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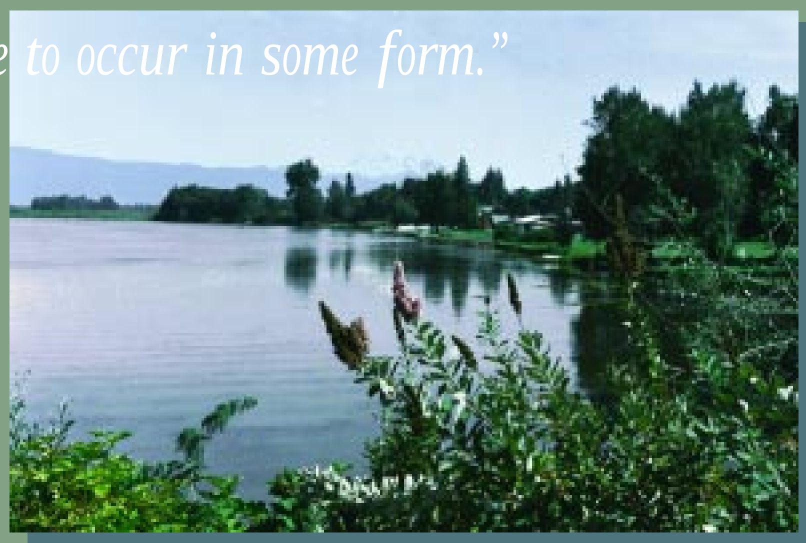


The study of climate impacts notes how climate, natural resources, and socioeconomic systems affect each other.

IMPACTS OF CLIMATE CHANGE ON THE PACIFIC NORTHWEST

SUMMARY

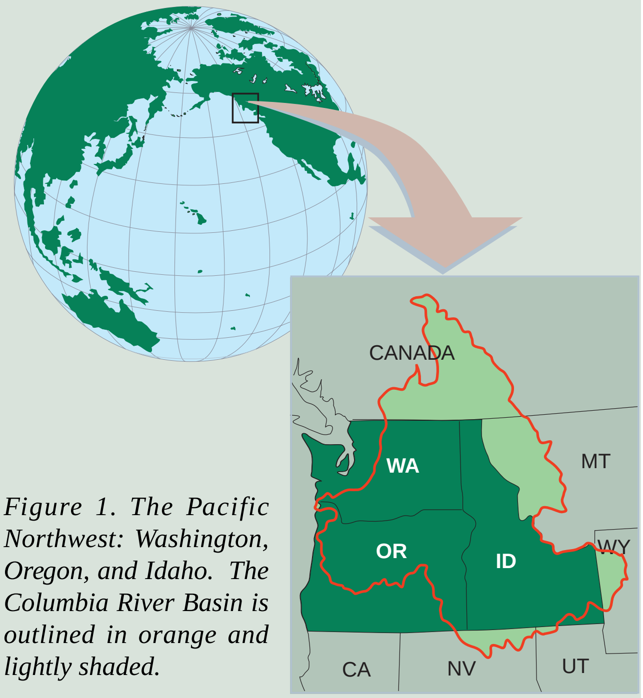


Figure 1. The Pacific Northwest: Washington, Oregon, and Idaho. The Columbia River Basin is outlined in orange and lightly shaded.

Introduction

Climate scientists generally agree that humans are changing the climate, and that if we continue pumping carbon dioxide (CO_2) into the atmosphere, the climate of the 21st century will be different from the climate of the 20th century.[1] What might future climate be like in the Pacific Northwest (PNW, Figure 1)? What can we learn from past climate variations? How can we best adapt to climate change? This report attempts to answer these questions, and is a summary of a longer report[2] about the impacts of climate variability and change on the Pacific Northwest. These reports represent an ongoing research effort by the Climate Impacts Group (CIG), a group of scientists and policy analysts at the University of Washington.

