perry, Port Gamble S'Klallam, carves a totem pole from a cedar tree. Photo: Tiffany Royal, NWIFC.

6.6 WILDFIRE

Disturbances like wildfire can quickly change forest composition, replacing existing communities with new ones. Wildfire is a natural component of forest processes that serves important ecological functions, but large wildfires can profoundly change ecosystem structures and functions. Wildfires also impact water quality through increased erosion and the subsequent delivery of sediment into water bodies.[378]

Observed and Projected Changes

Between 1987 and 2003, large wildfires in the western United States increased in frequency and duration. The fire season has lengthened in conjunction with higher summer temperatures and reduced snowpack associated with climate change.[379] The area of forest burned between 1987 and 2003 was 6 times greater than the area burned between 1970 and 1986.[380] Across the country, the 2015 fire season burned 9.4 million acres and cost the U.S. Forest Service $1.7 billion—$700 million more than the amount allocated by Congress for this purpose.

Large wildfires (greater than 50,000 acres in extent) are projected to increase by 30 percent in the western United States, particularly in the Rocky Mountains and the PNW.[381] Models suggest that the time between fires in western Washington will decrease by 48 percent.[382] In the western Cascades, the average area burned from 1980 to 2006 was 1,100 acres. That is projected to increase to 1,900 acres by the 2020s, 3,200 acres by the 2040s, and 9,100 acres by the 2080s.[383] While forests in western Washington may not have been prone to fires in the past, changes brought about by warmer summers, lower soil moisture, and higher rates of evapotranspiration leave them more vulnerable today.[384] For example, the 2015 Paradise Fire in the rainforests of the Queets River valley in Olympic National Park followed the driest May and June recorded in the Forks, WA, area since records began in 1895.[385] Ultimately the fire consumed 2,800 acres of temperate rainforest.[386]

6.7 DISEASE AND PESTS

Increase in the frequency and intensity of drought due to climate change can potentially alter the impacts of forest pests, parasites, and diseases. Drought stress lowers plant defenses and some studies indicate that previous insect or fungal outbreaks can increase the susceptibility of trees to drought-induced mortality.[387] Disturbances like wildfire and pests acting together can amplify the effects and can quickly change forest structure. Human modifications to the landscape through land use and forest management practices can further compound these disturbances if lack of genetic diversity or homogenous forest stand structure increases vulnerability.

The main biological cause of tree mortality in the western U.S. is the mountain pine beetle, which is responsible for the death of hundreds of millions of trees in recent decades.[388] Warming temperatures have prevented the usual winter die-off of mountain pine beetle and allowed them to complete additional reproductive cycles throughout the year. Drought and heat stress also leave host trees less able to repel the insects. The western spruce budworm is the most prominent defoliator in the western U.S., causing tree damage and death in multiple types of conifers. Budworm outbreaks are also associated with drought-stressed trees.

Forest pathogens in western forests include Swiss needle cast, white pine blister rust, sudden oak death, and laminated root rot. Swiss needle cast interacts with warmer temperatures and lower soil moisture to reduce Douglas fir productivity and forest health. In Washington, this disease causes the most damage near the Pacific coast due to the favorable conditions for fungal growth: mild winters and wet springs and summers. In 2015, almost 350,000 acres of Douglas fir with Swiss needle cast symptoms were found in an aerial survey.[389] This was an increase of 120,000 acres since the previous survey in 2012. The most severely affected stands were located near the coast and in the Grays Harbor area.

Pathogens and parasites also pose a threat to wildlife species. The biggest risk to large game species may be the introduction of new diseases or parasites at the same time that pathogens and parasites are able to survive year-round as freeze-free periods increase.[390] For example, the decline of moose populations across their range in the northern U.S. is attributed to changing conditions that favor ticks, parasites, and bacterial infections. Warmer and shorter winters have been driving an explosion in tick populations and moose are succumbing to bacterial infections as well. While researchers are still attempting to tease out all the influences on moose mortality, the moose population in Minnesota has dropped 52 percent since 2010.[391]

Observed and Projected Changes

Mountain pine beetle, western spruce budworm, blister rust, and Swiss needle blight are all on the rise in Washington's forests because of climate change. About 3 million acres of forest in Washington are vulnerable to die-off or fires in the next 15 years due to insects and disease.[392] While introduced insect and disease organisms pose the greatest threat to forest health, native pest impacts can increase in response to drought, changes in stand density, or climate change.[393]

Mountain pine beetle outbreaks threaten large areas of the Olympic Mountains and mid-elevation forests of the western Cascade Mountains.[394] Models project that future outbreaks will move to higher elevations as temperatures become suitable for mountain pine beetle. By contrast, as temperatures rise at lower elevations, the mountain pine beetle are expected to move through their life cycle too quickly and emerge at the wrong time of year, thus limiting outbreaks in low elevation forests.[395]

Warmer temperatures combined with wetter winters and drier summers could increase the frequency and severity of Swiss needle cast.[396] One study of Oregon forests indicates that these combined impacts will become more substantial in low- to mid-elevation forests where conditions are warmer and drier.[397] Swiss needle cast outbreaks will also be able to expand farther north and into higher elevations due to warmer winters.[398]

6.8 LANDSLIDES AND MASS MOVEMENT

Mass movement is a geological term for the downslope movement of rock, soil, and debris. This can occur quickly in landslides, rock slides, debris flows, mudflows, and rock falls. Mass movement can also occur slowly through soil creep or slumps. The amount of material moved can be relatively small or quite large. While landslides and debris flows in streams can damage habitat, property, and infrastructure, they also supply the sediment and wood that build healthy ecosystems. They create habitat heterogeneity that improves salmonid productivity and the wood they carry enhances ecologic function and geomorphic processes.[399]

The stability of slopes depends on a suite of related processes. The geological composition and topography of the landscape are two important factors determining landslide probability. Many of the shorelines and river valleys in western Washington consist of sediments from glacial sources in the form of clay, sand, gravel, and glacial till—a mixture of particles of different sizes. Depending on the age and level of compaction, till can be well consolidated or quite loose. The movement of surface water and groundwater in slopes also plays a key role. Heavy rainfall can trigger landslides, especially when the soils are already saturated from preceding rains. When coarse, loose layers of glacial sediment sit on top of clay or bedrock, water infiltrating through the top material will be trapped by the denser layers below. This water acts like a lubricant and weakens the top layers, potentially leading to mass movement. Wave action on marine shorelines and bank erosion along streams can also trigger mass movement by destabilizing the toe of the slope. Earthquakes, both large and small, can trigger mass movement. Land-use practices also contribute to mass movement and the link between poor forest practices and increased mass movement is well established.[400] Removing vegetation reduces slope stability since roots physically bind the soil and plants draw water out of the soil through evapotranspiration.

Observed and Projected Changes

Observations of the effects of 20th century climate change on landslide rates and severity in western Washington are hampered by the lack of comprehensive long-term tracking. Establishing a baseline rate of mass movement is also challenged by the influence of ongoing changes to land use and land cover. Nonetheless, projected changes to the climatic drivers of slope stability can be extended to landslide activity. For example, a study of the Queets River basin on the Olympic Peninsula projected an 11 percent increase in areas with high susceptibility for landslides by 2045 based on a moderate GHG emission scenario.[401]

Drier summers will likely result in less mass movement during the summer months, but in autumn and winter, the likelihood of mass movement will increase because soil saturation will rise as the amount of precipitation falling during these months increases and more precipitation falls as rain rather than snow.[402] Rising sea levels, storm surge, and increasing flood flows in rivers can trigger mass movement through erosion at the toe of slopes. As discussed in *Section 4.6: Sediment in Streams*, receding glaciers leave behind unstable, oversteepened slopes that are susceptible to failure.

6.9 RESILIENCE IN TERRESTRIAL ENVIRONMENTS

The resilience of terrestrial environments increases with topographic and biological diversity. The amount of spatial heterogeneity correlates to the capacity of a site to buffer the impacts of climate change.[403] Because many species have a preferred local climate, changes to factors such as precipitation and temperature will compel organisms to disperse in order to maintain their preferred conditions. Diverse, fine-scale topographic features create an array of different micro-climates that increases the likelihood that organisms will find suitable locations. One analysis of the velocity of air temperature change around the world found that mountainous regions are projected to change more slowly than other types of areas. Mountain landscapes, such as the temperate conifer forests of the PNW, could act as a shelter against changes for many species.[404]

Along with the availability of micro-climates, species must be able to disperse through the landscape in order to reach the most suitable location. One of the greatest challenges facing terrestrial landscapes is the ongoing effect of existing stressors such as habitat fragmentation. Species are more likely to be able to keep pace with climate change velocity where land-cover changes have not created barriers to species movement.[405] Native wildlife has some adaptability to changing conditions, but human-caused stressors like habitat loss and fragmentation lower their resilience. Specialist species will be more at risk than generalist species, which have flexibility in their food and habitat requirements and high tolerance for varying climate conditions.[406] For example, elk show some resilience to climate change because they can move long distances and are tolerant of a broad range of climate conditions, habitat types, and forage sources.[407] However, Roosevelt elk on the Olympic Peninsula face decreasing nutritional quality in their food supply as invasive species replace more nutritious native herbaceous plants in their diet.[408]

Taking Action: Swinomish Indian Tribal Community Forest Resilience

Most of the uplands of the 7,500-acre Swinomish Indian Tribal Community Reservation are forested and the tribe is working to realize its vision for forests and communities that are resilient to climate change. The Swinomish Climate Change Initiative Impact Assessment Technical Report identified wildfire as the top-priority impact to upland tribal resources.[409] Wildfire poses a risk to public safety since much of the upland residential development on the reservation lies in or near forested areas, in what is known as the wildland-urban interface. The tribe is updating its Forest Management Plan for trust lands to implement landscape-scale forest management to improve resilience and decrease risk, but forest ownership in the area is complicated. Land ownership on the reservation resembles a checkerboard, with a mix of tribal and non-tribal parcels distributed throughout—a remnant of early federal policies of reservation land allotment. To promote ecologically sound and truly sustainable forest management practices emphasizing the value of living, healthy forests while also ensuring revenue for tribal members, the tribe is developing a "forest bank." The bank will fund forest management projects, such as restoration, protection, carbon management, thinning, and harvest where appropriate. The bank would create a structure where individual owners could reap the benefits of participation in the forest bank through transfer of land-use rights, management authority, and/or sale of carbon credits while preserving opportunities for value-added products. The bank is a means to use carbon sequestration credits, conservation easements, and restoration incentives to promote improved forest management and preserve valued cultural resources, while seeing to the tribe's economic viability into the future.

The Swinomish Reservation lies across the channel from La Conner. Photo: Jacob Tully, Swinomish.

> **"Forest conservation and climate change adaptation require new ways of doing business—which could open up new business opportunities."**
>
> – Brian Cladoosby, Chairman, Swinomish Indian Tribal Community[410]

7. IMPACTS ACROSS THE LANDSCAPE

7.1 CHAPTER SUMMARY

Species that are important to tribal ways of life and treaty rights are facing multiple stressors due to climate change impacts across the landscape. The major climate change impacts occurring across all the environment types of western Washington include the following:

- Interactions with existing stressors on ecosystems from historical land use and habitat fragmentation;[411]
- The incursion of invasive exotic species;[412]
- Impacts to tribal community health from the direct effects of flooding, heat-related illness, or respiratory disease;[413]
- Indirect effects to health and well-being from the loss of nutritious traditional foods, opportunity for physical exercise, intergenerational culture transfer, and community cohesion through sharing of harvest;[414]
- Infrastructure impacts from flood or wave damage to tribal buildings, historical sites, transportation routes, and utilities;[415] and
- Economic losses to tribal ventures that support economic development, tribal employment, and tribal government programs.[416]

> **"We live along the river in these mountains, along these hundreds and hundreds of watersheds, our Indian people. Everything that's floating out there has got a meaning to it. Everything in this watershed is important."**
>
> – Billy Frank Jr., Chairman Emeritus, NWIFC

7.2 INTERACTIONS WITH EXISTING ECOLOGICAL STRESSORS

In many parts of western Washington, the effects of climate change are occurring within the context of ecosystem structures and functions that have been degraded over the last 150 years. Land cover and land-use alterations, habitat fragmentation, and the incursion of invasive exotic species are disturbances that synergistically interact with climate change signals.[417] Pollution, disease, parasites, and over-exploitation of resources also interact with the effects of climate change on species populations and assemblages.[418] Historical loss of biological diversity can reduce population resilience to disturbance, even as the legacy impacts change the disturbance regimes. These impacts not only amplify the effect of climate change, they can hamper the adaptability of species by blocking paths of migration or reducing genetic resilience. For example, salmonids are made more susceptible to negative effects of climate due to the loss of diversity in habitat, populations, life history, and genetics.[419] The amplification of climate change impacts by existing stressors can be non-linear, creating challenges in distinguishing between them. Nonetheless, teasing out the exact proportions of the different types of impacts may not be necessary as we move forward with developing appropriate response strategies.

The effects of climate change combined with other stressors influences the locations and the timing of events in the living world. Many tribal traditions of fishing, hunting, and gathering are based on our understanding of the interconnectedness of our ecosystems and the species they support. Our traditional seasonal migrations through the landscape allowed for flexibility and resilience to disturbance. Our ancestors could choose the timing and location of fishing, gathering, and hunting activities based on the conditions present at the time. Now our communities face the possibility of traditional resources being lost from historical and established fishing, gathering, and hunting areas. Novel ecosystems comprising new assemblages of species may not easily mesh with our traditional practices.

> **"Washington tribes have fought long and hard to protect our natural resources—for our people and for all people."**
>
> – Kevin Lenon, Vice-Chair, Sauk-Suiattle Indian Tribe[420]

Taking Action: Tulalip Tribes' Conference for Regulatory Harmonization

The Tulalip Tribes have long been working to protect and restore the healthy ecosystems that support salmon. Even after 30 years and more than $50 million invested in planning and habitat restoration in the Snohomish basin, salmon stocks continue to decline, such that some runs are nearly extinct. Restoration cannot keep up with habitat loss and water quality degradation due to development. Tulalip Tribes are identifying key regulatory changes needed to protect and restore priority trust resources and information needs for monitoring climate, habitat changes, and effectiveness of regulatory changes in protecting priority trust resources.

Tulalip and NOAA staff, along with volunteers from the University of Washington, sample the Qwuloolt Estuary following a 20-year project to restore 400 acres of habitat. Photo: Kari Neumeyer, NWIFC.

The Joint Conference Pilot for Regulatory Harmonization developed by Tulalip Tribes provides an opportunity to address priority tribal trust resources, climate adaptation, new information needs, and more agile decision-making in response to emerging issues. The Joint Conference model invites state and federal agency participation in program and policy changes that remove barriers, set common standards, and identify measurable outcomes to show progress in ecosystem recovery and economic, cultural, and environmental gains that meet both local government and Tulalip objectives. The Joint Conference model also engages local government partners including Snohomish County, King County, the city of Everett, and other municipal governments with land-use authority to identify program revisions (e.g. Critical Areas Ordinances and Shoreline Master Programs) needed to better address public safety, reduce risks and liabilities associated with climate change, and meet Puget Sound ecological recovery goals. One of the primary drivers for the pilot is the effect of climate change. The Joint Conference will address sea level rise, ocean acidification, hydrologic shifts, ecosystem shifts, increasing hazards (flooding, landslide, and fire), and impacts to both the built environment and the natural world that our cultures and economies depend on.

7.3 INVASIVE SPECIES

The effects of climate change can lower ecosystem resilience to invasive species, and at the same time, invasive species can make ecosystems more vulnerable to climate change. Invasive plants and animals are already present in the aquatic, marine, and terrestrial environments, where they are the principal risk to seven out of nine eco-regions in Washington.[421] Changes to temperature and precipitation will alter the distribution of these exotic species.[422] Invasive species, including pathogens and pests, can alter the composition and function of ecosystems. Attempts to control invasive species through pesticides, herbicides, fungicide, and mechanical removal can also disturb and degrade ecosystems. One example of an invasive species that makes an ecosystem more vulnerable to the impacts of climate change is cheat grass, a species that has replaced native shrubs and grasses in some areas and is proving to be difficult to eradicate. Cheat grass matures early in summer, before most native grasses, providing a highly flammable fuel source that can increase the severity of wildfires and extend the wildfire season earlier into the spring.[423]

Existing stressors, such as habitat fragmentation and disturbance, leave terrestrial ecosystems increasingly susceptible to invasive species. Already, 25 percent of plants in Washington are threatened by the spread of invasive species.[424] Invasive plants and animals can change the nature of terrestrial ecosystems through competition, habitat change, hybridization, and predation. This could change the availability or quality of species used by the tribes for cultural, ceremonial, subsistence, or commercial purposes. For example, exotic species can reduce the availability or nutritional quality of forage plants for wildlife, leaving them less resilient to the effects of climate change.[425]

Our marine waters already have a number of invasive animals and plants that have been spread by commercial shipping and recreation. Freshwater aquatic invasive plants such as reed canary grass can alter fish habitat since the dense growth pattern reduces open water habitat. Japanese knotweed, a cane-like plant initially used to landscape homesteads, spreads rapidly and has displaced riparian vegetation across western Washington. Tribes in western Washington have removal programs that actively target knotweed. The arrival of new invasive fish and the spread of existing ones that compete with salmonids in freshwater habitats will depend in part on the impacts of climate change.[426] Warm water fish such as smallmouth bass could come into more competition with native salmon and trout as rising stream temperatures expand their ranges.[427]

7.4 TRIBAL COMMUNITY WELL-BEING AND INFRASTRUCTURE

Climate change impacts to tribal community health can arise from increased risk of flooding, storm events, and heat-related illness. Increased disease includes exposure to shellfish biotoxins and emerging diseases spread by insects.[428] Wildfire smoke carries a suite of air contaminants: harmful gases, heavy metals, polycyclic aromatic hydrocarbons, and other fine particles. Smoke plumes can travel great distances and can pose health risks, especially for people with respiratory and cardiovascular disease, elders, and young children.[429] The particulates in wildfire smoke are associated with asthma, pneumonia, and stroke, and can worsen chronic heart and lung diseases.[430]

Loss of tribal traditional foods due to climate change means a loss of high quality and diverse sources of nutrition and the opportunity for physical exercise associated with gathering and preparation. Psychological and spiritual harm can come about from the loss of opportunities for sharing cultural activities, fostering community cohesion, and mastery of traditional arts.[431] Barriers to accessing traditional foods due to climate change occur within the context of existing barriers: poverty, cultural disconnection, access restrictions, and ecosystem degradation from pollution or development.[432] Tribal members likely consumed 200 times more fish and shellfish historically, when species were more abundant and tribes had full access to fishing and gathering grounds.[433] Highly valued traditional foods such as camas, soapberry, gooseberry, and eulachon (also known as smelt or hooligan) have declined so much that they are now very difficult to access. Without access to these foods, the stories and language connected to them have no path for transfer to the next generations.[434]

> **"Native foods have been in this region for thousands of years. [People] want a connection with food, with the environment, with community. These foods help us remember who we are."**
>
> – Valerie Segrest, Traditional Plants and Foods Program Coordinator, Muckleshoot Tribe[435]

Climate change impacts related to heavy rain events, peak streamflows, and sea level rise have the potential to increase damage to tribal residences, important historical sites, and community and government buildings.[436] Utilities, transportation, and emergency response access routes are vulnerable to coastal and river erosion.[437] The costs of chronic road repair can be high. Financial losses could also occur from impacts to tribal ventures that support economic development, tribal employment, and tribal government programs and services.

Taking Action: Swinomish Climate Change Initiative

The Swinomish Indian Tribal Community has been pursuing the Swinomish Climate Change Initiative for almost a decade. In 2009 the tribe developed the Swinomish Climate Change Initiative Impact Assessment Technical Report, followed by the Climate Adaptation Action Plan in 2010.[438] These assessments identify vulnerabilities and risk in all types of ecosystems and in human systems such as infrastructure, agriculture, and human health. The tribe was also involved in the development of a pilot project that aimed to link climate change impacts to community health outcomes.[439] The pilot integrated the projected biophysical changes in local shorelines with perceptions of what constitutes community health among tribal members. In partnership with the USGS and the Tsleil-Waututh First Nation of British Columbia, Canada, they identified potential impacts to important shellfish harvesting areas and archaeological sites. By hosting a series of workshops with tribal members, they were able to identify which indigenous community health indicators (IHIs) best reflected the tribal members' own perceptions of priority and risk. The IHIs included factors such as natural resources security, cultural use, education, community connection, self-determination, and well-being. The tribe is currently working with other tribes in the region to expand the pilot project. The information garnered will be used to inform tribal climate change adaption planning and decisions to enhance ecosystem and tribal community resilience.

Swinomish fishermen travel under the Rainbow Bridge between the reservation and La Conner following the tribe's annual Blessing of the Fleet ceremony. Photo: Kari Neumeyer, NWIFC.

8. MOVING FORWARD: ADAPTATION AND OPPORTUNITIES

8.1 CHAPTER SUMMARY

The ecosystems of our homelands and waters are already experiencing the impacts of climate change. Given the level of historical and current GHG emissions in the global air and ocean system, more warming and associated impacts are still to come. We have already begun to define the scope of these impacts and to develop our capacity to adapt to them. Our strategies to increase resilience of ecosystems focus on the protection and restoration of ecological, geomorphic, and hydrological function as much as possible. Other actions to preserve long-term species and ecosystem persistence include the use of green infrastructure, such as living shorelines, and conservation of climate refugia, where changes are expected to occur more slowly or to a lesser degree.

Response to climate change also includes reduction of GHG emissions. The extent of future climate change will be determined by the quantity of GHG emissions over the coming years, and climate change adaptation becomes less effective as changes in the climate system grow. Communities around the world can work to reduce GHG emissions through renewable energy production, energy efficiency, and carbon sequestration (the long-term storage in biological or geological systems). Indigenous communities worldwide are promoting the prospect of leaving fossil fuels in the ground.[440] GHG emission reduction will require concerted effort on the local, regional, national, and international levels in order to prevent the worst-case scenarios of climate change impacts.

Tribal climate change programs include tracking long-term trends in environmental conditions. These efforts are driven by the needs of tribal communities and natural resources managers. Most programs involve collaboration with external groups, agencies, and research institutions, which is necessary to address the broad-scale impacts of climate change. Despite the wide array of studies in progress throughout the PNW, many data gaps remain. Identifying and addressing these data gaps is one of the next steps for tribal climate change programs.

8.2 CLIMATE CHANGE ADAPTATION

Adaptation actions minimize harm or increase resilience in response to existing or anticipated future changes. Ideally, adaptation strategies have benefits under the current climate and lay the foundation for addressing a range of future climate change scenarios. Several tribes already have a portfolio of actions considering multiple types of impacts and each tribe's prioritized values and goals. Because the list of potential actions is long, this section highlights key principles and strategies that are being put into practice. For a compendium of potential response strategies and key references see *Appendix E: Climate Change Response Strategies.*

Effective adaptation planning and actions follow a set of basic principles:

- The past is no longer an appropriate reference for future conditions;
- The sooner we take action, the lower the risks and costs will be;
- Top-priority strategies provide multiple benefits and avoid unintended negative consequences;
- Flexible policies and plans acknowledge uncertainty and are able to adapt to unforeseen developments;
- Sustainable strategies rely on natural processes and green infrastructure as much as possible;
- Effective and just actions take guidance from community values and goals; and
- Actions must be financially feasible over the long term.

Policy efforts play a significant role in implementing adaptation actions. Strategies include regulatory structures such as shoreline development restriction, risk prevention planning, incentives for protecting natural areas, and developing emergency preparedness. Collaboration with federal, state, and local partners is critical to tackle climate change impacts at the regional scale. Government-to-government agreements between the tribes and federal agencies can ensure continued or increased access to traditional foods on federal lands. Agreements between tribal governments in the U.S. and with Canadian First Nations could be explored to create networks of intertribal trade or sharing of traditional foods. Tribes have already begun to work together to share information, technology, and resources.

> **"When it comes to extreme measures taken to adapt to climate change, it does take an entire collaborative approach among agencies—it can't be done alone."**
>
> – Fawn Sharp, President, Quinault Indian Nation[441]

Even though there is uncertainty in predicting species response to climate change, adaptation efforts can move forward to restore, enhance, and preserve natural resilience to the greatest degree possible. Along with reducing the effects of existing stressors, adaptation requires the identification of processes and characteristics that are already buffering species and ecosystems from climate change. Adaptive qualities include habitat heterogeneity, genetic diversity, phenotypic plasticity, and adaptive evolution. Sources of resilience are also found in climate refugia. These areas will be able to continue to support habitat into the future because of the influence of local factors including topography, aspect (such as north-facing), and the presence of features such as cold-water springs. Identifying and protecting climate refugia can serve as the basis for networks of climate-ready landscapes that preserve long-term species or ecosystem persistence. For example, Climate Shield is a project of the U.S. Forest Service that supplies digital spatial data of cold-water refugia, streams with the highest probability of trout occupancy under future conditions.[442] The information is based on models that were developed using crowd-sourced fish distribution data sets.

Innovative solutions to address species loss are also under consideration. In some cases, new or less commonly used species could supplement traditional foods that are declining. The cultural and spiritual ramifications of such decisions would have to be carefully considered. Another option is assisted migration, also called facilitated dispersal or assisted colonization. This technique supports population persistence where natural migration or range shifts are not possible. Individuals are assisted into new locations by removing barriers to movement or by introducing species into suitable areas. Assisted migration is not without controversy. It is difficult to assess the risks involved when climate change is already altering communities and ecosystems. In addition, resource managers would have to consider how much they are willing to shape new ecosystems.[443]

Another tool for mitigating the effects of a changing climate is population rescue. Population rescue can entail evolutionary rescue, where rapid genetic change allows populations to persist in the face of overwhelming environmental alteration.[444] Artificial production of wildlife species for the purpose of population rescue has been successfully used for a number of species. One example is the South Fork Nooksack River spring chinook captive broodstock program, which seeks to recover the ESA-listed stock through a partnership between the Lummi Nation, the Nooksack Tribe, WDFW and NOAA. Historically, about 13,000 spring chinook are estimated to have returned to spawn in the South Fork. Even though there was no directed harvest on the run, loss and degradation of habitat led to a severe decline in the population. In 1999, only 100 returning adult chinook were surveyed.[445] To protect the population from disappearing, the partnership began collecting juvenile chinook in 2007 to rear and spawn at the WDFW Kendall Creek Hatchery and the NOAA Manchester Research Station before releasing the offspring into the river.[446]

Freshwater Aquatic Environments

For freshwater ecosystems, climate change adaptation includes reducing existing stressors and improving ecosystem health and function. The more robust and complex habitats are, the better fish and other aquatic species will fare. Restoration of ecological, geomorphic, and hydrological functions can address climate change impacts. Optimal adaptation of aquatic ecosystems calls for planning at the landscape scale with prioritization for the areas that promote connectivity.[447] Early planning efforts that balance the needs of aquatic ecosystems with human use are critical. Adaptation actions should be put into effect as soon as possible for maximum effect at the lowest possible costs.

Because many streams in Washington already experience stream temperatures exceeding the requirements of aquatic life, additional mitigation of rising temperatures is necessary. Strategies include reducing water withdrawals during low flow and high temperature periods, and identifying and protecting thermal refugia, such as groundwater inputs, cold-water tributary confluences, and deep pools.[448] Actions such as fencing to control grazing, and planting riparian vegetation are likely to reduce temperature impacts by shading streams.[449] Regulated river systems could benefit from modifying reservoir operations to control flow and temperature downstream.[450]

Actions undertaken to address the loss of connectivity between rivers and floodplains can allay some of the negative effects of climate change on salmonid habitat.[451] Reconnection of floodplains involves the removal of levees and bank armoring so that flows can move through the floodplain. It might also require moving infrastructure, buildings, or agriculture out of the floodplain. While such efforts may pose financial and political challenges, the benefits of recreating functional floodplains often outweigh the heavy long-term costs of chronic flooding, levee repair, and loss of fish and wildlife.

Levees constrict flows into a narrower space, which produces deeper flows and higher velocities during floods, compounding climate-induced effects of peak flows. These concentrated flows can even damage the levees themselves. Roads and urban development in the floodplain exacerbate flooding by reducing the amount of the watershed where rainfall can infiltrate into the ground. The impervious surfaces prevent groundwater recharge and keep the ground from filtering out pollutants from the water before it enters streams, lakes, and marine waters. One of the more profound effects of levees on river systems is the degradation, or lowering, of the channel bed elevation. Also know as incision, this process further disconnects the river from its floodplain. Where enhanced riparian and floodplain function can reverse channel incision, low flow impacts are likely to be lessened.[452]

Coastal and Marine Environments

Adaptation efforts in coastal environments will benefit from focusing on the protection and restoration of areas that will support biodiversity even as sea levels rise. Strategies that also include landscape-scale connectivity are valuable because they support range shifts of coastal species.[453] The use of living shorelines, also known as soft shoreline armoring, has multiple benefits. Living shorelines use natural materials with the goal of maintaining as much of the natural condition as is possible while still affording the needed level of protection. These techniques can consist of passive approaches, such as managing surface water, groundwater, and vegetation. Engineering solutions include re-grading artificially steepened slopes, placing logs on the upper beach (anchored or not), adding sediment (or beach nourishment), burying rock revetments, and planting native vegetation. Successful application of these techniques depends on the location and site-specific geomorphic context.

Ocean acidification and hypoxia can be addressed by reducing other types of ecosystem degradation, improving water quality from upland runoff, and exploring sustainable shellfish aquaculture. Identifying, protecting, and creating refuges for vulnerable organisms is an option being explored by the Puget Sound Restoration Fund and NOAA's Manchester Research Station.[454] This study is designed to examine the potential of kelp beds to ameliorate some of the effects of ocean acidification on local systems. The experiment will test whether kelp can capture enough CO_2 during photosynthesis to change local levels. Kelp will release the carbon back into the system when it decays after death, so it is a short-term strategy unless some form of commercial kelp harvest can be incorporated.

