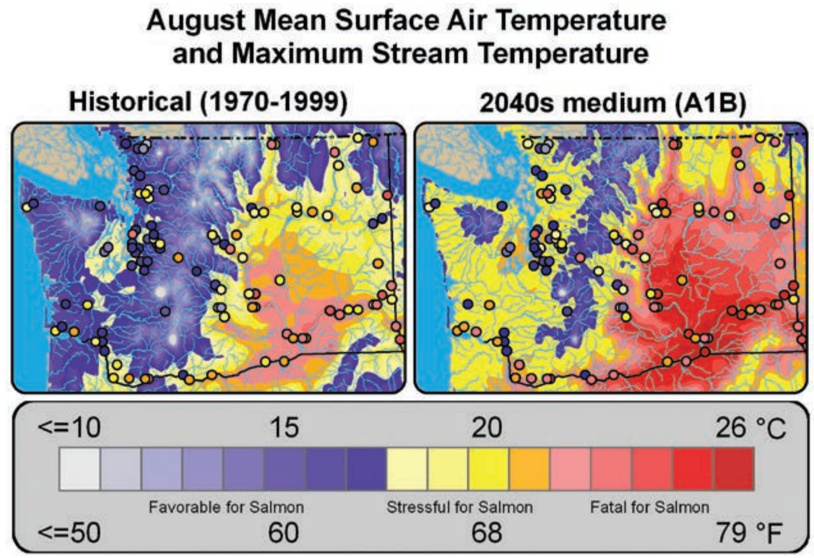
Climate Change and Salmon

North Coast & Cascades Network Science Brief

Importance

Climate plays a crucial role in the freshwater, estuarine and marine ecology of salmon, and projections for a warmer climate in the future have implications for Pacific Northwest salmon populations throughout their complex life histories. Key climate-related factors that affect salmon in the freshwater part of their life cycle include stream temperature and the volume and timing of streamflow. Climate influences estuarine and marine habitat for salmon directly via changes in water properties (e.g. temperature, salinity, water clarity, dissolved oxygen and pH) and indirectly through impacts on food webs, and it is likely that future climate change and ocean acidification will play important roles in altering these salmon habitats. In this brief we focus our discussion on freshwater impacts and the potential for ocean changes to impact early marine survival rates.

Key hydrologic factors coupled with climate that affect freshwater salmon habitat are thermal and streamflow regimes. Because the residence time of freshwater life stages varies considerably among the different salmon species and stocks, the responses of salmon to shifts in these factors depend to a great extent on stock-specific adaptations to local environmental factors and the way that different stocks occupy freshwater habitats in space and time. Because future climate changes are expected to both reduce streamflows and increase stream temperatures in what are already the low flow/warm season, populations with extensive freshwater habitat use in summer are likely to experience significant negative impacts on their freshwater productivity. Steelhead (*Oncorhynchus mykiss*), stream-type Chinook salmon (*O. tshawytscha*), sockeye salmon (*O. nerka*) and coho salmon (*O. kisutch*) are likely to have a greater sensitivity to freshwater habitat changes than those that migrate to sea at an earlier age (ocean-type Chinook salmon, pink salmon (*O. gorbuscha*), and chum salmon (*O. keta*). Resident (and anadromous) coldwater fish like bull trout (*Salvelinus confluentus*), rainbow trout (*O. mykiss*), and cutthroat trout (*O. clarkii*) are also likely to experience a reduction in high quality freshwater habitat in summer. Future climate scenarios also point to widespread increases in the frequency and intensity of fall and winter flooding in many Pacific Northwest (PNW) watersheds, and increases in flooding are likely to negatively impact the spawning success for many fall spawning salmon (all species) and bull trout populations.