The impacts of climate on natural resources depend on the characteristics of the human institutions that use and manage

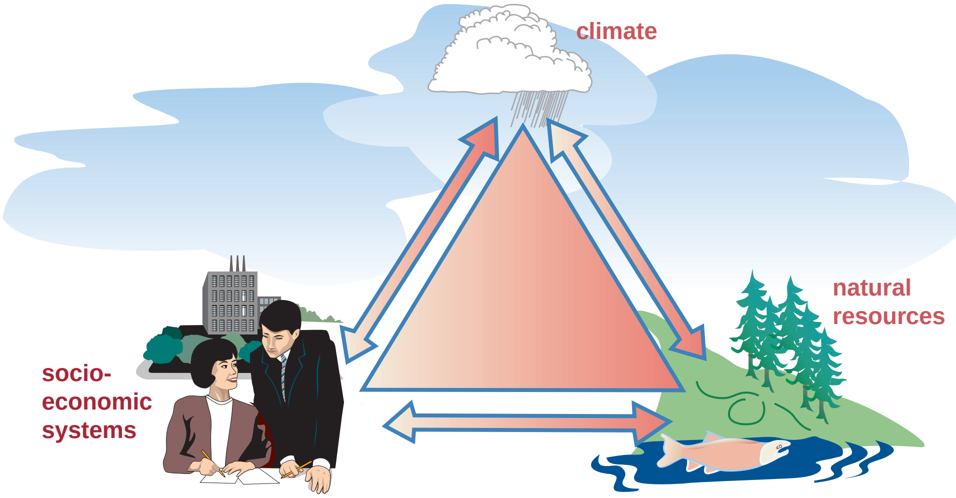


Figure 2. The study of climate impacts involves studying how climate, natural resources, and socioeconomic systems affect each other, not just how climate affects natural resources.

those resources. Thus, to understand the impacts of climate variations and change, we must understand the human institutions as well (Figure 2). One step in this understanding took place at a workshop in 1997, at which local scientists and decision-makers generated many ideas about how to adapt to climate change, which are mentioned later. In order to fully understand the impacts of climate change, it is also vitally important to understand how past fluctuations in climate have affected the region's natural resources, and how the human institutions have responded. It is from these efforts that we examine how climate change could affect the PNW, and how the region can best prepare for these changes.

Impacts of past climate variability

In common with much of the West, the PNW experiences huge seasonal fluctuations in precipitation, with low precipitation in summer and high precipitation in winter. Storage of water in reservoirs and as snow on the mountains provides water during the dry summers, supplying the region's ecosystems, agriculture, cities, and hydropower. Indeed, water in its various forms is central to our consideration of the impacts of climate variability.

On the broadest scale, atmospheric circulation patterns, especially those connected with the Pacific Ocean, influence the climate of the region. There are two main patterns of Pacific climate variability: the Pacific Decadal Oscillation (PDO) and the El Niño Southern Oscillation (ENSO). The PDO is a pattern that reverses on a 20-30 year timescale and is dominant in the North Pacific, and naturally the adjacent regions of North America see the greatest effects. ENSO, which recurs on a 2-7 year timescale, is dominant in the *tropical* Pacific but exerts considerable influence over the North Pacific and North America too. Like a quarterback calling one of two main types of plays, PDO and ENSO each tend to push PNW climate toward one of two main patterns: cool-wet or warm-dry (Figure 3). Despite the importance of his role, the quarterback is only one of many factors influencing the outcome of the play. Likewise, PDO and ENSO influence seasonal weather but do not control it. As Figure 3 illustrates, the cool-wet and warm-dry patterns each have a different set of impacts on the region's natural resources.

The time histories of PDO and ENSO can be correlated with time histories of other quantities, like snow depth, to gauge the impact that these year-to-year variations over the Pacific Ocean have on the region's natural resources. Even though the variations in temperature and precipitation are about the same size for PDO as for ENSO, the persistent nature of the

Climate change in the PNW

During this century, the PNW has become warmer and wetter. The average trend in temperature is +1.4° per century, and precipitation has increased an average of 2.9". While we cannot be sure that these changes are caused by rising levels of CO_2, they are consistent with scenarios of future climate in the PNW generated by computer programs called "climate models." Climate models apply the laws of physics to the "climate system" (the ocean, atmosphere, land, and sea ice) in order to calculate the effects that increases in atmospheric CO_2 levels will have on the climate. (CO_2 has increased more than 30% since the beginning of the industrial revolution, largely because of the burning of fossil fuels, and is expected to continue increasing at an ever-faster rate like compounding interest.)