Terrestrial and Upland Environments

One of the greatest challenges facing terrestrial landscapes is the ongoing effect of existing stressors such as habitat fragmentation. Enhancing landscape connectivity and habitat diversity provides short- and long-term benefits and reduces barriers to dispersal. For example, migration corridors help facilitate the range shifts of both plants and animals. Riparian corridors provide migration pathways while also supplying habitat for a wide variety of species and promoting the health of freshwater ecosystems.[455]

Assisted migration could be used in forests to introduce new species or sub-species that have a greater tolerance to warmer and drier conditions. This is counter to reforestation practices that use historical forest conditions as a reference, but in many areas the past is no longer an accurate template for the future. Land managers might also consider using forest disturbances such as wildfire as opportunities to establish new forest communities that offer a diversity of species and habitats. Forest practices such as targeted thinning enhance the diversity of forest structure and stand age classes, help with tailoring tree density to expected water limitations, and create wildfire fuel breaks.[456] Reducing wildfire risk also involves setting effective standards for fire-safe communities, fire buffer zones, and wildfire response. Pests and disease outbreaks could be managed with early warning monitoring systems and forest practices that produce resilient tree populations.[457]

Wildlife populations would benefit from efforts to restore and preserve genetic diversity and habitat heterogeneity. Species with declining populations may require assisted migration or the introduction of individuals from nearby locales with healthy populations. For example, mountain goats are declining in the North Cascades and augmentation of their numbers could be used to ensure that populations persist into the future.[458] Adaptations specific to the harvest of traditional foods can entail adjusting the timing of seasonal activities and even altering the types of species used. Cultivation of native plants would ensure reliable supplies. Several tribes have already established community gardens to grow traditional food and medicinal herbs.

Taking Action: Stillaguamish Tribe Floodplain Protection

More rainfall and less snowfall have been driving an increase in peak flows in the Stillaguamish River basin since 1954 (Figure 12).[459] Prior to 1950, a flow event of about 24,500 cubic feet per second (cfs) had a 10- to 20-year recurrence interval. This means that the probability of that flow event occurring in any given year ranged from 1 in 10 to 1 in 20. Between 1972 and 1995 the same flow was much more common with a 1- to 2-year recurrence interval.[460] Higher flows are associated with lower salmon survival and flows above 26,000 cfs are associated with salmon egg mortality rates of greater than 90 percent.[461] Today the Stillaguamish chinook run size is only 10 percent of the historical runs the tribe knew during treaty times.

The Stillaguamish Tribe of Indians initiated a multi-phase project to determine why flows are changing and what actions can be taken to protect salmon populations. The recent trend of increasing peak flows was found to be more related to climate change than to changes in land use. By 2070, heavier storms are expected as atmospheric rivers (plumes of moisture from the tropical Pacific Ocean commonly known as the Pineapple Express) are projected to get 26 to 30 percent stronger.[462] In response to this finding, the tribe developed a spatial tool to help prioritize the acquisition and restoration of floodplains and mature forests in the South Fork and North Fork Stillaguamish rivers. The tool is part of the Stillaguamish Watershed Council's Acquisition Strategy as they implement the chinook recovery plan for the river. The Stillaguamish Tribe is working with the Watershed Council to realize their vision of an intact, functioning floodplain that creates a habitat corridor along both forks of the Stillaguamish River. Jason Griffith, fisheries biologist with the tribe, envisions a solution that matches the scale of problem, describing it as "recovery [that] will be visible from space."

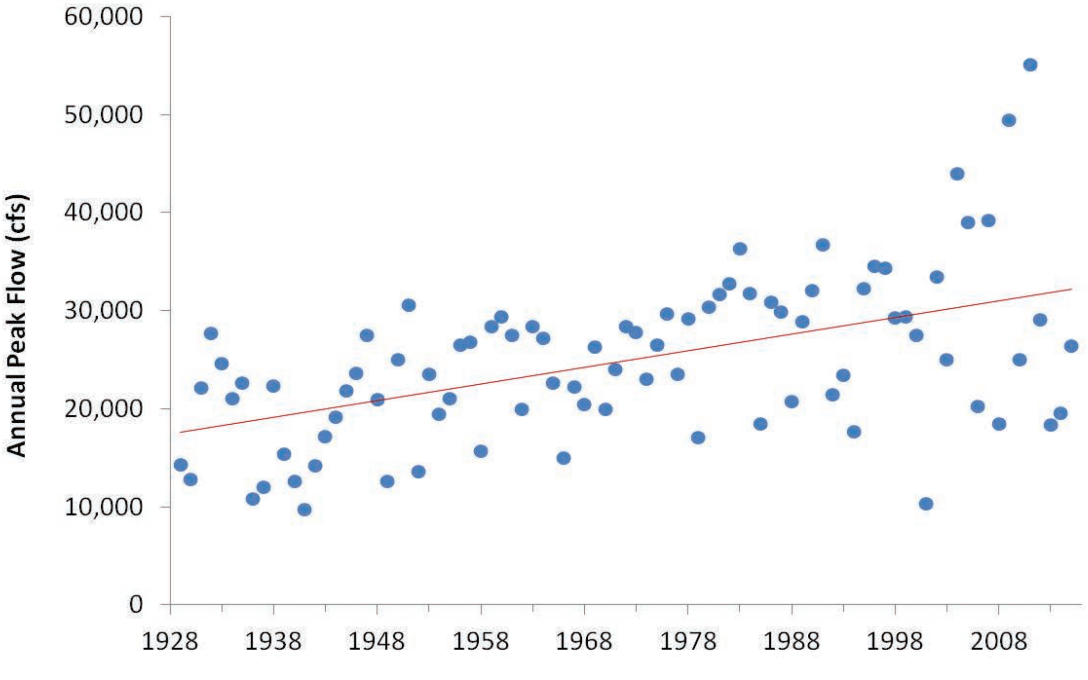


Figure 12: Annual peak streamflow for the North Fork Stillaguamish River near Arlington, WA, from 1928 to 2015 (USGS Gauge 12167000).[463] Although peak flows show wide interannual variation, the trendline (R=0.27) indicates an overall increase in annual peak flows over time.

8.3 TRADITIONAL KNOWLEDGE AND PRINCIPLES OF ENVIRONMENTAL STEWARDSHIP

Traditional knowledge (TK) can confer many benefits to climate change research and response strategies. Traditional knowledge can provide the foundation for environmental baseline data, forming research questions, identifying impacts, calibrating models with local observations, and identifying cultural values for adaptation efforts.[464] Tribal fishers and hunters have considerable knowledge of the movement and distribution of fish and wildlife that can inform and enhance climate adaptation.[465] Detailed local observations allow tribal communities to recognize changes in an important indicator species early on. For example, "the Quileute know something is wrong because there are no smelt eggs in time for Honoring Elders Day."[466] TK also can provide information on extreme events from the past that may become more frequent with climate instability. TK offers insights from sustainable management practices and adaptive strategies that tribes have honed over millennia. This systems-based knowledge can be more useful for constructing meaningful adaptation strategies than the natural resources management structures that consider each individual species or physical process independently from the interconnected systems in which they occur.

Considerations for Integrating Traditional Ways of Knowing

Traditional knowledge can be considered a dynamic process of relationships and responsibilities, rather than a static body of information.[467] TK may have restrictions on who may use it or how it should be used. The knowledge holders participate actively in obligations and responsibilities to their teachers, family, and community that may come with the knowledge. These relationships are spiritual as well as physical, and TK may have its origins in the realm of the sacred.

TK is often linked to a specific place and emphasizes interconnectedness and interdependence among all living beings. For example, seasonal signals may trigger important events, activities, or ceremonies, such as the timing of fishing season with the blooming of salmonberries.[468] For further information on TK, please see *Appendix A: Selected References.*

Co-production of knowledge between traditional ways of knowing and scientific practice can produce some challenges. Because the sharing of knowledge includes sharing the attendant responsibilities, the complete context of TK must be understood and respected. Removing TK from its context can be seen by tribal communities as a form of theft and cultural exploitation. There is also a fear—well-founded in history—that shared knowledge will be used against the tribes, limiting our traditional activities and resources through regulation, retaliation, or overexploitation.[469]


Coastal tribal members take a salmon to the ocean as part of a salmon blessing ceremony. Photo: Debbie Preston, NWIFC.

These concerns have caused many nations to adopt laws to prevent inappropriate use of TK and to ensure that TK supports and enhances inherent tribal sovereignty. Existing intellectual property, copyright, and patent laws do not protect tribal people nor do they make sure cultural norms or customs are upheld. Sensitive information shared by tribes can be considered in the public domain once it leaves tribal boundaries. Without intellectual property or patent protection, the release of sensitive information can lead to uses that are inappropriate, disrespectful, or defamatory.[470] To make sure TK is shared with free, prior, and informed consent, as described in the United Nations Declaration on the Rights of Indigenous Peoples, requires that knowledge holders have all the information they need to make an educated decision based on the risk of sharing the TK. Some knowledge might simply be too sacred or too vulnerable to be shared. Other types of knowledge are low risk, and could be very useful in climate change adaptation, such as changes in coastal currents, wildfire patterns, hydrological patterns, or phenology, the timing of key life cycle events.[471]

8.4 REDUCING GREENHOUSE GAS EMISSIONS

The measures we take to prevent the most harmful impacts of climate change to our communities and ecosystems must include the reduction of GHG emissions, sometimes referred to as climate change mitigation. Adaptation alone is not enough because response strategies become less effective as changes in climate systems grow. Reducing GHG emissions is not enough because climate change is already occurring and the impacts cannot be stopped or reversed quickly. There is a time lag in global atmospheric, oceanic, and geological cycles; the GHGs in these systems will remain there for centuries or millennia to come.

Climate change mitigation takes the form of alternative energy production, energy efficiency, and carbon sequestration or long-term storage in biological or geological systems. Emission reductions must be large enough to make a difference and must include all major emitting countries, all sectors (power plants, transportation, buildings, industry, agriculture), and all major GHGs. The body of climate science makes clear that it is essential to act now rather than wait. For example, the differences are considerable between low, medium, and high GHG emissions scenarios in projected increases to air temperatures (Figure 13). These results demonstrate how much we can slow down global warming by reducing GHG emissions. This can be done while benefiting communities, the environment, and the economy.

Recent observed trends of GHG emissions track most closely to the highest scenarios, which are described as "business as usual." Turning away from fossil fuel dependence addresses the associated climate impacts and, equally importantly, the political, socio-economic, and cultural conflicts and upheaval associated with this dependence.[472] In light of the current age of global market capitalism, GHG reduction projects that also fulfill short-term economic needs may be most successful. Along with preventing the worst ecosystem harm, reducing GHG emissions also has multiple economic and health benefits. Taking action to keep global temperature increases below 2°C would prevent 57,000 deaths from poor air quality in 2100.[473] Furthermore, approximately $3.1 billion in damages and adaptation costs from sea level rise and storm surge in 2100 could be avoided by keeping warming below 2°C, along with $6.6 to $11 billion in avoided damages to agriculture, $2.8 billion in avoided damages from flooding, and $11 to $180 billion in avoided damages from water shortages in key economic sectors.[474] Local economies also benefit from reducing GHGs. Alternative energy manufacturing jobs could be developed locally and a decentralized energy grid offers energy independence and resilience to disturbance, both natural and political. Energy efficiency retrofits also provide local jobs and immediate cost savings.

Lummi tribal members harvest Manila clams on Portage Bay, with Mount Baker in the background. Photo: Kari Neumeyer, NWIFC.

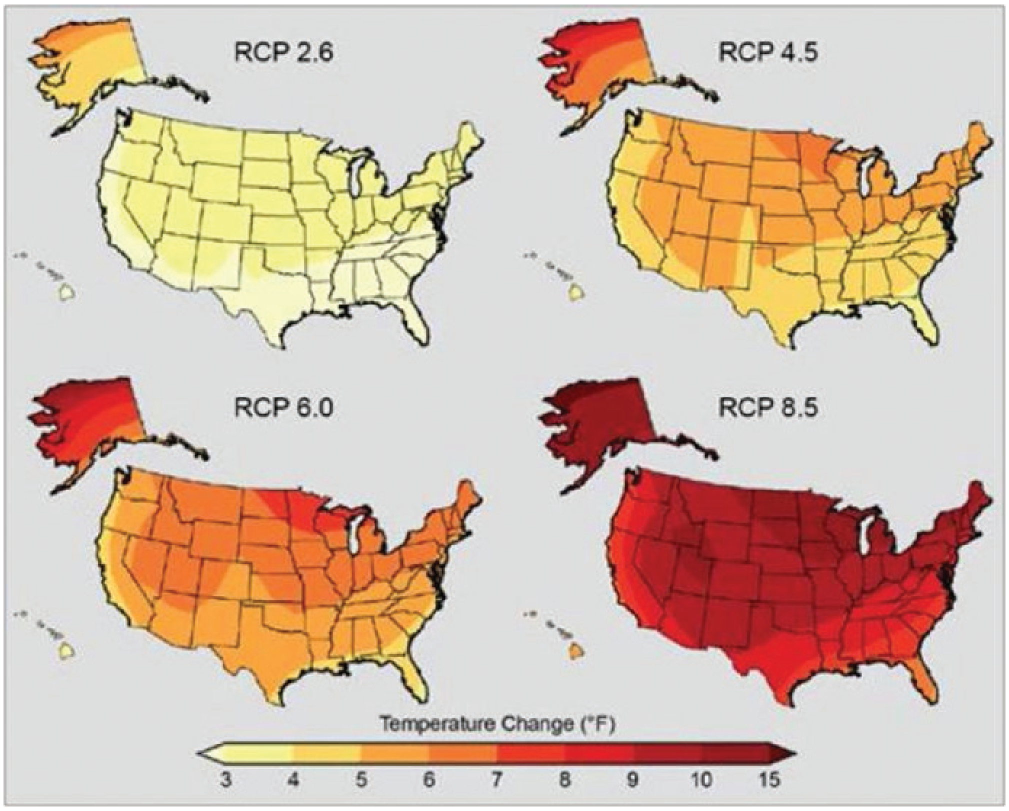


Figure 13: Air temperature changes projected for the end of the 21st century for four GHG emissions scenarios: very low (top left), low (top right), moderate (bottom left), and high (bottom right). For an explanation of the scenarios, see *Appendix D.* Source: IPCC 2014.

Even with the many economic benefits of keeping global warming below 2°C, that target has recently been shown to be inadequate to prevent the worst harm from occurring. The United Nations Framework Convention on Climate Change (UNFCCC) has determined that if warming (currently at 0.85°C) can be kept below 1.5°C, marine and terrestrial species would be better able to adapt to climate change and the effects of sea level rise and ocean acidification would remain at moderate levels.[475] The United Nations COP21 (the twenty-first session of the Conference of the Parties to the UNFCCC) negotiations met in December 2015 in Paris, France, and set targets for keeping global temperature rise below 2°C and to attempt to meet the limit of 1.5°C. At the signature ceremony in 2016, UN Secretary-General Ban Ki-Moon remarked, "Let us never forget—climate action is not a burden; indeed, it offers many benefits. It can help us eradicate poverty, create green jobs, defeat hunger, prevent instability and improve the lives of girls and women."[476]

Efforts around the world to promote renewable energy sources are gaining momentum. One example is solar power. The cost of a typical residential solar panel installation fell nearly 70 percent between 1998 and 2015.[477] One reason for this drop in price is that, unlike nonrenewable energy sources such as fossil fuels, solar energy is inexhaustible and the technology of capture and storage is becoming more effective over time. Technological improvements are similarly increasing the availability and efficiency of other renewable energy sources, such as wind and geothermal power.

Energy efficiency and energy conservation measures are one of the fastest, easiest, and most cost-effective ways to lower GHG emissions. Efficiency measures generally pay for themselves in energy savings over the life of the project. Better efficiency of tribal buildings can be achieved through better insulation, fixing leaks in windows and furnace ducts, improving energy performance of appliances, upgrading heating systems, and improving building codes. Energy efficiency can lower costs associated with transportation: cars, trucks, and fishing vessels. Energy efficiency and renewable energy production also have a tribal sovereignty dimension. Most of the power grid used by tribes in the PNW is not owned by tribes. Reducing wasted energy and creating local power grids will bring economic benefits to our tribes and foster our energy independence.

Carbon sequestration is a means of removing CO_2 from the atmosphere. Large amounts of carbon are locked up in the world's soils, grasslands, forests, peatlands, and wetlands. Plants use CO_2 during photosynthesis and the carbon is locked up in their tissues. When they die, the CO_2 is returned to the atmosphere as a by-product of decomposition. In the long term, CO_2 can remain in terrestrial systems in soils, leaf litter, and the woody tissues of long-lived species like trees. Carbon sequestration projects in forests and salt marshes may include market mechanisms or carbon credits. Companies or other entities that emit GHGs can purchase carbon offsets and the funds are used as incentives for preserving and restoring natural areas. Research in recent years has determined that sustainable forest practices can be used to maximize the carbon capture in PNW forests. Such practices include preserving mature and old-growth forests and waiting longer between timber harvests. Old forests continue to accumulate large quantities of carbon, including in their soils, for long time periods.[478] Disturbing these forests leads to long-term increases in emissions, even taking into account the carbon stored in the wood products. For PNW coastal Douglas fir, extending timber harvest rotations to a 70-year rotation age increased carbon stores by over three times compared to a 30-year rotation.[479] Coastal wetlands and salt marshes provide another avenue for maximizing carbon sequestration. They not only provide critical habitat, improve water quality, and attenuate floods, they also accumulate large amounts of carbon in the substrate. New efforts to create a national carbon market that supports salt marsh restoration, called Blue Carbon, are underway, based in part on research conducted in the Snohomish River delta.[480]

> **"The technology exists to safely and affordably transition away from fossil fuels. In fact, pushing the adoption of clean energy and the elimination of fossil fuels would not only vastly improve public health and ecological sustainability; it would open the door to extensive economic and employment opportunities."**
>
> – Fawn Sharp, President, Quinault Indian Nation[481]

Taking Action: Lummi Nation Energy Efficiency and Clean Energy

In 2014, the Lummi Nation developed the Residential Energy Efficiency Pilot Program with the purpose of reducing carbon emissions that result from energy use in the homes of Lummi tribal members. The pilot program is developing a system for performing residential energy audits and energy efficiency retrofitting and/or weatherization, while also quantifying energy and cost savings and emissions reductions. As of January 2016, construction was completed on eight homes, resulting in 30 percent reduction in total energy use (kWh) and a 24 percent reduction in total carbon emissions (tons/year). Construction on several additional homes is underway. Examples of common problems that have been identified and corrected thus far include insufficient insulation, leaky furnace ductwork, improper building ventilation, and inefficient and/or hazardous appliances.

The Lummi Nation is also working to lessen its environmental impact, its energy demands, and its long-term energy costs by using geothermal energy. As part of the construction of the new Tribal Administration Building, the Lummi Nation Planning Department had a geothermal heat pump system installed in 2011. The heat pump circulates fluid in a closed loop system that uses the earth as a heat source in the winter and a heat sink during the summer. The geothermal system regulates air temperatures, and is expected to reduce the cost of heating and cooling the building by 50 percent compared to conventional ventilation systems. These and other projects that the Lummi Nation has undertaken in the continued pursuit of becoming more energy self-sufficient are the subject of the recently adopted Lummi Nation Strategic Energy Plan: 2016–2026.

A totem pole carved by Lummi Master Carver Jewell James is blessed in front of the Lummi Nation Administration Building before the 2015 Totem Pole Journey to the Northern Cheyenne Nation to bring attention to the threats posed by proposed fossil fuel terminals and transportation projects. Photo: Coal Stop.

8.5 NEXT STEPS AND RESEARCH NEEDS

All of the western Washington treaty tribes have studies underway that evaluate climate change impacts specific to each tribe. Many of the tribes have already completed assessments that range from comprehensive documentation of the vulnerability of tribal resources across multiple sectors to the specific analysis of a single priority species. For a listing of tribal climate change projects, see *Appendix F: Tribal Climate Change Studies.*

As more tribes complete initial assessments of vulnerability, risk, and adaptation potential, our next steps come into focus. Although not all tribes may choose to complete a formal vulnerability assessment or adaptation plan, initial studies provide a basis for incorporating the effects of climate change into tribal planning and policies. Along with pursuing climate change research and response at each individual tribe, we are also working together. We have developed a forum though the NWIFC to support collaboration and sharing of information about climate change and its impacts to tribal treaty-protected resources. Forum participants represent all 20 member tribes of the NWIFC, the Point No Point Treaty Council, and the Skagit River System Cooperative.

Uncertainties remain in future projections of climate and biophysical responses. One way to address this uncertainty is by planning for multiple scenarios and designing projects that are flexible enough to change with future conditions. The adaptive management process provides such flexibility in many sectors of environmental management. It uses scientific information to adjust management decisions and practices. It is especially applicable to the rapid and sometimes unforeseeable changes associated with climate change. An example of a formalized organization for the use of science in adaptive management is the Cooperative Monitoring, Evaluation and Research (CMER) Committee. This is a collaborative group of scientists and stakeholders that arose in 1987 from the Timber, Fish, and Wildlife Agreement in Washington state. CMER was tasked with generating scientific research on forest management practices and how they affect public resources. An analogous climate change program could supply relevant research into the impacts of climate change and the effectiveness of adaptation actions. They could also work with policy makers in developing regulations and incentives that promote resilience.

In each type of ecosystem and for each critical species, the next phases of research can be summarized into an overall pattern. Once initial assessments have been performed, activities generally include the following:

- Establishment of baseline data for environmental conditions and biological metrics against which to compare future trends;
- Identification of gaps in existing data and monitoring programs;
- Tracking of long-term changes to environmental conditions, including potential trigger points for taking action;
- Tracking of changes to ecosystem status or species distribution, abundance, and phenology;
- Modeling or downscaling existing models of future environmental conditions at the site-specific scale;
- Modeling future biological response to climate drivers at the ecosystem or species level;
- Development of coordinated intertribal and regional partnerships in climate change research and adaptation;
- Communication of monitoring results and modeling efforts to tribal leaders, community members, and managers across all departments of tribal government for planning and policy development;
- Identification of processes and characteristics that are already creating resilience in species and ecosystems;
- Identification and prioritization of adaptation actions, such as restoration of ecological, hydrological, and geomorphic function in impaired systems; identification and protection of intact ecosystems and climate refugia; and efforts to reduce GHG emissions;
- Implementation of pilot projects for adaptation actions;
- Expansion of pilot projects into large-scale natural resources management through intertribal and regional partnerships; and
- Adaptive management of climate change response activities as understanding improves and as conditions require.

Dungeness crab harvested off the coast of Washington state. Photo: Debbie Preston, NWIFC.

Despite the wide array of studies in progress at tribes and at research institutions throughout the PNW, many data gaps remain. Identifying and addressing these data gaps is a major next step for establishing and supporting tribal climate change programs. Some of the data gaps may be beyond our current capacity to fill. Increasing our capacity or building partnerships will be required. Refining research needs is an ongoing process and a complete listing of all research questions at the level of detail needed for each tribe is beyond the scope of this report. A selection of example research topics is presented below.

Modeling and future projections:

- Climate variables downscaled from global climate projections to the regional and sub-regional scale;
- Models that forecast biological responses to climate drivers at the sub-regional scale:
    - Physiological and behavioral response of important species such as salmon, trout, halibut, black cod, whiting, rockfish, Dungeness crab, geoduck, and shrimp;
    - Species and trophic interactions in freshwater aquatic ecosystems;
    - Changes to primary production in marine food webs;
    - Species and trophic interactions in marine ecosystems;
    - Terrestrial vegetation composition change;
    - Effects of extreme events on species and ecosystems; and
- Models of species range and distribution for use in identifying climate refugia for protection and restoration.

Data collection and analysis:

- Expanded networks of direct measurements of key climate variables such as air temperature and precipitation to calibrate regionally downscaled models;
- Analysis of the large amounts of existing data for long-term trends;
- Research protocols for appropriate integration of TK in climate change studies, including suitable protection for TK components;
- Assessments of feedback loops and interdependencies of species and ecosystems; and
- Timing of the appearance of climate change signals in data records and events that will trigger management actions.

Freshwater Aquatic:

- Stream temperature, including spatial and temporal patterns;
- Dissolved oxygen;
- pH;
- Stream base flow;
- Groundwater-surface water interactions ;

- Sediment dynamics;
- Glacier loss;
- Wetland hydroperiod;
- Conditions of riparian vegetation and its effectiveness in improving thermal regimes in streams;
- Fish response to changing temperatures, flows, disease vectors, and life cycle impacts.

Coastal and Marine Indicators:

- Refinement of relative sea level rise trends to include local factors that affect surface elevation (e.g. vertical land movement);
- Shoreline erosion rates;
- Nearshore sediment transport rates and amounts;
- Saltwater intrusion into freshwater aquifers;
- Estuarine circulation and changes to salinity gradients ;
- Loss of nearshore habitat due to sea level rise;
- Shoreline modification and impacts to sea level rise adaptation;
- Rocky intertidal and sandy beach species density and diversity;
- Coastal plankton species composition;
- Fish, crustacean, and mollusk responses to changes in temperature, ocean acidification, hypoxia, harmful algal blooms, and recruitment timing;
- Optimal metrics for tracking ocean acidification that best reflect biological responses (e.g. pH, partial pressure CO_2, or dissolved inorganic carbon).

Terrestrial Indicators

- Changes to critical habitat and habitat connectivity;
- Geographic distribution of genetic variability and climate tolerances;
- Pest and disease outbreaks;
- Competition with invasive exotic species;
- Changes in plant species composition;
- Effects of different forestry management practice on resilience;
- Range shifts of large mammal and ungulate populations;
- Changes to migration, nesting, feeding patterns, and food availability for wildlife;
- Water bird population dynamics;
- Amphibian populations;
- Qualitative data on effects to tribal cultures, communities, and individuals.

Translating data into action for natural resources managers and policymakers:

- Information needs and optimal level of detail for both policymakers and managers;
- Decision support tools that integrate diverse information sources and assess benefits of potential strategies;
- Ways to include climate change in regulations and engineering standards;
- Analysis of water management practices and water use demands relative to availability, including population growth and long-term projections of future water use and wastewater treatment needs;
- Governance for reducing GHG emissions and fossil fuel transport through the PNW;
- Integrated approaches that combine adaptation with sustainable development; and
- Assessment of barriers to adaptation—financial, political, social, and institutional.

Response Actions:

- How to prioritize adaptation actions;
- How to measure effectiveness of adaptation techniques, including how successful short-term actions fare in the long-term;
- How to integrate natural science, social science, clinical care, engineering, and other disciplines;
- How to curtail damaging human behaviors;
- Emergency response for extreme events such as floods, droughts, and wildfires; and
- Development of our own native food supplies (gardens with native plants, sustaining local herds, or hatcheries).

Taking Action: Suquamish Tribe Developing a Zooplankton Imaging System

Chemical and physical changes to marine waters resulting from carbon pollution can be monitored, but it is much more difficult to monitor the impacts of those changes on the many forms of life that inhabit the water. The Suquamish Tribe is working on developing technology to monitor changes in zooplankton (animal plankton that include the larval stages of fish and shellfish and other tiny creatures). Zooplankton drift with the currents, consuming phytoplankton (plant plankton) and are in turn consumed by larger animals. They are at the base of many marine food webs and contain the next generations of most economically important species. Their thin body walls and fast rate of development make them highly vulnerable to changes in water conditions. For decades, zooplankton have been studied by collecting them in plankton nets and identifying, counting, and measuring them individually through a microscope. While adequate for taxonomy, this method is too expensive and time-consuming to apply on the scale and frequency needed to establish baselines and assess changes over time. Several groups are seeking to address this technology gap though applying recent advances in computing, digital imaging, and computer image recognition.

A microscopic view of copepod, a type of zooplankton. Photo: Matt Wilson/Jay Clark, NOAA NMFS AFSC/National Oceanic and Atmospheric Administration/Department of Commerce.

The Suquamish Tribe is working with computer and oceanography scientists at the University of Washington to develop a zooplankton imaging and recognition system. The system works by feeding a narrow stream of seawater through a 10-millimeter chamber where a digital camera captures images of the zooplankton and other debris as they flow by. Each image is analyzed by a computer model and the output includes the probability of correct classification for each image. Although image recognition systems will probably not replace taxonomists, tedious tasks like counting and measuring common taxa could be automated while scientists focus on identifying rare or difficult taxa. The cost for components of a bench top system is estimated at less than $3,000. The imaging and recognition system could be adapted to many other types of ecological sampling, such as fish smolt traps. Inexpensive lenses could be used to photograph the smolts, which would bring the cost down enough for widespread autonomous deployment.

9. CONCLUSIONS

The climate is changing and the dominant driver is the human-caused buildup of CO_2 and other heat-trapping GHGs in the atmosphere, driven largely by burning fossil fuels and land use. These changes are already causing harm in many parts of the world and in our homelands and waterways. Impacts have already been observed and are projected to continue in freshwater aquatic, marine, and terrestrial ecosystems. These changes have profound implications for the plants and animals important to our communities, ways of life, and treaty-reserved rights.

We have lived in our homelands for many thousands of years and we have persevered through many changes to our environment and through enormous social upheaval. On behalf of future generations, we are taking action now to prevent the worst harm from climate change. We will continue working together to be proactive in facing future challenges, ensuring ecosystem survival, and protecting our treaty rights and traditional lifeways. Along with risks, climate change also presents opportunities. In this time of change, we have the chance to develop healthier, self-sustaining ecosystems and to promote resilient, equitable, and flourishing communities.

"We know that if we are going to save the salmon, we must be more like them. No matter what obstacles are put in their way, the salmon never quit, and we won't either."

– Billy Frank Jr., Chairman Emeritus, NWIFC

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11. CITATIONS

[1] Northwest Indian Fisheries Commission. 2016. State of Our Watersheds: A Report by the Treaty Tribes in Western Washington. Salmon and Steelhead Habitat Inventory and Assessment Program. Olympia, WA.

[2] Judge, M.M. 2011. 2011 Implementation Status Assessment Final Report: A Qualitative Assessment of Implementation of the Puget Sound Chinook Salmon Recovery Plan. Prepared for the National Marine Fisheries Service. Available at http://treatyrightsatrisk.org/wp-content/uploads/2012/11/implement-rpt.pdf

[3] Fresh, K., M. Dethier, C. Simenstad, M. Logsdon, H. Shipman, C. Tanner, T. Leschine, T. Mumford, G. Gelfenbaum, R. Shuman, J. Newton. 2011. Implications of Observed Anthropogenic Changes to the Nearshore Ecosystems in Puget Sound. Prepared for the Puget Sound Nearshore Ecosystem Restoration Project. Technical Report 2011-03.

[4] Northwest Indian Fisheries Commission. 2016. State of Our Watersheds: A Report by the Treaty Tribes in Western Washington. Salmon and Steelhead Habitat Inventory and Assessment Program. Olympia, WA.

[5] Northwest Indian Fisheries Commission. 2016. State of Our Watersheds: A Report by the Treaty Tribes in Western Washington. Salmon and Steelhead Habitat Inventory and Assessment Program. Olympia, WA.

[6] O'Neill, C.A. 2013. Fishable Waters. American Indian Law Journal 1(2): 181- 452.

