
Impacts of Climate Change on Washington Resources

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*Climate Science in the
Public Interest*

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The Future Ain't What It Used to Be: Preparing for Climate Disruption

Washington's economy and natural resources are sensitive to climate changes

- we know this from experience
- the water cycle plays an especially prominent role in transmitting climate impacts into resource impacts

skiing water supplies hydropower
aquatic
ecosystems flooding forests

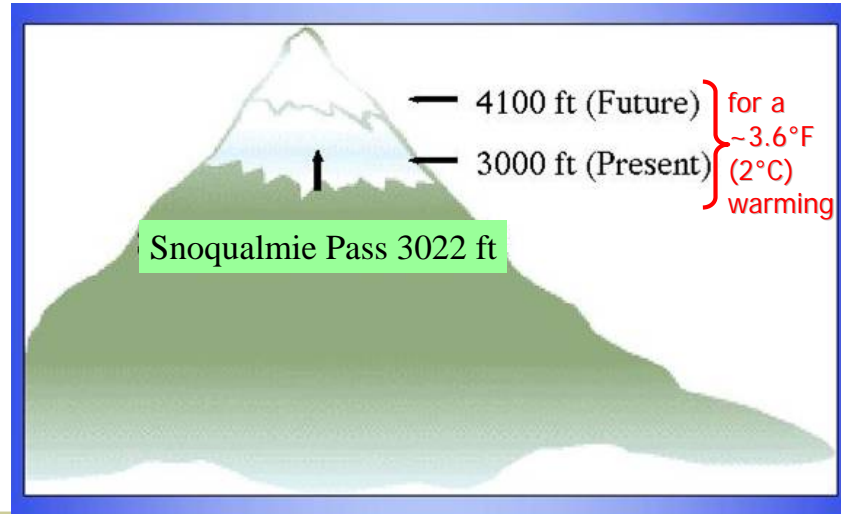
- ***“drought” – a water supply shortage – is our region's greatest climate vulnerability***

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There is no question that Washington's economy and natural resources are sensitive to climate change. We all know this to be true from our experience, such as last winter's meager snowpack that had severe negative impacts on irrigation supplies for the Yakima basin and the extremely limited season in local ski resorts. We also know that the water cycle plays an especially prominent role in transmitted climate impacts into resource impacts in Washington state. Our research has indicated that regional "drought" -- or water supply shortages brought by a lack of either precipitation or annual snowpack -- is our region's greatest climate vulnerability because it impacts so many sectors simultaneously.

The main impact of a warmer climate: **LESS SNOW**



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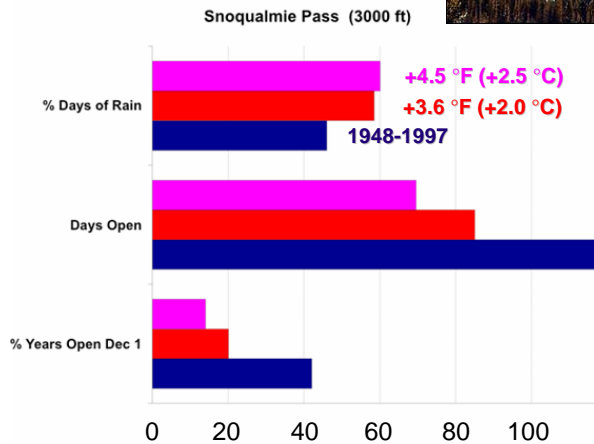


One of the most obvious impacts of a warmer climate in our region is simple: less snow in our mountains. Snowlines rise about 1000 feet for a 3.6 F rise in surface temperatures.

Warmer winters have a negative impact on skiing in Washington



- delayed season openings, a shorter ski season, and lower quality ski conditions
- lowest elevation (warmest) areas are impacted the most (Snoqualmie Pass and Stevens Pass)