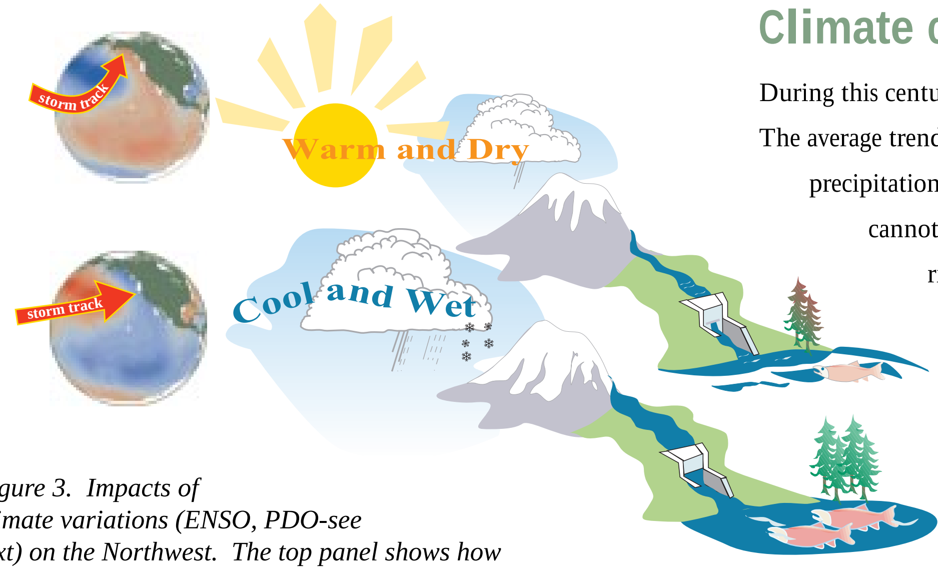


Figure 3. Impacts of climate variations (ENSO, PDO-see text) on the Northwest. The top panel shows how conditions over the North Pacific (specifically changes in sea surface temperature [SST], colors) lead to slightly warmer, drier weather with less snow, less water in the rivers, less abundant salmon, and more difficulties for trees. The bottom panel shows how the opposite changes in SST have the opposite effects.

PDO means that it has stronger impacts on some quantities than does ENSO. For that reason and because its timescale (20-30 years) is a bit closer to the climate-change timescale (50-100 years), we focus on PDO and its impacts (Figure 3). A cool-wet winter tends to have deeper than average snowpack, which results in more spring runoff and more soil moisture in the spring and summer. As a result, there is more water for both natural uses (salmon in the freshwater stage of their life cycle, trees going through their spring growth) and human uses (irrigated agriculture, hydropower, municipal water supply). Figure 4 shows just how much the PDO affects climate, water resources, salmon, and forests in the PNW. Even though the variations in temperature and precipitation associated with the PDO are small, they have had a significant impact on some of the region's natural resources. These impacts offer useful clues about how climate change may affect the region.

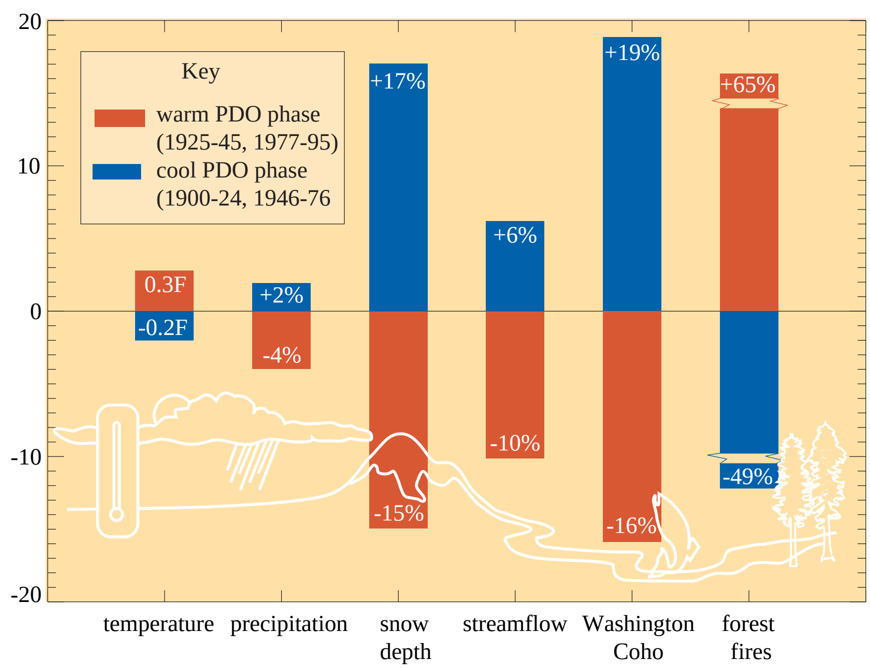


Figure 4. Changes as a percentage of average (except for temperature) for available data during the warm and cool phases of the PDO. Temperature (averaged over the PNW, for October-March), total annual precipitation (averaged over the PNW); snow depth (average from 15 January to 15 April at Snoqualmie Pass, Washington); streamflow (at The Dalles, corrected for the changing effects of dams); annual catch of Washington coho salmon; area burned by forest fires in Washington and Oregon.