[7] Bash, J., C. Berman, and S. Bolton. 2001. Effects of Turbidity and Suspended Solids on Salmonids. Final Research Report, Research Project T1803, Task 42. Prepared for Washington State Transportation Commission by Center for Streamside Studies, University of Washington, Seattle, WA.

Brown, C. and D. Hallock. 2009. Washington State Dissolved Oxygen Standard: A Review and Discussion of Freshwater Intragravel Criteria Development. Washington State Department of Ecology Environmental Assessment Program, Olympia, WA.

Brown, J. 2011. The impact of fine sediment pollution on Chinook survival to emergence in the North Fork Stillaguamish River. Stillaguamish Tribe of Indians, Natural Resources Department.

Crozier, L.G., and R.W. Zabel. 2006. Climate impacts at multiple scales: evidence for differential population responses of juvenile Chinook salmon. Journal of Animal Ecology 75(5): 1100-1109.

Elsner, M.M., L. Cuo, N. Voisin, J.S. Deems, A.F. Hamlet, J.A. Vano, K.E.B. Mickelson, S.Y. Lee, and D.P. Lettenmaier. 2010. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change 102(1-2): 225-260.

Grah, O. and J. Beaulieu. 2013. The effect of climate change on glacier ablation and baseflow support in the Nooksack River basin and implications on Pacific salmonid species protection and recovery. Climatic Change 120: 657-670.

Isaak, D. J., S. Wollrab, D. Horan, and G. Chandler. 2012. Climate change effects on stream and river temperatures across the northwest U.S. from 1980-2009 and implications for salmonid fishes. Climatic Change 113 (2): 499-524.

Mantua, N.J., I. Tohver, and A.F. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change 102: 187-223.

Nooksack Indian Tribe, U.S. Environmental Protection Agency, and Tetra Tech. 2016. Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA. EPA Region 10 Climate Change and TMDL Pilot. In cooperation with Washington Department of Ecology and NOAA Fisheries.

Ward, E.J., J.H. Anderson, T.J. Beechie, G.R. Pess, and M.J. Ford. 2015. Increasing hydrologic variability threatens depleted anadromous fish populations. Global Change Biology 21(7): 2500-2509.

[8] Cheung, W.W.L, R.D. Brodeur, T.A. Okey, and D. Pauly. 2015. Projecting future changes in distributions of pelagic fish species of Northeast Pacific shelf seas. Progress in Oceanography 130: 19-3.

[9] Cheung, W.W.L, R.D. Brodeur, T.A. Okey, and D. Pauly.2015. Projecting future changes in distributions of pelagic fish species of Northeast Pacific shelf seas. Progress in Oceanography 130: 19-3.

[10] Kroeker, K.J., R.L. Kordas, R. Crim, I.E. Hendriks, L. Ramajo, G.S. Singh, C.M. Duarte, and J.P. Gattuso. 2013. Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. Global Change Biology 19: 1884-1896.

Levin, L.A., W. Ekau, A.J. Gooday, F. Jorissen, J.J. Middelburg, S.W. A. Naqvi, C. Neira, N.N. Rabalais, and J. Zhang. 2009. Effects of natural and human-induced hypoxia on coastal benthos. Biogeosciences 6: 2063-2098.

[11] Moore, S.K., N.J. Mantua, and E.P. Salathé Jr. 2011. Past trends and future scenarios for environmental conditions favoring the accumulation of paralytic shellfish toxins in Puget Sound shellfish. Harmful Algae 10(5): 521-529.

Sun, J., D.A. Hutchins, Y. Feng, E.L. Seubert, D.A. Caron, and F.X. Fu. 2011. Effects of changing pCO_2 and phosphate availability on domoic acid production and physiology of the marine harmful bloom diatom Pseudo-nitzschia multiseries. Limnology and Oceanography 56(3):829-840.

[12] Donatuto, J., E.E. Grossman, J. Konovsky, S. Grossman, and L.W. Campbell. 2014. Indigenous Community Health and Climate Change: Integrating Biophysical and Social Science Indicators. Coastal Management 42(4): 355-373.

[13] National Research Council. 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Washington, DC: The National Academies Press.

Nooksack Indian Tribe, U.S. Environmental Protection Agency, and Tetra Tech. 2016. Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA. EPA Region 10 Climate Change and TMDL Pilot. In cooperation with Washington Department of Ecology and NOAA Fisheries.

[14] Halofsky, J.E., D.L. Peterson, K.A. O'Halloran, C. Hawkins Hoffman (Eds.). 2011. Adapting to climate change at Olympic National Forest and Olympic National Park. General Technical Report PNW-GTR-844. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR.

Lawler J.J. and M. Mathias. 2007. Climate Change and the Future of Biodiversity in Washington. Report prepared for the Washington Biodiversity Council.

[15] Chen, I. C., J.K. Hill, R. Ohlemüller, D.B. Roy, and C.D. Thomas. 2011. Rapid range shifts of species associated with high levels of climate warming. Science 333: 1024-1026.

[16] WSDOE. 2012. Preparing for a Changing Climate: Washington State's Integrated Climate Response Strategy. Washington State Department of Ecology Publication No. 12-01-004.

[17] Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E. Lugo, C.J. Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks, and B.M. Wotton. 2001. Climate change and forest disturbances. Bioscience 51(9): 723-734.

[18] Raymond, C. L., D.L. Peterson, and R.M. Rochefort (Eds.). 2014. Climate change vulnerability and adaptation in the North Cascades region, Washington. Gen. Tech. Rep. PNW-GTR-892. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

[19] Harrington, C.A. and P.J. Gould. 2015. Tradeoffs between chilling and forcing in satisfying dormancy requirements for Pacific Northwest tree species. Frontiers in Plant Science 6:120-132.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. BioScience 47(11):769-784.

[20] Donatuto, J., E.E. Grossman, J. Konovsky, S. Grossman, and L.W. Campbell. 2014. Indigenous Community Health and Climate Change: Integrating Biophysical and Social Science Indicators. Coastal Management 42(4): 355-373.

Jamestown S'Klallam Tribe. 2013. Climate Change Vulnerability Assessment and Adaptation Plan. Petersen, S. and J. Bell (Eds.). A collaboration of the Jamestown S'Klallam Tribe and Adaptation International.

Lynn, K., J. Daigle, J. Hoffman, F. Lake, N. Michelle, D. Ranco, C. Viles, G. Voggesser, and P. Williams. The impacts of climate change on tribal traditional foods. Climatic Change (2013) 120:545-556.

[21] Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner. 2013. Long-Term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press.

[22] Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner. 2013. Long-Term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press.

[23] Vose, R.S., S. Applequist, M. Squires, I. Durre, M.J. Menne, C.N. Williams, Jr., C. Fenimore, K. Gleason, and D. Arndt. 2014. Improved historical temperature and precipitation time series for U.S. climate divisions. Journal of Applied Meteorology and Climatology, 53, 1232-1251.

[24] Riedel J. and M.A. Larrabee. 2011. North Cascades National Park Complex glacier mass balance monitoring annual report, Water year 2009: North Coast and Cascades Network. Natural Resource Technical Report NPS/NCCN/NRTR – 2011/483. National Park Service, Fort Collins, CO.

Pelto, M.S. 2010. Forecasting temperate alpine glacier survival from accumulation zone observations. Cryosphere 3:323-350.

[25] Elsner, M.M., L. Cuo, N. Voisin, J.S. Deems, A.F. Hamlet, J.A. Vano, K.E.B. Mickelson, S.Y. Lee, and D.P. Lettenmaier. 2010. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change 102(1-2): 225-260.

[26] Tohver, I.M., A.F. Hamlet, and S.Y. Lee. 2014. Impacts of 21st-century climate change on hydrologic extremes in the Pacific Northwest region of North America. Journal of the American Water Resources Association 50(6): 1461-1476.

[27] Tohver, I.M., A.F. Hamlet, and S.Y. Lee. 2014. Impacts of 21st-century climate change on hydrologic extremes in the Pacific Northwest region of North America. Journal of the American Water Resources Association 50(6): 1461-1476.

[28] Elsner, M.M., L. Cuo, N. Voisin, J.S. Deems, A.F. Hamlet, J.A. Vano, K.E.B. Mickelson, S.Y. Lee, and D.P. Lettenmaier. 2010. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change 102(1-2): 225-260.

[29] Isaak, D.J., S.J. Wenger, E.E. Peterson, J. M. Ver Hoef, S. Hostetler, C.H. Luce, J.B. Dunham, J. Kershner, B.B. Roper, D. Nagel, D. Horan, G. Chandler, S. Parkes, and S. Wollrab. 2011. NorWeST: An interagency stream temperature database and model for the Northwest United States. U.S. Fish and Wildlife Service, Great Northern Landscape Conservation Cooperative Grant. Available at www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html

[30] Ficklin, D.L., I.T. Stewart, and E.P. Maurer. 2016. Effects of climate change on stream temperature, dissolved oxygen, and sediment concentration in the Sierra Nevada in California. Water Resources Research 49: 2765-2782.

[31] Nooksack Indian Tribe, U.S. Environmental Protection Agency, and Tetra Tech. 2016. Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA. EPA Region 10 Climate Change and TMDL Pilot. In cooperation with Washington Department of Ecology and NOAA Fisheries.

[32] Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle, WA.

[33] Stavros, E.N., J.T. Abatzoglou, D. McKenzie, and N.K. Larkin. 2014. Regional projections of the likelihood of very large wildland fires under a changing climate in the contiguous Western United States. Climatic Change126:455-468.

[34] Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle, WA.

[35] Field, D., D. Cayan, and F. Chavez. 2006. Secular warming in the California current and North Pacific. California Cooperative Oceanic Fisheries Investigations Reports, 47, 92-108. Available at http://www.calcofi.org/publications/calcofireports/v47/Vol_47_Field_ Warming_In_The_Ca_Current.pdf

[36] National Research Council. 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Washington, DC: The National Academies Press.

Mote, P.W. A. Petersen, S. Reeder, H. Shipman, and L. Whitely Binder. 2008. Sea Level Rise in the Coastal Waters of Washington State. Report prepared by the Climate Impacts Group, University of Washington and the Washington Department of Ecology.

[37] Komar, P.D. and J.C. Allen. 2000. Analyses of Extreme Waves and Water Levels on the Pacific Northwest Coast. Report to the Oregon Department of Land Conservation and Development Salem, Oregon. Available at http://www.oregon.gov/lcd/ocmp/docs/publications/extreme_wavestide_rpt.pdf

[38] Feely, R.A., S. Alin, J. Newton, C. Sabine, M. Warner, A. Devol, C. Krembs, and C. Maloy. 2010. The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary. Estuarine, Coastal and Shelf Science 88: 442-449.

Roberts, M., T. Mohamedali, B. Sackmann, T. Khangaonkar, and W. Long. 2014. Puget Sound and the Straits Dissolved Oxygen Assessment: Impacts of Current and Future Human Nitrogen Sources and Climate Change through 2070. Washington State Department of Ecology Publication No. 14-03-007, Olympia, WA. Available at https://fortress.wa.gov/ecy/publications/SummaryPages/1403007.html

[39] de Chavez, R. and V. Tauli-Corpuz (Eds.). 2008. Guide on Climate Change and Indigenous Peoples. Tebtebba Foundation, Indigenous Peoples' International Centre for Policy Research and Education. Baguio City, Philippines. Available at http://www.tebtebba.org

[40] Townsend, C.L. and J.T. Figge. 2002. Northwest Origins: An Introduction to the Geologic History of Washington State. The Burke Museum of Natural History and Culture, University of Washington. Available at http://www.burkemuseum.org/static/geo_history_wa/index.htm

[41] Judge, M.M. 2011. 2011 Implementation Status Assessment Final Report: A Qualitative Assessment of Implementation of the Puget Sound Chinook Salmon Recovery Plan. Prepared for the National Marine Fisheries Service. Available at http://treatyrightsatrisk.org/wp-content/uploads/2012/11/implement-rpt.pdf

[42] Fresh, K., M. Dethier, C. Simenstad, M. Logsdon, H. Shipman, C. Tanner, T. Leschine, T. Mumford, G. Gelfenbaum, R. Shuman, and J. Newton. 2011. Implications of Observed Anthropogenic Changes to the Nearshore Ecosystems in Puget Sound. Prepared for the Puget Sound Nearshore Ecosystem Restoration Project. Technical Report 2011-03.

[43] Washington State Department of Natural Resources. 2001. The Washington State ShoreZone Inventory. Nearshore Habitat Program, Aquatic Resources Division. Digital data available at http://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-inventory

[44] United States v. Washington, 873 F. Supp. 1422 at 1430, (W.D. Wash. 1994). Upheld by 9th Cir. in 1998. United States v. Washington, 157 F. 3d 630 (9th Cir. 1998).

[45] O'Neill, C.A. 2013. Fishable Waters. American Indian Law Journal 1(2): 181- 452.

[46] Dlugokencky, E. and P. Tans. 2015. National Oceanic and Atmospheric Administration – Earth System Research Laboratory – Global Monitoring Division. Available at http://www.esrl.noaa.gov/gmd/ccgg/trends/

[47] Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner. 2013. Long-Term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press.

[48] National Research Council. 2011. America's Climate Choices. Washington, DC: The National Academies Press.

[49] Melillo, J.M., T.C. Richmond, and G.W. Yohe (Eds.). 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program. Available at globalchange.gov

[50] IPCC. 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press.

[51] Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner. 2013. Long-Term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press.

[52] Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner. 2013. Long-Term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press.

[53] NOAA National Centers for Environmental Information, State of the Climate: Global Analysis for Annual 2015, published online January 2016. Available at http://www.ncdc.noaa.gov/sotc/global/201513

[54] Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner. 2013. Long-Term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press.

[55] IPCC. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (Eds.)]. Available at http://www.ipcc.ch/report/ar5/syr

[56] Cuffey, K.M., G.D. Clow, R.B. Alley, M. Stuiver, E.D. Waddington, and R.W. Saltus. 1995. Large Arctic Temperature Change at the Wisconsin-Holocene Glacial Transition. Science 270(5235): 455-458.

[57] National Academies of Sciences, Engineering, and Medicine. 2016. Frontiers in Decadal Climate Variability: Proceedings of a Workshop. Washington, DC: National Academies Press.

[58] Deser, C., R. Knutti, S. Solomon, and A.S. Phillips. 2012. Communication of the role of natural variability in future North American climate. Nature Climate Change, 2(11): 775-779.

[59] Dobrowski, S.Z., J. Abatzoglou, A.K. Swanson, J.A. Greenberg, A.R. Mynsberge, Z.A. Holden, M.K. Schwartz. 2013. The climate velocity of the contiguous United States during the 20th century. Global Change Biology, 19(1): 241-251.

[60] IPCC. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (Eds.)]. Available at http://www.ipcc.ch/report/ar5/syr

[61] National Academies of Sciences, Engineering, and Medicine. 2016. Attribution of Extreme Weather Events in the Context of Climate Change. Washington, DC: The National Academies Press.

[62] Heilprin, J. 2014. UN: 2013 extreme events due to warming Earth. KPCC Public Radio Online. Available at http://www.scpr.org/news/2014/03/24/43009/un-2013-extreme-events-due-to-warming-earth

[63] NOAA. 2014. Billion-Dollar Weather and Climate Disasters: Overview. Available at http://www.ncdc.noaa.gov/billions

[64] Rhein, M., S.R. Rintoul, S. Aoki, E. Campos, D. Chambers, R.A. Feely, S. Gulev, G.C. Johnson, S.A. Josey, A. Kostianoy, C. Mauritzen, D. Roemmich, L.D. Talley and F. Wang. 2013. Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press.

[65] Vose, R.S., S. Applequist, M. Squires, I. Durre, M.J. Menne, C.N. Williams, Jr., C. Fenimore, K. Gleason, and D. Arndt. 2014. Improved historical temperature and precipitation time series for U.S. climate divisions. Journal of Applied Meteorology and Climatology, 53, 1232-1251.

[66] Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K.T. Redmond, and J.G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 6. Climate of the Northwest U.S. NOAA Technical Report NESDIS 142-6. 83 pp. Available at http://www.nesdis.noaa.gov/technical_reports/NOAA_NESDIS_ Tech_Report_142-6-Climate_of_the_Northwest_U.S.pdf

[67] Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle, WA.

[68] U.S. Global Change Research Program. 2009. Global Climate Change Impacts in the United States, T.R. Karl, J. M. Melillo, and T.C. Peterson (Eds.). New York, NY: Cambridge University Press.

[69] Vose, R.S., S. Applequist, M. Squires, I. Durre, M.J. Menne, C.N. Williams, Jr., C. Fenimore, K. Gleason, and D. Arndt. 2014. Improved historical temperature and precipitation time series for U.S. climate divisions. Journal of Applied Meteorology and Climatology, 53, 1232-1251.

[70] Riedel, J. and M.A. Larrabee. 2011. North Cascades National Park Complex glacier mass balance monitoring annual report, Water year 2009: North Coast and Cascades Network. Natural Resource Technical Report NPS/NCCN/NRTR – 2011/483. National Park Service, Fort Collins, CO.

Pelto, M.S. 2010. Forecasting temperate alpine glacier survival from accumulation zone observations. Cryosphere 3:323-350.

[71] Elsner, M.M., L. Cuo, N. Voisin, J.S. Deems, A.F. Hamlet, J.A. Vano, K.E.B. Mickelson, S.Y. Lee, and D.P. Lettenmaier. 2010. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change 102(1-2): 225-260.

[72] Tohver, I.M., A.F. Hamlet, and S.Y. Lee. 2014. Impacts of 21st-century climate change on hydrologic extremes in the Pacific Northwest region of North America. Journal of the American Water Resources Association 50(6): 1461-1476.

[73] Tohver, I.M., A.F. Hamlet, and S.Y. Lee. 2014. Impacts of 21st-century climate change on hydrologic extremes in the Pacific Northwest region of North America. Journal of the American Water Resources Association 50(6): 1461-1476.

[74] Elsner, M.M., L. Cuo, N. Voisin, J.S. Deems, A.F. Hamlet, J.A. Vano, K.E.B. Mickelson, S.Y. Lee, and D.P. Lettenmaier. 2010. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change 102(1-2): 225-260.

[75] Isaak, D.J., S.J. Wenger, E.E. Peterson, J. M. Ver Hoef, S. Hostetler, C.H. Luce, J.B. Dunham, J. Kershner, B.B. Roper, D. Nagel, D. Horan, G. Chandler, S. Parkes, and S. Wollrab. 2011. NorWeST: An interagency stream temperature database and model for the Northwest United States. U.S. Fish and Wildlife Service, Great Northern Landscape Conservation Cooperative Grant. Available at http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html.

[76] Ficklin, D.L., I.T. Stewart, and E.P. Maurer. 2016. Effects of climate change on stream temperature, dissolved oxygen, and sediment concentration in the Sierra Nevada in California. Water Resources Research 49: 2765-2782.

[77] Nooksack Indian Tribe, U.S. Environmental Protection Agency, and Tetra Tech. 2016. Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA. EPA Region 10 Climate Change and TMDL Pilot. In cooperation with Washington Department of Ecology and NOAA Fisheries.

[78] Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle, WA.

[79] Stavros, E.N., J.T. Abatzoglou, D. McKenzie, and N.K. Larkin. 2014. Regional projections of the likelihood of very large wildland fires under a changing climate in the contiguous Western United States, Climatic Change 126:455-468.

[80] Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle, WA.

[81] Field, D., D. Cayan, and F. Chavez. 2006. Secular warming in the California current and North Pacific. California Cooperative Oceanic Fisheries Investigations Reports, 47, 92-108. Available at http://www.calcofi.org/publications/calcofireports/v47/Vol_47_Field_ Warming_In_ The_Ca_Current.pdf

[82] National Research Council. 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Washington, DC: The National Academies Press.

Mote, P.W., A. Petersen, S. Reeder, H. Shipman, and L. Whitely Binder. 2008. Sea Level Rise in the Coastal Waters of Washington State. Report prepared by the Climate Impacts Group, University of Washington and the Washington Department of Ecology.

[83] Komar, P.D. and J.C. Allen. 2000. Analyses of Extreme Waves and Water Levels on the Pacific Northwest Coast. Report to the Oregon Department of Land Conservation and Development, Salem, OR. Available at http://www.oregon.gov/lcd/ocmp/docs/publications/extreme_ wavestide_rpt.pdf

[84] Feely, R.A., S. Alin, J. Newton, C. Sabine, M. Warner, A. Devol, C. Krembs, and C. Maloy. 2010. The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary. Estuarine, Coastal and Shelf Science 88: 442-449.

Roberts, M., T. Mohamedali, B. Sackmann, T. Khangaonkar, and W. Long. 2014. Puget Sound and the Straits Dissolved Oxygen Assessment: Impacts of Current and Future Human Nitrogen Sources and Climate Change through 2070. Washington State Department of Ecology Publication No. 14-03-007, Olympia, WA. Available at https://fortress.wa.gov/ecy/publications/SummaryPages/1403007.html

[85] Mauger, G. and A. Snover. 2015. Future scenarios for climate change in Puget Sound. Encyclopedia of Puget Sound. Puget Sound Institute at the University of Washington Tacoma Center for Urban Waters. Available at http://www.eopugetsound.org/articles/future-scenarios-climate-change-puget-sound

[86] Mote, P., A. K. Snover, S. Capalbo, S. D. Eigenbrode, P. Glick, J. Littell, R. Raymondi, and S. Reeder. 2014. Chapter 21: Northwest. Climate Change Impacts in the United States. In The Third National Climate Assessment. Melillo, J.M., T.C. Richmond, and G.W. Yohe (Eds.). U.S. Global Change Research Program, Washington, DC. Available at http://nca2014.globalchange.gov

[87] Mote, P. W., and E. P. Salathé. 2010. Future climate in the Pacific Northwest. Climatic Change, 102, 29-50. Available at http://www.atmos.washington.edu/~salathe/papers/published/Mote_Salathe_2010.pdf

[88] Mauger, G. and A. Snover. 2015. Future scenarios for climate change in Puget Sound. Encyclopedia of Puget Sound. Puget Sound Institute at the University of Washington Tacoma Center for Urban Waters. Available at http://www.eopugetsound.org/articles/future-scenarios-climate-change-puget-sound

[89] Lynch, A.J., B.J.E. Myers, C. Chu, L.A. Eby, J.A. Falke, R.P. Kovach, T.J. Krabbenhoft, T.J. Kwak, J. Lyons, C.P. Paukert, and J. E. Whitney. 2016. Climate change effects on North American inland fish populations and assemblages. Fisheries 41(7): 346-361.

[90] Pearson, R. G. 2006. Climate change and the migration capacity of species. Trends in Ecology and Evolution 21, 111-113.

91 Isaak, D. J., M.K. Young, C.H. Luce, S.W. Hostetler, S.J. Wenger, E.E. Peterson, J.M. Ver Hoef, M.C. Groce, D.L. Horan, and D.E. Nagel. 2016. Slow climate velocities of mountain streams portend their role as refugia for cold-water biodiversity. Proceedings of the National Academy of Sciences 113(16): 4374-4379.

[92] Dobrowski, S.Z., J. Abatzoglou, A.K. Swanson, J.A. Greenberg, A.R. Mynsberge, Z.A. Holden, M.K. Schwartz. 2013. The climate velocity of the contiguous United States during the 20th century. Global Change Biology, 19(1): 241-251.

[93] Lynch, A.J., B.J.E. Myers, C. Chu, L.A. Eby, J.A. Falke, R.P. Kovach, T.J. Krabbenhoft, T.J. Kwak, J. Lyons, C.P. Paukert, and J. E. Whitney. 2016. Climate change effects on North American inland fish populations and assemblages. Fisheries 41(7): 346-361.

[94] Bash, J., C. Berman, and S. Bolton. 2001. Effects of Turbidity and Suspended Solids on Salmonids. Final Research Report, Research Project T1803, Task 42. Prepared for Washington State Transportation Commission by Center for Streamside Studies, University of Washington, Seattle, WA.

Brown, C. and D. Hallock. 2009. Washington State Dissolved Oxygen Standard: A Review and Discussion of Freshwater Intragravel Criteria Development. Washington State Department of Ecology Environmental Assessment Program, Olympia, WA.

Brown, J. 2011. The impact of fine sediment pollution on Chinook survival to emergence in the North Fork Stillaguamish River. Stillaguamish Tribe of Indians, Natural Resources Department.

Crozier, L.G., and R.W. Zabel. 2006. Climate impacts at multiple scales: evidence for differential population responses of juvenile Chinook salmon. Journal of Animal Ecology 75(5): 1100-1109.

Elsner, M.M., L. Cuo, N. Voisin, J.S. Deems, A.F. Hamlet, J.A. Vano, K.E.B. Mickelson, S.Y. Lee, and D.P. Lettenmaier. 2010. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change 102(1-2): 225-260.

Grah, O. and J. Beaulieu. 2013. The effect of climate change on glacier ablation and baseflow support in the Nooksack River basin and implications on Pacific salmonid species protection and recovery. Climatic Change 120:657-670.

Isaak, D. J., S. Wollrab, D. Horan, and G. Chandler. 2012. Climate change effects on stream and river temperatures across the northwest U.S. from 1980-2009 and implications for salmonid fishes. Climatic Change 113 (2): 499-524.

Mantua, N.J., I. Tohver, and A.F. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change 102: 187-223.

Nooksack Indian Tribe, U.S. Environmental Protection Agency, and Tetra Tech. 2016. Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA. EPA Region 10 Climate Change and TMDL Pilot. In cooperation with Washington Department of Ecology and NOAA Fisheries.

Ward, E. J., Anderson, J.H., Beechie, T.J., Pess, G.R. and Ford, M.J. 2015. Increasing hydrologic variability threatens depleted anadromous fish populations. Global Change Biology 21(7): 2500-2509.

[95] Cheung, W.W.L, R.D. Brodeur, T.A. Okey, and D. Pauly. 2015. Projecting future changes in distributions of pelagic fish species of Northeast Pacific shelf seas. Progress in Oceanography 130: 19-3.

[96] Cheung, W.W.L., R.D. Brodeur, T.A. Okey, and D. Pauly. 2015. Projecting future changes in distributions of pelagic fish species of Northeast Pacific shelf seas. Progress in Oceanography 130: 19-3.

[97] Kroeker, K.J., R.L. Kordas, R. Crim, I.E. Hendriks, L. Ramajo, G.S. Singh, C.M. Duarte, and J.P. Gattuso. 2013. Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. Global Change Biology 19: 1884-1896.

Levin, L.A., W. Ekau, A.J. Gooday, F. Jorissen, J.J. Middelburg, S.W.A. Naqvi, C. Neira, N.N. Rabalais, and J. Zhang. 2009. Effects of natural and human-induced hypoxia on coastal benthos. Biogeosciences 6: 2063-2098.

[98] Moore, S.K., N.J. Mantua, and E.P. Salathé Jr. 2011. Past trends and future scenarios for environmental conditions favoring the accumulation of paralytic shellfish toxins in Puget Sound shellfish. Harmful Algae 10(5): 521-529.

Sun, J., D.A. Hutchins, Y. Feng, E.L. Seubert, D.A. Caron, and F.X. Fu. 2011. Effects of changing pCO_2 and phosphate availability on domoic acid production and physiology of the marine harmful bloom diatom Pseudo-nitzschia multiseries. Limnology and Oceanography 56(3):829-840.

[99] Donatuto, J., E.E. Grossman, J. Konovsky, S. Grossman, and L.W. Campbell. 2014. Indigenous Community Health and Climate Change: Integrating Biophysical and Social Science Indicators. Coastal Management 42(4): 355-373.

[100] National Research Council. 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Washington, DC: The National Academies Press.

Nooksack Indian Tribe, U.S. Environmental Protection Agency, and Tetra Tech. 2016. Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA. EPA Region 10 Climate Change and TMDL Pilot. In cooperation with Washington Department of Ecology and NOAA Fisheries.

[101] Halofsky, J.E., D.L. Peterson, K.A. O'Halloran, C. Hawkins Hoffman (Eds.). 2011. Adapting to climate change at Olympic National Forest and Olympic National Park. General Technical Report PNW-GTR-844. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR.

Lawler J.J. and M. Mathias. 2007. Climate Change and the Future of Biodiversity in Washington. Report prepared for the Washington Biodiversity Council.

[102] Chen, I.C., J.K. Hill, R. Ohlemüller, D.B. Roy, and C.D. Thomas. 2011. Rapid range shifts of species associated with high levels of climate warming. Science 333, 1024-1026.

[103] WSDOE. 2012. Preparing for a Changing Climate: Washington State's Integrated Climate Response Strategy. Washington State Department of Ecology Publication No. 12-01-004.

[104] Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E. Lugo, C.J. Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks, and B.M. Wotton. 2001. Climate change and forest disturbances. Bioscience 51(9): 723-734.

[105] Raymond, C. L., Peterson, D.L., Rochefort, R.M. (Eds.). 2014. Climate change vulnerability and adaptation in the North Cascades region, Washington. Gen. Tech. Rep. PNW-GTR-892. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

[106] Harrington, C.A. and P.J. Gould. 2015. Tradeoffs between chilling and forcing in satisfying dormancy requirements for Pacific Northwest tree species. Frontiers in Plant Science 6:120-132.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. BioScience 47(11):769-784.

[107] Donatuto, J., E.E. Grossman, J. Konovsky, S. Grossman, and L.W. Campbell. 2014. Indigenous Community Health and Climate Change: Integrating Biophysical and Social Science Indicators. Coastal Management 42(4): 355-373.

Jamestown S'Klallam Tribe. 2013. Climate Change Vulnerability Assessment and Adaptation Plan. Petersen, S. and J. Bell (Eds.). A collaboration of the Jamestown S'Klallam Tribe and Adaptation International.

Lynn, K., J. Daigle, J. Hoffman, F. Lake, N. Michelle, D. Ranco, C. Viles, G. Voggesser, and P. Williams. 2013. The impacts of climate change on tribal traditional foods. Climatic Change 120:545-556.

[108] Mantua, N.J., I. Tohver, and A.F. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change 102: 187-223.

Nooksack Indian Tribe, U.S. Environmental Protection Agency, and Tetra Tech. 2016. Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA. EPA Region 10 Climate Change and TMDL Pilot. In cooperation with Washington Department of Ecology and NOAA Fisheries.

Ward, E.J., J.H. Anderson, T.J. Beechie, G.R. Pess, and M.J. Ford. 2015. Increasing hydrologic variability threatens depleted anadromous fish populations. Global Change Biology 21(7): 2500-2509.