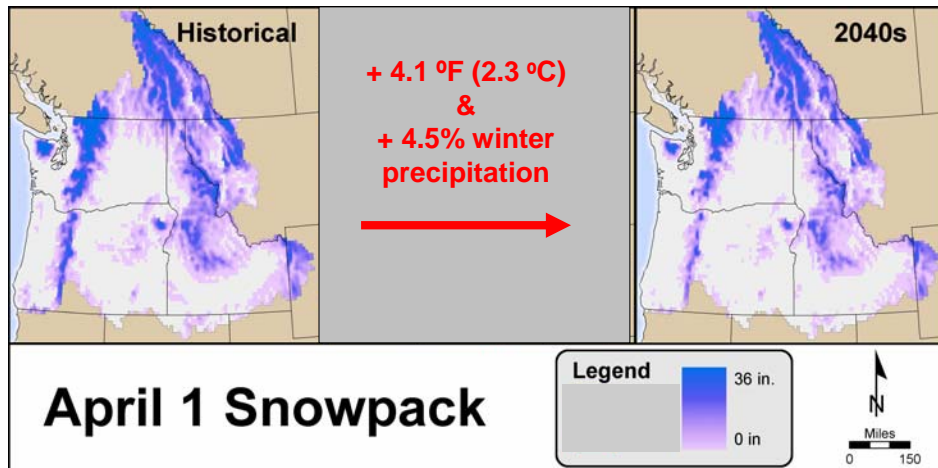
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Results from a study recently completed by our group quantified the impacts of two future climate scenarios for local ski resorts (Snoqualmie Pass, Stevens Pass, and Mission Ridge). A few of the results for impacts on Snoqualmie Pass skiing are shown in the graphic in this slide. The basic message from this study is that a warmer climate will delay season openings, lead to a shorter ski season, and degrade skiing conditions, at each of these resorts. The lowest elevation (warmest) area (Snoqualmie Pass) is impacted most, while the highest elevation (coolest) area (Mission Ridge in this group) is impacted least.

Springtime snowpack will decline, especially at the warmest locations

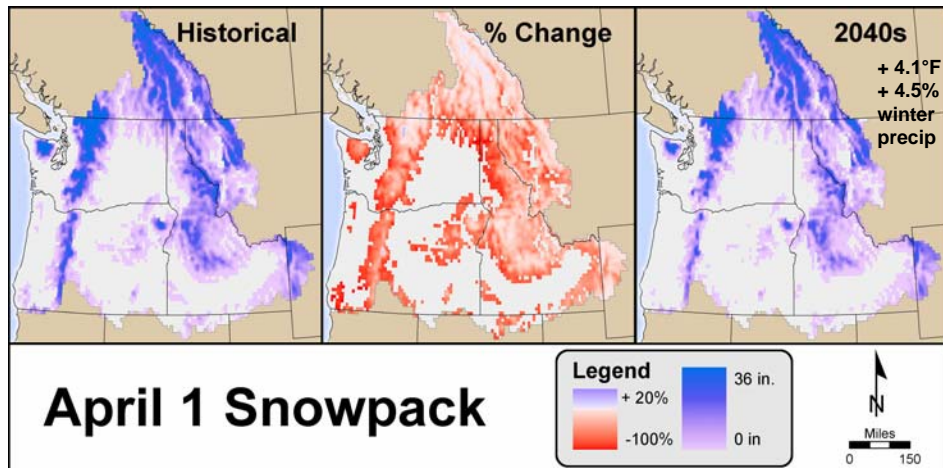


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Our group has been running simulation models to quantify the impacts of plausible future climate changes for snowpack, soil moisture, and river runoff in our region. The panel at left shows a long-term average for April 1 snowpack for the period 1915-2000. The panel at right shows April 1 snowpack for a warmer (+4.1F) and wetter (+4.5% winter precipitation) future climate scenario. Note that in each panel, the deepest snowpack is found in the highest elevations of the Olympics and Cascades, and also in the Canadian Rockies in the upper Columbia River Basin.

