Forecasting impacts of climate and water-use for Chinook salmon by Pacific rim bioregions - Christine Petersen[1], Francisco Madriñán[1], Mary Ruckelshaus[2], Tim Beechie[2]

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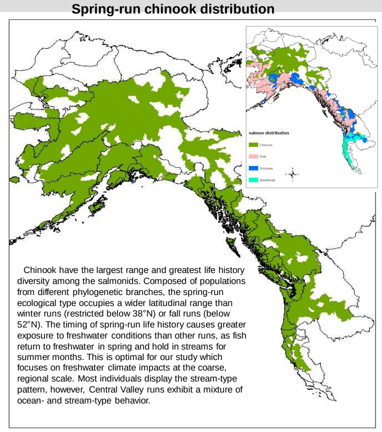
Climate change and future water management will alter many aspects of Pacific salmon habitat including food webs, water flows and quality, pathogens, ocean productivity, and land cover. However, anticipated habitat changes and salmon life histories vary greatly across the geographic range. Locally adapted populations may display variable responses in abundance to climate based on likelihood of exposure to physiologically limiting conditions, habitat capacity, or individual population variation. We frame our investigation as a comparison of four interior basins across the latitudinal distribution of spring-run Chinook in North America: Sacramento, Columbia, Fraser, and Yukon river basins. For each basin, our mechanistic life cycle model is parameterized to represent spatially realistic functional relationships between stage-specific survival and temperature, flow, and other ocean and habitat variables for a subset of populations. Density-dependence is imposed for early life history stages, and habitat capacity is inferred both from intrinsic potential analyses and prior escapement and smolt studies. Population dynamics under potential future scenarios of climate change are simulated through changes in temperature and tributary flow data downscaled for watersheds by the Climate Impacts Group at the University of Washington. We explore restoration and water management options contributing to qualities of population resilience. Here, we present initial results from the upper Columbia River and the Butte and Mill Creek tributaries to the Sacramento River.

Overview

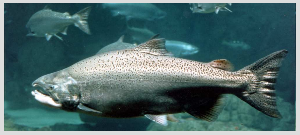
We ask how climate impacts for salmon vary latitudinally and among regions. We examine population dynamics of spring-run Chinook salmon at multiple basins from California to Alaska, and extract generalized understanding of latitudinal trends in climate impacts for Chinook. We then evaluate the potential for restoration strategies to increase salmon resilience to climate change along the latitudinal gradient.

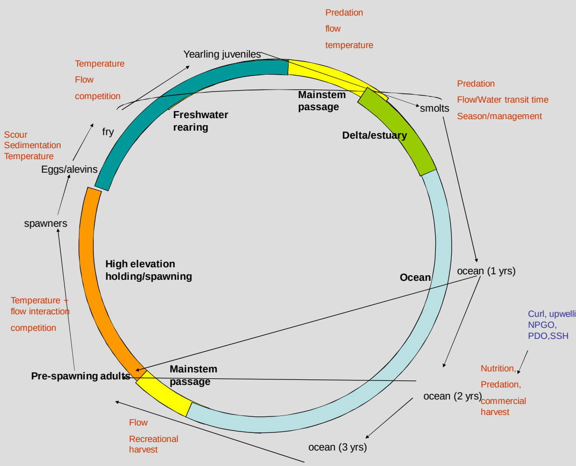
Integrated lifetime survival is a dynamic, multivariate process which is influenced by climate, harvest, habitat capacity and trophic dynamics and capacity at freshwater and oceanic habitats through which individuals proceed. We employ a mechanistic modeling approach to analyze the relative influence of habitat restoration in the face of climate change along a latitudinal gradient. With a particular focus on effects of temperature and flow response, we hope to characterize sensitivity of Chinook salmon populations to direct effects of freshwater climate variability and trends, and rank feasible freshwater restoration options for their likely impacts throughout the range.

Spring-run chinook distribution



Chinook have the largest range and greatest life history diversity among the salmonids. Composed of populations from different phylogenetic branches, the spring-run ecological type occupies a wider latitudinal range than winter runs (restricted below 38°N) or fall runs (below 52°N). The timing of spring-run life history causes greater exposure to freshwater conditions than other runs, as fish return to freshwater in spring and hold in streams for summer months. This is optimal for our study which focuses on freshwater climate impacts at the coarse, regional scale. Most individuals display the stream-type pattern, however, Central Valley runs exhibit a mixture of ocean- and stream-type behavior.