[109] Riedel, J. and M.A. Larrabee. 2011. North Cascades National Park Complex glacier mass balance monitoring annual report, Water year 2009: North Coast and Cascades Network. Natural Resource Technical Report NPS/NCCN/NRTR – 2011/483. National Park Service, Fort Collins, CO.

Pelto, M.S. 2010. Forecasting temperate alpine glacier survival from accumulation zone observations. Cryosphere 3:323-350.

Elsner, M.M., L. Cuo, N. Voisin, J.S. Deems, A.F. Hamlet, J.A. Vano, K.E.B. Mickelson, S.Y. Lee, and D.P. Lettenmaier. 2010. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change 102(1-2): 225-260.

[110] Tohver, I.M., A.F. Hamlet, and S.Y. Lee. 2014. Impacts of 21st-century climate change on hydrologic extremes in the Pacific Northwest region of North America. Journal of the American Water Resources Association 50(6): 1461-1476.

Luce, C.H., J. T. Abatzoglou, and Z.A. Holden. 2013. The missing mountain water: slower westerlies decrease orographic enhancement in the Pacific Northwest USA. Science 342: 1360-1364.

Elsner, M.M., L. Cuo, N. Voisin, J.S. Deems, A.F. Hamlet, J.A. Vano, K.E.B. Mickelson, S.Y. Lee, and D.P. Lettenmaier. 2010. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change 102(1-2): 225-260.

[111] Isaak, D.J., S.J. Wenger, E.E. Peterson, J. M. Ver Hoef, S. Hostetler, C.H. Luce, J.B. Dunham, J. Kershner, B.B. Roper, D. Nagel, D. Horan, G. Chandler, S. Parkes, and S. Wollrab. 2011. NorWeST: An interagency stream temperature database and model for the Northwest United States. U.S. Fish and Wildlife Service, Great Northern Landscape Conservation Cooperative Grant. Available at www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html

[112] Nooksack Indian Tribe, U.S. Environmental Protection Agency, and Tetra Tech. 2016. Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA. EPA Region 10 Climate Change and TMDL Pilot. In cooperation with Washington Department of Ecology and NOAA Fisheries.

[113] Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle, WA.

[114] Isaak, D.J., C.H. Luce, B.E. Rieman, D.E. Nagel, E.E. Peterson, D.L. Horan, S. Parkes, and G.L. Chandler. 2010. Effects of climate change and wildlife on stream temperatures and salmonid thermal habitat in a mountain river network. Ecological Applications 20(5):1350-1371.

[115] Rahel, F.J., and J.D. Olden. 2008. Assessing the effects of climate change on aquatic invasive species Conservation Biology 22(3):521-533.

[116] Campbell S.K. and V.L. Butler. 2010. Archaeological evidence for resilience of Pacific Northwest salmon populations and the socioecological system over the last 7,500 years. Ecology and Society 15(1):17.

[117] Fall, J.A., D. Holen, T.M. Krieg, R. La Vine, K. Stickman, M. Ravenmoon, J. Hay, and J. Stariwat. 2010. The Kvichak watershed subsistence salmon fishery: an ethnographic study. Alaska Department of Fish and Game Division of Subsistence Technical Paper No. 352, Anchorage, AK.

[118] Cozzetto, K., K. Chief, K. Dittmer, M. Brubaker, R. Gough, K. Souza, F. Ettawageshik, S. Wotkyns, S. Opitz-Stapleton, S. Duren, and P. Chavan. 2013. Climate change impacts on the water resources of American Indians and Alaska Natives in the U.S. Climatic Change (2013) 120:545-556.

[119] Lackey, R. 2000. Restoring wild salmon to the Pacific Northwest: Chasing an illusion? In: Koss, P. and M. Katz (Eds). What We Don't Know about Pacific Northwest Fish Runs – An Inquiry into Decision-Making. Portland State University, Portland, OR. Available at http://www.epa.gov/wed/pages/staff/lackey/pubs/illusion.htm

[120] Grah, O. and J. Beaulieu. 2013. The effect of climate change on glacier ablation and baseflow support in the Nooksack River basin and implications on Pacific salmonid species protection and recovery Climatic Change 120 (1-2): 657-670.

[121] Elsner, M.M., L. Cuo, N. Voisin, J.S. Deems, A.F. Hamlet, J.A. Vano, K.E.B. Mickelson, S.Y. Lee, and D.P. Lettenmaier. 2010. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change 102(1-2): 225-260.

[122] Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle. Available at https://cig.uw.edu/resources/specialVreports/psVsok

[123] Mote, P.W. 2006. Climate-driven variability and trends in mountain snowpack in western North America. Journal of Climate, 19, 6209-6220.

[124] Mote, P.W., A.F. Hamlet, M. Clark, and D.P. Lettenmaier. 2005. Declining mountain snowpack in western North America. Bulletin of the American Meteorological Society 86(1): 39-49.

[125] USDA/NRCS National Water and Climate Center. 2015. Washington SNOTEL Current Snow Water Equivalent (SWE) % of Normal, Portland, Oregon. Available at ftp://ftp.wcc.nrcs.usda.gov/data/water/wcs/gis/maps/wa_swepctnormal_update.pdf

[126] Riedel, J.L., S. Wilson, W. Baccus, M. Larrabee, T.W. Fudge, and A.G. Fountain. 2015. Glacier status and contribution to streamflow in the Olympic Mountains, Washington, USA. Journal of Glaciology 61(225).

[127] Olympic National Park. 2015. Glaciers and Climate Change. Available at http://www.nps.gov/olym/naturescience/glaciers.htm

[128] Olympic National Park. 2015. Glaciers and Climate Change. Available at http://www.nps.gov/olym/naturescience/glaciers.htm

[129] Olympic National Park. 2015. Glaciers and Climate Change. Available at http://www.nps.gov/olym/naturescience/glaciers.htm

[130] Riedel, J., and M.A. Larrabee. 2011. North Cascades National Park Complex glacier mass balance monitoring annual report, Water year 2009: North Coast and Cascades Network. Natural Resource Technical Report NPS/NCCN/NRTR – 2011/483. National Park Service, Fort Collins, CO.

[131] Beaulieu, J. and O. Grah. 2015. Nooksack River Watershed Glacier Monitoring Summary Report 2015. Prepared for the Nooksack Indian Tribe. Deming, WA.

[132] Lee, S.Y. and A.F. Hamlet. 2011. Skagit River Basin Climate Science Report, a summary report prepared for Skagit County and the Envision Skagit Project by the Department of Civil and Environmental Engineering and The Climate Impacts Group at the University of Washington. Seattle, WA.

[133] Beaulieu, J. and Grah, O. 2015. Nooksack River Watershed Glacier Monitoring Summary Report 2015. Prepared for the Nooksack Indian Tribe. Deming, WA.

[134] Beaulieu, J. and Grah, O. 2015. Nooksack River Watershed Glacier Monitoring Summary Report 2015. Prepared for the Nooksack Indian Tribe. Deming, WA.

[135] Elsner, M.M., L. Cuo, N. Voisin, J.S. Deems, A.F. Hamlet, J.A. Vano, K.E.B. Mickelson, S.Y. Lee, and D.P. Lettenmaier. 2010. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change 102(1-2): 225-260.

[136] Elsner, M.M., L. Cuo, N. Voisin, J.S. Deems, A.F. Hamlet, J.A. Vano, K.E.B. Mickelson, S.Y. Lee, and D.P. Lettenmaier. 2010. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change 102(1-2): 225-260.

[137] Murphy, R.D. 2016. Modeling the Effects of Forecasted Climate Change and Glacier Recession on Late Summer Streamflow in the Upper Nooksack River Basin.. Western Washington University Masters Thesis Collection. Paper 461. Available at http://cedar.wwu.edu/wwuet/461

[138] Nooksack Indian Tribe, U.S. Environmental Protection Agency, and Tetra Tech. 2016. Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA. EPA Region 10 Climate Change and TMDL Pilot. In cooperation with Washington Department of Ecology and NOAA Fisheries.

[139] Rieman, B.E. and D.J. Isaak. 2010. Climate Change, Aquatic Ecosystems, and Fishes in the Rocky Mountain West: Implications and Alternatives for Management. General Technical Report RMRS-GTR-250. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

[140] Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. BioScience 47(11):769-784.

[141] Beamish, R.J., B.E. Riddell, K.L. Lange, E. Farley Jr., S. Kang, T. Nagasawa, V. Radchenko, O. Temnykh, and S. Urawa. 2009. The Effects of Climate on Pacific Salmon – a Summary of Published Literature. North Pacific Anadromous Fish Commission, Vancouver, BC.

[142] Karvonen, A., P. Rintamäki, J. Jokela, and E.T. Valtonen. 2010. Increasing water temperature and disease risks in aquatic systems: climate change increases the risk of some, but not all, diseases. International Journal for Parasitology 40(13): 1483-1488.

[143] Dietrich, J.P, A.L. Van Gaest, S. A. Strickland, and M. R. Arkoosh. 2014. The impact of temperature stress and pesticide exposure on mortality and disease susceptibility of endangered Pacific salmon. Chemosphere 108: 353-359.

[144] Brown, C., and D. Hallock. 2009. Washington State Dissolved Oxygen Standard: A Review and Discussion of Freshwater Intragravel Criteria Development. Washington State Department of Ecology Environmental Assessment Program, Olympia, WA.

[145] Crozier, L.G., and R.W. Zabel. 2006. Climate impacts at multiple scales: evidence for differential population responses of juvenile Chinook salmon. Journal of Animal Ecology. 75(5): 1100-1109.

[146] National Marine Fisheries Service. 2008. Endangered Species Act – Section 7 Consultation Biological Opinion And Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation. Statewide Consultation for EPA's Proposed Approval of Revised Washington Water Quality Standards for Designated Uses, Temperature, Dissolved Oxygen, and Other Revisions. National Oceanic and Atmospheric Administration, Northwest Region, Seattle, WA.

[147] Isaak, D.J., C.H. Luce, B.E. Rieman, D.E. Nagel, E.E. Peterson, D.L. Horan, S. Parkes, and G.L. Chandler. 2010. Effects of climate change and wildlife on stream temperatures and salmonid thermal habitat in a mountain river network. Ecological Applications 20(5): 1350-1371.

[148] Northwest Treaty Tribes. August 12, 2015. Puyallup Tribe: Will a Wall of Warm Water Stop Salmon? http://nwtreatytribes.org/puyallup-tribe-will-a-wall-of-warm-water-stop-salmon

[149] Isaak, D.J., S. Wollrab, D. Horan, and G. Chandler. 2012. Climate change effects on stream and river temperatures across the northwest U.S. from 1980-2009 and implications for salmonid fishes. Climatic Change 113 (2): 499-524.

[150] Isaak, D.J., S. Wollrab, D. Horan, and G. Chandler. 2012. Climate change effects on stream and river temperatures across the northwest U.S. from 1980-2009 and implications for salmonid fishes. Climatic Change 113 (2): 499-524.

[151] U.S. Environmental Protection Agency. 2014. Quantitative Assessment of Temperature Sensitivity of the South Fork Nooksack River under Future Climates using QUAL2Kw. Western Ecology Division, National Health and Environmental Effects Research Laboratory, Corvallis, OR. Available at http://www.epa.gov/nscep

[152] Isaak, D.J., S.J. Wenger, E.E. Peterson, J. M. Ver Hoef, S. Hostetler, C.H. Luce, J.B. Dunham, J. Kershner, B.B. Roper, D. Nagel, D. Horan, G. Chandler, S. Parkes, and S. Wollrab. 2011. NorWeST: An interagency stream temperature database and model for the Northwest United States. U.S. Fish and Wildlife Service, Great Northern Landscape Conservation Cooperative Grant. Available at www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html

[153] Mantua, N.J., I. Tohver, and A.F. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change 102: 187-223.

[154] U.S. Environmental Protection Agency. 2014. Quantitative Assessment of Temperature Sensitivity of the South Fork Nooksack River under Future Climates using QUAL2Kw. Western Ecology Division, National Health and Environmental Effects Research Laboratory, Corvallis, OR. Available at http://www.epa.gov/nscep

[155] Mantua, N.J., I. Tohver, and A.F. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change 102: 187-223.

[156] Grah, O. and J. Beaulieu. 2013. The effect of climate change on glacier ablation and baseflow support in the Nooksack River basin and implications on Pacific salmonid species protection and recovery Climatic Change 120 (1-2): 657-670.

[157] Beamer, E.M., and G.R. Pess. 1999. The effects of peak flows on Chinook (Oncorhynchus tshawytscha) spawning success in two Puget Sound River Basins. Proceedings from Watershed Management to Protect Declining Species. American Water Resources Association Annual Water Resources Conference. December 6-9, 1999. Seattle, WA.

[158] Stillaguamish Tribe of Indians. 2013. Peak Flow Research. Available at http://stillaguamish.nonprofitsites.com/peak_flow_research.asp

[159] Brown, J. 2011. The impact of fine sediment pollution on Chinook survival to emergence in the North Fork Stillaguamish River. Stillaguamish Tribe of Indians, Natural Resources Department.

[160] Kuhlman, K., J. Freimund, and G. Gabrisch. 2016. Lummi Nation Climate Change Mitigation and Adaptation Plan: 2016-2026. Lummi Natural Resources Department, Water Resources Division. Report at http://lnnr.lummi-nsn.gov/LummiWebsite/userfiles/360_Climate%20Change%20Assessment%20FINAL.pdf

[161] Montgomery, D.R., J.M. Buffington, N.P. Peterson, D. Schuett-Hames, and T.P. Quinn. 1996. Streambed scour, egg burial depths and the influence of salmonid spawning on bed surface mobility and embryo survival. Canada Journal of Fisheries and Aquatic Sciences 53: 1061-1070.

[162] Mantua, N.J., I. Tohver, and A.F. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change 102: 187-223.

[163] Nooksack Indian Tribe, U.S. Environmental Protection Agency, and Tetra Tech. 2016. Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA. EPA Region 10 Climate Change and TMDL Pilot. In cooperation with Washington Department of Ecology and NOAA Fisheries.

[164] Nooksack Indian Tribe, U.S. Environmental Protection Agency, and Tetra Tech. 2016. Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA. EPA Region 10 Climate Change and TMDL Pilot. In cooperation with Washington Department of Ecology and NOAA Fisheries.

[165] Crozier, L.G., and R.W. Zabel. 2006. Climate impacts at multiple scales: evidence for differential population responses of juvenile Chinook salmon. Journal of Animal Ecology. 75(5): 1100-1109.

[166] Whitehead, P. G., R. L. Wilby, R. W. Battarbee, M. Kernan, and A.J. Wade. 2009. A review of the potential impacts of climate change on surface water quality. Hydrological Sciences 54(1): 101-123.

[167] National Fish, Wildlife and Plants Climate Adaptation Partnership. 2012. National Fish, Wildlife and Plants Climate Adaptation Strategy. Association of Fish and Wildlife Agencies, Council on Environmental Quality, Great Lakes Indian Fish and Wildlife Commission, National Oceanic and Atmospheric Administration, and U.S. Fish and Wildlife Service. Washington, DC.

[168] National Marine Fisheries Service. 2015. Draft Environmental Impact Statement to Analyze Impacts of NOAA's National Marine Fisheries Service Proposed 4(d) Determination under Limit 6 for Five Early Winter Steelhead Hatchery Programs in Puget Sound. Seattle, WA.

[169] Hanson, K.C., and K.G. Ostrand. 2011. Potential effects of global climate change on National Fish Hatchery operations in the Pacific Northwest, USA. Aquaculture Environment Interactions 1: 175-186.

[170] Tohver, I.M. and A.F. Hamlet. 2010. Chapter 7 in Final Report for the Columbia Basin Climate Change Scenarios Project, Climate Impacts Group, Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, WA.

[171] Safeeq, M., G.E. Grant, S.L. Lewis, and C.L. Tague. 2013. Coupling snowpack and groundwater dynamics to interpret historical streamflow trends in the western United States. Hydrological Processes 27: 655-668.

[172] Pelto, M.S. 2008. Impact of climate change on North Cascade alpine glaciers and alpine runoff. Northwest Science 82(1): 65-75.

[173] Stewart, I., D.R. Cayan, and M.D. Dettinger. 2005. Changes toward earlier streamflow timing across western North America. Journal of Climate, 18: 1136-1155.

[174] Elsner, M.M., L. Cuo, N. Voisin, J.S. Deems, A.F. Hamlet, J.A. Vano, K.E.B. Mickelson, S.Y. Lee, and D.P. Lettenmaier. 2010. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change 102(1-2): 225-260.

[175] Elsner, M.M., L. Cuo, N. Voisin, J.S. Deems, A.F. Hamlet, J.A. Vano, K.E.B. Mickelson, S.Y. Lee, and D.P. Lettenmaier. 2010. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change 102(1-2): 225-260.

[176] Elsner, M.M., L. Cuo, N. Voisin, J.S. Deems, A.F. Hamlet, J.A. Vano, K.E.B. Mickelson, S.Y. Lee, and D.P. Lettenmaier. 2010. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change 102(1-2): 225-260.

[177] Tohver, I.M., A.F. Hamlet, and S.Y. Lee. 2014. Impacts of 21st-century climate change on hydrologic extremes in the Pacific Northwest region of North America. Journal of the American Water Resources Association 50(6): 1461-1476.

[178] Mauger, G. and A. Snover. 2015. Future scenarios for climate change in Puget Sound. Encyclopedia of Puget Sound. Puget Sound Institute at the University of Washington Tacoma Center for Urban Waters. Available at http://www.eopugetsound.org/articles/future-scenarios-climate-change-puget-sound

[179] Tohver, I.M., A.F. Hamlet, and S.Y. Lee. 2014. Impacts of 21st-century climate change on hydrologic extremes in the Pacific Northwest region of North America. Journal of the American Water Resources Association 50(6): 1461-1476.

[180] Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle, WA.

[181] Tohver, I.M., A.F. Hamlet, and S.Y. Lee. 2014. Impacts of 21st-century climate change on hydrologic extremes in the Pacific Northwest region of North America. Journal of the American Water Resources Association 50(6): 1461-1476.

[182] U.S. Global Change Research Program. 2009. Global Climate Change Impacts in the United States, T.R. Karl, J. M. Melillo, and T.C. Peterson, (Eds.). New York, NY: Cambridge University Press.

[183] Jamestown S'Klallam Tribe. 2013. Climate Change Vulnerability Assessment and Adaptation Plan. Petersen, S. and J. Bell (Eds.). A collaboration of the Jamestown S'Klallam Tribe and Adaptation International.

[184] Shared Strategy for Puget Sound. 2007. Puget Sound Chinook Recovery Plan. Submitted by the Shared Strategy Development Committee and adopted by the National Marine Fisheries Service. Seattle, WA.

[185] Jiménez Cisneros, B.E., T. Oki, N.W. Arnell, G. Benito, J.G. Cogley, P. Döll, T. Jiang, and S.S. Mwakalila. 2014. Freshwater resources. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press.

[186] Nooksack Indian Tribe, U.S. Environmental Protection Agency, and Tetra Tech. 2016. Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA. EPA Region 10 Climate Change and TMDL Pilot. In cooperation with Washington Department of Ecology and NOAA Fisheries.

[187] Nooksack Indian Tribe, U.S. Environmental Protection Agency, and Tetra Tech. 2016. Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA. EPA Region 10 Climate Change and TMDL Pilot. In cooperation with Washington Department of Ecology and NOAA Fisheries.

[188] Bash, J., C. Berman, and S. Bolton. 2001. Effects of Turbidity and Suspended Solids on Salmonids. Final Research Report, Research Project T1803, Task 42. Prepared for Washington State Transportation Commission by Center for Streamside Studies, University of Washington, Seattle, WA.

[189] Bash, J., C. Berman, and S. Bolton. 2001. Effects of Turbidity and Suspended Solids on Salmonids. Final Research Report, Research Project T1803, Task 42. Prepared for Washington State Transportation Commission by Center for Streamside Studies, University of Washington, Seattle, WA.

[190] Czuba, J.A., C.S. Magirl, C.R. Czuba, E.E. Grossman, C.A. Curran, A.S. Gendaszek, and R.S. Dinicola. 2011. Sediment Load from Major Rivers into Puget Sound and its Adjacent Waters. U.S. Geological Survey Fact Sheet 2011-3083.

[191] Jiménez Cisneros, B.E., T. Oki, N.W. Arnell, G. Benito, J.G. Cogley, P. Döll, T. Jiang, and S.S. Mwakalila. 2014. Freshwater resources. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press.

[192] Naik, P.K. and D.A. Jay. 2011. Distinguishing Human and Climate Influences on the Columbia River: Changes in Mean Flow and Sediment Transport. Journal of Hydrology 404(3-4): 259-277.

[193] Lee, S.Y. and A.F. Hamlet. 2011. Skagit River Basin Climate Science Report, a summary report prepared for Skagit County and the Envision Skagit Project by the Department of Civil and Environmental Engineering and The Climate Impacts Group at the University of Washington.

[194] Lee, S.Y., A.F. Hamlet, E.E. Grossman. 2016. Impacts of Climate Change on Regulated Streamflow, Hydrologic Extremes, Hydropower Production, and Sediment Discharge in the Skagit River Basin. Northwest Science 90(1): 23-43.

[195] Czuba, J.A., C.R. Czuba, C.S. Magirl, F.D. Voss. 2010. Channel-conveyance capacity, channel change, and sediment transport in the lower Puyallup, White, and Carbon Rivers, western Washington: U.S. Geological Survey Scientific Investigations Report 2010-5240.

[196] Lee, S.Y. and A.F. Hamlet. 2011. Skagit River Basin Climate Science Report, a summary report prepared for Skagit County and the Envision Skagit Project by the Department of Civil and Environmental Engineering and The Climate Impacts Group at the University of Washington.

[197] Lee, S.Y. and A.F. Hamlet. 2011. Skagit River Basin Climate Science Report, a summary report prepared for Skagit County and the Envision Skagit Project by the Department of Civil and Environmental Engineering and The Climate Impacts Group at the University of Washington.

[198] Beaulieu, J. and O. Grah. 2015. Nooksack River Watershed Glacier Monitoring Summary Report 2015. Prepared for the Nooksack Indian Tribe. Deming, WA.

[199] Jiménez Cisneros, B.E., T. Oki, N.W. Arnell, G. Benito, J.G. Cogley, P. Döll, T. Jiang, and S.S. Mwakalila. 2014. Freshwater resources. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press.

[200] Whitehead, P. G., R. L. Wilby, R. W. Battarbee, M. Kernan, and A. J. Wade. 2009. A review of the potential impacts of climate change on surface water quality. Hydrological Sciences 54(1): 101-123.

[201] Henning, J. 2004. An Evaluation of Fish and Amphibian Use of Restored and Natural Floodplain Wetlands. Final Report EPA Grant CD-97024901-1. Washington Department of Fish and Wildlife, Olympia, WA.

[202] Henning, J. 2004. An Evaluation of Fish and Amphibian Use of Restored and Natural Floodplain Wetlands. Final Report EPA Grant CD-97024901-1. Washington Department of Fish and Wildlife, Olympia, WA.

[203] Mongillo, P.E. and M. Hallock. 1999. Washington state status report for the Olympic mudminnow. Washington Department of Fish and Wildlife. Olympia, WA.

[204] Henning, J. 2004. An Evaluation of Fish and Amphibian Use of Restored and Natural Floodplain Wetlands. Final Report EPA Grant CD-97024901-1. Washington Department of Fish and Wildlife, Olympia, WA.

[205] Raymond, C.L., D.L. Peterson, R.M. Rochefort (Eds.). 2014. Climate change vulnerability and adaptation in the North Cascades region, Washington. Gen. Tech. Rep. PNW-GTR-892. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

[206] Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle, WA.

[207] Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle, WA.

[208] Winter, T.C. 2000. The vulnerability of wetlands to climate change: A hydrologic landscape perspective. Journal of the American Water Resources Association. 36(2): 305-311.

[209] Winter, T.C. 2000. The vulnerability of wetlands to climate change: A hydrologic landscape perspective. Journal of the American Water Resources Association. 36(2): 305-311.

[210] Glick, P., J. Clough, and B. Nunley. 2007. Sea Level Rise and Coastal Habitats in the Pacific Northwest: An Analysis for Puget Sound, Southern Washington, and Northwestern Oregon. National Wildlife Federation, Reston, VA.

[211] Buttrick, S., K. Popper, M. Schindel, B. McRae, B. Unnasch, A. Jones, and J. Platt. 2015. Conserving Nature's Stage: Identifying Resilient Terrestrial Landscapes in the Pacific Northwest. The Nature Conservancy, Portland OR. Available at http://nature.ly/resilienceNW.

[212] Mantua, N.J., I. Tohver, and A.F. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change 102: 187-223.

[213] McHenry, M., G. Pess, T. Abbe, H. Coe, J. Goldsmith, M. Liermann, R. McCoy, S. Morley, and R. Peters. 2007. The Physical and Biological Effects of Engineered Logjams (ELJs) in the Elwha River, Washington. Prepared for the Salmon Recovery Funding Board and the Interagency Committee for Outdoor Recreation.

Abbe, T.B. and D.R. Montgomery. 1996. Large woody debris jams, channel hydraulics and habitat formation in large rivers. Regulated Rivers: Research and Management 12: 201-221.

Sawyer, A.H., M. Bayani Cardenas, and J. Buttles. 2012. Hyporheic temperature dynamics and heat exchange near channel-spanning logs, Water Resources Research 48: W01529.

[214] Capon, S.J., L.E. Chambers, R. MacNally, R.J. Naiman, P. Davies, N. Marshall, J. Pittock, M. Reid, Y. Capon, M. Douglas, and J. Catford. 2013. Riparian ecosystems in the 21st century: hotspots for climate change adaptation? Ecosystems 16(3): 359-381.

[215] Waples, R.S., T. Beechie, and G.R. Pess 2009. Evolutionary history, habitat disturbance regimes, and anthropogenic changes: What do these mean for resilience of Pacific salmon populations? Ecology and Society14(1): 3.

[216] Muñoz, N.J., A.P. Farrell, J.W. Heath, and B.D. Neff. 2015. Adaptive potential of a Pacific salmon challenged by climate change. Nature Climate Change 5: 163-166.

[217] Isaak, D.J., M.K. Young, C.H. Luce, S.W. Hostetler, S.J. Wenger, E.E. Peterson, J.M. Ver Hoef, M.C. Groce, D.L. Horan, and D.E. Nagel. 2016. Slow climate velocities of mountain streams portend their role as refugia for cold-water biodiversity. Proceedings of the National Academy of Sciences 113(16): 4374-4379.

[218] Isaak, D.J., M.K. Young, C.H. Luce, S.W. Hostetler, S.J. Wenger, E.E. Peterson, J.M. Ver Hoef, M.C. Groce, D.L. Horan, and D.E. Nagel. 2016. Slow climate velocities of mountain streams portend their role as refugia for cold-water biodiversity. Proceedings of the National Academy of Sciences 113(16): 4374-4379.

[219] Mantua, N.J., L.G. Crozier, T.E. Reed, D.E. Schindler and R.S. Waples. 2015. Correspondence: Response of chinook salmon to climate change. Nature Climate Change 5: 613-615.

[220] Crozier, L.G., M.D. Scheuerell, and R.W. Zabel. 2011. Using time series analysis to characterize evolutionary and plastic responses to environmental change: a case study of a shift toward earlier migration date in Sockeye Salmon. American Naturalist 178(6): 755-773.

[221] Doctor, K., B. Berejikian, J.J. Hard and D. VanDoornik. 2014. Growth-mediated life history traits of steelhead reveal phenotypic divergence and plastic response to temperature. Transactions of the American Fisheries Society 143(2): 317-333.

[222] Mantua, N.J., L.G. Crozier, T.E. Reed, D.E. Schindler and R.S. Waples. 2015. Correspondence: Response of chinook salmon to climate change. Nature Climate Change 5: 613-615.

[223] Gonzalez, A., O. Ronce, R. Ferriere, M.E. Hochberg. 2013. Evolutionary rescue: an emerging focus at the intersection between ecology and evolution. Philosophical Transaction of the Royal Society B Biological Sciences 368(1610): 20120404.

[224] Crozier, L.G., M.D. Scheuerell, and R.W. Zabel. 2011. Using time series analysis to characterize evolutionary and plastic responses to environmental change: a case study of a shift toward earlier migration date in Sockeye Salmon. American Naturalist 178(6): 755-773.

[225] Crozier, L.G., M.D. Scheuerell, and R.W. Zabel. 2011. Using time series analysis to characterize evolutionary and plastic responses to environmental change: a case study of a shift toward earlier migration date in Sockeye Salmon. American Naturalist 178(6): 755-773.

[226] Kovach, R.P., A.J. Gharrett, and D.A. Tallmon. 2012. Genetic change for earlier migration timing in a Pink Salmon population. Proceedings of the Royal Society B: Biological Sciences 279(1743): 3870-3878.

[227] Dalton, M. (Ed.). 2016. Climate Change Vulnerability Assessment for the Treaty of Olympia Tribes: A Report to the Quinault Indian Nation, Hoh Tribe, and Quileute Tribe. Prepared by the Oregon Climate Change Research Institute. Corvallis, OR.

[228] Nooksack Indian Tribe, U.S. Environmental Protection Agency, and Tetra Tech. 2016. Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA. EPA Region 10 Climate Change and TMDL Pilot. In cooperation with Washington Department of Ecology and NOAA Fisheries.

[229] Field, D., D. Cayan, and F. Chavez. 2006. Secular warming in the California current and North Pacific. California Cooperative Oceanic Fisheries Investigations Reports, 47, 92-108. Available at http:// www.calcofi.org/publications/calcofireports/v47/Vol_47_Field_ Warming_In_The_Ca_Current.pdf

[230] Mote, P.W., A. Petersen, S. Reeder, H. Shipman, and L. Whitely Binder. 2008. Sea Level Rise in the Coastal Waters of Washington State. Report prepared by the Climate Impacts Group, University of Washington and the Washington Department of Ecology.

National Research Council. 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Washington, DC: The National Academies Press.

[231] National Research Council. 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Washington, DC: The National Academies Press.

[232] Feely, R.A., S. Alin, J. Newton, C. Sabine, M. Warner, A. Devol, C. Krembs, and C. Maloy. 2010. The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary. Estuarine, Coastal and Shelf Science 88: 442-449.

Roberts, M., T. Mohamedali, B. Sackmann, T. Khangaonkar, and W. Long. 2014. Puget Sound and the Straits Dissolved Oxygen Assessment: Impacts of Current and Future Human Nitrogen Sources and Climate Change through 2070. Washington State Department of Ecology Publication No. 14-03-007, Olympia, WA. Available at https://fortress.wa.gov/ecy/publications/SummaryPages/1403007.html

[233] Donatuto, J., E.E. Grossman, J. Konovsky, S. Grossman, and L.W. Campbell. 2014. Indigenous Community Health and Climate Change: Integrating Biophysical and Social Science Indicators. Coastal Management 42(4): 355-373.