The coldest locations are less sensitive to warming

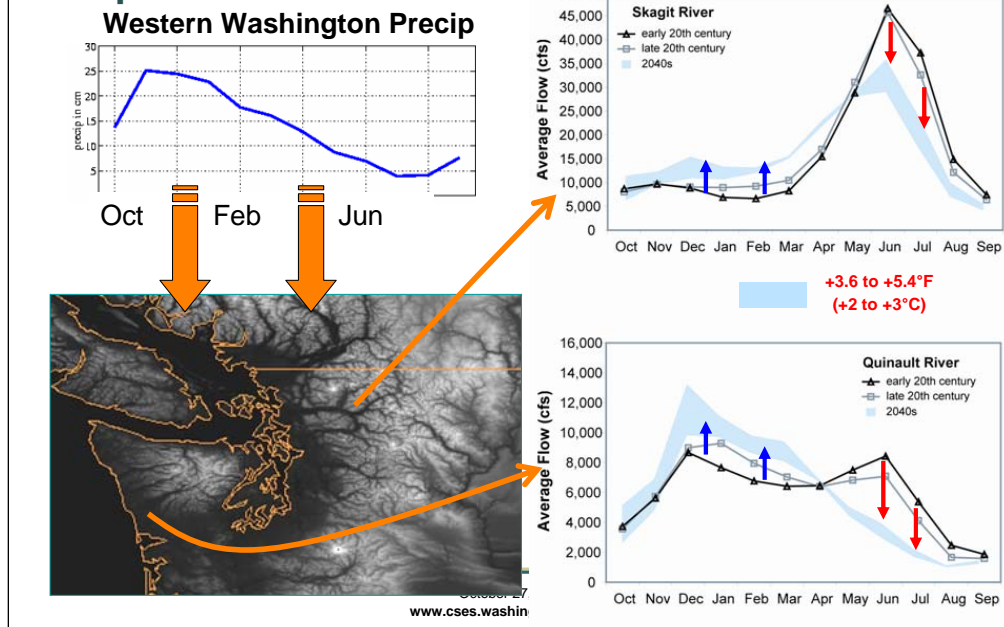


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The panel in the middle shows the % change in snowpack between the “historical average for 1915-2000 and the future climate scenario for the 2040s. This figure highlights the fact that the largest declines (100% losses!) in April 1 snowpack are found in the warmest snow-accumulating locations, specifically in the lower elevations of the Olympics, Cascades, and west slopes of the mountains in Idaho. Also note that there is little change in the April 1 snowpack in the highest elevation (coldest) locations in the study region -- snowpack is nearly unchanged in the Canadian portion of the upper Columbia Basin.

Streamflow patterns are temperature dependent



Because of the PNW region's complex topography, the seasonal variations in precipitation yield a wide range of hydrologic regimes.

Even within Western Washington there are vastly different seasonal hydrographs in spite of essentially homogenous seasonal precipitation:

- the relatively high elevation Skagit basin yields peak runoff in June, when its heavy snowpack melts; the Skagit Basin contains enough low elevation terrain that a second, smaller seasonal peak occurs in late fall/early winter.
- The Quinault Basin has more area at lower elevations, but still carries an appreciable snowpack. The balance of terrain yields a pair of seasonal runoff peaks, one in early-winter, the other in June.

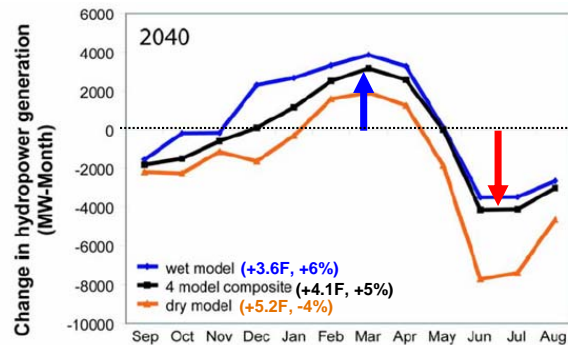
One common factor to all streams in the Northwest is a late summer low flow period. This period is relatively brief in the Skagit, about 2 months in the Quinault, and longer in the "warmest" river basins in Western Washington (Chehalis, Skokomish, and other low elevation basins in Western Washington).

The black lines in the right panels depict measured average monthly streamflows for the early 20th century for the Skagit and Quinault Rivers, while the gray lines depict the same data for measured streamflows in the late 20th century. The light blue bands indicate the range of simulated flows for a range of future climate scenarios for the decade of the 2040s (+3.6 to +5.4 F). For both river basins, the basic changes include increased winter flows and decreased summer flows as more winter precipitation falls as rain and less accumulates in snow.

Impacts on Columbia Basin hydropower supplies



- **Winter and Spring:** increased generation
- **Summer:** decreased generation
- **Annual:** total production will depend on annual precipitation



NWPCC (2005)

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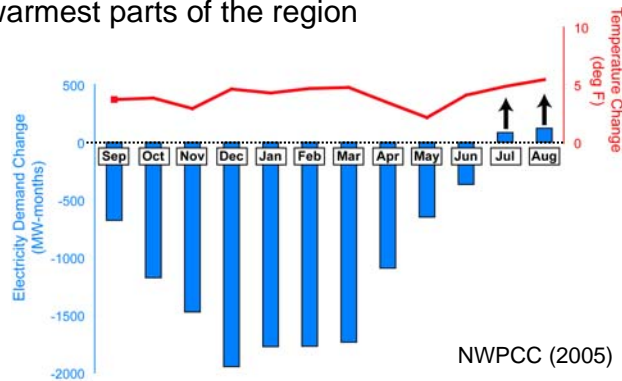
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The same kind of flow timing shifts have been simulated for our region's largest river, the Columbia. The consequences of the timing shifts in Columbia Basin runoff include a timing shift in the capacity to generate hydropower. A range of future climate scenarios suggest increased hydropower generation in winter and spring and decreased hydropower generation in summer. The annual total hydropower production depends on the changes in annual precipitation.