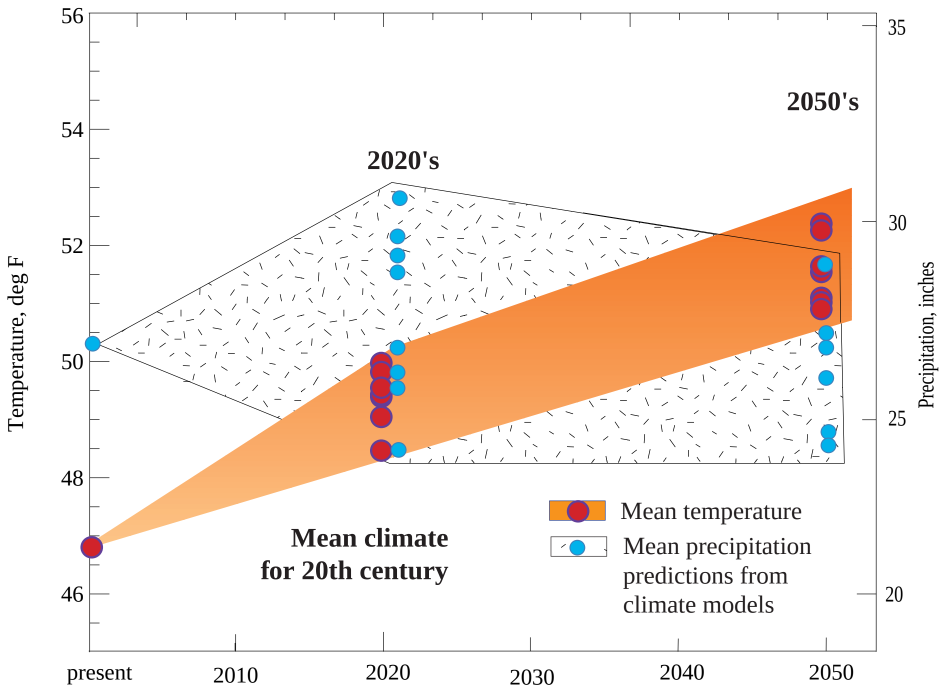


Figure 5. Changes in average temperature and precipitation from seven climate model scenarios. Each dot represents a 10-year average for one model.

What can we see in the future of the PNW? Warmth. We examined seven climate models, and all show substantial increases in temperature by the 2020's (Figure 5), well outside the natural range of climate in the 20th century. The models suggest small changes in yearly average precipitation, but the seasonal trends are larger: nearly all the climate models show wetter winters and drier summers in the future.

Can we believe these models? They have a number of deficiencies, to be sure, but they have captured past trends in the PNW fairly well (Figure 6). As CO_2 accumulates faster in the atmosphere, these past trends will probably accelerate as shown.

Impacts on water resources

Climate models, when combined with models of the region's river systems, can give us details about how climate change could affect the region's water resources. The most significant change, one we can be fairly sure will happen, is that snow cover will shrink in coming decades, with lower elevations losing snow first. During the winter, warmer temperatures will mean that precipitation falls less as snow and more as rain, reducing the amount of water stored naturally for later use. A shift from snowfall to rainfall at moderate elevations leads to a number of changes in the PNW's "water year." Less snow means earlier and lower spring runoff, and less water available for summer use; we can point to specific years in the