[234] Anderson, T.L. and D.P. Parker. 2009. Economic development lessons from and for North American Indian economies. Australian Journal of Agricultural and Resource Economics 53:105-127.

[235] Donatuto, J., E.E. Grossman, J. Konovsky, S. Grossman, and L.W. Campbell. 2014. Indigenous Community Health and Climate Change: Integrating Biophysical and Social Science Indicators. Coastal Management. 42 (4): 355-373.

[236] Dalton, M. (Ed.). 2016. Climate Change Vulnerability Assessment for the Treaty of Olympia Tribes: A Report to the Quinault Indian Nation, Hoh Tribe, and Quileute Tribe. Prepared by the Oregon Climate Change Research Institute. Corvallis, OR.

[237] Lewandowska, A.M., D.G. Boyce, M. Hofmann, B. Matthiessen, U. Sommer, and B. Worm. 2014. Effects of sea surface warming on marine plankton. Ecology Letters 17(5): 614-623.

[238] Lewandowska, A.M., D.G. Boyce, M. Hofmann, B. Matthiessen, U. Sommer, and B. Worm. 2014. Effects of sea surface warming on marine plankton. Ecology Letters 17(5): 614-623.

[239] Kudela, R.M., W.P. Cochlan, T.D. Peterson, and C.G. Trick. 2006. Impacts on phytoplankton biomass and productivity in the Pacific Northwest during the warm ocean conditions of 2005. Geophysical Research Letters 33: L22S06.

[240] Pacific Salmon Commission. 2015. News Release No. 10, September 11, 2015. Vancouver, B.C. Available at http://cars.fisheries.org/wp-content/uploads/2015/10/PSC-NewsRelease10-Sept-11-2015-1.pdf

[241] Hamilton, K. 1985. A study of the variability of the return migration route of Fraser River sockeye salmon (Oncorhynchus nerka). Canadian Journal of Zoology 63: 1930-1943.

[242] Daly, E.A. and R.D. Brodeur. 2015. Warming Ocean Conditions Relate to Increased Trophic Requirements of Threatened and Endangered Salmon. PLoS ONE 10(12): e0144066.

[243] Peterson, W.T., C.A. Morgan, J.O. Peterson, J.L. Fisher, B.J. Burke, and K. Fresh. 2014. Ocean Ecosystem Indicators of Salmon Marine Survival in the Northern California Current. NOAA Northwest Fisheries Science Center. Available at http://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/documents/Peterson_etal_2014.pdf

[244] Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis. 1997. A Pacific decadal climate oscillation with impacts on salmon. Bulletin of the American Meteorological Society 78:1069-1079.

[245] Daly, E.A. and R.D. Brodeur. 2015. Warming Ocean Conditions Relate to Increased Trophic Requirements of Threatened and Endangered Salmon. PLoS ONE 10(12): e0144066.

[246] Loomis, L. 2016. Tough Times Mean Hard Decisions in Planning Fishing Seasons. Northwest Treaty Tribes, April 6, 2016. Available at http://nwtreatytribes.org/tough-times-mean-hard-decisions-planning-fishing-seasons

[247] Hallegraeff , G.M. 2010. Ocean climate change, phytoplankton community responses, and harmful algal blooms: a formidable predictive challenge. Journal of Phycology. 46: 220-235.

[248] Dalton, M.M., P.W. Mote, and A.K. Snover (Eds.). 2013. Climate Change in the Northwest: Implications for Our Landscapes, Waters, and Communities. Washington, DC: Island Press.

[249] Peterson, W. and F. Schwing. 2008. California Current Ecosystem. In Climate Impacts on U.S. Living Marine Resources: National Marine Fisheries Service Concerns, Activities and Needs. (Ed.) K. E. Osgood. U.S. Department of Commerce, NOAA Tech. Memo. NMFS-F/SPO-89. Available at http://spo.nmfs.noaa.gov/tm/TM%20SPO%2089.pdf

[250] Cheung, W.W.L, R.D. Brodeur, T.A. Okey, and D. Pauly.2015. Projecting future changes in distributions of pelagic fish species of Northeast Pacific shelf seas. Progress in Oceanography 130: 19-3.

[251] Cheung, W.W.L, R.D. Brodeur, T.A. Okey, and D. Pauly.2015. Projecting future changes in distributions of pelagic fish species of Northeast Pacific shelf seas. Progress in Oceanography 130: 19-3.

[252] Moore, S. K., N.J. Mantua, and E.P. Salathé, Jr. 2011. Past trends and future scenarios for environmental conditions favoring the accumulation of paralytic shellfish toxins in Puget Sound shellfish. Harmful Algae, 10, 521-529.

[253] Moore, S. K., N.J. Mantua, and E.P. Salathé, Jr. 2011. Past trends and future scenarios for environmental conditions favoring the accumulation of paralytic shellfish toxins in Puget Sound shellfish. Harmful Algae, 10, 521-529.

[254] Kudela, R.M., C. Anderson, J.M. Birch, H. Bowers, D.A. Caron, Y. Chao, G. Doucette, J.D. Farrara, A.G. Gellene, K. Negrey, M.D. Howard, J.P. Ryan, C.A. Scholin, Jason Smith, Jayme Smith, and G. Sukhatme. 2015. Harmful algal bloom hotspots really are hot: a case study from Monterey Bay, California. American Geophysical Union Fall Meeting, San Francisco, CA. December 18, 2015. Abstract OS51C-02.

[255] Bond, N.A., M.F. Cronin, H. Freeland, and N. Mantua. 2015. Causes and impacts of the 2014 warm anomaly in the NE Pacific. Geophysical Research Letters 42: 3414-3420.

[256] NASA. 2016 The Demise of the Warm Blob. National Aeronautic and Space Agency Earth Observatory. February 16, 2016. Available at http://earthobservatory.nasa.gov/IOTD/view.php?id=87513&eocn=home&eoci=iotd_readmore

[257] NASA. 2016 The Demise of the Warm Blob. National Aeronautic and Space Agency Earth Observatory. February 16, 2016. Available at http://earthobservatory.nasa.gov/IOTD/view.php?id=87513&eocn=home&eoci=iotd_readmore

[258] Whitney, F.A. 2015. Anomalous winter winds decrease 2014 transition zone productivity in the NE Pacific. Geophysical Research Letters 42(2): 428-431.

[259] Winters, C. 2016. Another year of small coho runs could hamper fisheries. Everett Herald. March 11, 2016. http://archive.heraldnet.com/article/20160311/NEWS01/160319842

[260] Rhein, M., S.R. Rintoul, S. Aoki, E. Campos, D. Chambers, R.A. Feely, S. Gulev, G.C. Johnson, S.A. Josey, A. Kostianoy, C. Mauritzen, D. Roemmich, L.D. Talley and F. Wang. 2013. Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press.

[261] Rhein, M., S.R. Rintoul, S. Aoki, E. Campos, D. Chambers, R.A. Feely, S. Gulev, G.C. Johnson, S.A. Josey, A. Kostianoy, C. Mauritzen, D. Roemmich, L.D. Talley and F. Wang. 2013. Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press.

[262] Field, D., D. Cayan, and F. Chavez. 2006. Secular warming in the California current and North Pacific. California Cooperative Oceanic Fisheries Investigations Reports, 47, 92-108. Available at http:// www.calcofi.org/publications/calcofireports/v47/Vol_47_Field_ Warming_In_The_Ca_Current.pdf

[263] Bassin, C.J., J.B. Mickett, J.A. Newton, and M.J. Warner. 2011. Decadal Trends in Temperature and Dissolved Oxygen in Puget Sound: 1932-2009. Hood Canal Dissolved Oxygen Program Integrated Assessment and Modeling Study Report. Available at http://www.hoodcanal.washington.edu/documents/HCDOPPUB/hcdop_iam_marine_ch_3_sec_2.pdf

[264] Snover, A.K., P.W. Mote, L. Whitely Binder, A.F. Hamlet, and N.J. Mantua. 2005. Uncertain Future: Climate Change and its Effects on Puget Sound. A report for the Puget Sound Action Team by the Climate Impacts Group, Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Seattle, WA.

[265] Mote, P.W. and E.P. Salathé. 2010. Future climate in the Pacific Northwest. Climatic Change 102 (1-2): 29-50.

[266] Mauger, G. and A. Snover. 2015. Future scenarios for climate change in Puget Sound. Encyclopedia of Puget Sound. Puget Sound Institute at the University of Washington Tacoma Center for Urban Waters. Available at http://www.eopugetsound.org/articles/future-scenarios-climate-change-puget-sound

[267] Bassin, C.J., J.B. Mickett, J.A. Newton, and M.J. Warner. 2011. Decadal Trends in Temperature and Dissolved Oxygen in Puget Sound: 1932-2009. Hood Canal Dissolved Oxygen Program Integrated Assessment and Modeling Study Report. Available at http://www.hoodcanal.washington.edu/documents/HCDOPPUB/hcdop_iam_marine_ch_3_sec_2.pdf

[268] Mote, P.W., A. Petersen, S. Reeder, H. Shipman, and L. Whitely Binder. 2008. Sea Level Rise in the Coastal Waters of Washington State. Report prepared by the Climate Impacts Group, University of Washington and the Washington Department of Ecology.

[269] Mote, P.W., A. Petersen, S. Reeder, H. Shipman, and L. Whitely Binder. 2008. Sea Level Rise in the Coastal Waters of Washington State. Report prepared by the Climate Impacts Group, University of Washington and the Washington Department of Ecology.

[270] Tillmann, P. and D. Siemann. 2011. Climate Change Effects and Adaptation Approaches in Marine and Coastal Ecosystems of the North Pacific Landscape Conservation Cooperative Region: A Compilation of Scientific Literature–Phase I Final Report. Produced by the National Wildlife Federation for the U.S. Fish and Wildlife Service North Pacific Landscape Conservation Cooperative.

[271] Donatuto, J., E.E. Grossman, J. Konovsky, S. Grossman, and L.W. Campbell. 2014. Indigenous Community Health and Climate Change: Integrating Biophysical and Social Science Indicators. Coastal Management 42(4): 355-373.

[272] Beamer, E., A. McBride, C. Greene, R. Henderson, G. Hood, K. Wolf, K. Larsen, C. Rice, and K. Fresh. 2005. Delta and Nearshore Restoration for the Recovery Of Wild Skagit River Chinook Salmon: Linking Estuary Restoration To Wild Chinook Salmon Populations. Prepared as a supplement to the Skagit Chinook Recovery Plan.

[273] Aitken, J.K. 1998. The Importance of Estuarine Habitats to Anadromous Salmonids of the Pacific Northwest: A Literature Review. U.S. Fish and Wildlife Service. Lacey, WA.

[274] Johnson, O.W., W.S. Grant, R.G. Kope, K. Neely, F.W. Waknitz, and R.S. Waples. 1997. Status review of chum salmon from Washington, Oregon, and California. U.S. Dept. Commerce, NOAA Technical Memorandum. NMFS-NWFSC-32.

[275] Whitman, T., D. Penttila, K. Krueger, P. Dionne, K. Pierce Jr. and T. Quinn. 2014. Tidal elevation of surf smelt spawn habitat study for San Juan County Washington. Friends of the San Juans, Salish Sea Biological and Washington Department of Fish and Wildlife.

[276] IPCC. 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press. Available at http://www.ipcc.ch

[277] National Research Council. 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Washington, DC: The National Academies Press.

[278] National Research Council. 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Washington, DC: The National Academies Press.

[279] NOAA. 2013. Sea Levels Online: Sea Level Variations of the United States Derived from National Water Level Observation Network Stations 1854 to present. National Oceanic and Atmospheric Administration Ocean Service, Center for Operational Oceanographic Products and Services (CO-OPS). Revised: 10/15/2013. Available at http://tidesandcurrents.noaa.gov/sltrends/sltrends.html

[280] Craig, D. 1993. Preliminary Assessment of Sea Level Rise in Olympia, Washington: Technical and Policy Implications. Policy and Program Development Division, Olympia Public Works Department, Olympia, WA.

[281] Witter, R.C., H.M. Kelsey, and E. Hemphill-Haley. 2001. Pacific storms, El Niño and Tsunamis, Competing mechanisms for sand deposition in a coastal marsh, Euchre Creek, Oregon, Journal of Coastal Research 17: 563-583.

[282] Komar, P.D. and J.C. Allen. 2000. Analyses of Extreme Waves and Water Levels on the Pacific Northwest Coast. Report to the Oregon Department of Land Conservation and Development Salem, OR. Available at http://www.oregon.gov/lcd/ocmp/docs/publications/extreme_wavestide_rpt.pdf

[283] Mauger, G. and A. Snover. 2015. Future scenarios for climate change in Puget Sound. Encyclopedia of Puget Sound. Puget Sound Institute at the University of Washington Tacoma Center for Urban Waters. Available at http://www.eopugetsound.org/articles/future-scenarios-climate-change-puget-sound

[284] National Research Council. 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present and Future. Washington, DC: The National Academies Press.

[285] Joughin, I., B.E. Smith, and B. Medley. 2014. Marine Ice Sheet Collapse Potentially Under Way for the Thwaites Glacier Basin, West Antarctica. Science 344 (6185): 735-738.

[286] Mouginot, J., E. Rignot, B. Scheuchl, I. Fenty, A. Khazendar, M. Morlighem, A. Buzzi, and J. Paden. Fast retreat of Zachariæ Isstrøm, northeast Greenland. Science Express November 12, 2015. Available at http://www.sciencemag.org/content/suppl/2015/11/11/science.aac7111.DC1/Mouginot-SM.pdf

[287] Kopp, R.E., R.M. Horton, C.M. Little, J.X. Mitrovica, M. Oppenheimer, D.J. Rasmussen, B.H. Strauss, and C. Tebaldi. 2014. Probabilistic 21st and 22nd century sea level projections at a global network of tide gauge sites. 2: 383-406.

[288] Mazzone, Scott. December 17, 2015. Personal communication.

[289] Ahearn, A. 2015. Washington Tribe Confronts Climate Change, Sea Level Rise. KUOW Earthfix News, November 9, 2015. Available at http://kuow.org/post/washington-tribe-confronts-climate-change-sea-level-rise

[290] Rhein, M., S.R. Rintoul, S. Aoki, E. Campos, D. Chambers, R.A. Feely, S. Gulev, G.C. Johnson, S.A. Josey, A. Kostianoy, C. Mauritzen, D. Roemmich, L.D. Talley and F. Wang. 2013. Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press.

[291] Feely, R.A., S. Alin, J. Newton, C. Sabine, M. Warner, A. Devol, C. Krembs, and C. Maloy. 2010. The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary. Estuarine, Coastal and Shelf Science 88: 442-449.

[292] Kroeker, K.J., R.L. Kordas, R. Crim, I.E. Hendriks, L. Ramajo, G.S. Singh, C.M. Duarte, and J.P. Gattuso. 2013. Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. Global Change Biology 19: 1884-1896.

[293] Sun, J., D.A. Hutchins, Y. Feng, E.L. Seubert, D.A. Caron, and F.X. Fu. 2011. Effects of changing pCO_2 and phosphate availability on domoic acid production and physiology of the marine harmful bloom diatom Pseudo-nitzschia multiseries. Limnology and Oceanography 56(3): 829-840.

[294] Dutkiewicz, S., J.J. Morris, M.J. Follows, J. Scott, O. Levitan, S.T. Dyhrman, and I. Berman-Frank. 2015. Impact of ocean acidification on the structure of future phytoplankton communities, Nature Climate Change 2015(5): 1002-1006.

[295] Dutkiewicz, S., J.J. Morris, M.J. Follows, J. Scott, O. Levitan, S.T. Dyhrman, and I. Berman-Frank. 2015. Impact of ocean acidification on the structure of future phytoplankton communities, Nature Climate Change 2015(5): 1002-1006.

[296] Bednaršek, N., R.A.Feely, J.C.P. Reum, B. Peterson, J. Menkel, S.R. Alin, and B. Hales. 2014. Limacina helicina shell dissolution as an indicator of declining habitat suitability owing to ocean acidification in the California Current Ecosystem. Proceedings of the Royal Society B: Biological Science, 281: 20140123.

[297] Miller, J.J., M. Maher, E. Bohaboy, C.S. Friedman, and P. McElhany. 2016. Exposure to low pH reduces survival and delays development in early life stages of Dungeness crab (Cancer magister). Marine Biology 163 (5): 118.

[298] Miller, J.J., M. Maher, E. Bohaboy, C.S. Friedman, and P. McElhany. 2016. Exposure to low pH reduces survival and delays development in early life stages of Dungeness crab (Cancer magister). Marine Biology 163 (5): 118.

[299] Haigh, R., D. Ianson, C.A. Holt, H.E. Neate, A.M. Edwards. 2015. Effects of ocean acidification on temperate coastal marine ecosystems and fisheries in the Northeast Pacific. PLoS ONE 10(2): e0117533.

[300] Haigh, R., D. Ianson, C.A. Holt, H.E. Neate, A.M. Edwards. 2015. Effects of ocean acidification on temperate coastal marine ecosystems and fisheries in the Northeast Pacific. PLoS ONE 10(2): e0117533.

[301] Haigh, R., D. Ianson, C.A. Holt, H.E. Neate, A.M. Edwards. 2015. Effects of ocean acidification on temperate coastal marine ecosystems and fisheries in the Northeast Pacific. PLoS ONE 10(2): e0117533.

[302] Haigh, R., D. Ianson, C.A. Holt, H.E. Neate, A.M. Edwards. 2015. Effects of ocean acidification on temperate coastal marine ecosystems and fisheries in the Northeast Pacific. PLoS ONE 10(2): e0117533.

[303] Haigh, R., D. Ianson, C.A. Holt, H.E. Neate, A.M. Edwards. 2015. Effects of ocean acidification on temperate coastal marine ecosystems and fisheries in the Northeast Pacific. PLoS ONE 10(2): e0117533.

[304] Okey, T.A., H.M. Alidina, V. Lo, S. Jessen. 2014. Effects of climate change on Canada's Pacific marine ecosystems: A summary of scientific knowledge. Reviews in Fish Biology and Fisheries 24(2): 519-559.

[305] Rhein, M., S.R. Rintoul, S. Aoki, E. Campos, D. Chambers, R.A. Feely, S. Gulev, G.C. Johnson, S.A. Josey, A. Kostianoy, C. Mauritzen, D. Roemmich, L.D. Talley and F. Wang. 2013. Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press.

[306] IPCC. 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press. Available at http://www.ipcc.ch

[307] Feely, R.A., S. Alin, J. Newton, C. Sabine, M. Warner, A. Devol, C. Krembs, and C. Maloy. 2010. The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary. Estuarine, Coastal and Shelf Science 88: 442-449.

[308] Feely, R.A., S. Alin, J. Newton, C. Sabine, M. Warner, A. Devol, C. Krembs, and C. Maloy. 2010. The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary. Estuarine, Coastal and Shelf Science 88: 442-449.

[309] Bednaršek, N., R. A. Feely, J. C. P. Reum, B. Peterson, J. Menkel, S. R. Alin, and B. Hales. 2014. Limacina helicina shell dissolution as an indicator of declining habitat suitability owing to ocean acidification in the California Current Ecosystem. Proceedings of the Royal Society B: Biological Science, 281: 20140123.

[310] Feely, R.A., S. Alin, J. Newton, C. Sabine, M. Warner, A. Devol, C. Krembs, and C. Maloy. 2010. The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary. Estuarine, Coastal and Shelf Science 88: 442-449.

[311] Rhein, M., S.R. Rintoul, S. Aoki, E. Campos, D. Chambers, R.A. Feely, S. Gulev, G.C. Johnson, S.A. Josey, A. Kostianoy, C. Mauritzen, D. Roemmich, L.D. Talley and F. Wang. 2013. Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press.

Kroeker, K.J., R.L. Kordas, R. Crim, I.E. Hendriks, L. Ramajo, G.S. Singh, C.M. Duarte, and J.P. Gattuso. 2013. Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. Global Change Biology 19: 1884-1896.

[312] Sasse, T.P., B.I. McNeil, R.J. Matear, and A. Lenton. 2015. Quantifying the influence of CO_2 seasonality on future aragonite undersaturation onset. Biogeosciences 12: 6017-6031.

[313] Harvey, B.P., D. Gwynn-Jones, and P.J. Moore. 2013. Meta-analysis reveals complex marine biological responses to the interactive effects of ocean acidification and warming. Ecology and Evolution 3(4): 1016-1030.

[314] Bednaršek, N., R. A. Feely, J. C. P. Reum, B. Peterson, J. Menkel, S. R. Alin, and B. Hales. 2014. Limacina helicina shell dissolution as an indicator of declining habitat suitability owing to ocean acidification in the California Current Ecosystem. Proceedings of the Royal Society B: Biological Science 281: 20140123.

[315] Wootton, J.T., C. Pfister, and J. Forester. 2008. Dynamic patterns and ecological impacts of declining ocean pH in a high-resolution multi-year dataset. Proceedings of National Academy of Sciences 105: 18848-18853.

[316] Haigh, R., D. Ianson, C.A. Holt, H.E. Neate, A.M. Edwards. 2015. Effects of ocean acidification on temperate coastal marine ecosystems and fisheries in the Northeast Pacific. PLoS ONE 10(2): e0117533.

[317] Levin, L.A., W. Ekau, A.J. Gooday, F. Jorissen, J.J. Middelburg, S. W. A. Naqvi, C. Neira, N.N. Rabalais, and J. Zhang. 2009. Effects of natural and human-induced hypoxia on coastal benthos. Biogeosciences 6: 2063-2098.

[318] Levin, L.A., W. Ekau, A.J. Gooday, F. Jorissen, J.J. Middelburg, S. W. A. Naqvi, C. Neira, N.N. Rabalais, and J. Zhang. 2009. Effects of natural and human-induced hypoxia on coastal benthos. Biogeosciences 6: 2063-2098.

[319] Washington State Department of Ecology. 2012. Puget Sound Dissolved Oxygen Map. Available at http://www.ecy.wa.gov/programs/eap/Nitrogen/Effects.html

[320] Palsson, W.A., R.E. Pacunski, T.R. Parra, and Beam.J. 2008. The effects of hypoxia on marine fish populations in Southern Hood Canal, Washington. American Fisheries Society Symposium 64:255-280.

[321] Chan, F., J.A. Barth, J. Lubchenco, A. Kirincich, H. Weeks, W.T. Peterson, B.A. Menge. Emergence of anoxia in the California Current Large Marine Ecosystem. Science 319 (5865): 920.

[322] Chan, F., J.A. Barth, J. Lubchenco, A. Kirincich, H. Weeks, W.T. Peterson, B.A. Menge. Emergence of anoxia in the California Current Large Marine Ecosystem. Science 319 (5865): 920.

[323] Chan, F., J. A. Barth, J. Lubchenco, A. Kirincich, H. Weeks, W. T. Peterson, B. A. Menge. Emergence of anoxia in the California Current Large Marine Ecosystem. Science 319 (5865): 920.

[324] Sperling, E.A., C.A. Frieder, and L.A. Levin. 2016. Biodiversity response to natural gradients of multiple stressors on continental margins. Proceedings of the Royal Society B 283(1829).

[325] Long, M.C., C. Deutsch, and T. Ito. 2016. Finding forced trends in oceanic oxygen. Global Biogeochemical Cycles 30(2): 381-397.

[326] Roberts, M., T. Mohamedali, B. Sackmann, T. Khangaonkar, and W. Long. 2014. Puget Sound and the Straits Dissolved Oxygen Assessment: Impacts of Current and Future Human Nitrogen Sources and Climate Change through 2070. Washington State Department of Ecology Publication No. 14-03-007, Olympia, WA. Available at https://fortress.wa.gov/ecy/publications/SummaryPages/1403007.html

[327] Long, M.C., C. Deutsch, and T. Ito. 2016. Finding forced trends in oceanic oxygen. Global Biogeochemical Cycles 30(2): 381-397.

[328] Simenstad, C., D. Reed, and M. Ford. 2006. When is restoration not? Incorporating landscape-scale processes to restore self-sustaining ecosystems in coastal wetland restoration Ecological Engineering 26: 27-39.

[329] Lee, S.Y. and A.F. Hamlet. 2011. Skagit River Basin Climate Science Report, a summary report prepared for Skagit County and the Envision Skagit Project by the Department of Civil and Environmental Engineering and The Climate Impacts Group at the University of Washington. Seattle, WA.

[330] Haigh, R., D. Ianson, C.A. Holt, H.E. Neate, A.M. Edwards. 2015. Effects of ocean acidification on temperate coastal marine ecosystems and fisheries in the Northeast Pacific. PLoS ONE 10(2): e0117533.

[331] Kovacs, K.M., C. Lydersen, J.E. Overland, and S.E. Moore. 2011. Impacts of changing sea-ice conditions on Arctic marine mammals. Marine Biodiversity 41:181-194.

[332] Kovacs, K.M., C. Lydersen, J.E. Overland, and S.E. Moore. 2011. Impacts of changing sea-ice conditions on Arctic marine mammals. Marine Biodiversity 41:181-194.

[333] Johannessen, S.C. and R.W. MacDonald. 2009. Effects of local and global change on an inland sea: the Strait of Georgia, British Columbia, Canada. Climate Research 40:1-21.

[334] Chen, I.C., J.K. Hill, R. Ohlemüller, D.B. Roy, and C.D. Thomas. 2011. Rapid range shifts of species associated with high levels of climate warming. Science 333: 1024-1026.

[335] Littell, J.S., E.E. Oneil, D. McKenzie, J.A. Hicke, J.A. Lutz, R.A. Norheim, and M.M. Elsner. 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. Climatic Change 102: 129-158.

[336] WSDOE. 2012. Preparing for a Changing Climate: Washington State's Integrated Climate Response Strategy. Washington State Department of Ecology Publication No. 12-01-004.

Hegland, S. J., A. Nielsen, A. Lázaro, A.L. Bjerknes, and Ø. Totland. 2009. How does climate warming affect plant-pollinator interactions? Ecology Letters 12(2): 184-195.

[337] Stavros, E.N., J.T. Abatzoglou, D. McKenzie, and N.K. Larkin, 2014. Regional projections of the likelihood of very large wildland fires under a changing climate in the contiguous Western United States. Climatic Change126: 455-468.

[338] Adelsman, H. and J. Ekrem. 2012. Preparing for a Changing Climate: Washington State's Integrated Climate Response Strategy. Washington State Department of Ecology. Olympia, WA. Available at https://fortress.wa.gov/ecy/publications/documents/1201004.pdf

[339] Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle, WA.

[340] Mahle, G. and L. Tom. 2012. Where Words Touch the Earth. In Grossman, Z. and A. Parker (Eds.). Asserting Native Resilience: Pacific Rim Indigenous Nations Face the Climate Crisis. Oregon State University Press. Corvallis, OR. Available at http://academic.evergreen.edu/g/grossmaz/climate.html

[341] Dalton, M. (Ed.) 2016. Climate Change Vulnerability Assessment for the Treaty of Olympia Tribes. A Report to the Quinault Indian Nation, Hoh Tribe, and Quileute Tribe. Prepared by The Oregon Climate Change Research Institute. Corvallis, OR.

[342] Jamestown S'Klallam Tribe. 2013. Climate Change Vulnerability Assessment and Adaptation Plan. Petersen, S. and J. Bell (Eds.). A collaboration of the Jamestown S'Klallam Tribe and Adaptation International.

[343] Dalton, M. (Ed.) 2016. Climate Change Vulnerability Assessment for the Treaty of Olympia Tribes. A Report to the Quinault Indian Nation, Hoh Tribe, and Quileute Tribe. Prepared by The Oregon Climate Change Research Institute. Corvallis, OR.

[344] Krohn, E. and V. Segrest. 2010. The Traditional Foods of Puget Sound Project Final Report 2008-2010. Northwest Indian College Cooperative Extension Office. Available at http://www.nptao.arizona.edu/ridge_update/nwic%20final%20report.pdf

[345] Krohn, E. and V. Segrest. 2010. The Traditional Foods of Puget Sound Project Final Report 2008-2010. Northwest Indian College Cooperative Extension Office. Available at http://www.nptao.arizona.edu/ridge_update/nwic%20final%20report.pdf

[346] Richards, R.T. and S.J. Alexander, 2006. A social history of wild huckleberry harvesting in the Pacific Northwest. General Technical Report PNWGTR-657. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

[347] Charnley, S., A.P. Fischer, and E.T. Jones. 2008. Traditional and local ecological knowledge about forest biodiversity in the Pacific Northwest. General Technical Report PNW-GTR-751. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR.

[348] Charnley, S., A.P. Fischer, and E.T. Jones. 2008. Traditional and local ecological knowledge about forest biodiversity in the Pacific Northwest. General Technical Report PNW-GTR-751. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR.

[349] Krueger, Katie. July 4, 2016. Personal communication.

[350] Charnley, S., A.P. Fischer, and E.T. Jones. 2008. Traditional and local ecological knowledge about forest biodiversity in the Pacific Northwest. General Technical Report PNW-GTR-751. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR.

[351] Potash M.L., J. LeCompte-Mastenbrook, W. KingGeorge, and T. Fuentes. 2008. Management Monitoring Plan for the Enhancement of Big Huckleberry (Vaccinium membranaceum) in Government Meadows, Mt. Baker-Snoqualmie National Forest. USDA Forest Service, Snoqualmie Ranger District, North Bend, WA. Available at http://www.fs.fed.us/r6/mbs/projects

[352] Potash M.L., J. LeCompte-Mastenbrook, W. KingGeorge, and T. Fuentes. 2008. Management Monitoring Plan for the Enhancement of Big Huckleberry (Vaccinium membranaceum) in Government Meadows, Mt. Baker-Snoqualmie National Forest. USDA Forest Service, Snoqualmie Ranger District, North Bend, WA. Available at http://www.fs.fed.us/r6/mbs/projects

[353] Charnley, S., A.P. Fischer, and E.T. Jones. 2008. Traditional and local ecological knowledge about forest biodiversity in the Pacific Northwest. General Technical Report PNW-GTR-751. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR.

[354] Walther, G.R., E. Post, P. Convey, A. Menzel, C. Parmesan, T. J.C. Beebee, J.M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein. 2002. Ecological Responses to Recent Climate Change. Nature 416(6879): 389-95.

[355] Littell, J.S., E.E. Oneil, D. McKenzie, J.A. Hicke, J.A. Lutz, R.A. Norheim, M.M. Elsner. 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. Climatic Change 102: 129-158.