Warming climate impacts on electricity demand

- reductions in winter heating demand
- smaller increases in summer air conditioning demand in the warmest parts of the region



NWPCC (2005)

Data source: NWPCC 5th Report Appendix N (2005)
Figure by: Climate Impacts Group, University of Washington

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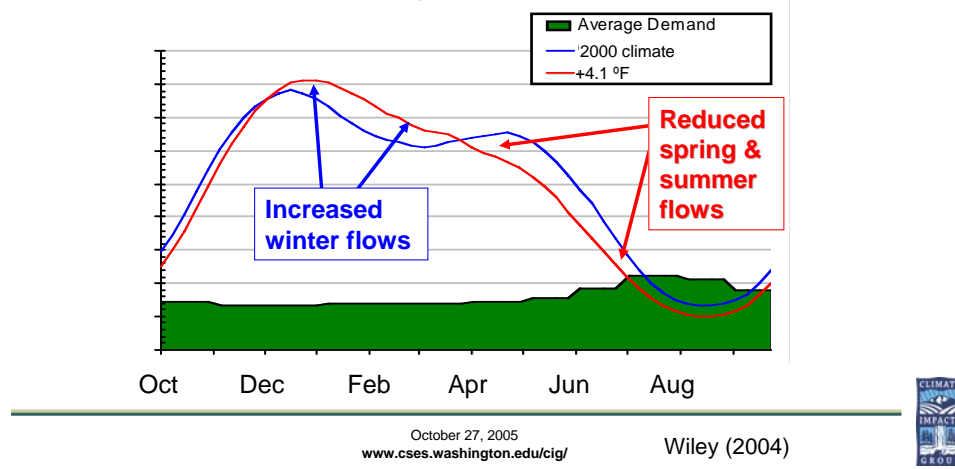


A warming climate also impacts the demand for electricity to heat homes and offices. A warmer climate reduces winter electricity demand by reducing the need for heating, but increases summer electricity demand by increasing the need for air conditioning. The authors of this study believe that the increases in summer cooling demands shown here are likely to significantly underestimate the actual increases in summer demand because their calculations did not estimate the impacts of ever-increasing numbers of buildings with air conditioners.

For recent years, the monthly electricity demand during the winter is ~25000 MW; during the summer it's more like 20000 MW. So, the changes in winter demand in this figure are a reduction of about 10%.

Impacts on Seattle's water supply

- **reduced summertime inflows, increasing the size and extending the time of the summertime inflow-demand deficit**
 - this is common to all our region's municipal (surface) water supplies



A recently completed study by the UW's Matt Wiley examined the impacts of a warmer climate on Seattle's water supply, the bulk of which comes from reservoirs on the Cedar and Tolt Rivers. This graphic shows inflows into Seattle's water supply reservoirs for the year 2000 (in blue) and in a climate that is +4.1 F warmer (in red). The green shading indicates average demand on the system.

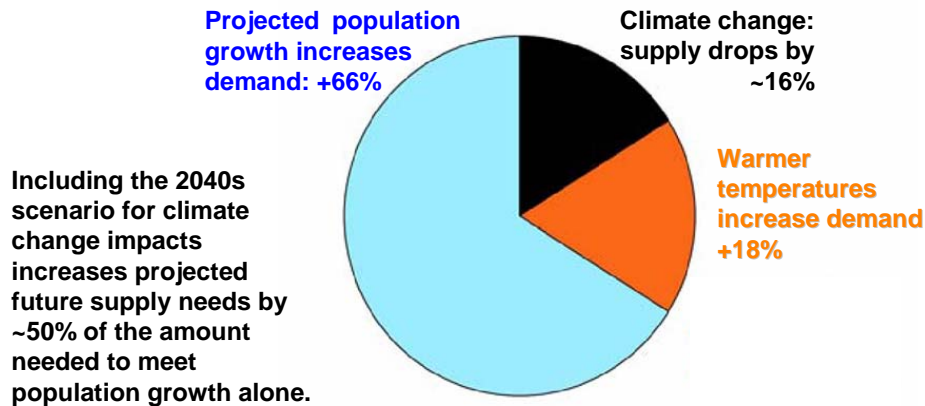
The reduced spring and summer inflows that come with a warmer climate increase the annual inflow-demand deficit that exists every summer, and this increased deficit must be met with the limited reservoir storage and groundwater resources that exist in Seattle's water supply system.

The increased flows in winter generally cannot be captured because of limited reservoir storage capacity and the need to maintain space in reservoirs to manage flood risks in the winter and spring. This situation is common at all our region's municipal surface water supply systems.

Factors driving Portland Oregon's future water supply



Bull Run Watershed



Palmer and Hahn (2004)

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A 2004 study by the UW's Palmer and Hahn evaluated two factors expected to be important for Portland's water supply in the 2040s: (1) population growth and (2) climate change impacts on supply and demand. Population growth is expected to increase demands on Portland's water supply system by 66%. The climate change scenario examined here increases the summer inflow-demand deficit and reduces their annual supply by 16%, and warming temperatures increased demands on the system by 18%. The bottom line in this study was that including the 2040s climate change scenario increased projected future supply needs by 50% of the amount needed to meet population growth alone.