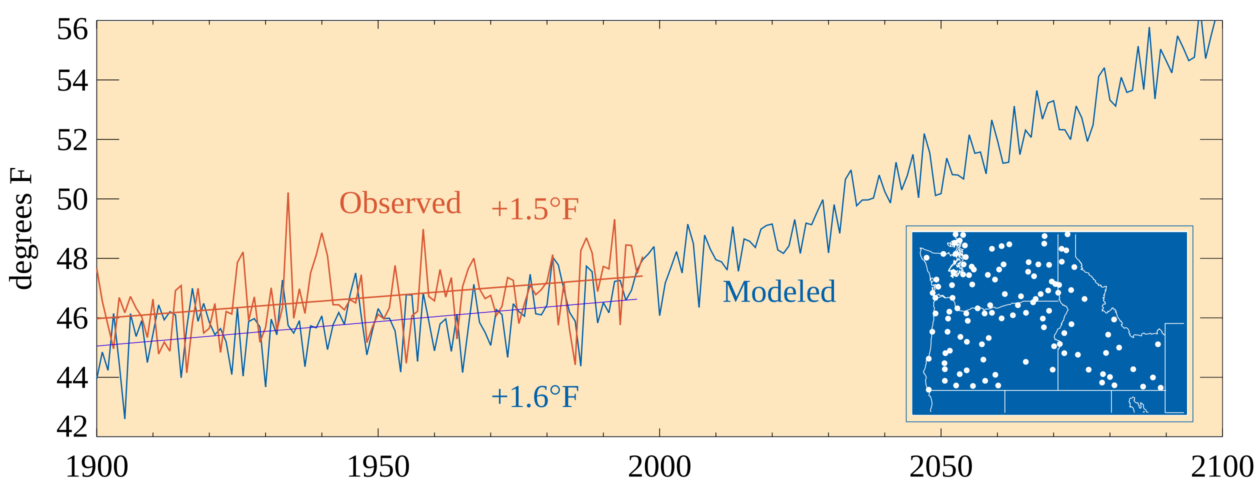


Figure 6. Trends in temperature averaged over 113 stations in the PNW with long records, compared to the average temperature simulated in a 200-year climate model run. Note the good agreement in both the average temperature and the trends over the 20th century. Individual years are not expected to match up. Inset shows location of stations.

past, like 1992, when this has been the case. Higher winter runoff increases river flow and the likelihood of floods, mostly in lower elevation river basins. In addition, increases in summer temperatures raise the rate at which plants draw water out of the soil. When climate change scenarios are applied to models that simulate the region's rivers, the peak flows from spring snowmelt happen earlier: about one month earlier for the Columbia (Figure 7). Less water will be available in summer.

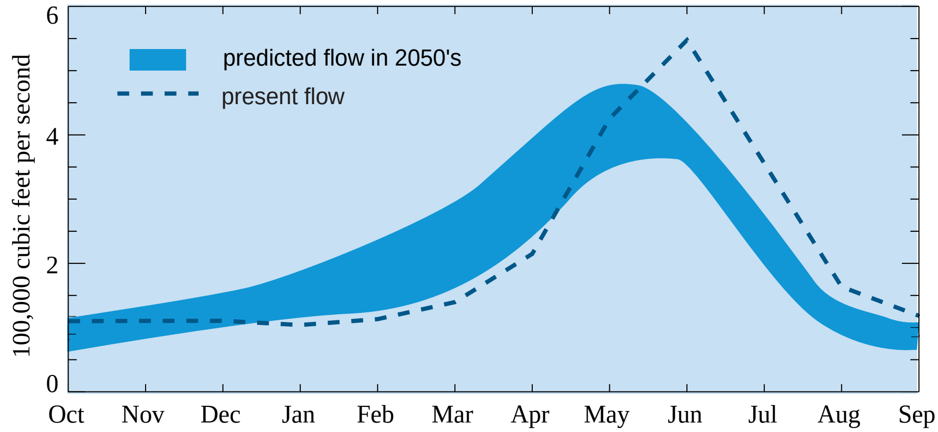
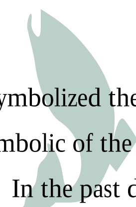


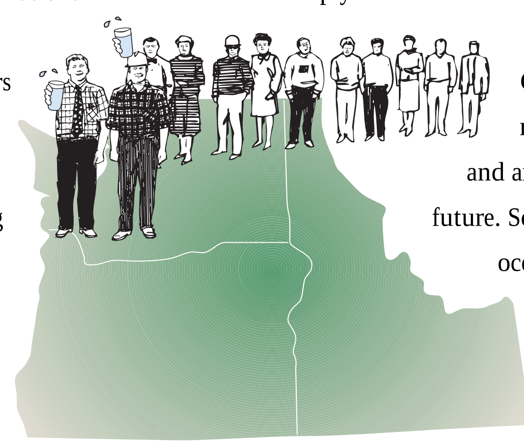
Figure 7. Columbia River flow at present (dashed) and in 2050, as simulated by several climate models.