[356] Raymond, C.L., D.L. Peterson, R.M. Rochefort (Eds). 2014. Climate change vulnerability and adaptation in the North Cascades region, Washington. General Technical Report PNW-GTR-892. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

[357] Sheehan, T., Bachelet, D., Ferschwiler, K. 2015. Projected major fire and vegetation changes in the Pacific Northwest of the conterminous United States under selected CMIP5 climate futures. Ecological Modeling 317: 16-29.

[358] Raymond, C.L., D.L. Peterson, R.M. Rochefort (Eds). 2014. Climate change vulnerability and adaptation in the North Cascades region, Washington. General Technical Report PNW-GTR-892. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

[359] Zolbrod, A. and D. Peterson. 1999. Response of high-elevation forests in the Olympic Mountains to climatic change. Canadian Journal of Forest Research 29: 1966-1978.

[360] Shanley, C.S., S. Pyare, M.I. Goldstein, P.B. Alaback, D.M. Albert, C.M. Beier, T.J. Brinkman, R.T. Edwards, E. Hood, A. MacKinnon, M.V. McPhee, T.M. Patterson, L.H. Suring, D.A. Tallmon, and M.S. Wipfli. 2015. Climate change implications in the northern coastal temperate rainforest of North America. Climatic Change 130(2): 155-170.

[361] Dalton, M. (Ed.) 2016. Climate Change Vulnerability Assessment for the Treaty of Olympia Tribes. A Report to the Quinault Indian Nation, Hoh Tribe, and Quileute Tribe. Prepared by The Oregon Climate Change Research Institute. Corvallis, OR.

[362] Littell, J.S., E.E. Oneil, D. McKenzie, J.A. Hicke, J.A. Lutz, R.A. Norheim, M.M. Elsner. 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. Climatic Change 102: 129-158.

[363] Littell, J.S., D.L. Peterson, and M. Tjoelker. 2008. Douglas-fir growth in mountain ecosystems: water limits tree growth from stand to region. Ecological Monographs 78: 349-368.

[364] Halofsky, J.E., D.L. Peterson, K.A. O'Halloran, C. Hawkins Hoffman (Eds.). 2011. Adapting to climate change at Olympic National Forest and Olympic National Park. General Technical Report PNW-GTR-844. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR.

[365] Chen, I.C., J.K. Hill, R. Ohlemüller, D.B. Roy, and C.D. Thomas. 2011. Rapid range shifts of species associated with high levels of climate warming. Science 333: 1024-1026.

[366] Glick, P. 2005. The Waterfowlers' Guide to Global Warming. National Wildlife Federation. Washington, DC.

[367] Glick, P. 2005. The Waterfowlers' Guide to Global Warming. National Wildlife Federation. Washington, DC.

[368] Harrington, C.A. and P.J. Gould. 2015. Tradeoffs between chilling and forcing in satisfying dormancy requirements for Pacific Northwest tree species. Frontiers in Plant Science 6:120-132.

[369] Harrington, C.A. and P.J. Gould. 2015. Tradeoffs between chilling and forcing in satisfying dormancy requirements for Pacific Northwest tree species. Frontiers in Plant Science 6:120-132.

[370] Hegland, S. J., A. Nielsen, A. Lázaro, A.L. Bjerknes, and Ø. Totland. 2009. How does climate warming affect plant-pollinator interactions? Ecology Letters 12(2): 184-195.

[371] Hegland, S. J., A. Nielsen, A. Lázaro, A.L. Bjerknes, and Ø. Totland. 2009. How does climate warming affect plant-pollinator interactions? Ecology Letters 12(2): 184-195.

[372] Krosby, M., H. Morgan, M. Case, and L. Whitely Binder. 2015. Stillaguamish Tribe Natural Resources Climate Change Vulnerability Assessment. Prepared by the Climate Impacts Group, University of Washington. Seattle, WA.

[373] Harrington, C.A. and P.J. Gould. 2015. Tradeoffs between chilling and forcing in satisfying dormancy requirements for Pacific Northwest tree species. Frontiers in Plant Science 6: 120-132.

[374] Littell, J.S., E.E. Oneil, D. McKenzie, J.A. Hicke, J.A. Lutz, R.A. Norheim, M.M. Elsner. 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. Climatic Change 102: 129-158.

[375] Lee, S.Y. and A.F. Hamlet. 2011. Skagit River Basin Climate Science Report, a summary report prepared for Skagit County and the Envision Skagit Project by the Department of Civil and Environmental Engineering and The Climate Impacts Group at the University of Washington.

[376] Beechie, T., H. Imaki, J. Greene, A. Wade, H. Wu, G. Pess, P. Roni, J. Kimball, J. Stanford, P. Kiffney, and N. Mantua. 2013. Restoring salmon habitat for a changing climate. River Research and Applications 29(8): 939-960.

[377] WSDOE. 2012. Preparing for a Changing Climate: Washington State's Integrated Climate Response Strategy. Washington State Department of Ecology Publication No. 12-01-004.

[378] WSDOE. 2012. Preparing for a Changing Climate: Washington State's Integrated Climate Response Strategy. Washington State Department of Ecology Publication No. 12-01-004.

[379] Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier spring increase Western U.S. forest wildfire activity. Science 313 (5789): 940-943.

[380] Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier spring increase Western U.S. forest wildfire activity. Science 313 (5789): 940-943.

[381] Stavros, E.N., J.T. Abatzoglou, D. McKenzie, and N.K. Larkin .2014. Regional projections of the likelihood of very large wildland fires under a changing climate in the contiguous Western United States, Climatic Change 126: 455-468.

[382] Sheehan, T., D. Bachelet, and K. Ferschweiler. 2015. Projected major fire and vegetation changes in the Pacific Northwest of the conterminous United States under selected CMIP5 climate futures. Ecological Modeling. 317 (2015): 16-29.

[383] Littell, J.S., M. McGuire Elsner, L.C. Whitely Binder, and A.K. Snover (Eds). 2009. The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate. Climate Impacts Group, University of Washington, Seattle, WA. Available at http://www.cses.washington.edu/db/pdf/wacciaexecsummary638.pdf

[384] Littell, J.S., E.E. Oneil, D. McKenzie, J.A. Hicke, J.A. Lutz, R.A. Norheim, and M.M. Elsner. 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. Climatic Change 102(1-2): 129-158.

[385] Rice, A. 2015. Paradise Fire grows to 949 acres in Jefferson County; growth rate reined in by weather. Peninsula Daily News. June 24, 2015. Available at http://www.peninsuladailynews.com/article/20150624/NEWS/306249978

[386] InciWeb Incident Information System. 2015. Paradise Fire Final Update, September 3, 2015. Available at http://inciweb.nwcg.gov/incident/article/4305/29045

[387] Vose, J.M., J.S. Clark, C.H. Luce, T. Patel-Weynand (Eds.). 2016. Effects of Drought on Forests and Rangelands in the United States: A Comprehensive Science Synthesis. U.S. Department of Agriculture, Forest Service, Research and Development General Technical Report WO-93b.

[388] Meddens, A.J.H., J.A. Hicke, and C.A. Ferguson. 2012. Spatiotemporal patterns of observed bark beetle-caused tree mortality in British Columbia and the Western United States. Ecological Applications. 22: 1876-1891.

[389] Dozic, A., M. Fischer, C. Hersey, G. Kohler, D. Omdal, A. Ramsey, K. Ripley, Z. Heath, A. Nelson, and B. Smith. 2016. Forest Health Highlights in Washington – 2015. Washington State Department of Natural Resources Forest Health Program and the U.S. Department of Agriculture, Forest Service.

[390] Dalton, M. (Ed.) 2016. Climate Change Vulnerability Assessment for the Treaty of Olympia Tribes: A Report to the Quinault Indian Nation, Hoh Tribe, and Quileute Tribe. Prepared by the Oregon Climate Change Research Institute. Corvallis, OR.

[391] Minnesota Department of Natural Resources. 2016. Moose Research: Adult moose mortality project. Available at http://www.dnr.state.mn.us/moose/adult.html#deaths

[392] Adelsman, H. and J. Ekrem. 2012. Preparing for a Changing Climate: Washington State's Integrated Climate Response Strategy. Washington State Department of Ecology. Olympia, WA. Available at https://fortress.wa.gov/ecy/publications/documents/1201004.pdf

[393] Campbell, S., K. Waddell, and A. Gray. 2010. Washington's Forest Resources, 2002-2006: Five-Year Forest Inventory and Analysis Report. General Technical Report PNW-GTR-800. U.S. Department of Agriculture, Forest Service Pacific Northwest Research Station. Portland, OR.

[394] Littell, J.S., E.E. Oneil, D. McKenzie, J.A. Hicke, J.A. Lutz, R.A. Norheim, and M.M. Elsner. 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. Climatic Change 102(1-2): 129-158.

[395] Littell, J.S., E.E. Oneil, D. McKenzie, J.A. Hicke, J.A. Lutz, R.A. Norheim, and M.M. Elsner. 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. Climatic Change 102(1-2): 129-158.

[396] Lee, E.H., P.A. Beedlow, R.S. Waschmann, D.T. Tingey, C. Wickham, S. Cline, M. Bollman, and C. Carlile. 2016. Douglas-fir displays a range of growth responses to temperature, water, and Swiss needle cast in western Oregon, USA. Agricultural and Forest Meteorology 221: 176-188.

[397] Lee, E.H., P.A. Beedlow, R.S. Waschmann, D.T. Tingey, C. Wickham, S. Cline, M. Bollman, and C. Carlile. 2016. Douglas-fir displays a range of growth responses to temperature, water, and Swiss needle cast in western Oregon, USA. Agricultural and Forest Meteorology 221: 176-188.

[398] Lee, E.H., P.A. Beedlow, R.S. Waschmann, D.T. Tingey, C. Wickham, S. Cline, M. Bollman, and C. Carlile. 2016. Douglas-fir displays a range of growth responses to temperature, water, and Swiss needle cast in western Oregon, USA. Agricultural and Forest Meteorology 221: 176-188.

[399] Benda, L.E., C. Veldhuisen, and J. Black. 2003. Debris flows as agents of morphological heterogeneity at low-order confluences, Olympic Mountains, Washington. Geological Society of America Bulletin 115: 1110-1121.

Bigelow, P.E., L.E. Benda, D.J. Miller, and K.M. Burnett, K.M., 2007. On debris flows, river networks, and the spatial structure of channel morphology. Forest Science 53: 220-238.

[400] Montgomery, D.R., K.M. Schmidt, H.M. Greenberg, and W.E. Dietrich. 2000. Forest clearing and regional landsliding. Geology 28(4): 311-314.

[401] Barik, M.G. 2010. Cited in Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle, WA.

[402] Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle, WA.

[403] Buttrick, S., K. Popper, M. Schindel, B. McRae, B. Unnasch, A. Jones, and J. Platt. 2015. Conserving Nature's Stage: Identifying Resilient Terrestrial Landscapes in the Pacific Northwest. The Nature Conservancy, Portland OR. Available at http://nature.ly/resilienceNW

[404] Loarie, S.R., P.B. Duffy, H. Hamilton, G.P. Asner, C.B. Field, and D.D. Ackerly. 2009. The velocity of climate change. Nature 462: 1052-1055.

[405] Loarie, S.R., P.B. Duffy, H. Hamilton, G.P. Asner, C.B. Field, and D.D. Ackerly. 2009. The velocity of climate change. Nature 462: 1052-1055.

[406] Halofsky, J.E., D.L. Peterson, K.A. O'Halloran, C. Hawkins Hoffman (Eds.). 2011. Adapting to climate change at Olympic National Forest and Olympic National Park. General Technical Report PNW-GTR-844. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR.

[407] Raymond, C.L., D.L. Peterson, R.M. Rochefort (Eds). 2014. Climate change vulnerability and adaptation in the North Cascades region, Washington. General Technical Report PNW-GTR-892. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

[408] Dalton, M. (Ed.) 2016. Climate Change Vulnerability Assessment for the Treaty of Olympia Tribes: A Report to the Quinault Indian Nation, Hoh Tribe, and Quileute Tribe. Prepared by the Oregon Climate Change Research Institute. Corvallis, OR.

[409] Swinomish Indian Tribal Community. 2009. Swinomish Climate Change Initiative Impact Assessment Technical Report. Office of Planning and Community Development , La Conner, WA. Available at http://www.swinomish.org/climate_change/project/reports.html

[410] Ford, L. 2015. Swinomish and Ecotrust receive federal funding for forest conservation, carbon sequestration. Ecotrust press release September 17, 2015. Available at http://www.ecotrust.org/press-releases/swinomish-and-ecotrust-receive-federal-funding-for-forest-conservation-carbon-sequestration

[411] Staudt, A., A.K. Leidner, J. Howard, K.A. Brauman, J.S. Dukes, L.J. Hansen, C. Paukert, J. Sabo, and L.A Solórzano. 2013. The added complications of climate change: understanding and managing biodiversity and ecosystems. Frontiers in Ecology and the Environment. 11(9): 494-501.

[412] Dale, V. H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E. Lugo, C.J. Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks, and B.M. Wotton. 2001. Climate change and forest disturbances. Bioscience 51(9): 723-734.

Halofsky, J.E., D.L. Peterson, K.A. O'Halloran, C. Hawkins Hoffman (Eds.). 2011. Adapting to climate change at Olympic National Forest and Olympic National Park. General Technical Report PNW-GTR-844. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR.

[413] Jamestown S'Klallam Tribe. 2013. Climate Change Vulnerability Assessment and Adaptation Plan. Petersen, S. and J. Bell (Eds.). A collaboration of the Jamestown S'Klallam Tribe and Adaptation International.

[414] Donatuto, J., E.E. Grossman, J. Konovsky, S. Grossman, and L.W. Campbell. 2014. Indigenous Community Health and Climate Change: Integrating Biophysical and Social Science Indicators. Coastal Management 42(4): 355-373.

Lynn, K., J. Daigle, J. Hoffman, F. Lake, N. Michelle, D. Ranco, C. Viles, G. Voggesser, and P. Williams. 2013. The impacts of climate change on tribal traditional foods. Climatic Change 120:545-556.

[415] Kuhlman, K., J. Freimund, and G. Gabrisch. 2016. Lummi Nation Climate Change Mitigation and Adaptation Plan: 2016-2026. Lummi Natural Resources Department, Water Resources Division. Available at http://lnnr.lummi-nsn.gov/LummiWebsite/userfiles/360_Climate%20Change%20Assessment%20FINAL.pdf

[416] Jamestown S'Klallam Tribe. 2013. Climate Change Vulnerability Assessment and Adaptation Plan. Petersen, S. and J. Bell (Eds.). A collaboration of the Jamestown S'Klallam Tribe and Adaptation International. Blyn, WA. Available at http://www.jamestowntribe.org/programs/nrs/nrs_climchg.htm

[417] Staudt, A., A.K. Leidner, J. Howard, K.A. Brauman, J.S. Dukes, L.J. Hansen, C. Paukert, J. Sabo, and L.A. Solórzano. 2013. The added complications of climate change: understanding and managing biodiversity and ecosystems. Frontiers in Ecology and the Environment. 11(9): 494-501.

[418] Lynch, A.J., B.J.E. Myers, C. Chu, L.A. Eby, J.A. Falke, R.P. Kovach, T.J. Krabbenhoft, T.J. Kwak, J. Lyons, C.P. Paukert, and J. E. Whitney. 2016. Climate change effects on North American inland fish populations and assemblages. Fisheries 41(7): 346-361.

[419] Lynch, A.J., B.J.E. Myers, C. Chu, L.A. Eby, J.A. Falke, R.P. Kovach, T.J. Krabbenhoft, T.J. Kwak, J. Lyons, C.P. Paukert, and J. E. Whitney. 2016. Climate change effects on North American inland fish populations and assemblages. Fisheries 41(7): 346-361.

[420] Lummi Nation. 2016. Lummi Nation responds to U.S. Army Corps' decision on Gateway Pacific coal terminal. Press release dated May 9, 2016.

[421] Lawler, J.J. and M. Mathias. 2007. Climate Change and the Future of Biodiversity in Washington. Report prepared for the Washington Biodiversity Council.

[422] Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E. Lugo, C.J. Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks, and B.M. Wotton. 2001. Climate change and forest disturbances. Bioscience 51(9): 723-734.

[423] Bradley, B.A. 2009. Regional analysis of the impacts of climate change on cheatgrass invasion shows potential risk and opportunity. Global Change Biology 15: 196-208.

[424] Lawler J.J. and M. Mathias. 2007. Climate Change and the Future of Biodiversity in Washington. Report prepared for the Washington Biodiversity Council.

[425] Halofsky, J.E., D.L. Peterson, K.A. O'Halloran, C. Hawkins Hoffman (Eds.). 2011. Adapting to climate change at Olympic National Forest and Olympic National Park. General Technical Report PNW-GTR-844. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR.

[426] Rahel, F. J. and J. D. Olden. 2008. Assessing the effects of climate change on aquatic invasive species. Conservation Biology 22(3):521-533.

[427] Washington Invasive Species Council. 2008 Invaders at the Gate: Washington Invasive Species Council. 2008 Strategic Plan. Olympia, WA.

[428] Jamestown S'Klallam Tribe. 2013. Climate Change Vulnerability Assessment and Adaptation Plan. Petersen, S. and J. Bell (Eds.). A collaboration of the Jamestown S'Klallam Tribe and Adaptation International.

[429] Climate Impacts Group. 2013. Section 12: Human Health. Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers. Available at http://cses.washington.edu/db/pdf/snoveretalsok2013sec12.pdf

[430] National Resources Defense Council. 2013. Where There's Fire, There's Smoke: Wildfire Smoke Affects Communities Distant from Deadly Flames. Issue Brief 13-09-b. Available at https://www.nrdc.org/sites/default/files/wildfire-smoke-IB.pdf

[431] Donatuto, J., E.E. Grossman, J. Konovsky, S. Grossman, and L.W. Campbell. 2014. Indigenous Community Health and Climate Change: Integrating Biophysical and Social Science Indicators. Coastal Management 42(4): 355-373.

[432] Lynn, K., J. Daigle, J. Hoffman, F. Lake, N. Michelle, D. Ranco, C. Viles, G. Voggesser, and P. Williams. 2013. The impacts of climate change on tribal traditional foods. Climatic Change 120: 545-556.

[433] Krohn, E. and V. Segrest. 2010. The Traditional Foods of Puget Sound Project Final Report 2008-2010. Northwest Indian College Cooperative Extension Office. Available at http://www.nptao.arizona.edu/ridge_update/nwic%20final%20report.pdf

[434] Krohn, E. and V. Segrest. 2010. The Traditional Foods of Puget Sound Project Final Report 2008-2010. Northwest Indian College Cooperative Extension Office. Available at http://www.nptao.arizona.edu/ridge_update/nwic%20final%20report.pdf

[435] Eckart, K. 2012. Traditional Foods Help Remind Us Who We Are. Yes Magazine, Issue 63–Fall 2012. Available at http://www.yesmagazine.org/issues/its-your-body/tribe-revives-traditional-diet

[436] Jamestown S'Klallam Tribe. 2013. Climate Change Vulnerability Assessment and Adaptation Plan. Petersen, S. and J. Bell (Eds.). A collaboration of the Jamestown S'Klallam Tribe and Adaptation International. Blyn, WA. Available at http://www.jamestowntribe.org/programs/nrs/nrs_climchg.htm

[437] Kuhlman, K., J. Freimund, and G. Gabrisch. 2016. Lummi Nation Climate Change Mitigation and Adaptation Plan: 2016-2026. Lummi Natural Resources Department, Water Resources Division. Available at http://lnnr.lummi-nsn.gov/LummiWebsite/userfiles/360_Climate%20Change%20Assessment%20FINAL.pdf

[438] Swinomish Indian Tribal Community. 2009. Swinomish Climate Change Initiative Impact Assessment Technical Report. Office of Planning and Community Development , La Conner, WA. Available at http://www.swinomish.org/climate_change/project/reports.html

Swinomish Indian Tribal Community. 2010. Swinomish Climate Change Initiative Climate Adaptation Action Plan. Office of Planning and Community Development , La Conner, WA. 144 p. Available at http://www.swinomish.org/climate_change/project/reports.html

[439] Donatuto, J., E.E. Grossman, J. Konovsky, S. Grossman, and L.W. Campbell. 2014. Indigenous Community Health and Climate Change: Integrating Biophysical and Social Science Indicators. Coastal Management 42(4): 355-373.

[440] de Chavez, R. and V. Tauli-Corpuz (Eds.). 2008. Guide on Climate Change and Indigenous Peoples. Tebtebba Foundation, Indigenous Peoples' International Centre for Policy Research and Education. Baguio City, Philippines. Available at www.tebtebba.org

[441] Ahearn, A. 2015. Washington Tribe Confronts Climate Change, Sea Level Rise. KUOW Earthfix News, November 9, 2015. Available at http://kuow.org/post/washington-tribe-confronts-climate-change-sea-level-rise

[442] Isaak, D., M. Young, D. Nagel, D. Horan, and M. Groce. 2015. The cold-water climate shield: Delineating refugia for preserving salmonid fishes through the 21st Century. Global Change Biology. 21: 2540-2553.

[443] Lawler, J.J. and J.D. Olden. 2011. Reframing the debate over assisted colonization. Frontiers in Ecology and the Environment, 9(10): 569-574.

[444] Gonzalez, A., O. Ronce, R. Ferriere, and M.E. Hochberg. 2013. Evolutionary rescue: an emerging focus at the intersection between ecology and evolution. Philosophical Transaction of the Royal Society B Biological Sciences 368(1610): 20120404.

[445] Northwest Treaty Tribes. 2013. South Fork Nooksack Chinook Captive Broodstock Reach Spawning Age. Posted September 24, 2013. Available at http://nwtreatytribes.org/south-fork-nooksack-captive-chinook-broodstock-reach-spawning-age

[446] Northwest Treaty Tribes. 2013. South Fork Nooksack Chinook Captive Broodstock Reach Spawning Age. Posted September 24, 2013. Available at http://nwtreatytribes.org/south-fork-nooksack-captive-chinook-broodstock-reach-spawning-age

[447] Capon, S.J., L.E., Chambers, R. MacNally, R.J. Naiman, P. Davies, N. Marshall, J. Pittock, M. Reid, Y. Capon, M. Douglas, and J. Catford. 2013. Riparian ecosystems in the 21st century: hotspots for climate change adaptation? Ecosystems 16(3): 359-381.

[448] Mantua, N.J., I. Tohver, and A.F. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change 102: 187-223.

[449] Beechie, T., H. Imaki, J. Greene, A. Wade, H. Wu, G. Pess, P. Roni, J. Kimball, J. Stanford, P. Kiffney, and N. Mantua. 2013. Restoring salmon habitat for a changing climate. River Research and Applications 29(8): 939-960.

[450] Mantua, N.J., I. Tohver, and A.F. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change 102: 187-223.

[451] Beechie, T., H. Imaki, J. Greene, A. Wade, H. Wu, G. Pess, P. Roni, J. Kimball, J. Stanford, P. Kiffney, and N. Mantua. 2013. Restoring salmon habitat for a changing climate. River Research and Applications 29(8): 939-960.

[452] Beechie, T., H. Imaki, J. Greene, A. Wade, H. Wu, G. Pess, P. Roni, J. Kimball, J. Stanford, P. Kiffney, and N. Mantua. 2013. Restoring salmon habitat for a changing climate. River Research and Applications 29(8): 939-960.

[453] Schmitz, O.J., J.J. Lawler, P. Beier, C. Groves, G. Knight, D.A. Boyce Jr., J. Bulluck, K.M. Johnston, M.L. Klein, K. Muller, D.J. Pierce, W.R. Singleton, J.R. Strittholt, D.M. Theobald, S.C. Trombulak, and A.E. Trainor. 2015. Conserving biodiversity: practical guidance about climate change adaptation approaches in support of land-use planning. Natural Areas Journal 35: 190-203.

[454] Sanders, J. OA Refuges and Seaweed Experimentation. 2015. Ocean Acidification Report, 2(1). Global Ocean Health. Available at http://globaloceanhealth.cmail2.com/t/ViewEmail/d/61D86FD16FC74196/5F3CC9C9C5CEF61ED9767B6002735221#BETSY

[455] Krosby, M., R. Norheim, D. Theobald, and B. McRae. 2014. Riparian Climate-Corridors: Identifying Priority Areas for Conservation in a Changing Climate. Climate Impacts Group, University of Washington, Seattle, WA.

[456] Littell, J.S., E.E. Oneil, D. McKenzie, J.A. Hicke, J.A. Lutz, R.A. Norheim, and M.M. Elsner. 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. Climatic Change 102(1-2): 129-158.

[457] Raymond, C.L., Peterson, D.L., and Rochefort, R.M. (Eds.) 2014. Climate change vulnerability and adaptation in the North Cascades region, Washington. General Technical Report PNW-GTR-892. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

[458] Raymond, C.L., Peterson, D.L., and Rochefort, R. M. (Eds.) 2014. Climate change vulnerability and adaptation in the North Cascades region, Washington. General Technical Report PNW-GTR-892. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

[459] Hall, J.E., T. J. Beechie, and G.R. Pess. 2014. Influence of climate and land cover on river discharge in the North Fork Stillaguamish River. Northwest Fisheries Science Center, NOAA Fisheries. Report to Stillaguamish Tribe of Indians. Available at http://www.stillaguamishwatershed.org/subpages/Documents_sci_stilly.html.

[460] Waples, R.S., G.R. Pess, and T. Beechie. 2008. Evolutionary history of Pacific salmon in dynamic environments. Evolutionary Applications 1:189-206.

[461] Scofield, C. and J. Griffith. 2014. 2013 Annual Report Stillaguamish River Smolt Trapping Project. Stillaguamish Tribe of Indians Natural Resource Department. Arlington, WA. Available at http://www.stillaguamish.com/images/Natural_Resources//Mainstem_Stillaguamish_Smolt_Trap_Annual_Report_2013.pdf

[462] Warner, M.D., C.E. Mass, and E.P. Salathé. 2014. Changes in winter atmospheric rivers along the North American West Coast in CMIP5 climate models. Journal of Hydrometerology 16: 118-128.

[463] United States Geological Survey. 2015. USGS 12167000 NF Stillaguamish River Near Arlington, WA. National Water Information System: Site Inventory, Available at http://waterdata.usgs.gov/nwis/inventory/?site_no=12167000

[464] Riedlinger, D. and F. Berkes. 2001. Contributions of traditional knowledge to understanding climate change in the Canadian arctic. Polar Record 37(203): 315-328.

[465] Riedlinger, D. and F. Berkes. 2001. Contributions of traditional knowledge to understanding climate change in the Canadian arctic. Polar Record 37(203): 315-328.

[466] Stumpff, L.M. 2009. Climate change and tribal consultation: from dominance to détente. Proceedings of the 2009 George Wright Society Conference, Portland, OR. Available at http://www.georgewright.org/0914stumpff.pdf

[467] Williams, T. and P. Hardison. 2013. Culture, law, risk and governance: contexts of traditional knowledge in climate change adaptation. Climatic Change (2013) 120:531-544.

[468] Mahle, G. and L. Tom. 2012. Where Words Touch the Earth. In Grossman, Z. and A. Parker. (Eds.) Asserting Native Resilience: Pacific Rim Indigenous Nations Face the Climate Crisis. Oregon State University Press. Corvallis, OR. Available at http://academic.evergreen.edu/g/grossmaz/climate.html

[469] Climate and Traditional Knowledges Workgroup (CTKW). 2014. Guidelines for Considering Traditional Knowledges in Climate Change Initiatives. Prepared for the Department of Interior Advisory Committee on Climate Change and Natural Resource Science (ACCCNRS). Available at http://climatetkw.wordpress.com

[470] Climate and Traditional Knowledges Workgroup (CTKW). 2014. Guidelines for Considering Traditional Knowledges in Climate Change Initiatives. Prepared for the Department of Interior Advisory Committee on Climate Change and Natural Resource Science (ACCCNRS). Available at http://climatetkw.wordpress.com

[471] Williams, T. and P. Hardison. 2013. Culture, law, risk and governance: contexts of traditional knowledge in climate change adaptation. Climatic Change (2013) 120:531-544.

[472] Klein, N. 2014. This Changes Everything: Capitalism vs. the Climate. New York City, NY: Simon and Schuster.

[473] EPA. 2015. Change in the United States: Benefits of Global Action. United States Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-15-001. Available at https://www.epa.gov/cira

[474] EPA. 2015. Change in the United States: Benefits of Global Action. United States Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-15-001. Available at https://www.epa.gov/cira

[475] UNFCCC. 2015. Report on the structured expert dialogue on the 2013-2015 review. United Nations Framework Convention on Climate Change Subsidiary Body for Scientific and Technological Advice Forty-second session Bonn, 1-11 June 2015. Available at http://unfccc.int/resource/docs/2015/sb/eng/inf01.pdf

[476] United Nations. 2016. Declaring Era of Consumption without Consequences Over, Secretary-General Commends Paris Climate Agreement Signatories for Making Historic Pledge to Protect Planet. United Nations Secretary-General press release SG/SM/17695-ENV/DEV/1660-L/T/4447, 22 April 2016. Available at http://www.un.org/press/en/2016/sgsm17695.doc.htm

[477] Barbose, G. and N. Darghouth. 2015. Tracking the Sun VIII: The Installed Price of Residential and Non-Residential Photovoltaic Systems in the United States. Energy Technologies Area, Lawrence Berkeley National Laboratory. Available at https://emp.lbl.gov/sites/all/files/lbnl-188238_1.pdf

[478] Luyssaert, S., E.D. Schulze, A. Börner, A. Knoh, D. Hessenmöller, B.E. Law, P. Ciais, and J. Grace. 2008. Old-growth forests as global carbon sinks. Nature 455: 213-215.

[479] Foster, B.C., T.A. Robards and W.S. Keeton. 2010. Carbon Dynamics Associated with Even-Aged Forest Management. Report for Climate Action Reserve (CAR). Los Angeles CA.

[480] Crooks, S., J. Rybczyk, K. O'Connell, D.L. Devier, K. Poppe, and S. Emmett-Mattox. 2014. Coastal Blue Carbon Opportunity Assessment for the Snohomish Estuary: The Climate Benefits of Estuary Restoration. Report by Environmental Science Associates, Western Washington University, EarthCorps, and Restore America's Estuaries.