A warmer climate and flooding, stormwater & wastewater management

- At mid-elevations more precipitation will fall as rain and less as snow, leading to an increased frequency of river flooding
- At high elevations there are competing factors:
 - reduced snowpack may reduce flood risks in spring
 - elevated spring soil moisture may increase vulnerability to flooding during spring storms
- **a warmer atmosphere holds more moisture:** theory and climate models suggest an increased intensity of precipitation
 - if WA precipitation events become more intense, it will increase the risk of urban flooding and combined sewer overflows



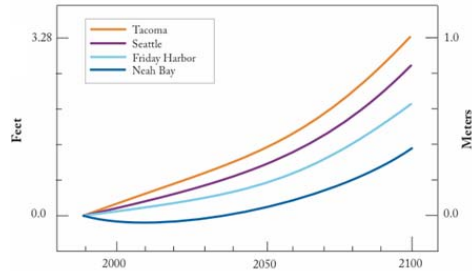
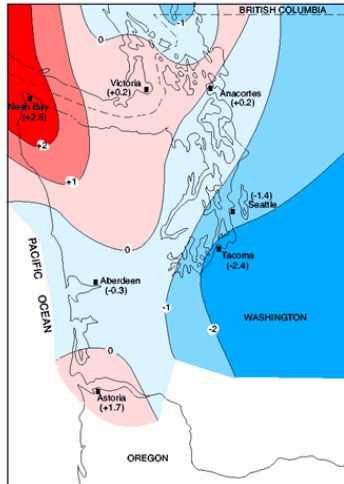
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A warmer climate is likely to have impacts on flooding, stormwater, and wastewater management. Rising snowlines with warmer temperatures will increase runoff during storm events as more precipitation falls as rain and less as snow. The reduction in spring snowpack due to warmer temperatures, by itself, will likely reduce the risk of springtime flooding, but that factor will be opposed by the likely increases in spring soil moisture that come with early snowmelt.

Theory and climate modeling studies also suggest that a warmer climate will bring an increased intensity of precipitation with individual storms, and if this general impact takes place in Washington it will increase the risk of urban flooding and combined sewer overflows.

Sea Level Rise scenarios depend on regional tectonics



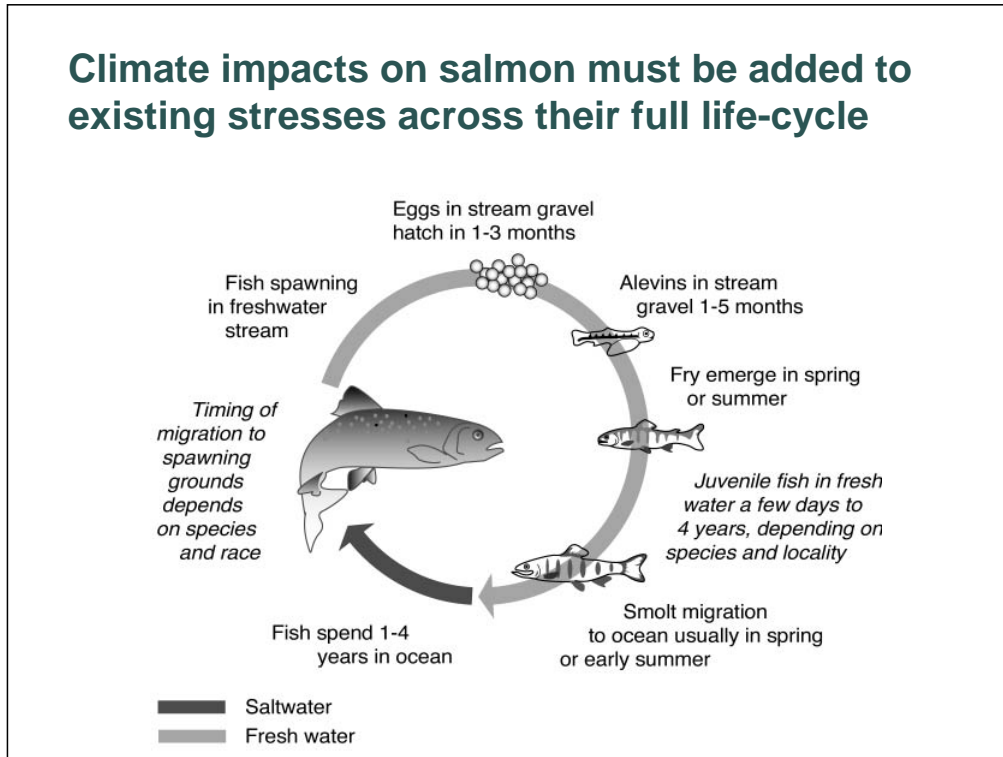
- this means that relative sea level rise will be greatest in South Puget Sound (~3.3ft by 2100), and least near Neah Bay (~1.3ft by 2100)