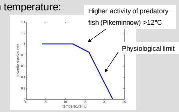
Lifecycle model details

- Density dependence- Beverton-Holt relationship fit for stages where analysis and/or literature suggests intraspecific competition.
- Carrying capacity- Intrinsic potential (Columbia)/Linear stream km of optimum historical spawning/rearing habitat.
- Mainstem passage-

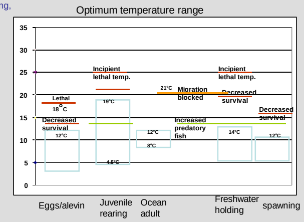
Columbia River- parameter estimates from PIT tag studies, water transit time-passage correlation

Sacramento Delta passage – daily reach specific mortality estimates taken from Fall-run acoustic tag study (Perry, Skalski, MacFarlane) adjusted for projected days of delta exposure

- Ocean mortality- conduct model comparison with indices correlated to smolt-to-adult survival
  1. upwelling-Columbia River(Scheuerell & Williams 2006)
  2. Wells index- Central Valley
- Fecundity – literature values
- Harvest- 1. no harvest 2. constant escapement, 3. constant harvest rate
- Site-specific analyses for functional relationship to flow and habitat characteristics. Landscape/streamflow values measured at intermediate/coarse scale from USGS, NOAA BiOP, Climate Impacts Group, State of Salmon data layers.
- Functional relationships with temperature:



Optimum temperature range



Model summary

→Beverton-Holt stage-specific survival model (similar to 'Shiraz') (Scheuerell et al. 2006, McElhany *et al.*). Relationships between survival and environmental factors are essential to the model.

→To compare likely response to climate and land- and water-use scenarios, we calculate temperature-flow relationships and stage-specific carrying capacities from prior regional studies.

→Scenarios of land- and water uses:
1. recent historical period,
2. Future climate models--two emissions scenarios
3. selected restoration options--including high/low water and land use patterns

→Climate values influence multiple habitats occupied within the annual period to simulate seasonal autocorrelation.

→Comparison throughout range of limiting factors and habitat features contributing to resilience

→Restoration potential is assessed by the amount of potential population response to land- and water-use changes in the face of climate change.

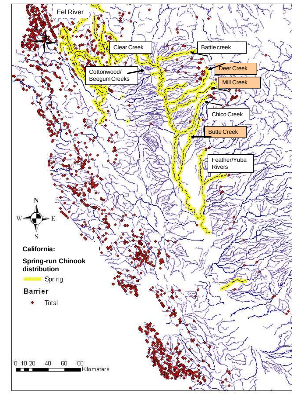
Future Climate and streamflow models

Extensive collaboration with members of the Climate Impacts Group at the University of Washington (Fengge Su, Nate Mantua). Fine-scale resolution (1/16deg) temperature, precipitation data downscaled from 15-GCM (global climate model) average under historical and future emissions scenarios. Watershed process model with GCM input produces floodplain hydrology, streamflow, sediment transport data products.

Sacramento River: Restoration options

Three wild spring-runs of chinook remain in the Central Valley. One population in Butte creek displays an earlier peak of return timing (Mar/Apr.) than a second population which returns to higher elevation Deer and Mill creeks during April/May. Mill Creek frequently experiences stream flows barely adequate for passage during late spring, partially due to agricultural diversion.

Spring-run chinook historically occupied 17 Central Valley tributaries.



Climate and the temperature-flow relationship:

Salmon populations demonstrate local adaptation to environmental conditions, particularly in traits of return timing, growth, and fecundity *(Quinn&Kinnison 2001).* Yet, there is little evidence that populations have evolved substantially different physiological temperature limits by bioregion.

The Butte creek population experienced heat induced mortality in 2002 and 2003 in stream reaches exceeding 20℃ for >~10 days *(Ward et al. 2004).* This is well below the empirically determined incipient lethal temperature for short-term exposure (~25℃), and may be interpreted as a field-based assessment of effective temperature tolerance, including interaction with disease.

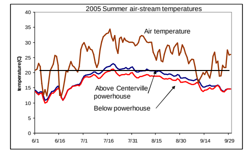
Restoration potential:

Currently, system capacity is limited by permanent barriers which restrict access to cool, high elevation habitat suitable for summer holding and spawning. Manipulated reservoir releases to maintain minimum flows effectively mitigate direct effects of drought or a warming trend.