The future, therefore, probably holds increases in winter flooding and — paradoxically— increases in summer drought. How will the region fare? In the Columbia Basin, an extensive network of dams help store water for summer use and guard against flooding. When flooding threatens, the Army Corps of Engineers, which manages reservoirs for flood control, has clear authority to prevent flooding. But the water management system lacks a single clear authority to prevent or mitigate droughts. When droughts occur, hundreds of entities including states, irrigation districts, fisheries managers, and tribes all assert their rights to scarce water. Droughts, like the 1994 drought in the Yakima Valley, cause bitter disputes and huge economic losses for those who depend on summer water and do not receive it. In a future with drier summers, such conflicts and losses will become more frequent. Furthermore, the region's vigorous population growth rate has been about twice the national rate for the last 30 years, and is expected to add another 5 million inhabitants in the next 30 years (concentrated west of the Cascade Mountains). Population growth will increase the demand for water at a time when climate change is squeezing the existing water supply.

Salmon



Pacific salmon once symbolized the bounty of the PNW, but today they are also symbolic of the costs of industrialization and resource exploitation. In the past decade, sharp restrictions on fishing opportunities for sport, tribal, and commercial fishers have had devastating impacts on the local economies that once revolved around salmon. In March 1999, the National Marine Fisheries Service listed 8 PNW salmon stocks as threatened, and one as endangered, under the federal Endangered Species Act. These listings bring the regional total to 24 ESA-protected salmon stocks, and more are currently under review. There are widespread fears that declining numbers of wild salmon and the expanding number of ESA-protected stocks will force socio-economic hardships on a scale that dwarfs that of the former salmon industry. Local, county, state, tribal, and federal agencies are now scrambling to develop regulations that will comply with federal ESA mandates.



Climate variations have clearly played a role in PNW salmon history (Figure 4), and are expected to be important in the future. Some have suggested that unfavorable ocean conditions associated with the warm phase of the PDO (top of Figure 3) have masked management efforts aimed at rebuilding PNW salmon numbers in the past two decades.

There are strong indications that anthropogenic climate change will add to the already long list of human-caused problems that now plague PNW salmon. Trends towards warmer temperatures (see Figure 6) in streams, estuaries, and the coastal ocean, combined with reduced summer streamflow — a likely byproduct of climate change (see Figure 7) — may push already-threatened salmon stocks over the brink to extinction.

Forests

Some types of trees grow better with more CO_2 in the air, but for most Northwestern trees, the normal summer dry period is the strongest limitation they face to growth. Furthermore, drought increases the likelihood that trees will be weakened or killed by insects or forest fires. Both tree growth and forest fires depend on the PDO: warm-dry PDO means lower rates of tree growth (except at high elevation, where snow limits tree growth) and greater risk of fires. Looking to the future then, a warmer climate poses problems for Northwest forests. Less snow means drier soil, making it harder for seedlings to get started and harder for bigger trees to grow (again, except at high elevation). But perhaps the greater threat to forests is that posed by the possible increases in "disturbances", wildfire and pests in particular, which can damage or kill large sections of forest and "wipe the slate clean" for a new forest. In a changing climate, there may not be any nearby trees suitable for establishing a new forest; the slate may stay clean in some areas. This is more likely to occur east of the Cascades because of the naturally dry conditions.