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Sea level rise scenarios for Puget Sound depend on regional land movements. A combination of plate tectonics and glacial rebound are causing South Puget Sound to subside and the Olympic Peninsula to rise. This means that relative sea level rise will be greatest in South Puget Sound and least near Neah Bay. The sea level rise scenarios shown in the right panel depict mid-range estimates for the next century. There is large uncertainty in sea level rise scenarios, with low-end estimates about 20% of what's shown in this graphic, and high-end scenarios about 200% of what is shown.

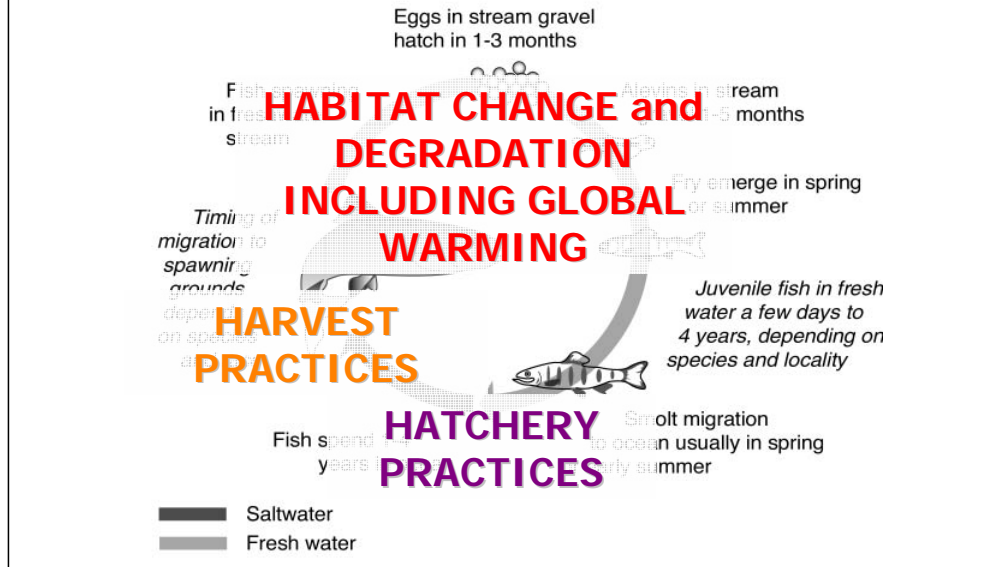
Climate impacts on salmon must be added to existing stresses across their full life-cycle



In order to translate future climate scenarios into impacts on salmon, we need models that link climate to habitat and productivity. The life cycle for salmon offers a natural framework for extending climate scenarios into consequences for salmon.

Impacts are cumulative ...

Salmon Life Cycle



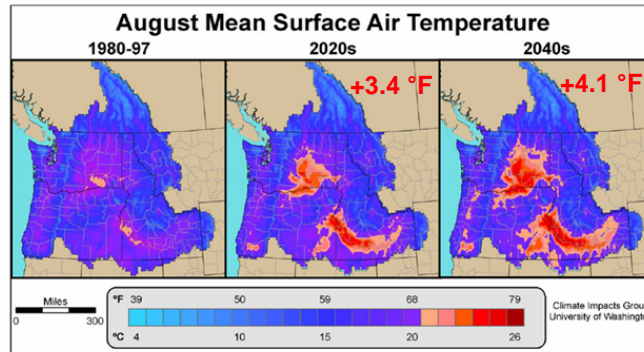
The key for understanding climate change impacts on salmon comes with understanding the cumulative impacts of all the factors that influence salmon during their life cycle. Climate change (global warming) can be considered as being a part of habitat change and habitat degradation, but the ultimate impacts of climate change on NW salmon cannot be assessed in isolation from the impacts of other factors influencing habitat, or harvest and hatchery practices.

This framework also suggests that at least some of the negative impacts of climate change on salmon can be mitigated by alleviating existing negative impacts on salmon that come with other aspects of habitat, hatchery and harvest practices.

Temperature thresholds for coldwater fish in freshwater

- **Warming temperatures will increasingly stress coldwater fish in the warmest parts of our region**

A monthly average temperature of 68°F (20°C) has been used as an upper limit for resident cold water fish habitat, and is known to stress Pacific salmon during periods of freshwater migration, spawning, and rearing.