Status and Trends

Increased stream temperatures caused by climate change are likely to affect salmon and resident coldwater fish by direct impacts on their physiology, and indirect impacts mediated through altered food webs and disease and parasite environments. Future stream temperature scenarios have been developed from future air temperature scenarios and observed relationships between stream temperature and air temperature. Stream temperature scenarios are predicted to be similar on both sides of the Cascade Range in the early part of the 21st century (above). However, by mid-century the lower elevation streams, particularly on the east side of the Cascades, are forecasted to warm at a greater rate than those at higher elevations. This pattern becomes more striking by the end of the century, when lowland areas on both sides of the Cascades undergo the greatest warming. These projections consistently indicate that shifts to increasingly stressful thermal regimes for salmon will be greatest for eastern Washington, where historic water temperatures are generally warmer than in western Washington.

Warming associated with climate change is expected to increase the distribution, frequency and persistence of thermal migration barriers and thermally stressful waters for salmon. The persistence of summertime water temperatures greater than 21˚C (70˚F) is predicted to start earlier in the year, and endure until later in the year. The critical thermal threshold of weekly average temperatures for salmon was determined as 21°C (70˚F) by the Environmental Protection Agency (2007). Weekly water temperatures exceeding this threshold result in lowered immunity to pathogens, migration barriers and fish kills. The projected increases in stream temperature alone suggest an intensification of thermal stress for Washington's salmon. Stocks with summer adult return migrations in already warm water bodies are likely at the greatest risk from future warming. These include many summer-run steelhead, sockeye and summer Chinook salmon populations in the Columbia Basin.

Opposite Salmon leap at Olympic National Park. NPS/OLYM

Above Historical and future stream temperatures in Washington. Colored shading shows the historic (1970–1999) mean surface air temperatures for August, and shaded circles show the simulated mean of the annual maximum for weekly water temperatures for select locations. After Mantua et al. 2010. Figure: Robert Norheim

Increased stream temperatures also pose risks to the quality and quantity of favorable rearing habitat for juvenile stream-type Chinook and coho salmon and steelhead (summer and winter run) because these stocks spend at least one summer rearing in fresh water. Reductions in the volume of summer and fall low flows in warmer, low elevation basins will also reduce the availability of spawning habitat for salmon populations early in the fall. Moreover, the lower base flows projected for many western Washington streams in the summer months are expected to exacerbate

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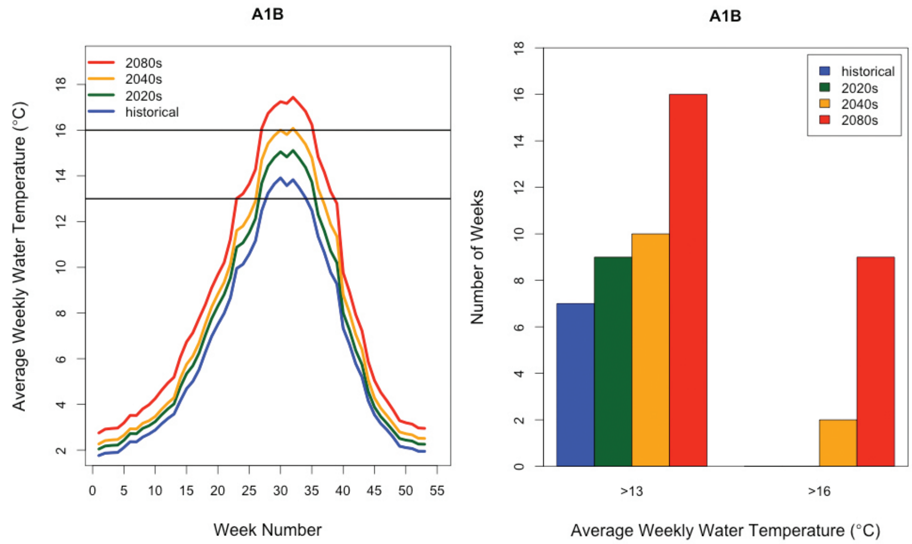


Above Changes in weekly water temperature at Ruby Creek, in the Skagit River basin, under future climate change scenarios (left) and the number of weeks exceeding 55°F (13°C) and 61°F (16°C). After Hamlet et al. 2010.