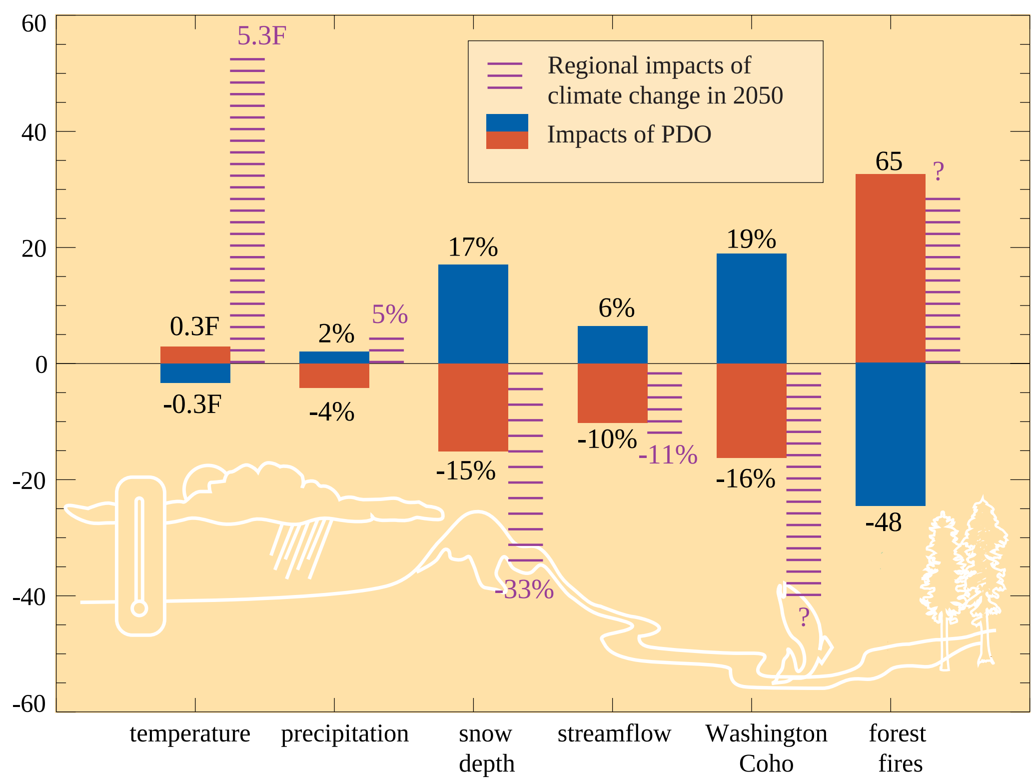


Figure 8. Regional impacts of climate change in 2050 (using the average of seven climate model scenarios, hatched bars) compared to impacts of PDO (as in Figure 4).

Coasts

Both the physical landscape and the ecosystems of the coasts will be affected by climate change and rising sea level. Changes in wave direction may increase coastal erosion, as often happens during El Niño events. Increased winter precipitation will probably lead to more frequent landslides; recent wet winters have shown that thousands of homes are at risk from landslides around Puget Sound and on the Oregon coast, and climate models consistently project wetter winters. Several areas of the coast, like southern Puget Sound, are already at great risk of inundation. Temporary coastal flooding also occurs near the mouths of rivers like the Skagit in Washington when a river flood coincides with high tide. These risks pose important policy challenges because there is increasing pressure for commercial and residential development along many parts of the PNW coast. Biological impacts include damage to wetlands and the invasion of exotic species like Cordgrass, which was introduced in the 1890's from Chesapeake Bay, and flourished in the warm spell of the 1980's.

Summary of impacts

From the modeling studies described above and from other work, we can compare the likely impacts of human-caused climate change in the 2050s with the impacts of PDO-related climate variations (Figure 8). PDO has significant impacts even with small changes in temperature. Because of its much larger changes in temperature, climate change has the potential for much larger impacts: large reductions in spring snowpack and summer streamflow. Rising temperatures and other changes pose difficulties for salmon but cannot yet be quantified. Forest fires and droughts may reduce forested area in the PNW.

What Can We Do to Prepare?

Climate change is sure to occur in some form. We do not yet know in detail what form it will take, but we know enough already to begin planning. The region's decision-makers should begin thinking about how to cope with a changing climate; at present, many natural resource-dependent commercial enterprises and government agencies operate on the assumption that climate is unchanging. It will take considerable effort to replace that assumption. Recent experience anticipating year-to-year climate variations, like those connected with El Niño and La Niña, provides some practice at anticipating and planning for climate change.

The single most important thing that the region can do to prepare for climate change is develop an ongoing dialog between decision-makers and climate scientists. An increased awareness of how climate affects the region will increase resilience to climate variations and change; conversely, as climate scientists learn how seasonal climate forecasts are used, they can make more useful forecasts and provide more useful information on climate change.

The ideas proposed below lack specifics and need to be analyzed in greater detail before they form policy recommendations. They are presented here to give an illustration of the sorts of choices the region will face in coming years.

Water

A fundamental challenge in changing any aspect of regional water management is the diversity of interests and authorities (federal, state, regional, local, tribal, private) involved in water management, at least in the Columbia Basin. We propose more intelligent government, not necessarily more government.

There are three basic options to ensure that future water supply is adequate for future demand, but the specifics may require big changes.

1. Increase supply
   * develop new storage capability, including reservoirs and groundwater recharge
   * reuse water where possible
   * find new sources (e.g., groundwater)
   * use seasonal forecasts to manage water better at the watershed level
   * increase cooperation among users
   * connect water systems to improve flexibility.
2. Decrease demand
   * introduce water markets, allowing market forces to set water prices
   * develop new technology to increase water use efficiency
   * adopt more efficient agricultural irrigation methods
   * reduce irrigated acreage
   * adopt methods to reduce soil moisture loss
   * encourage water conservation during seasonal lows.
3. Increase institutional flexibility
   * develop a shared information resource, a regional water management database that could improve cooperation among federal,state, and academic communities.