[481] Sharp, F. 2016. Tribes have up close perspective on climate change. Seattle Times. April 23, 2016. Available at http://www.seattletimes.com/opinion/tribes-have-up-close-perspective-on-climate-change/

CLIMATE CHANGE AND OUR NATURAL RESOURCES

A Report from the Treaty Tribes in Western Washington

APPENDICES

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APPENDICES

TABLE OF CONTENTS

APPENDIX A: SELECTED REFERENCES

Climate Change and Tribes

Dalton, M.M., P.W. Mote, and A.K. Snover (Eds.). 2013. Climate Change in the Northwest: Implications for Our Landscapes, Waters, and Communities. Washington, DC: Island Press. (see Chapter 8 – Northwest Tribes: Cultural Impacts and Adaptation Responses). Available at occri.net

de Chavez, R. and V. Tauli-Corpuz (Eds.). 2008. Guide on Climate Change and Indigenous Peoples. Tebtebba Foundation, Indigenous Peoples' International Centre for Policy Research and Education. Baguio City, Philippines. Available at www.tebtebba.org

Grossman, Z. and A. Parker (Eds.). 2012. Asserting Native Resilience: Pacific Rim Indigenous Nations Face the Climate Crisis. Corvallis, OR: Oregon State University Press.

Parker, A., Z. Grossman, E. Whitesell, B. Stephenson, T. Williams, P. Hardison, L. Ballew, B. Burnham, J. Bushnell, and R. Klosterman. 2006. Climate Change and Pacific Rim Indigenous Nations. Northwest Indian Applied Research Institute, The Evergreen State College, Olympia, WA.

Special Issue on "Climate Change and Indigenous Peoples in the United States: Impacts, Experiences, and Actions" edited by Maldonado, J.K., R.E. Pandya, and B.J. Colombi. Climatic Change Volume 120 Issue 3 (October 2013).

For studies conducted by western Washington treaty tribes, please see *Appendix F: Tribal Climate Change Programs*.

Overview of Climate Change in the PNW

Dalton, M.M., P.W. Mote, and A.K. Snover (Eds.). 2013. Climate Change in the Northwest: Implications for Our Landscapes, Waters, and Communities. Washington, DC: Island Press.

Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K.T. Redmond, and J.G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 6. Climate of the Northwest U.S. NOAA Technical Report NESDIS 142-6. Available at globalchange.gov

Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle, WA. Available at cig.uw.edu

Mauger, G. and A. Snover. 2015. Future scenarios for climate change in Puget Sound. Encyclopedia of Puget Sound. Puget Sound Institute at the University of Washington Tacoma Center for Urban Waters, Tacoma, WA. Available at www.eopugetsound.org

Mote, P.W. and E.P. Salathé Jr. 2010. Future Climate in the Pacific Northwest. Climatic Change 102: 29-50.

Mote, P., A.K. Snover, S. Capalbo, S.D. Eigenbrode, P. Glick, J. Littell, R. Raymondi, and S. Reeder. 2014. Climate Change Impacts in the United States. Chapter 21: Northwest. In The Third National Climate Assessment. Melillo, J.M., T.C. Richmond, and G.W. Yohe (Eds.). U.S. Global Change Research Program, Washington, DC. Available at globalchange.gov

Snover, A.K, G.S. Mauger, L.C. Whitely Binder, M. Krosby, and I. Tohver. 2013. Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers. State of Knowledge Report prepared for the Washington State Department of Ecology. Climate Impacts Group, University of Washington, Seattle, WA.

Climate Basics

The American Association for the Advancement of Science (AAAS). 2014. What We Know: The Reality, Risks and Response to Climate Change. Washington, DC. Available at whatweknow.aaas.org/get-the-facts

The Royal Society and the U.S. National Academy of Sciences 2014. Climate Change Evidence & Causes. Available at nas-sites.org/americasclimatechoices

Global and National Climate Change

Intergovernmental Panel on Climate Change (IPCC). 2012. Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX). [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (Eds.)]. Cambridge, UK: Cambridge University Press. Available at www.ipcc.ch

IPCC. 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press. Available at www.ipcc.ch

IPCC. 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press. Available at www.ipcc.ch

IPCC. 2014. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlomer, C. von Stechow, T. Zwickel and J.C. Minx (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press. Available at www.ipcc.ch

IPCC. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri, and L.A. Meyer (Eds.)]. IPCC, Geneva, Switzerland. Available at www.ipcc.ch

Melillo, J.M., T.C. Richmond, and G.W. Yohe (Eds.). 2014. The Third National Climate Assessment, U.S. Global Change Research Program, Washington, DC. Available at globalchange.gov

U.S. Global Change Research Program. 2009. Global Climate Change Impacts in the United States. Karl, T.R, J.M. Melillo, and T.C. Peterson (Eds.). New York, NY: Cambridge University Press.

Traditional Knowledge

Climate and Traditional Knowledges Workgroup (CTKW). 2014. Guidelines for Considering Traditional Knowledges in Climate Change Initiatives. Prepared for the Department of Interior Advisory Committee on Climate Change and Natural Resource Science (ACCCNRS). Available at climatetkw.wordpress.com

Morishima, G. 2014. Climate Change and Indigenous Peoples: A Primer. Prepared for the Department of Interior Advisory Committee on Climate Change and Natural Resource Science (ACCCNRS). Available at climatetkw.wordpress.com/primer

Viles, C. 2014. Annotated Bibliography: Examples of Traditional Knowledges in Climate Research. Supplement to the Guidelines for Considering Traditional Knowledges in Climate Change Initiatives. Developed by the Pacific Northwest Tribal Climate Change Project at the University of Oregon, with support from Tulalip Tribes, North Pacific Landscape Conservation Cooperative and the USDA Forest Service Pacific Northwest Research Station. Available at climatetkw.wordpress.com

Vinyeta, K. and K. Lynn. 2013. Exploring the Role of Traditional Ecological Knowledge in Climate Change Initiatives. United States Department of Agriculture Forest Service Pacific Northwest Research Station General Technical Report PNW-GTR-879. Available at www.fs.fed.us/pnw

Williams, T. and P. Hardison. 2013. Culture, law, risk and governance: contexts of traditional knowledge in climate change adaptation. Climatic Change (2013) 120: 531-544.

Special Invited Feature on Traditional Ecological Knowledge and Wisdom in Ecological Applications Volume 10 Issue 5 (October 2000).

Adaptation

Beechie, T., H. Imaki, J. Greene, A. Wade, H. Wu, G. Pess, P. Roni, J. Kimball, J. Stanford, P. Kiffney, N. Mantua. 2013. Restoring salmon habitat for a changing climate. River Research and Applications, 29(8): 939–960.

Gregg, R.M., L.J. Hansen, K.M. Feifel, J.L. Hitt, J.M. Kershner, A. Score, and J.R. Hoffman. 2011. The State of Marine and Coastal Adaptation in North America: A Synthesis of Emerging Ideas. EcoAdapt, Bainbridge Island, WA. Available at ecoadapt.org

Needelman, B.A., S. Crooks, C.A. Shumway, J.G. Titus, R. Takacs, and J.E. Hawkes. 2012. Restore-Adapt-Mitigate: Responding to Climate Change Through Coastal Habitat Restoration. B.A. Needelman, J. Benoit, S. Bosak, and C. Lyons (Eds.). Restore America's Estuaries, Washington D.C. Available at estuaries.org

Tillmann, P. and D. Siemann. 2011. Climate Change Effects and Adaptation Approaches in Marine and Coastal Ecosystems of the North Pacific Landscape Conservation Cooperative Region: A Compilation of Scientific Literature. Produced by National Wildlife Federation and U.S. Fish and Wildlife Service Region 1 Science Applications Program. Available at pajk.arh.noaa.gov/Articles/articles/NPLCC_MarineClimateEffects.pdf

Data Sources

A selection of climate change data sources are available at nwtreatytribes.org/climatechange/.

APPENDIX B: GLOSSARY OF TERMS

Ablation: the processes that reduce the mass of a glacier, such as melting, sublimation, and avalanches.

Adaptation: activities that minimize harm or increase benefits in response to actual or anticipated changes.

Aggradation: building up a surface through deposition. In a stream, it is the accumulation of sediment in the channel or floodplain when the amount of sediment available (sediment supply) is greater than the capacity of the stream to transport it.

Anoxia: in waters (surface, ground, or salt water), depletion of dissolved oxygen; severe hypoxia.

Atmospheric river: a relatively narrow plume of water vapor transported through the atmosphere. One type of strong atmospheric river commonly called the Pineapple Express brings moisture from the tropical Pacific Ocean near Hawaii to the West Coast of the U.S. These phenomena correspond to storms in the PNW. For more information, please see: www.esrl.noaa.gov/psd/atmrivers/

Assisted migration: also called facilitated dispersal or assisted colonization, supports population persistence where natural migration or range shifts are not possible. Individuals are assisted into new locations by removing barriers to movement or by introducing species into suitable areas.

Base flow: the streamflow sustained during dry weather. In many streams, it is composed mainly of deep and shallow subsurface flows. Also called low flow, groundwater recession flow, low-water discharge, and fair-weather flow.

Beach nourishment: the addition of sediment to a beach, also called beach replenishment. It can be used to address beach erosion as part of living shorelines/soft shoreline protection. It protects beach resources by dissipating wave energy across the face of the beach while avoiding the negative impacts of hard shoreline armoring. It typically requires reapplication because it does not stop the physical drivers of erosion. Please see living shorelines entry below.

Biological dispersal: the movement of genetic material through the landscape via individuals, seeds, or spores.

Bud burst: the first appearance of leaves on a plant at the start of the growing season.

Carbon cycle: a system of reservoirs (storage areas) and transfer between these reservoirs (fluxes). Reservoirs occur in the ocean, atmosphere, carbonate sedimentary rocks, and organic carbon of the Earth's biota. Fluxes include gas exchange between the ocean and atmosphere, photosynthesis of plants (converting CO_2 into energy), and respiration by animals (releasing CO_2 as a by-product of creating energy). The largest reservoir by far is carbonate sedimentary rock, which forms through the slow burial of plant and animal matter on land and on the ocean floor (eventually to become limestone, coal, gas, and oil) that takes place on the order of millions of years.

Carbon sequestration: the process of removing CO_2 from the atmosphere and storing it. Storage can be geological or biological and can be natural or technological.

Climate: long-term patterns or averages of factors such as temperature, precipitation, humidity, and wind over decades, centuries, or millennia. A minimum of 30 years is the standard of the World Meteorological Organization. The global climate system is driven by the energy balance between different regions. The main external input into the climate system is solar radiation from sunlight. The various parts of the system, including the atmosphere, oceans, living organisms, earth's surface, and frozen regions, all are complex systems in their own right and they interact with each other, creating feedback loops.

> **What is the difference between climate and weather?**
> Weather refers to local changes to the state of the atmosphere over short time scales (minutes to weeks), such as thunderstorms, rain showers, heat waves, etc. Weather is highly dynamic and can be described by temperature,

precipitation, wind speed, and cloud cover. Climate is the average weather condition over a period of decades or more. For example, snow (a weather event) has been recorded in South Florida, but the winter climate (the average over the last six decades) is warm with average temperatures in the 60s and 70s.[1]

Climate change: a major shift or a disruption in the patterns of long-term averages of climate variables, such as temperature, precipitation, or wind.

What is the difference between global warming and climate change?
Global warming is the long-term warming of global average temperatures in the air and oceans. This warming can lead to climate change. It can occur due to natural factors or human activities that change the composition of the atmosphere and the surface of the earth.

Climate change mitigation: actions that reduce the levels of greenhouse gases in the atmosphere, such as enhancing energy efficiency or switching from fossil fuels to renewable energy sources.

Climate refugia: places in the landscape where climate change effects occur more slowly or not at all. They provide stable and diverse habitats that allow biodiversity to persist despite changing environmental conditions. The minimum size of refugia depends on the area required to maintain viable populations.

Climate system: the complex system of and interactions among the following components: atmosphere, hydrosphere (water), cryosphere (ice and snow), lithosphere (rock), and biosphere (living organisms).

Climate variability: variations in the state of the climate beyond individual weather events. Climate variability occurs on all spatial and time scales.

Climate velocity: the rate at which climate conditions change across the landscape.

Coastal squeeze: loss of shoreline habitat when armoring or other development prevents landward migration of the intertidal zone in response to sea level rise.

Downscaling: a method to derive local- or regional-scale data from global models. Dynamical downscaling uses a regional climate model with the global climate model (GCM) output for the boundary conditions or a higher resolution GCM. Statistical downscaling uses historical relationships to connect global atmospheric variables of GCMs to regional climate variables. See *Appendix D: Overview of Climate Models* for more detail.

El Niño-Southern Oscillation (ENSO): El Niño is a basin-wide warming of the sea surface in the tropical Pacific Ocean associated with a tropical and subtropical surface pressure pattern called the Southern Oscillation. ENSO has a major impact on winds, sea surface temperatures, and precipitation patterns in the tropical Pacific. During an ENSO event, the prevailing easterly trade winds weaken, sending warm water toward the central and eastern tropical Pacific Ocean and reducing upwelling along the west coast of North and South America. Sea surface temperatures warm, further weakening the trade winds. The time scale is generally 2 to 7 years and the cold phase of ENSO is called La Niña. In the Pacific Northwest, El Niño brings warmer winter temperatures, slightly less precipitation, less snow, and lower probabilities of major storms. These effects will vary depending on the intensity; moderate, strong, and very strong El Niños can have different effects.

Energy conservation: The reduction or elimination of a service in order to save energy.

Energy efficiency: The reduction of energy use by a service in order to save energy.

Ephemeral wetland: A wetland that periodically dries out, typically in middle to late summer. Also known as ephemeral ponds, seasonal ponds, temporary ponds, or vernal pools.

Evapotranspiration: The combination of evaporation of water and transpiration by plants that releases water into the atmosphere.

Evolutionary rescue: relatively rapid genetic change that allows population recovery in the face of environmental disturbance that could have caused extinction.

Extirpation: Local extinction.

Glaciation: a climatic episode characterized by extensive glaciers or ice sheets that develop and then recede.

Glacier mass balance: the difference between accumulation and loss in glacier mass over a period of time (a year or a season). Surface mass balance is the difference between surface accumulation and surface ablation (the processes that reduce the mass of a glacier, such as melting, sublimation, and avalanches).

Global Warming: increase in average global temperatures at sea, on land, and in the atmosphere.

Greenhouse effect: The trapping of heat in the atmosphere. Certain gases in the atmosphere absorb the infrared radiation of solar energy that is reflected by the Earth's surface and in the atmosphere. Greater concentrations of these greenhouse gases will lead to increases in the average temperature of the lower atmosphere.

Greenhouse gas (GHG): Any gas that absorbs radiation in the atmosphere, such as carbon dioxide (the most common in the atmosphere), methane, nitrous oxide, ozone, sulfur hexafluoride, hydrofluorocarbons, perfluorocarbons, and water vapor.

Habitat fragmentation: the breakup of large habitat areas into small patches that are isolated from each other and have less total area.

Hydromodification: Alteration of the natural flow of water through a landscape. It can take many forms, such as dams, levees, channel straightening, or conversion to roads, buildings, and agriculture.

Hydroperiod: in a wetland, the seasonal patterns of inundation that include the frequency, duration, and water level.

Hypoxia: low dissolved oxygen in water. The state of Washington has a dissolved oxygen fresh water standard of 9.5 mg/L for summer salmonid habitat. In marine environments, the criteria range from 7.0 mg/L for waters of extraordinary quality to 4.0 mg/L for fair quality.

Landslide: the downslope movement of soil, rock, or debris. Landslides can range in size, speed, and pattern of movement. Also see mass movement.

Living shorelines: also known as soft shoreline armoring or alternative shoreline protection. Natural bank stabilization techniques that use plants, sand, wood, and limited amounts of rock to provide shoreline protection while maintaining natural ecological and geomorphic processes. Used as an alternative to hard shoreline stabilization such as bulkheads, revetments, and concrete sea walls, which can increase erosion rates while diminishing habitat quality and quantity.

Mass movement: also known as mass wasting, the movement of earth surface material due to gravity and potentially influenced by the action of water, wind, ice, and vegetation. The speed ranges from gradual soil creep to rapid landslides, mudflows, and rock falls.

Nearshore: the shoreline from the top of the upland bank or bluff on the landward side down to the depth of water that light can penetrate and where plants can photosynthesize, called the photic zone. The upper extent encompasses the terrestrial upland that contributes sediment, shade, organic material like leaf litter, and the insects that fish eat. The lower range of the photic zone depends on water clarity. In Puget Sound, underwater vegetation can be found to depths of 30 to 100 feet below Mean Lower Low Water (MLLW).

Ocean acidification: the increase in acidity of ocean water over a period of decades or longer due to the increased concentration of CO_2. Acidity refers to a drop in pH, a dimensionless measure of the concentration of hydrogen ions (H^+). pH is measured on a logarithmic scale, so a pH decrease of 1 unit corresponds to a 10-fold increase in the concentration of H^+ and acidity.

Pacific Decadal Oscillation (PDO): the pattern of variations in sea surface temperatures in the Pacific Basin that occurs when winter winds shift direction in the North Pacific. The phases of the PDO can last 20 to 30 years. In the positive phase, ocean surface temperatures in the eastern North Pacific are warmer than in the central and western Pacific. In the cool phase the eastern North Pacific is cooler. The PDO correlates with atmospheric circulation, ocean circulation, precipitation, and winter temperatures on land. PDO also correlates to population size of salmon returning to spawn. Cool PDO phases have coincided with large returns of chinook and coho in Oregon rivers. In the subsequent warm phase, salmon numbers declined steadily.[2]

Phenology: the study of the timing of biological events, such as migration, reproduction, or blooming. Seasonal and climate changes influence phenology through day length, temperature, and precipitation.

Phenotypic plasticity: the ability to shift the expression of physiological characteristics due to environmental factors without genetic changes.

Relative sea level rise: the increase in water level of the ocean at a specific location, that includes both global sea level rise and local vertical land motion, such as subsidence or uplift.

Resilience: the capacity to prepare for, respond to, and recover from significant hazards and threats with minimum damage. Can be applied to community well-being, the economy, and the environment.

Risk: the probability that harm will occur multiplied by the severity of the consequence of the harm.

Runoff: the portion of precipitation that flows over the ground or below the ground to eventually return to a body of water.

Salmonid: fish belonging to the family Salmonidae, which includes salmon, trout, char, and whitefish.

Saltwater intrusion: the displacement of fresh water or groundwater by salt water, usually in coastal and estuarine areas.

Saturation state: in seawater relative to aragonite (a form of calcium carbonate), it is a measure of the potential of aragonite to form or dissolve. Aragonite ($CaCO_3$) is formed from calcium ions (Ca^{2+}) and carbonate ions ($CaCO_3$) dissolved in seawater. This reaction can also proceed in the opposite direction, where aragonite can dissolve into the individual ions.

The saturation state of seawater relative to aragonite is the ratio of the concentrations of dissolved calcium and carbonate ions in seawater multiplied by each other and the concentration of aragonite when it is in equilibrium (neither forming or dissolving):

$$\Omega = [Ca^{2+}] \times [CO_3^{\ 2-}]) / [CaCO_3]$$

where Ω is the calculated saturation state, $[Ca^{2+}]$ is the seawater concentration of dissolved calcium ions, $[CO_3^{\ 2-}]$ is the seawater concentration of carbonate ions, and $[CaCO_3]$ is the solubility of aragonite in seawater.

When $\Omega = 1$, the seawater is exactly in equilibrium or saturation with respect to aragonite, so there is no net precipitation (formation) or dissolution. When $\Omega > 1$, the seawater is said to be supersaturated and aragonite will precipitate. When $\Omega < 1$, the seawater is said to be undersaturated with respect to aragonite and the mineral will dissolve.

When carbon dioxide from the atmosphere is added to surface seawater, a series of chemical reactions increases the acidity of surface seawater and results in fewer carbonate ions, thus the saturation state of seawater with respect to aragonite decreases.

Sensitivity: the degree to which a natural or built system is directly or indirectly affected by climate change or variability.

Snow water equivalent (SWE): the depth of the liquid water held in a mass of snow if it were to completely melt.

Snowpack: seasonal accumulation of slow-melting snow.

Storm surge: the temporary increase in sea levels at a specific location above the level expected from tidal variation alone due to extreme meteorological conditions such as low atmospheric pressure and/or strong winds.

Stratification: in oceans, as the surface water warms, it becomes more buoyant and less dense, thus it mixes less with the layers below.

Subsidence: the downward settling of the ground surface due to tectonic forces, compaction after dewatering, or extraction of groundwater or oil.

Transpiration: the process of water evaporating from plant leaves after moisture is carried from the roots to small pores on the underside of leaves, where it changes to vapor and is released to the atmosphere.

Turbidity: the opaqueness of a stream due to sediment and/or organic matter suspended in the water column.

Upwelling: the rising of deeper colder water to shallower depths. Along the west coast of North America, this occurs when water rises to replace the surface water that has drifted away from shore due to northward blowing winds and the friction between ocean layers. The nutrients brought to the surface by the upwelling support the marine food web.

Vulnerability: susceptibility to harm from climate change impacts. It consists of the sensitivity to impacts, the degree of exposure to those impacts, and the capacity to adapt to changes.

APPENDIX C: COMMON AND SCIENTIFIC NAMES OF SPECIES

COMMON NAME	SCIENTIFIC NAME
Salmonids:	
Bull trout	*Salvelinus confluentus*
Chinook salmon	*Oncorhynchus tshawytscha*
Chum salmon	*Oncorhynchus keta*
Coho salmon	*Oncorhynchus kisutch*
Cutthroat trout	*Oncorhynchus clarkii*
Dolly Varden trout	*Salvelinus malma*
Pink salmon	*Oncorhynchus gorbuscha*
Sockeye salmon	*Oncorhynchus nerka*
Steelhead/rainbow trout	*Oncorhynchus mykiss*
Other Finfish:	
Black cod (sablefish)	*Anoplopoma fimbria*
Chub mackerel	*Scomber japonicus*
Copper rockfish	*Sebastes caurinus*
Grunters (plain fish midshipman)	*Porichthys notatu*
Hooligan (also called eulachon or smelt)	*Thaleichthys pacificus*
Jack mackerel	*Trachurus symmetricus*
Lingcod	*Ophidon elongatus*
Northern anchovy	*Engraulis mordax*
Olympic mudminnow	*Novumbra hubbsi*
Pacific cod	*Gadus macrocephalus*
Pacific halibut	*Hippoglossus stenolepsis*
Pacific herring	*Clupea pallasii*
Pacific lamprey	*Entosphenus tridentatus*
Pacific sand lance	*Ammodytes hexapterus*
Pacific whiting	*Merluccius productus*
Rockfish	*Sebastes spp.*
Sardine	*Sardinops sagax caerulea*
Sculpin	*Cottidae spp.*
Smallmouth bass	*Micropterus dolomieu*
Sturgeon	*Acipenser spp.*
Surf smelt	*Hypomesus pretiosus*
Three-spine stickleback	*Gasterosteus aculeatus*
Mollusks:	
Blue mussel	*Mytilus edulis*
Butter clam	*Saxidomus gigantea*
California mussel	*Mytilus californianus*

COMMON NAME	SCIENTIFIC NAME
Mollusks (cont.):	
Geoduck	*Panopea generosa*
Horse clam	*Tresus sp.*
Littleneck clam	*Leukoma staminea*
Manila clam	*Venerupis philippinarum*
Olympia oyster	*Ostrea lurida*
Pacific oyster	*Crassostrea gigas*
Pinto abalone	*Haliotis kamtschatkana*
Razor clam	*Siliqua sp.*
Rock scallop	*Crassadoma gigantea*
Crustaceans:	
Barnacle	*Balanus spp.*
Crawfish	*Pacifastacus leniusculus*
Dungeness crab	*Cancer magister*
Shrimp	*Pandalus spp.*
Spot prawn	*Pandalus platyceros*
Other Marine Organisms:	
Eelgrass	*Zostera marina*
Giant Pacific octopus	*Octopus dofleini*
Pacific squid	*Loligo opalescens*
Pteropod (sea butterfly)	*Limacina helicina*
Sea cucumber	*Cucumaria spp.*
Sea urchin	*Strongylocentrotus spp.*
Marine Mammals:	
California sea lion	*Zalophus californianus*
Gray whale	*Eschrichtius robustus*
Northern fur seal	*Callorhinus ursinus*
Orca	*Orcinus orca*
Pacific harbor seal	*Phoca vitulina richardsi*
Terrestrial Mammals:	
American beaver	*Castor canadensis*
Black bear	*Ursus americanus*
Cougar	*Puma concolo*
Deer	*Odocoileus spp.*
Fisher	*Martes pennanti*

COMMON NAME	SCIENTIFIC NAME
Terrestrial Mammals (cont.):	
Mink	*Mustella vison*
Moose	*Alces alces*
Mountain goat	*Oreamnos americanus*
River otter	*Lontra canadensis*
Rocky Mountain elk	*Cervus elaphus nelsoni*
Roosevelt elk	*Cervus elaphus roosevelti*
Snowshoe hare	*Lepus americanus*
Birds:	
Canada goose	*Branta canadensis*
Canvasback	*Aythya valisineria*
Cassin's auklet	*Ptychoramphus aleuticus*
Common murre	*Uria aalge*
Harlequin duck	*Histrionicus histrionicus*
Mallard	*Anas platyrhynchos*
Ruddy duck	*Oxyura jamaicensis*
Sooty shearwater	*Puffinus griseus*
Wild turkey	*Meleagris gallopavo*
Trees:	
Beaked hazelnut	*Corylus cornuta*
Douglas fir	*Pseudotsuga menziesii*
Lodgepole pine	*Pinus contorta*
Pacific madrone	*Arbutus menziesii*
Pacific silver fir	*Abies amabilis*
Pacific yew	*Taxus brevifola*
Silver fir	*Abie salba*
Sitka spruce	*Picea sitchensis*
Western hemlock	*Tsuga heterophylla*
Western larch	*Larix occidentalis*
Western red cedar	*Thuja plicata*
Western white pine	*Pinus monticola*
Yellow cedar	*Supressus nootkatensis*
Other plants:	
Bear grass	*Xerophyllum tenax*
Big huckleberry	*Vaccinium membranaceum*
Camas	*Camassia quamash*

COMMON NAME	SCIENTIFIC NAME
Other plants (cont.):	
Cheat grass	*Bromus tectorum*
Gooseberry	*Ribes divaricatum*
Horsetails	*Equisetum spp.*
Japanese knotweed	*Fallopia japonica*
Nodding onion	*Allium cernuum*
Oceanspray	*Holodiscus discolor*
Pacific ninebark	*Physocarpus capitatus*
Reed canary grass	*Phalaris arundinacea*
Salmonberry	*Rubus spectabilis*
Skunk cabbage	*Lysichiton americanus*
Soapberry	*Shepherdia canadensis*
Willow	*Salix spp.*
Insects and Pathogens:	
Laminated root rot (caused by)	*Phellinus weirii*
Mountain pine beetle	*Dendroctonus ponderosae*
Swiss needle cast (caused by)	*Phaeocryptopus gaeumannii*
Sudden oak death (caused by)	*Phytophthora ramorum*
Western spruce budworm	*Choristoneura occidentalis*
White pine blister rust (caused by)	*Cronartium ribicola*

APPENDIX D: AN OVERVIEW OF CLIMATE MODELS

Global Climate Models

Climate projections are descriptions of likely outcomes in the future. Unlike a prediction, a projection is an expectation of what might happen that is conditional on a set of assumptions that can change. Global Climate Models (GCMs) take many forms, and each model is run using multiple scenarios of greenhouse gas emissions and land use. These multiple runs are used in an ensemble to produce a range of estimates of future conditions and a measure of the level of uncertainty due to model error and climate variability.[3] The GCM results can be downscaled, or refined to give more detail at the local level.

Climate system models are continually improved over time. Since 2011 a standardized set of models has been carried out by research groups around the world under a framework called the Coupled Model Intercomparison Project Phase 5 (CMIP5). CMIP5 is a multi-model experiment coordinated by the World Climate Research Programme that was designed to explore why models produce different projections under similar conditions, and to explore projections on a decadal time scale.[4] Uncertainty in climate models arises from uncertainty in the basis of the models: the amount of future greenhouse gas (GHG) emissions and other drivers of climate change, the response of the climate system, and the initial conditions in the model.[5] The range of results from different models using the same drivers can quantify uncertainty in the response of the climate system. Uncertainty in initial conditions can be measured by the spread of results from one model using different runs.

Scenarios

Future climate projections are based on the GHG concentrations already in the atmosphere, the natural variability of the global climate, and a number of future GHG emission scenarios. The models use a series of scenarios to encompass the factors that drive GHG emissions by human activity: population size, economic activity, lifestyle, energy use, land-use patterns, technology, and climate policy.[6] Scenario selection depends on the question under consideration and the specific level of risk tolerance. It should be noted that so far observational records most closely match the trajectories of the high-emission scenarios.

The International Panel on Climate Change (IPCC) Fifth Assessment Report in 2014 used a series of four Representative Concentration Pathways (RCPs). Each scenario describes the amount of radiative forcing in the atmosphere that is expected in the year 2100 based on the concentration of GHGs. Radiative forcing is the difference between how much solar radiation enters the Earth's atmosphere and how much is reflected back to space. The radiative forcing is the energy trapped by the atmosphere measured in watts per square meter. Each RCP also describes the pathway, or trajectory, taken to reach the outcome. For long-term climate simulations, Extended Concentration Pathways (ECP) expand the RCPs to 2300. Predicting social and economic factors so far into the future is a challenge, so basic rules were applied to the RCPs to describe future GHG emissions and land use over the next centuries.

Each RCP describes the GHG emission trajectory and concentration that results in that amount of radiative forcing relative to pre-industrial levels (Figure A-1).[7] The RCPs are as follows:

- RCP 8.5: Radiative forcing reaches 8.5 W/m^2 in 2100 and continues to rise. This is described as the high GHG emission or "business as usual" scenario.
- RCP 6: Reaches 6 W/m^2 in 2100 then stabilizes soon after through implementation of strategies for reducing emissions. This is described as the moderate emission scenario.
- RCP 4.5: Reaches 4.5 W/m^2 then stabilizes after 2100. This is described as the low emission scenario.
- RCP 2.6: Radiative forcing peaks at 3.1 W/m^2 by the middle of the century, then declines to 2.6 by 2100. This is the very low scenario, where GHG emissions are reduced substantially.