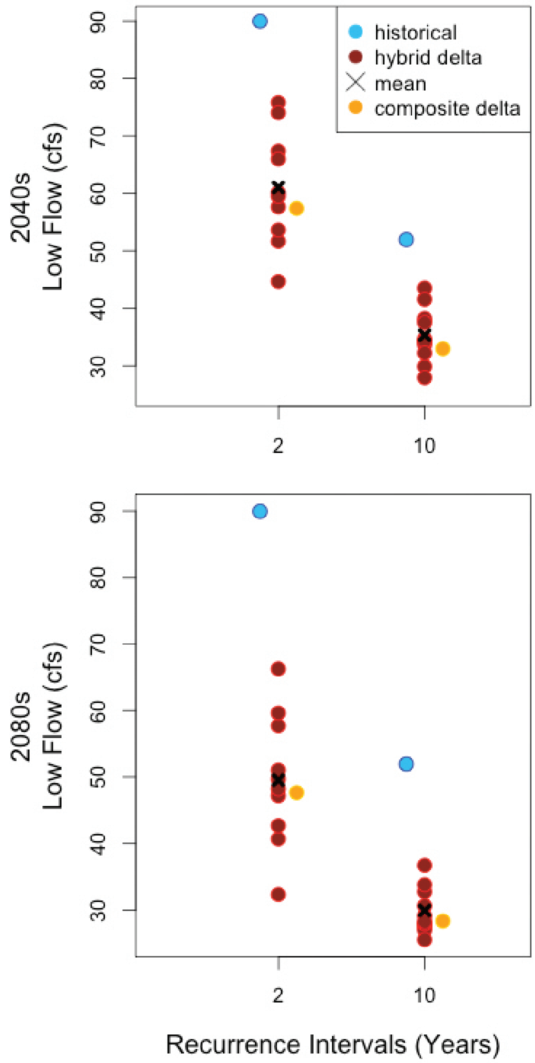
Opposite Above The 7-day minimum low flow statistics with a 2-year and 100 year return interval for the Ruby Creek gage near Newhalem for historical, for the 2040's (top) and 2080's (bottom) and for two different approaches to future climate model output downscaling: hybrid delta and composite delta means. The results are for the A1B greenhouse gas emissions scenario. The hybrid delta approach allows better simulation of the hydrologic conditions leading to low flows than the composite delta approach because it simulates changes near the extremes of precipitation and temperature better. In all cases, the future low flows are projected to be lower than the historical low flows.

Opposite Below Elwha River peak flow events from 1910-2010. The upward trend is one example of statistically significant changes in winter flow patterns in Pacific Northwest rivers.

the effect of the warmer air temperatures on the stream thermal regimes. (The stream temperature modeling used in the WACCIA report was only based on regressions between air and water temperature and did not explicitly consider the influence of streamflow on stream temperature – for a given amount of heating, temperature change is inversely proportional to the volume of water being heated, so lower flows will result in more warming).

Although cool-season stream temperature changes and impacts are not assessed in this study, it is possible that climate-induced warming in winter and spring will lead to earlier and perhaps longer growing seasons, increased aquatic food-web productivity, and more rapid juvenile salmon growth and development rates that may benefit parts of the freshwater life cycle for some or even many of Washington's salmon. It seems likely that the potential for positive impacts of future stream warming are greatest in Washington's coldest streams, either in the maritime climatic zones of Western Washington or in high elevation stream reaches. Also, warming of temperatures can result in intrusion of previously excluded species such as coho salmon into bull trout spawning habitat where coho may outcompete the bull trout.