Salmon

For millennia, wild salmon have thrived in highly variable and unpredictable environments by evolving a diversity of behaviors, enabling them to inhabit a wide variety of environments in streams, estuaries, and the open ocean. Widespread losses and degradation of salmon habitat in streams and estuaries in the PNW have resulted in equally widespread losses in salmon biodiversity.

Fisheries managers have managed salmon by attempting to reduce year-to-year variations in salmon abundance, controlling harvest, and supplementing wild salmon runs with hatcheries. An underlying assumption was that the ocean environment was stable, and that the freshwater phase of a salmon's life cycle could be controlled in hatcheries.

Climate change will bring more uncertainty to the various environments of Pacific salmon. Rather than attempt to eliminate variability and uncertainty through the use of technology (hatcheries), it may prove more effective to embrace environmental variations as an essential component in salmon ecology. In this approach to fishery management, the new goal is to protect the *interrelationships* that allow salmon populations to sustain themselves in a changing world. For salmon, resilience to environmental variations depends on the diversity of their population as a whole, which in turn depends on the availability of healthy and complex habitat in streams, estuaries, and the open ocean. The most effective climate insurance we can purchase for Pacific salmon may be to increase available healthy and connected habitat, while continuing to control harvests.

Forests

At a workshop on climate change in the Northwest, forest managers and academics agreed on several strategies to recommend for coping with climate change. When making decisions about planting and management plans, forest managers should incorporate natural patterns of climate variability and projections of future climate change rather than viewing climate as constant. Recognizing that the details of future climate are uncertain, a full range of biodiversity should be maintained in order to maintain flexibility; species with a broad range of climates should be considered. Some species should be actively moved to follow suitable climates, especially after fires or pests destroy part of a forest. Finally, decision-making should be informed by careful monitoring of forest condition and climate-related changes.

Coasts

Climate variability and change have yet to be recognized widely as important and timely issues for the coastal zone. The standard way of dealing with coastal erosion is with protection strategies such as dikes, levies, and shoreline hardening. A wide range of coastal problems could be dealt with by changing land-use controls, construction setbacks, and zoning. Public funds could be better spent in ways other than subsidizing coastal development (especially redevelopment after damage) in obviously hazardous places.

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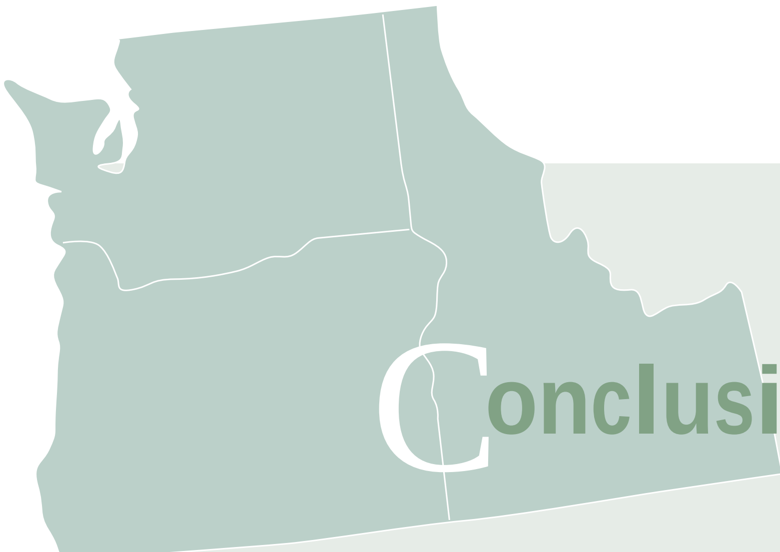
[1] A review of evidence to support these statements can be found at www.ncdc.noaa.gov/ol/climate/globalwarming.html
[2] Available from the JISAO/SMA Climate Impacts Group, fax (206) 616-5775.



Conclusions

Climate change is coming to the Northwest. Are we ready? By planning now, and by incorporating information about climate variability and change into decisions about how we manage our natural resources, we can reduce the negative impacts of (and take better advantage of the opportunities brought by) both human-caused climate change and natural climate variability.

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