The RCP scenarios superseded the IPCC Special Report on Emissions Scenarios (SRES) projections published in 2000 (Figure A-1).[8] These scenarios included 40 different narratives for GHG emissions, land use, and other drivers of climate change. They did not include explicit GHG emission controls, climate policy, or implementation of the United Nations Framework Convention on Climate Change. The major groups of SRES scenarios are as follows:

- The A1 storyline describes very rapid economic and global population growth that peaks mid-century and then declines with new technologies. There are three groups that describe the direction of change in the energy system: A1FI (fossil intensive), A1T (non-fossil energy sources), or A1B (balance across all sources). A1FI is described as a high emission, “business as usual” scenario and A1B as a moderate emission scenario.
- The A2 storyline describes continuously increasing global population with slower economic growth and technological change. This is described as a high emission scenario
- The B1 storyline describes global population growth that peaks mid-century and then declines. Clean and resource-efficient technologies are implemented without additional climate initiatives. This is described as a low emission scenario.
- The B2 storyline describes increasing global population at a rate lower than A2, with slower and more diverse technological change than in the B1 and A1 storylines. This is described as a moderate emission scenario.

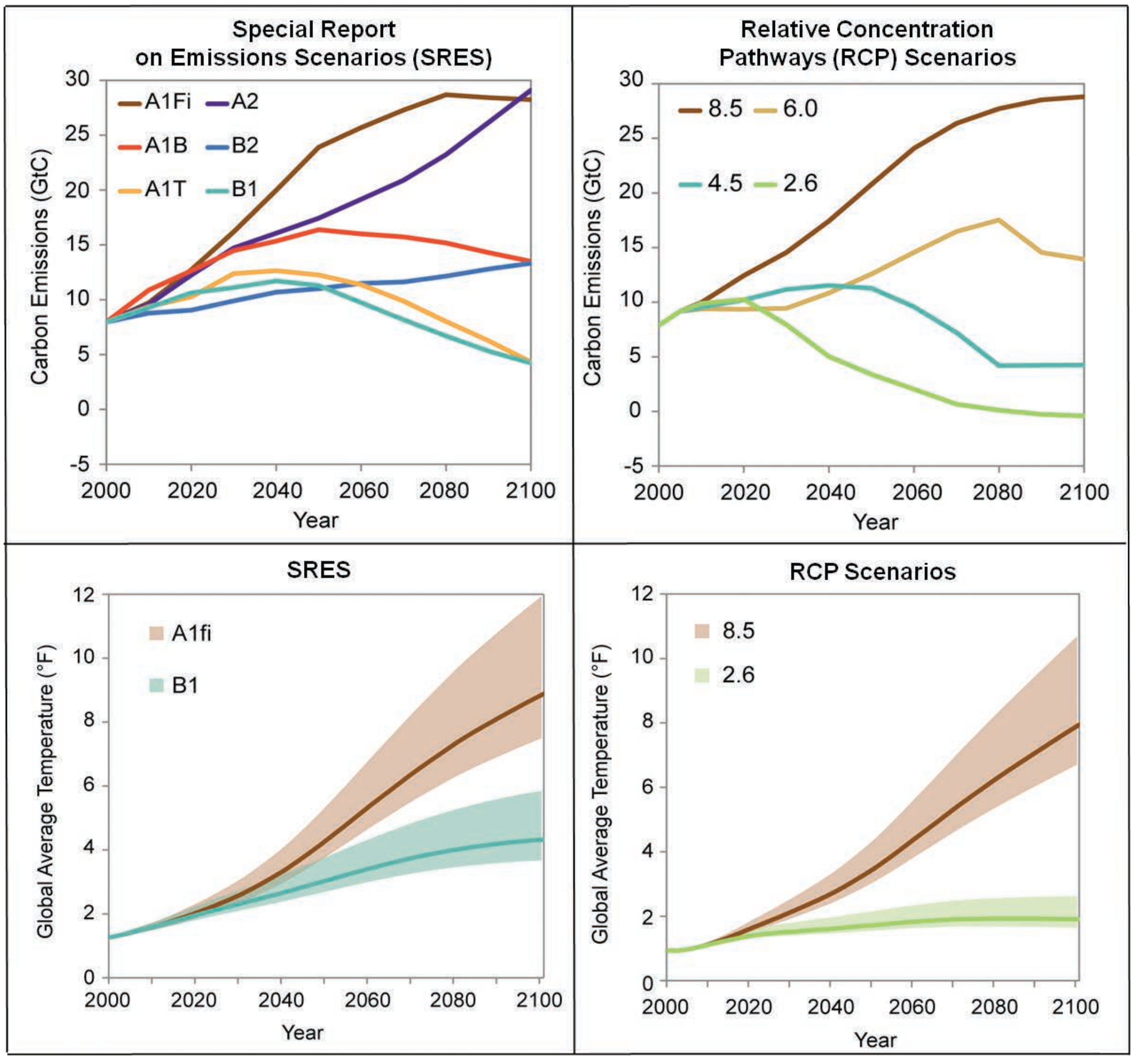

Figure A-1: A comparison of SRES and RCP scenarios for annual carbon emissions (top) and the resulting temperature change (bottom). For temperature, the lines represent the central estimate and the shaded area represents the likely range. Source: adapted from Melillo et al. 2014 with data from CMIP3 and CMIP5.[9]

Regional Climate Models

GCMs are typically run at a scale of 100 to 300 km (62 to 186 mile) grids, a resolution that is too coarse to capture regional conditions.[10] Two types of downscaling methods, statistical and dynamical, can be used to produce projections at a resolution appropriate for decision-making at the local level. Dynamical downscaling uses either a regional climate model with the GCM output for the boundary conditions or a higher resolution GCM. Dynamical models include physical processes that occur at the regional level such as the influence of local topography on weather systems. They can also capture how certain processes will change as the climate changes, such as the snow albedo effect. There is a feedback loop produced because snow reflects more heat than bare ground or open water, which are dark. More snow melt leads to greater heat absorption, which in turn causes more snow melt. Multiple GCMs can be dynamically downscaled to produce probabilistic predictions of regional climate. Statistical downscaling uses historical relationships to connect global atmospheric variables of GCM to regional climate variables. Statistical models do not require as much computing power as dynamical models, so it is generally more cost-effective to run multiple models using statistical methods.

APPENDIX E: CLIMATE CHANGE RESPONSE STRATEGIES

Sources of Information

The following compendium of potential response strategies draws from a number of existing studies along with discussions with tribal staff and regional climate change experts. The key references used for this section are as follows:

Dalton, M.M., P.W. Mote, and A.K. Snover (Eds.). 2013. Climate Change in the Northwest: Implications for Our Landscapes, Waters, and Communities. Washington, DC: Island Press.

Dalton, M. (Ed.) 2016. Climate Change Vulnerability Assessment for the Treaty of Olympia Tribes: A Report to the Quinault Indian Nation, Hoh Tribe, and Quileute Tribe. Prepared by the Oregon Climate Change Research Institute. Corvallis, OR.

Glicksman, R.L., C. O'Neill, Y. Huang, W.L. Andreen, R.K. Craig, V. Flatt, W. Funk, D. Goble, A. Kaswan and R.R.M. Verchick. 2011. Climate Change and the Puget Sound: Building the Legal Framework for Adaptation. Center for Progressive Reform White Paper No. 1108.

Greene, M., T. Thaler, G. Griffith, T. Crossett, and J.A. Perry (Eds.). 2014. Forest and Water Climate Adaptation: A Plan for the Nisqually Watershed. Model Forest Policy Program in association with the Nisqually River Foundation and the Cumberland River Compact; Sagle, ID. Available at www.mfpp.org

Hernández-Padilla, Y., M. Levkowitz, K. Plimpton, and K. Schick. 2015. Coping with a Changing Coast: Adaptation Strategies to Protect the Coastal Culture and Environment of the Jamestown S'Klallam Tribe. University of Washington prepared for Jamestown S'Klallam Tribe. Available at depts.washington.edu/poeweb/keep/keystones/JST%20Keystone_Final%20Report.pdf

Jamestown S'Klallam Tribe. 2013. Climate Change Vulnerability Assessment and Adaptation Plan. Petersen, S. and J. Bell (Eds.). A collaboration of the Jamestown S'Klallam Tribe and Adaptation International. Blyn, WA. Report, appendices, maps, and fact sheets at www.jamestowntribe.org

Kuhlman, K., J. Freimund, and G. Gabrisch. 2016. Lummi Nation Climate Change Mitigation and Adaptation Plan: 2016-2026. Lummi Natural Resources Department, Water Resources Division. Available at lnnr.lummi-nsn.gov

Nooksack Indian Tribe, U.S. Environmental Protection Agency, and Tetra Tech. 2016. Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA. EPA Region 10 Climate Change and TMDL Pilot. In cooperation with Washington Department of Ecology and NOAA Fisheries.

Petersen, S., J. Bell, I. Miller, C. Jayne, K. Dean, and M. Fougerat. 2015. Climate Change Preparedness Plan for the North Olympic Peninsula. A Project of the North Olympic Peninsula Resource Conservation and Development Council and the Washington Department of Commerce, funded by the Environmental Protection Agency. Available at www.noprcd.org

Raymond, C.L., D.L. Peterson, and R.M. Rochefort (Eds.). 2014. Climate change vulnerability and adaptation in the North Cascades region, Washington. Gen. Tech. Rep. PNW-GTR-892. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Swinomish Indian Tribal Community. 2010. Swinomish Climate Change Initiative Climate Adaptation Action Plan. Office of Planning and Community Development. La Conner, WA. Available at www.swinomish.org

Washington State Blue Ribbon Panel on Ocean Acidification. 2012. Ocean Acidification: From Knowledge to Action, Washington State's Strategic Response. Edited by H. Adelsman and L. Whitely Binder. Washington Department of Ecology, Olympia, WA. Publication No. 12-01-015.

Freshwater Hydrology

- Flooding:
  - Use natural flood protection (e.g. vegetation or engineered logjams).
  - Restore native plant species in riparian areas.
  - Expand current restoration projects to mitigate increasing flood risk.
  - Control invasive plant species in flood-prone reaches.
- Low flows:
  - Manage upland vegetation to retain water and snow in order to slow spring snowmelt and runoff.
  - Restore mid- and high-elevation wetlands that have been altered by past management.
  - Protect wetland-fed streams that maintain higher summer flows.
  - Increase upland water storage by managing for greater beaver populations.
    - Accommodate and maintain higher beaver populations.
    - Trap and relocate perceived nuisance beavers.
  - Water conservation and reuse:
    - Integrate climate change scenarios into water supply system.
    - Upgrade facilities to reduce water use (administrative buildings, housing, museums, cultural centers, commercial buildings).
    - Gray water recycling systems.
    - Coordinate with partners on water conservation education.
- Water quality:
  - Prevent or limit groundwater extraction from shallow aquifers.
  - Develop adaptive stormwater management practices (e.g. remove impervious surface, replace undersized culverts).
  - Include climate change projections in identification of potential areas for stream bank and upland erosion.
  - Inventory disturbed areas for candidate sites for riparian and upland vegetation restoration.

Salmonid Population Resilience

- Restore structure and function of streams:
  - Increase habitat and refugia in side channels, cold tributaries, and headwater streams.
  - Restore habitat heterogeneity in stream channels.
  - Remove levees.
  - Restore and protect riparian vegetation.
- Restore floodplain structure and processes:
  - Increase off-channel habitat and protect refugia in side channels and channels fed by wetlands.
  - Restore floodplain complexity.
  - Increase use of engineered logjams and large woody debris where feasible.
  - Reduce roads and infrastructure in the floodplain.
  - Designate and restore natural floodplain boundaries.
  - Increase floodplain habitat.
  - Increase culvert capacity.
- Spawning habitat resilience:
  - Increase protection of alternative spawning habitat.
  - Consider removing natural barriers to increase spawning habitat.
- Remove non-native species:
  - Survey and map non-native species.

  - Consider information from surveys of warmer basins farther south as indicators of vulnerability.
  - Remove or control non-native fish species.
  - Remove barriers to fish passage where this will not increase threats from non-native species.
  - Maintain or construct barriers to prevent spread of non-native species.
- Increase population resilience by increasing fish health:
  - Increase public education to eliminate disease vectors.
  - Direct treatment or removal of infected fish.
  - Survey fish health conditions.
  - Collaborate and standardize health survey methods among agencies.
  - Consider changes in hatchery practices.
- Monitor changes in aquatic food web dynamics:
  - Assess food webs for baseline data.
  - Monitor food web dynamics for changes with warming.
- Adjust hatchery practices:
  - Water intake.
  - Timing of salmon release.
- Adjust harvest timing.

Freshwater Wetlands

- Reduce direct human impact on sensitive wetland habitats.
- Explore retention of snowpack near sensitive habitat.
- Retain water levels in wetlands when controlled by reservoir systems.
- Increase resilience by preserving biodiversity.
- Monitor and prioritize regions for wetlands management.
- Maintain hydrology of critical habitats.
- Use vegetation to increase shading of wetlands and microhabitats.
- Increase microhabitat structures (e.g. woody debris) for microclimate refugia, nesting, habitat, and egg deposition structures.
- Increase resilience to disease and pathogens:
  - Use decontamination procedures and consider microbial treatments.
  - Educate the public about disease sensitivities.
  - Manage or limit recreation and other use through closures or other means.
- Provide dispersal cover between aquatic and upland habitats.
- Increase beaver populations to create more wetland habitat.

Terrestrial and Riparian Vegetation Communities

- Increase resilience by promoting native genotypes and adapted genotypes of native species:
  - Consider assisted migration where compatible with treaty rights.
  - Emphasize use of plant species that will be robust to climate change in restoration projects.
  - Plant genetically adapted species from appropriate seed zones.

- Increase habitat connectivity and permeability:
    - Increase use of conservation easements.
    - Protect and restore migration corridors.
- Increase resilience of forest stands to disturbances by increasing tree vigor:
    - Thin to accelerate development of late-successional forest conditions, decrease stand density, and increase tree vigor.
    - Harvest to variable densities.
    - Plant insect- or pathogen-resistant species or genotypes.
    - Increase stand-level biodiversity and minimize monocultures.
    - Treat existing pathogen outbreaks with more aggressive management.
    - Increase landscape biodiversity and heterogeneity by modifying species composition.
    - Increase diversity of age classes and restore patch mosaic.
    - Protection of critical habitat structures (e.g. snags and nest trees).
    - Allow shifts in native species ranges.
- Culturally important or rare plant species:
    - Identify areas where rare plants could be established.
    - Seed collection and seed banks.
- Maintain or increase the extent of subalpine areas for traditional uses of plant species:
    - Maintain huckleberry production through tree removal and prescribed fire.

Wildlife Populations

- Reduce existing stressors.
- Facilitate recovery with habitat manipulation.
- Relocate species as necessary.
- Increase habitat connectivity and heterogeneity.
- Maintain and enhance habitat quality to boost survival of all life stages.
- Protect critical areas:
    - Prioritize habitats for active management and protection across jurisdictional boundaries.
    - Focus monitoring on sensitive habitats and species in priority regions.
    - Periodically review and revise priorities.
- Increase monitoring of specialist species that are expected to be sensitive to climate change:
    - Identify climate refugia.
    - Adjust monitoring protocols to detect species’ responses to climate change.
- Conserve winter range for ungulate species:
    - Identify critical winter habitat for ungulate species.
    - Increase collaboration with partners to conserve critical winter habitat.

Disturbances from Wildfire, Pests, and Disease

- Plan for more frequent and severe fire and greater area burned:
    - Incorporate climate change into fire management plans.
    - Plan post-fire response for large fires.
    - Consider planting fire-tolerant tree species post-fire in areas with increasing fire frequency.
    - Manage and plan growth in the wildland-urban interface.
    - Increase management of human ignition sources.
    - Increase use of conservation easements.

- Increase resilience of existing vegetation by reducing hazardous fuels:
  - Thin and prescribe burn to reduce hazardous fuels in the wildland-urban interface.
  - Consider thinning outside of wildland-urban interface if fire risk necessitates.
  - Consider using more prescribed fire where scientific evidence supports change to more frequent fire regime.
  - Increase coordination and shared risk with state and federal partners.
  - Anticipate greater need for seed sources and propagated plants.
  - Experiment with planting native grass species to compete with cheat grass postfire.
  - Increase postfire monitoring in areas not currently monitored.
- Increase forest landscape resilience to large and extensive insect or pathogen outbreaks:
  - Design forest gaps that create establishment opportunities.
  - Increase diversity of patch sizes.
  - Consider planting desired species (assisted migration) rather than relying on natural regeneration and migration.
  - Protect remnant habitat from insect outbreaks.
- Invasive Species:
  - Prevent invasive plants from establishing after disturbances.
  - Include invasive species prevention strategies in all projects.
  - Coordinate invasive species management with partners.

Sea Level Rise and Storm Surge

- Protect and restore salt marshes and coastal wetlands:
  - Identify and protect ecologically significant areas such as nursery grounds, spawning grounds, and areas of high species diversity.
  - Preserve and restore the structural complexity and biodiversity of vegetation in tidal marshes and eelgrass meadows.
  - Allow salt marshes and coastal wetlands to migrate inland through setbacks, density restrictions, and land purchase. This may not be appropriate in some locations due to biological or geological processes that prevent wetland migration inland.
  - Promote salt marsh accretion by introducing sediment through re-establishing distributary channels on river deltas.
  - Remove hard protection or other barriers to tidal and riverine flow.
  - Incorporate salt marsh protection into infrastructure planning (e.g. transportation planning, wastewater utilities).
  - Establish rolling easements, a type of easement placed along the shoreline to prevent property owners from armoring the shoreline. As the sea advances, the easement automatically moves or "rolls" landward. Unlike setbacks, which prohibit development near the shore, rolling easements place no restrictions on development with the understanding that the landowner will not be able to prevent shoreline erosion with armoring. If erosion threatens a structure, the owner will have to relocate the building or allow erosion to occur.
- Preserve habitat for vulnerable species:
  - Adapt protections of important biogeochemical zones and critical habitats as the locations of these areas change with climate.
  - Connect landscapes with corridors to enable migrations.
  - Design estuaries with dynamic boundaries and buffers.
  - Replicate habitat types in multiple areas to spread risks associated with climate change.
- Living Shorelines:
  - Replace shoreline armoring with living shorelines through beach nourishment, planting vegetation, addition of wood, and limited use of rock to provide shoreline protection while maintaining natural ecological and geomorphic processes.

  - Remove shoreline hardening structures such as bulkheads, dikes, and other engineered structures to allow for shoreline migration.
  - Plant submerged aquatic vegetation such as eelgrass to stabilize sediment and reduce erosion.
  - Create and restore salt marsh by planting the appropriate vegetation.
  - Create dunes along backshores of beach; includes planting dune grasses and sand fencing to induce settling of wind-blown sands.
  - Use natural breakwaters of oysters, rock, or other natural materials to dissipate wave action and protect shorelines and tidal marshes along energetic estuarine shores.
  - Restrict or prohibit development in erosion zones.
  - Redefine flood hazard zones to match projected expansion of flooding frequency and extent.
  - Increase shoreline setbacks.
  - Composite systems that incorporate elements of two or more methods (e.g. breakwater, sand replenishment, and planting vegetation).
- Maintain shorelines using “hard” measures only when absolutely necessary to preserve existing development and infrastructure since they may not be sustainable for protecting coastal land in the long term and they have potential negative impacts on habitats and ecosystems.
- Maintain sediment transport:
  - Trap or add sand through beach nourishment (the addition of sand to a shoreline to enhance or create a beach area).
  - Create a regional sediment management plan.
  - Develop adaptive stormwater management practices (e.g. promoting natural buffers, adequate culvert sizing) to preserve natural sediment flow and protect water quality.
- Preserve coastal land (including infrastructure):
  - Integrate coastal management into land-use planning.
  - Create permitting rules that constrain locations for landfills, hazardous waste dumps, mine tailings, and toxic chemical facilities.
  - Land acquisition program–purchase coastal land that is damaged or prone to damage and use it for conservation.
- Invasive species management:
  - Strengthen rules that prevent the introduction of invasive species (e.g. enforce no-discharge zones for ballast water).
  - Remove invasive species and restore native species.
- Maintain water quality:
  - Plug drainage canals to prevent subsidence-inducing saltwater intrusion; protect land subject to flooding.
  - Design new coastal drainage systems, especially where improvements are already needed.

Ocean Acidification and Shellfish Management

- Work with international, national, and regional partners to advocate for a comprehensive strategy to reduce carbon dioxide emissions.
- Strengthen local source control programs to achieve needed reductions in inputs of upland sources of nutrients and organic carbon.
- Investigate and develop commercial-scale water treatment methods or hatchery designs to protect larvae from corrosive seawater.
- Identify, protect, and manage refuges for organisms vulnerable to OA and other stressors.
- Provide a forum for agricultural, business, and other stakeholders to engage with coastal resource users and managers in developing and implementing solutions.
- Establish and maintain a monitoring network to measure ocean conditions and biological responses.

- Develop the ability to make short-term forecasts of corrosive conditions for shellfish hatcheries, growing areas, and other areas of concern.
- Explore feasibility of sustainable shellfish aquaculture.
- Adjust hatchery practices:
  - Timing of shellfish water intake.
  - Explore upland seeding operations to allow for proper growth and development under controlled conditions. Once they reach sufficient size and maturity, they could be transplanted to established beds.
- Re-establish shellfish beds after shoreward habitat migration.

Social and Cultural Resilience

- Education and communication:
  - Include climate change in school curricula.
  - Communicate risks and opportunities with tribal leaders and tribal members.
  - Integrate the resilience efforts of multiple departments within each tribe.
- Address risks to infrastructure:
  - Coastal erosion.
  - Chronic road repair.
  - Road closure and access to traditional gathering sites.
  - Development in channel migration zone.
- GHG emission reduction:
  - Renewable energy sources for tribal and other communities.
  - Carbon sequestration opportunities such as forests and Blue Carbon in estuaries and salt marshes.
  - Address short-term and long-term risks of oil and coal transport through pipelines, railroads, and marine vessels.

APPENDIX F: TRIBAL CLIMATE CHANGE STUDIES

All of the western Washington treaty tribes have climate change studies in progress that evaluate the impacts specific to each tribe. The assessments, studies, and reports completed at the time of publication of this document are presented below:

Jamestown S'Klallam Tribe:

Jamestown S'Klallam Tribe. 2013. Climate Change Vulnerability Assessment and Adaptation Plan. Petersen, S. and J. Bell (Eds.). A collaboration of the Jamestown S'Klallam Tribe and Adaptation International. Blyn, WA. Report, appendices, maps, and fact sheets at www.jamestowntribe.org

Hernández-Padilla, Y., M. Levkowitz, K. Plimpton, and K. Schick. 2015. Coping with a Changing Coast: Adaptation Strategies to Protect the Coastal Culture and Environment of the Jamestown S'Klallam Tribe. Prepared for Jamestown S'Klallam Tribe by the University of Washington. Seattle, WA. Available at depts.washington.edu/poeweb/keep/keystones/JST%20Keystone_Final%20Report.pdf

Lummi Nation:

Kuhlman, K., J. Freimund, and G. Gabrisch. 2016. Lummi Nation Climate Change Mitigation and Adaptation Plan: 2016-2026. Lummi Natural Resources Department, Water Resources Division. Bellingham, WA. Available at lnnr.lummi-nsn.gov

Kuhlman, K., J. Freimund, and G. Gabrisch. 2016. Lummi Nation Strategic Energy Plan: 2016-2026. Lummi Natural Resources Department, Water Resources Division. Bellingham, WA. Available at lnnr.lummi-nsn.gov

Nooksack Indian Tribe:

Beaulieu, J. and O. Grah. 2015. Nooksack River Watershed Glacier Monitoring Summary Report 2015. Prepared for the Nooksack Indian Tribe. Deming, WA.

Grah, O. and J. Beaulieu. 2013. The effect of climate change on glacier ablation and baseflow support in the Nooksack River basin and implications on Pacific salmonid species protection and recovery. Climatic Change 120: 557-567.

Nooksack Indian Tribe, U.S. Environmental Protection Agency, and Tetra Tech. 2016. Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA. EPA Region 10 Climate Change and TMDL Pilot. In cooperation with Washington Department of Ecology and NOAA Fisheries.

Puyallup Tribe:

Puyallup Tribe of Indians. 2016. Climate Change Impact Assessment and Adaptation Options. A collaboration of the Puyallup Tribe of Indians and Cascadia Consulting Group. Available at www.puyallup-tribe.com/#2

Quileute Tribe:

Krueger, K. 2016. Climate Plan for the Quileute Tribe of the Quileute Reservation. Prepared for Quileute Natural Resources. La Push, WA. Available at www.quileutenation.org/climate-change

Shannon, D.T., R. Kopperl, and S. Kramer. 2016. Quileute Traditional Ecological Knowledge and Climate Change Documents Review. Prepared for the Quileute Tribe by Willamette Cultural Resources Associates, Ltd. Seattle, WA. Available at www.quileutenation.org/climate-change

Quinault Indian Nation, Hoh Tribe, and Quileute Tribe:

Dalton, M. (Ed.) 2016. Climate Change Vulnerability Assessment for the Treaty of Olympia Tribes: A Report to the Quinault Indian Nation, Hoh Tribe, and Quileute Tribe. Prepared by the Oregon Climate Change Research Institute. Corvallis, OR.

Sauk-Suiattle Indian Tribe:
Sauk-Suiattle Indian Tribe. 2014. Flood and Erosion Hazard Assessment for the Sauk-Suiattle Indian Tribe: Phase 1 Report for the Sauk River Climate Impacts Study. A collaboration of the Sauk-Suiattle Indian Tribe and Natural Systems Design. Darrington, WA.

Stillaguamish Indian Tribe:
Hall, J.E., T.J. Beechie, and G.R. Pess. 2014. Influence of climate and land cover on river discharge in the North Fork Stillaguamish River. Contract report by NOAA Fisheries, Northwest Fisheries Science Center for the Stillaguamish Tribe of Indians. Seattle, WA. Available at www.eopugetsound.org.

Krosby, M., H. Morgan, M. Case, and L. Whitely Binder. 2015. Stillaguamish Tribe Natural Resources Climate Change Vulnerability Assessment. Prepared by the Climate Impacts Group, University of Washington for the Stillaguamish Tribe of Indians. Seattle, WA.

Tohver, I., L. Whitely Binder, G. Mauger, and M. Krosby. 2015. Summary of Projected Changes in Physical Conditions in the Stillaguamish Watershed and Treaty Areas. Prepared by the Climate Impacts Group, University of Washington for the Stillaguamish Tribe of Indians. Seattle, WA.

Swinomish Indian Tribal Community:
Swinomish Indian Tribal Community. 2009. Swinomish Climate Change Initiative Impact Assessment Technical Report. Office of Planning and Community Development, La Conner, WA. Available at www.swinomish.org

Swinomish Indian Tribal Community. 2010. Swinomish Climate Change Initiative Climate Adaptation Action Plan. Office of Planning and Community Development. La Conner, WA. Available at www.swinomish.org

Donatuto, J., E.E. Grossman, J. Konovsky, S. Grossman and L.W. Campbell. 2014. Indigenous community health and climate change: Integrating biophysical and social science indicators. Coastal Management 42(4): 355-373.

Upper Skagit Indian Tribe:
Convivium Renewable Energy. 2013. Feasibility of Wind to Serve Upper Skagit's Bow Hill Tribal Lands and Feasibility Update for Residential Renewable Energy. Prepared for Upper Skagit Indian Tribe. Sedro-Woolley, WA. Available at energy.gov/sites/prod/files/2015/12/f27/usit_final_report.pdf

Nisqually River Foundation, with the Nisqually Indian Tribe as a partner:
Greene, M., T. Thaler, G. Griffith, T. Crossett, and J.A. Perry (Eds.). 2014. Forest and Water Climate Adaptation: A Plan for the Nisqually Watershed. Model Forest Policy Program in association with the Nisqually River Foundation and the Cumberland River Compact, Sagle, ID. Available at www.mfpp.org/wp-content/uploads/2011/04/Nisqually-Forest-Water-Climate-Adaptation-Plan-Final-2014.pdf

North Olympic Peninsula Resource Conservation and Development Council, with the Makah Tribe, Jamestown S'Klallam Tribe, and Lower Elwha Klallam Tribe as partners:
Petersen, S., J. Bell, I. Miller, C. Jayne, K. Dean, and M. Fougerat. 2015. Climate Change Preparedness Plan for the North Olympic Peninsula. A Project of the North Olympic Peninsula Resource Conservation and Development Council and the Washington Department of Commerce, funded by the Environmental Protection Agency. Available at www.noprcd.org

APPENDIX CITATIONS

[1] Southeast Regional Climate Center. 2015. Period of Record Monthly Climate Summary for Station Miami WSCMO Airport, Florida (085663) Period of Record : 7/1/1948 to 4/30/2012. Available at http://www.sercc.com/cgi-bin/sercc/cliMAIN.pl?fl5663

[2] Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis. 1997. A Pacific decadal climate oscillation with impacts on salmon. Bulletin of the American Meteorological Society 78:1069-1079.

[3] IPCC. 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY: Cambridge University Press. Available at http://www.ipcc.ch

[4] Taylor, K.E., R.J. Stouffer, and G.A. Meehl. 2012. An Overview of CMIP5 and the experiment design. Bulletin of the American Meteorological Society 93: 485-498.

[5] Dalton, M.M., P.W. Mote, and A.K. Snover (Eds.). 2013. Climate Change in the Northwest: Implications for Our Landscapes, Waters, and Communities. Washington, DC: Island Press. Available at http://occri.net/wp-content/uploads/2013/11/ClimateChangeInTheNorthwest.pdf

[6] IPCC. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (Eds.)]. IPCC, Geneva, Switzerland. Available at http://www.ipcc.ch/report/ar5/syr

[7] van Vuuren, D.P., J. Edmonds, M. Kainuma, K. Riahi, A. Thomson, K. Hibbard, G.C. Hurtt, T. Kram, V. Krey, J.F. Lamarque, T. Masui, M. Meinshausen, N. Nakicenovic, S.J. Smith, and S.K. Rose. 2011. The representative concentration pathways: an overview. Climatic Change 109:5-31.

[8] Nakicenovic, N. and R. Swart (Eds.). 2000. Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. Available at http://www.grida.no/climate/ipcc/emission/index.htm

[9] Melillo, J.M., T.C. Richmond, and G.W. Yohe (Eds.). 2014. The Third National Climate Assessment, U.S. Global Change Research Program, Washington, DC. Available at http://nca2014.globalchange.gov

[10] Dalton, M.M., P.W. Mote, and A.K. Snover (Eds.). 2013. Climate Change in the Northwest: Implications for Our Landscapes, Waters, and Communities. Washington, DC: Island Press. Available at http://occri.net/wp-content/uploads/2013/11/ClimateChangeInTheNorthwest.pdf

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