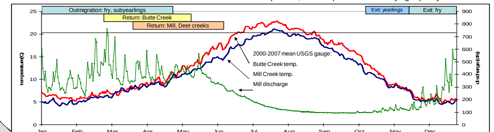
Management implications from early modeling results:

Our model shows that total lifetime survival is more sensitive to mortality rates during early eggs and parr stages.

- Permit access to more high elevation spawning habitat via engineering solutions or barrier removal
- Restorations to enhance small runs in the historically occupied tributaries such as Battle and Clear creek
- Delta channel management to direct fish away from high mortality reaches (Perry, Skalski, MacFarlane).



Summer 2005 mean temperatures above and below Centerville powerhouse on Butte Creek. (Ward, McReynolds, Garman CDFG). Mean temperature by reach varies substantially due to qualities of landscape and streamflow. Fish concentrate in reaches and pools with cool thermal qualities, which implies reduced carrying capacity.



Wenatchee Basin- Upper Columbia case study

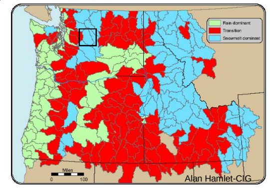


Fig. 1. 21st century projection: HUC4 Watersheds classified as likely to remain 1. rainfall dominant (Green. low snowpack, peak flows in winter), 2. Snowmelt dominated (Blue. High snowpack, peak flows in late spring. Increased precipitation may offset warming), and 3. Watersheds undergoing transition from snowmelt to rainfall dominant.

Locally adapted populations display run timing optimal for the prevalent snowmelt or rainfall dominated hydrology. The Wenatchee basin is expected to remain a snowmelt dominated system (Fig. 1). Thus the magnitude of selection for adaptive traits may remain lower here than for locations transitioning to a rainfall dominant system due to diminished snowpack in the Western Cascades, or eastern Oregon. Nonetheless, 21st century streamflow projections for Wenatchee predict an lower peak spring freshet and shift towards earlier snowmelt.

Response to flow has both regional components (i.e. predominant hydrologic regime), and site-specific factors such as minor natural barriers, stream geology, slope, and rainfall of the five major tributaries of the Wenatchee basin (Figure 2).

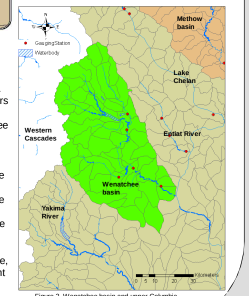


Figure 2. Wenatchee basin and upper Columbia watersheds below Grand Coulee Dam

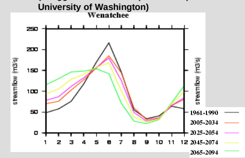
Early modeling results:

There is evidence that Wenatchee subpopulations are limited by mainstem passage mortality, and may experience density-dependence at some stages despite abundances below historical levels. We confirm sensitivity of some Wenatchee populations to landscape factors such as fine-sediment loading identified in prior studies (Honea *et al.* 2009).

In our next stage of simulating effects of future climate, we seek to determine the relative weight of such current limiting factors against the magnitude of population response to climate trends or scenarios of restoration.

Simulated daily streamflow (cfs)

(Fengge Su- Climate Impacts Group- University of Washington)



The VIC model is forced by projected precipitation and temperature with delta method under scenario A2 The monthly change factors for the A2 scenario were calculated by comparing the monthly means of the15 GCM output for the 30-year future time slice to the monthly GCM-average historic run output for a 30 year baseline period (1961-1990)

Surface runoff from the VIC hydrology model, and daily air temperature and precipitation has been gridded at 1/16 degree resolution.

Future Directions

→ Implementation of two climate projections, high and low projections of water diversion in Columbia River and Central Valley.

Wenatchee basin: Comparison of stream temperatures from historic period 1915-2006 and two emissions scenarios (A1B and B1) for 2010-2099. Streamflow comparison under A2 emissions for periods 1961-1990, 2005-2034, 2045-2074, 2065-2094

→Parameterize additional case studies in Fraser River and Alaska. We will employ modeling decisions which best facilitate interregional comparisons of the influence of temperature and flow regimes on population resilience and habitat characteristics.

→ Rank potential restoration options for mitigating anticipated population response to temperature and rainfall trends in the Central Valley

→Enhance population dynamics model via links with concurrent projects from NCEAS salmon-climate working group members:

Pacific Rim River Typology
Salmonid Rivers Observatory Network (SaRON)
Jack Stanford, Huan Wu, John Kimball- University of Montana

Air-Stream temperature model
Omar Aziz- JISAO University of Washington

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