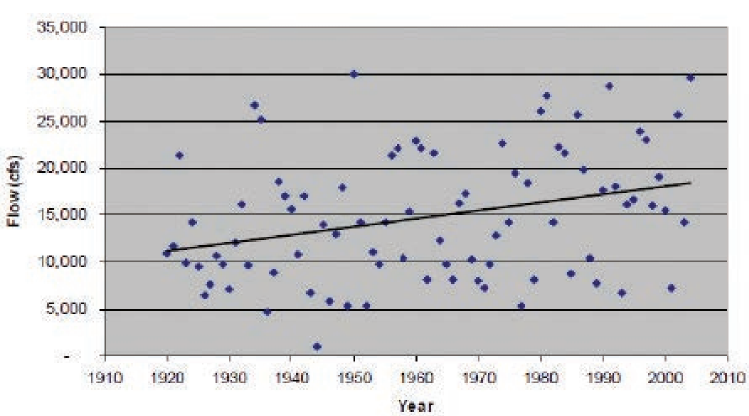
As increased temperatures cause snow lines to rise, a greater intensity and frequency of winter flooding is projected for Washington's mid-elevation basins, where transient runoff currently dominates streamflow on both sides of the Cascades. Increased winter flooding, resulting from a greater contribution of rainfall to streamflow, is likely to negatively impact the egg-to-fry survival rates for pink, chum, sockeye, Chinook, and coho salmon due to an increased intensity and frequency of redd scouring. However, the impact of increasing winter flooding will likely vary among species and populations because redd depth is a function of fish size; deeper redds will be less vulnerable to scouring and the deposition of fine sediments. Parr-to-smolt survival rates will likely be reduced for coho and stream-type Chinook salmon and steelhead because greater peak flows may displace rearing juveniles out of preferred habitats if the habitat lacks side-channels that provide slow-water off-channel refugia. Reductions in spring snowmelt may negatively impact the success of smolt migrations from snowmelt-dominant streams where the timing of seaward migration has evolved to match the timing of peak flows.



Because earlier snowmelt and increased evaporation will reduce surface runoff and deplete shallow soil moisture earlier in the year, most of Washington's rainfall-dominant and mixed rainfed/snowfed river basins are expected to have an extended period of summer low flows.

In contrast, low-flow projections for snowmelt-dominant basins demonstrate that they are less sensitive to rising temperatures. Historically, the lowest flows for snowmelt-dominant basins tend to occur in the winter when precipitation is stored as snow. However as temperatures rise and rainfall contributes more to streamflows in these basins, today's snowmelt dominant basins may experiences increases in winter streamflow. For the mixed rainfed/snowfed basins in particular, the combination of increased summer stream temperatures and reduced summer flow is likely to limit rearing habitat for salmon with stream-type life histories (wherein juveniles rear in fresh water for one or more years), increase mortality rates during spawning migrations for summer-run adults, and reduce the availability of spawning habitat that is most vulnerable to both dewatering and scour.

While there has been substantial work done to use simulation models to evaluate climate change impacts on aspects of freshwater habitat for salmon, very little work has focused on evaluating climate change impacts on coastal estuaries and the nearshore coastal ocean where salmon appear to experience high levels of mortality that then strongly influence total marine survival and adult abundance. However, periods with weak upwelling winds in spring and summer and warmer than average coastal ocean temperatures have been associated with a suite of changes in marine habitat and food webs that contribute to reductions in growth and survival rates for many PNW salmon populations. Specifically, cold periods have tended to favor especially productive food webs for salmon that include larger and fattier zooplankton communities, and fewer predators and competitors for juveniles salmon. The opposite has been true with warm periods. Future climate scenarios point to warming trends in the upper ocean that will increase the stratification of the upper ocean and likely inhibit the upwelling of cold, nutrient rich water that fuels a productive coastal ocean in the PNW region. Warmer surface waters will also favor an influx of subtropical predators and competitors for juvenile and maturing salmon. However, some climate models suggest that this warming may be countered in the coastal zone by an intensification of upwelling favorable winds in spring and summer. At this point, it is not clear if future changes in the coastal ocean will amplify or dampen the impacts of climate change on salmon freshwater habitat, but it will be a critical part of climate impacts on salmon in the future.



Discussion

The impacts of climate change on the life history and long-term viability of coldwater fish species are key considerations for PNW national parks. To the extent that these species are bellwethers of freshwater habitat viability and aquatic ecosystem change, they also serve as indicators of a variety of adverse environmental impacts on pristine ecosystems.

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