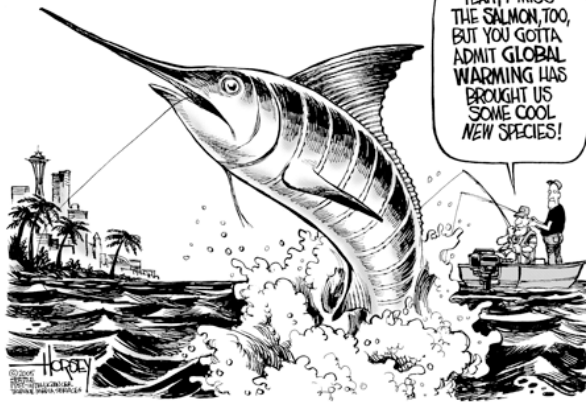


It is well known that there are temperature thresholds for coldwater fish, and that warming temperatures will increasingly stress coldwater fish in the warmest parts of the Pacific Northwest. A monthly average temperature of 68F has been used as an upper limit for resident cold water fish habitat, and is known to stress Pacific salmon during periods of freshwater migration, spawning, and rearing. The left panel in the bottom of this slide highlights the parts of our region that had August average temperatures greater than 68F for the 1980-1997 period with the pink shading -- scenarios for a warmer future climate are shown in the middle and right panels. Note that the regions with temperatures greater than the 68F threshold increase with increasing warming so that by the 2040s about 20% of the region is shading in pink and red -- mostly in the lower Columbia Basin and Snake River valley.

Because salmon move through these regions during parts of their lifecycle, this doesn't necessarily mean that salmon will be eliminated from these regions. It does, however, suggest increased stress on populations that use these areas during summer, such as summer and fall chinook, summer steelhead, and sockeye salmon.

Species distributions change with temperature

Puget Sound, 2045...



134 lb marlin caught 40 mi. west of Westport, WA, Sept 2, 2005

Photo obtained from the Seattle Times web-archives

From the Seattle Post-Intelligencer, October 20, 2005

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David Horsey's recent cartoon depicts a pair of conflicted anglers in the 2040s lamenting the loss of salmon to global warming but appreciating the appearance of more tropical gamefish. It's a funny take on what appears to have at least a germ of truth behind it...

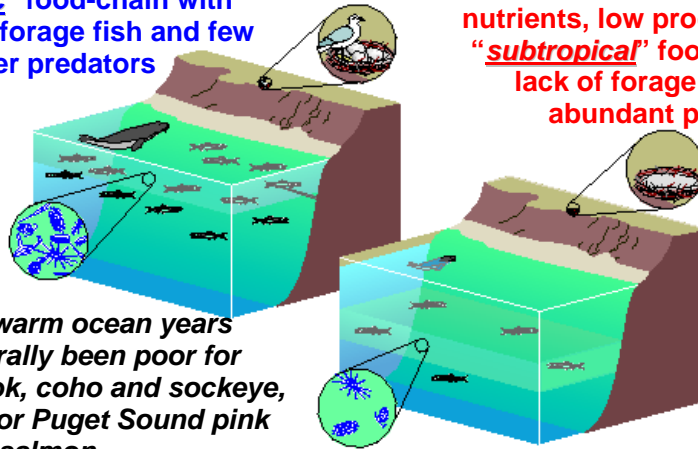
On September 2nd of this year, a lucky group of anglers targeting albacore 40 miles west of Westport caught a 134lb striped marlin. Marlin have been rare off the coast of Washington, but another striped marlin was brought to Westport in the exceptionally warm September of 1997.

Upwelling food webs in our coastal ocean

Cool water, weak stratification
high nutrients, a productive
“*subarctic*” food-chain with
abundant forage fish and few
warm water predators



Warm stratified ocean, few
nutrients, low productivity
“*subtropical*” food web, a
lack of forage fish and
abundant predators



Recently, warm ocean years have generally been poor for NW chinook, coho and sockeye, but good for Puget Sound pink and chum salmon.

For the California Current, the broad upwelling ecosystem off the coast of southern British Columbia south to the US/Mexico border, climate variations appear to influence the entire food web. The left panel of this schematic depicts a cool, weakly stratified upper ocean. Nutrients are easily upwelling into the surface layer, and these conditions coincide with a highly productive subarctic food web. Predation pressure on juvenile salmon (smolts) is slight, in part because of an abundance of other smolt-sized forage fish (herring and anchovies) and a relative lack of migratory predators like hake and jack mackerel. The net result is high smolt survival and excellent feeding conditions for maturing salmon.

In contrast, warm periods bring a sharply stratified coastal ocean which inhibits the upwelling of deep nutrient rich water, thereby limiting phytoplankton productivity. The warm water eras also see a dominance of “subtropical” zooplankton species, a relative lack of forage fish, and an influx of warmwater predators like hake and jack mackerel that are typically found to the south or in offshore waters. The net result is poor smolt survival due to intense predation pressure (by fish and diving birds), as well as poor growth for maturing salmon.

Recently, warm ocean years have generally been poor for NW chinook, coho and sockeye, but good for Puget Sound pink and chum salmon.

Climate change impacts on Washington's forests



- **CO₂ fertilization**
 - A transient impact
- **a longer dry season**
 - reduced regeneration, increased vulnerability to fires and pests (except in especially cool-wet locations)
- **shifts in species ranges**
 - subalpine forests “invading” alpine meadows; a northward march--or a loss--of species?

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Climate change impacts on Washington's forests will come through a number of pathways. CO₂ fertilization studies have indicated only transient benefits for tree growth because alleviating CO₂ as a limiting factor for growth soon leads to other factors (like water availability or the availability of other nutrients) as the new critical limiting factor.

A warmer climate will lead to a longer dry season, and for all but today's cool-wet locations this will reduce regeneration, increase vulnerability to fires and pests.

Changes in climate will also promote shifts in species ranges. For example, subalpine forests are likely to successfully expand to higher elevations and invade alpine meadows. More uncertain will be the ability of tree species to successfully expand their range northward to keep pace with a warming climate. If they cannot do so, they're at risk of becoming isolated and eventually extirpated if local growing conditions become unsuitable.

Impacts on growth and regeneration: limiting factors vary

subalpine forests

- [snowpack](#) for seedling establishment and growing season length at treeline
- [summer soil moisture](#) for growth and seedling establishment at lower elevations



semi-arid forests

- [summer soil moisture](#)

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Impacts on growth and regeneration will vary depending on forest type, because different forest types are subject to different limiting factors. This slide compares and contrasts some of the key limiting factors for Washington's subalpine and semi-arid forests.

Ecosystem thresholds: the case of the Mountain Pine Beetle

- a massive outbreak of the mountain pine beetle in BC has killed 100 billion board feet (approx. 9 years of harvest)
- low temperatures (< -10°F) limit beetle activity
 - a recent lack of extreme cold, killing temperatures has allowed the beetle to thrive in epidemic numbers



Photos from <http://www.for.gov.bc.ca>

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Over just the past 6 years there has been a massive outbreak of the mountain pine beetle (MPB) in British Columbia's interior pine forests.

The BC Ministry of forests predicts MPB will kill 80% of Lodgepole Pine forests by 2013.

100 billion board feet is approximately 9 yrs of harvest - some of this timber is being salvaged

The climate link to this event comes through a recent lack of extreme cold, killing temperatures that has allowed the beetle larvae to survive through successive fall/winter seasons, warm spring/summer temperatures that accelerate the beetle's lifecycle so that they complete their reproductive cycles more rapidly, and moisture stress on the forests that inhibit their ability to fight off beetle attacks.

The photograph in the lower right corner was taken near Quesnel in central BC.

Old, dead trees are gray; newly killed trees are straw yellow or orange. Some trees may also be infested but do not turn color until nine months or so under attack.

Warmer climate and increased CO₂ impacts on agriculture



- increased crop yields – where sufficient soil moisture or irrigation water is available
 - but crops could suffer more days of heat & moisture stress where soil moisture/irrigation water supply decreases
- may stimulate crop pests, pathogens, and weeds
- summer irrigation water supplies are likely to decline where storage capacity is limited
 - the Yakima Basin, for example
- changes in crop types: new opportunities for some and lost opportunities for others
 - different varieties of wine grapes

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Warmer climate and increased CO₂ will also have impacts on agriculture. Where soil moisture or irrigation water is sufficient, warmer temperatures may increase crop yields. However, crops could suffer more days of heat and moisture stress where soil moisture and/or irrigation supplies decrease.

The positive impacts of warming temperatures and rising CO₂ may also stimulate crop pests, weeds and pathogens, and the net impact on crops may actually be negative.

Summer irrigation water supplies are likely to decline where storage capacity is limited, for instance in places like the Yakima River Basin.

And climate change will likely change a given region's suitability for specific crop types, bringing new opportunities for some species and lost opportunities for others. A given vineyard's suitability for wine varieties, for example, will likely change with a changing climate.

The photo is from the Seven Hills Vineyard in Walla Walla Washington

Climate change sharpens the tradeoffs in a world of multiple stresses

- **climate change will likely intensify existing conflicts over scarce natural resources**
 - most of our natural resources are now fully allocated and managers already grapple with difficult tradeoffs
 - summer water supplies for in and out of stream uses are especially vulnerable to climate warming

- **global warming impacts on Washington depend on both the climate change and on how we prepare**

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